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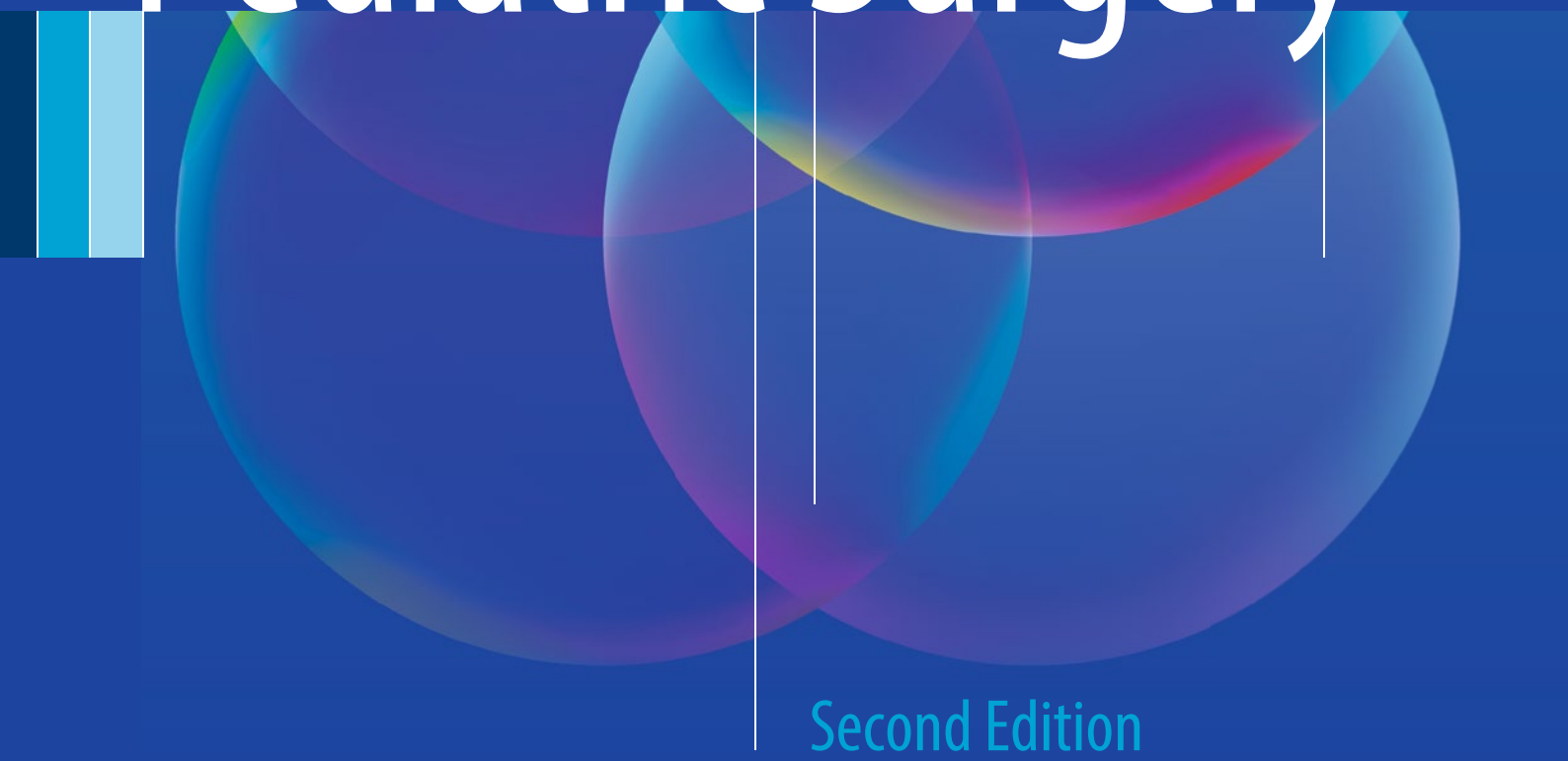
Fundamentals of Pediatric Surgery



Second Edition

Springer

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To Kim, Gina, Peter, Joey, and Michael, without whose love and support nothing would be possible or worthwhile.

–P.M.

To my Wife Maria and my sons Alessandro and Federico through whom all good things come.

–P.F.N.

To my wife and children for their constant support.

–M.D.R.

To my patients and their families, who entrust me with their most precious possession.
To my mentors, whose teachings motivate me to achieve excellence and precision.
To my family, whose love, support, and understanding provide the inspiration for the path I've chosen.
I am humbled and grateful.

–C.S.M.

Preface

Fundamentals of Pediatric Surgery, Second Edition is meant for pediatric and general surgeons, pediatric surgery fellows, surgery residents, and other advanced practitioners and intended to be a reliable source of up-to-date information regarding the everyday care of children with a surgical condition. Each chapter is written by an experienced authority in the field and addresses a specific aspect of clinical pediatric surgery, carefully edited to maintain a continuity of style and format while preserving the distinctive voice of the author. The goal is to provide practical and clinically relevant information in an accessible and straightforward presentation. The new edition features updates in every topic, many new authors, and three new associate editors. Every chapter begins with an abstract that highlights important themes and is written in a this-is-how-I-do-it narrative style that the reader ought to find familiar—more like an amiable conversation with a trusted mentor and friend rather than a dry or sterile lecture. Finally, nearly every chapter is followed by an additional comment written by the editors and intended to provide pearls, more in-depth analysis, or additional useful information.

In addition to providing a useful reference for pediatric surgeons and general surgeons in clinical practice, *Fundamentals of Pediatric Surgery, Second Edition* is also designed to be used by general surgical residents rotating in pediatric surgery and chief residents in Pediatric Surgery fellowship programs. The American Board of Surgery and the Accreditation Council for Graduate Medical Education (ACGME) consider experience in the clinical aspects of pediatric surgery a necessary and important aspect of the education and training of the general surgeon and most General Surgery residents are still expected to rotate on a Pediatric Surgery service. These brief rotations can be quite busy, with little time to read any of the excellent comprehensive pediatric surgery textbooks available, especially when what one really needs is a practical guide to the everyday care of the pediatric surgical patient. Enter *Fundamentals of Pediatric Surgery, Second Edition,* a concise easy-to-read textbook filled with detailed and relevant information that can help the resident care for the patient they are seeing in the clinic or in the hospital. The goal is to provide at least one reasonable and proven approach, recommended by a recognized expert, and presented in a context that includes a discussion of the underlying principles of care and essential clinical issues to be considered.

Finally, it is hoped that Pediatric Surgery fellows will find this book to be a rich and up-to-date source of pertinent information related to the actual day-to-day care of the surgical child and provide the foundation for what will be an exciting and lifelong education in the complexities of the surgical care of children. It was originally intended to be a valuable resource and study guide for preparation for the written and oral American Board of Surgery certifying examinations in Pediatric Surgery. It is our sincere hope that *Fundamentals of Pediatric Surgery*, *Second Edition*, designed with the more advanced practitioner in mind, will prove to be a useful and valuable complement to the many excellent pediatric surgical texts currently available.

Philadelphia, PA, USA
November 2015

Peter Mattei

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This book is the result of a great deal of time and effort on the part of dedicated contributing authors, all of whom are exceptionally busy taking care of patients but who felt they had something important to pass along to current and future generations of pediatric and general surgeons and therefore volunteered to contribute their chapters. We also have many people to thank in our home departments including our partners and associates, administrative assistants, and, of course, our patients' families, who give us the opportunity and privilege of caring for their children every day. We would be remiss in not mentioning the help and inspiration provided by the generations of surgery residents and fellows, brave folks who allow us the privilege of teaching and training them to be the best surgeons they can be. Finally, we want to thank our Developmental Editor, Portia Levasseur, without whom this textbook would not have been possible.

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Part I

Perioperative Care

Preoperative Assessment and Preparation

1

Ari Y. Weintraub and Lynne G. Maxwell

The goals of the preoperative evaluation are to identify active medical issues and to ensure that the management of these conditions is optimized prior to anesthesia and surgery. Unresolved medical issues are sometimes significant enough to warrant cancelation of procedures for further diagnostic workup or treatment. It is in the best interest of all involved to avoid this.

Risks of Anesthesia

The risk of dying from general anesthesia can only be extrapolated from large series and appears to be as low as 1 in 250,000 in healthy patients. To put this in perspective for parents, the risk of a motor vehicle collision on the way to the hospital or surgery center is greater than the risk of death under anesthesia. Common minor adverse effects including discomfort from airway management and postoperative nausea and vomiting (PONV) should be discussed, along with assurances that everything will be done to prevent and treat these relatively common complaints.

The American Society of Anesthesiologists (ASA) physical status score is a means of describing the physical condition of the patient. The physical status score was never intended to represent a measure of operative risk but instead serves primarily as a means of communication among care providers (Table 1.1). In addition, certain information is essential and should be included in the preoperative assessment of every patient: weight, blood pressure, oxygen saturation (SpO_2) by pulse oximetry in room air (and with supplemental O_2, if applicable), allergies, medications, cardiac and murmur history, and previous subspecialty encounters.

Patients who have previously undergone general anesthesia should be asked specifically regarding a history of adverse effects: emergence delirium, PONV, difficult intubation, or difficult intravenous access. Keep in mind that patients and their parents are often very anxious about recurrence of these events. The family history should also be reviewed for pseudocholinesterase deficiency (prolonged paralysis after succinylcholine) or any first-degree relative who experienced malignant hyperthermia.

Airway/Respiratory System

Many congenital syndromes are associated with craniofacial abnormalities that may complicate or even preclude routine airway management techniques (Table 1.2). In addition to a detailed physical examination, a history of past intubations and details of the methods needed to secure the airway are even more useful in planning an anesthetic. Some patients are given a "difficult airway letter" by an anesthesiologist, and this information should be shared with the anesthesia care team in advance of the scheduled operation. In the absence of such information, prior anesthetic records should be obtained and reviewed to guide airway management.

Asthma (reactive airway disease) is one of the most common chronic diseases in children, and the disease can be exacerbated by perioperative procedures, including anesthetic induction and emergence or endotracheal intubation. As with all chronic conditions, asthma should be optimally medically managed prior to an operation or general anesthesia. In addition to the regular appropriate use of "controller medications" (inhaled corticosteroids, intermediate-acting bronchodilators, leukotriene modifiers), to minimize perioperative bronchospasm, we typically recommend that patients

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Table 1.1 American Society of Anesthesiology (ASA) physical status (PS) classifications

Classification	Definition	Example
PS 1	Normal healthy person	
PS 2	Mild systemic disease without functional limitations	Well-controlled asthma
PS 3	Severe systemic disease	Acute lymphocytic leukemia
PS 4	Severe systemic disease that is a constant threat to life	Extreme prematurity
PS 5	Moribund patient, unexpected to survive without the procedure	Congenital heart disease for initiation of ECMO
PS 6	Brain-dead patient for organ procurement	
E	Suffix added for emergent procedures	

Table 1.2 Syndromes and craniofacial abnormalities associated with difficult ventilation or intubation

Syndrome	Associated airway features
Apert	Craniosynostosis, midface hypoplasia
Beckwith–Wiedemann syndrome	Macroglossia
Crouzon	Craniosynostosis, midface hypoplasia
Freeman–Sheldon (whistling face) syndrome	Microstomia
Goldenhar syndrome	Hemifacial microsomia, mandibular hypoplasia (uni- or bilateral)
Klippel–Feil syndrome	Limited cervical mobility
Mucopolysaccharide storage disorders	Redundant facial, pharyngeal, and supraglottic soft tissue; neck immobility
Pierre Robin sequence	Micrognathia, glossoptosis, cleft palate
Treacher Collins syndrome	Maxillary/mandibular hypoplasia
Trisomy 21 (Down syndrome)	Macroglossia, subglottic stenosis, midface hypoplasia

with asthma use their bronchodilators every 6 h for 48 h prior to anesthesia. A history of a recent flare requiring oral corticosteroids suggests poorly controlled disease and might warrant delay of an elective procedure until better control is achieved. Some recommend waiting 4–6 weeks after an acute exacerbation for the usual airway hyperreactivity to return to baseline. Patients with persistent poorly controlled reactive airway disease should be referred to their primary healthcare provider or pulmonologist for strategies to improve their status. These strategies sometimes include the administration of oral corticosteroids.

Children often have loose teeth as they transition from their primary to secondary dentition or due to poor oral hygiene or an underlying disorder such as osteogenesis imperfecta or ectodermal dysplasia. Because there is a significant risk of aspirating a tooth that is accidentally displaced during orotracheal intubation, loose teeth should be electively removed at induction. In some cases it is best to recommend a preoperative visit to a dentist.

Obstructive sleep apnea is seen commonly in patients with adenotonsillar hypertrophy, obesity, and some syndromes. Symptoms (snoring, daytime somnolence), results of sleep studies, and the need for noninvasive ventilation (CPAP, BIPAP) should be included in the preoperative assessment as airway obstruction is expected and should be anticipated in the postoperative period, often making inpatient observation and monitoring necessary.

A very common question is whether an anesthesiologist should cancel a procedure because of an upper respiratory infection. This can be a vexing problem for all parties involved and the decision is sometimes difficult to make with confidence. The patient with a current or recent URI undergoing general anesthesia is theoretically at increased risk of a postoperative respiratory complication, including laryngospasm, bronchospasm, hypoxia, and apnea, with the patients under 2 years of age at greatest risk. However, anesthetic management can also be tailored to reduce stimulation of a potentially hyperreactive airway. In addition, cancelation of a procedure can impose an emotional or economic burden on the patient, family, physician, and hospital or ambulatory surgical facility. Unless the patient is acutely ill, it is often acceptable to proceed with the procedure as planned. Patients with high fever, wheezing, or a productive cough may actually have a lower respiratory tract infection, and surgery is more likely to be canceled. Our approach is to discuss the urgency of the planned procedure with the surgeon and to review the risks and benefits of proceeding or rescheduling with the parents, including the possibility that the child may

have another URI at the time of the rescheduled procedure. Allowing the parents to participate in the decision-making process when appropriate usually leads to mutual satisfaction among all parties involved.

The patient with a difficult airway might require advanced airway management techniques, which often necessitates additional OR time and, in some cases, a planned period of postoperative mechanical ventilation or ICU stay.

The laryngeal mask airway is used routinely for general anesthesia. This technique allows the patient to breathe spontaneously, with or without pressure support from the anesthesia machine, and, in most cases, neuromuscular blocking agents are not used. Therefore, it is usually used for cases where skeletal muscle relaxation is not needed for safe conduct of the operation. Any requirement for muscle relaxation should be discussed in advance with the anesthesiologist.

Cardiovascular

At the time of the presurgical evaluation, up to 90 % of children are found to have an "innocent" murmur, probably due to turbulent flow at the aortic or pulmonary roots or in the subclavian or pulmonary arteries. Most of these children do not require a cardiology consultation and can be safely observed. These murmurs are frequently episodic and are associated with a normally split second heart sound, normal exercise tolerance, and normal electrocardiogram. Concomitant medical problems such as anemia and fever augment audibility of innocent murmurs because they increase cardiac output.

Nevertheless, a thorough history and physical examination will occasionally reveal findings that raise greater concern in a child with a murmur: an infant with failure to thrive or diaphoresis or tachypnea during feedings or the older child with dyspnea, tachypnea, exercise intolerance, or syncope. These findings warrant further evaluation, including an electrocardiogram, chest X-ray, consultation with a pediatric cardiologist, and, in some cases, an echocardiogram.

Children with congenital heart disease frequently require a surgical procedure. Assessment of the child's current health status includes a full history and physical examination and recent evaluation by the child's cardiologist. This communication should include a full description of the original lesion, documentation of any procedures performed for palliation or repair, residual abnormalities such as an intracardiac shunt or valve abnormality, current functional status, and results of the most recent echocardiogram.

Knowledge of the child's cardiac anatomy is essential to assess the risk of paradoxical emboli and endocarditis. The American Heart Association has published revised recommendations for antibiotic prophylaxis that are substantially different from those promulgated over the past 50 years (Table 1.3). Specifically, genitourinary and gastrointestinal procedures have been eliminated from those requiring prophylaxis, and prophylaxis for dental and respiratory tract procedures is restricted to patients with (1) unrepaired cyanotic congenital heart disease, (2) congenital heart defect repaired with prosthetic material within the prior 6 months, (3) cardiac transplantation, or (4) a history of endocarditis. Endotracheal intubation itself is not an indication for antibiotic prophylaxis. Patients with hemodynamically insignificant lesions such as bicuspid aortic valve or mitral valve prolapse no longer require prophylaxis for any procedure. Patients with congenital heart disease repaired with prosthetic material require prophylaxis only for the first 6 months after repair because endothelialization will have occurred. This is true for VSD and ASD repairs as long as there is no residual defect. Patients with prosthetic valves and those palliated with shunts or conduits require prophylaxis. Some cardiologists differ with these new guidelines. It is therefore advisable to request a recommendation from the cardiologist based on the child's condition and planned procedure.

Table 1.3 Cardiac conditions for which prophylaxis with dental or respiratory tract procedures is recommended

Congenital heart disease (CHD)[a]
Unrepaired cyanotic CHD, including palliative shunts and conduits
Completely repaired congenital heart defect with prosthetic material or device, whether placed by surgery or by catheter intervention, during the first 6 months after the procedure[b]
Repaired CHD with residual defects at the site or adjacent to the site of a prosthetic patch or prosthetic device (which inhibit endothelialization)
Cardiac transplantation recipients who develop cardiac valvulopathy
Prosthetic cardiac valves
Previous infective endocarditis

[a]Except for the conditions listed above, antibiotic prophylaxis is no longer recommended for any other form of CHD
[b]Prophylaxis is recommended because endothelialization of prosthetic material occurs within 6 months of the procedure
Source: Data from Wilson W, Taubert KA, Gewitz M et al. Prevention of infective endocarditis. Guidelines from the American Heart Association Rheumatic Fever, Endocarditis, and Kawasaki Disease Committee, Council on Cardiovascular Disease in the Young, and the Council on Clinical Cardiology, Council on Cardiovascular Surgery and Anesthesia, and Quality of Care and Outcomes Research Interdisciplinary Working Group. *Circulation* 116(15):1736–54, 2007

Although antibiotic prophylaxis is frequently administered orally to adults, it is usually given intravenously in children. When indicated, our practice is to give the antibiotic intravenously at induction of anesthesia, because the surgical preparation time generally allows sufficient time to achieve adequate blood levels before the incision is made. Starting an intravenous catheter in an awake child solely to administer antibiotics for antibiotics is rarely if ever necessary.

Surgical patients with long QT syndrome (LQTS), in which ion channels involved in repolarization function abnormally due either to a congenital defect or drug effect, are at risk for torsades de pointes, a potentially life-threatening ventricular tachycardia. Congenital LQTS occurs in 1 in 5000 individuals and can present at any age with syncope, seizures, or sudden cardiac death, usually after an increase in sympathetic activity such as exercise or emotional stress. Because volatile anesthetic agents and surgical stress increase the risk of developing ventricular tachycardia, a preoperative electrocardiogram should be obtained in patients who are symptomatic, have a family history of sudden death, or are taking drugs, which predispose to the condition (http://www.azcert.org/medical-pros/drug-lists/drug-lists.cfm). A QTc of more than 470 ms in males and 480 ms in females is diagnostic of LQTS. Since preoperative medical treatment is nearly always necessary, cardiology consultation should be obtained.

Any patient with congenital heart disease, cardiomyopathy, arrhythmia, or unexplained syncope requires a thorough cardiology evaluation before having an elective surgical procedure, especially one that requires a general anesthetic. In fact, anesthetists at most institutions will require that a letter of cardiology clearance be included in the medical record before the day of surgery. This letter is written by the consulting cardiologist and should include a detailed discussion of the anatomy of the defect, the current medical regimen, and specific recommendations regarding the perioperative care of the patient.

Gastroesophageal Reflux Disease

The majority of infants and a significant number of children have some degree of gastroesophageal reflux and the diagnosis of gastroesophageal reflux disease is increasing. Symptoms of GERD in infants and children differ substantially from those seen in adults and are often primarily respiratory in nature: cough, wheezing, or pneumonitis. Yet, despite a theoretical increase in the risk of aspiration of gastric contents during the induction of anesthesia, children with a history of GERD do not have an increased incidence of pulmonary aspiration as long as fasting guidelines have been followed. Unless there is a history of aspiration when fasting, an intravenous rapid sequence induction is not usually indicated. Patient with GERD should be taking appropriate chemoprophylaxis (H_2 blocker or proton pump inhibitor) as prescribed by their primary physician or gastroenterologist.

Obesity

Obesity is an increasing problem in children, with a recent estimated incidence of 15 %. As in adults, obese children have an increased incidence of obstructive sleep apnea, which can be associated with adverse respiratory events in the perioperative period. Problems during induction include difficult mask ventilation. Preoperative evaluation of children with a body mass index of 30 or greater should include a careful history of snoring and daytime somnolence. Patients with suspected obstructive sleep apnea should be referred to a pulmonologist for a sleep study and considered for therapy with a positive-pressure breathing device. In addition to airway and respiratory complications, obese patients have been found to have an increased incidence of postoperative complications such as infection, wound complications, and deep venous thrombosis when compared to children of normal weight.

Diabetes

Approximately 1 in 500 people under age 20 has diabetes; however, complications requiring surgical intervention, such as cardiovascular disease, are extremely rare in this age group. Nevertheless, patients with diabetes present for routine and emergent surgery with the same frequency as non-diabetic patients and their underlying diabetes must be addressed. As with any other chronic illness, the medical management of diabetes should be optimized before elective surgery, and a plan for perioperative glucose and insulin management should be formulated jointly by the endocrinologist and anesthesiologist. The stresses of surgery and its effects on a regular schedule can wreak havoc on normally well-controlled diabetes if not properly managed. The goal of perioperative management is no longer merely avoiding life-threatening hypoglycemia and severe hyperglycemia but to maintain euglycemia to the extent possible.

Regimens of multiple injections of long- and short-acting insulin are still common, but many patients with diabetes have insulin pumps that deliver a continuous subcutaneous infusion with on-demand boluses for carbohydrate intake or correction of hyperglycemia. Typical management includes the usual preoperative fast with clear liquids up to 2 h before the operation. Whenever possible, it is usually best to schedule the diabetic patient as the first case of the day. After consultation with the patient's endocrinologist, the insulin dosage regimen most often includes reduction of the long- or

moderate-acting insulin dose with a reduced or skipped short-acting insulin dose on the morning of surgery. Insulin pump infusions may be continued up until the time of surgery. Blood sugar should be checked upon arrival. Hypoglycemia requires intervention but oral treatment might require delaying the procedure due to fasting guidelines. Hyperglycemia (>250 mg/dL) should be treated with subcutaneous insulin or a bolus via the insulin pump. The presence of urine ketones will usually lead to cancelation or delay of an elective procedure.

An increasing number of institutions are allowing, and often advocating, continued use of the insulin pump throughout the perioperative period, although some institutions still consider insulin pumps unauthorized medical devices and prohibit their use. As long as the infusion set connecting the pump to the patient is not in the surgical field, there is generally no contraindication to continuing the insulin infusion via the pump. Although most pump manufacturers still recommend disconnecting the insulin pump in the setting of electrocautery use, there have been no credible reports of damage to the insulin pump or interrupted insulin delivery due to electrocautery, and we recommend continuing the use of the pump with placement of the grounding pad as close as possible to the surgical site (closer than to the infusion set). In institutions where insulin pump use is forbidden, for short procedures of less than 2-h duration, it is often sufficient to simply disconnect the insulin pump immediately before incision with monitoring of blood sugar by finger sticks regularly during the course of the anesthetic and administration of subcutaneous or intravenous insulin to correct hyperglycemia, using a sliding scale agreed upon in advance with the child's endocrinologist, with intravenous dextrose as needed for hypoglycemia. Longer procedures, or those requiring postoperative admission, sometimes require continuous intravenous insulin infusion along with dextrose-containing fluids in order to maintain glucose homeostasis. This might require a longer preoperative preparation time for obtaining intravenous access and initiating the infusions. The best glycemic control will generally be afforded by resuming the patient's normal management regimen as soon as possible. Involving an endocrinologist preoperatively to participate in planning for intra- and postoperative care is recommended.

Thyroid Disease

Thyroid disease is uncommon in childhood but is associated with certain pediatric conditions, including prematurity and trisomy 21. Hypothyroidism can lead to myocardial depression, arrhythmias, hypotension, hypothermia, or delayed gastric emptying, while hyperthyroidism can manifest as hyperthermia, tachycardia, hypertension, palpitations, or dysrhythmias. In addition, patients with very large goiters sometimes require imaging to exclude airway involvement. Both hypo- and hyperthyroidism have anesthetic and cardiovascular implications, and, whenever possible, patients should be euthyroid prior to an elective procedure.

Corticosteroids

Although there is little evidence to support the practice, many textbooks and practitioners advocate steroid supplementation during the perioperative period for patients receiving steroid therapy. Theoretically, chronic corticosteroid administration might suppress the hypothalamic–pituitary–adrenal (HPA) axis to the degree that an adrenal crisis is precipitated by the physiologic stress of surgery and anesthesia. In practice, patients who receive a short "pulse" of steroids (<14 days), for example, for treatment of an acute asthma exacerbation, generally do not require supplementation. The administration of "stress-dose" steroids is sometimes recommended for patients who have received supraphysiologic doses, multiple short courses of steroids, or chronic steroids. Adrenal suppression diminishes with time from completion of steroid therapy. In addition, the need for steroid supplementation and recommended doses and duration are also dependent on the degree of surgical stress. Patients exposed to minor surgical stress (hernia repair, extremity surgery) might require at most a single dose of hydrocortisone or methylprednisolone, whereas those who undergo a major operation (laparotomy or thoracotomy with blood loss requiring transfusion) might need multiple doses during the 2–3 day period of maximal physiologic stress. Consultation with an endocrinologist should be sought in these situations.

Anemia

The normal hemoglobin level varies with age. Term infants have a hemoglobin level between 14 and 18 g/dL, which, due to rapid weight gain and expansion of blood volume in the face of relatively low levels of erythropoietin, normally decreases to physiologic nadir of 9 or 10 g/dL by the age of 2–3 months. Preterm infants start with a lower hemoglobin level and have an even lower nadir of between 7 and 9 g/dL.

Hemoglobin is the most commonly requested preoperative laboratory test. Because the incidence of previously undetected anemia in healthy children undergoing elective surgery is extremely low (approximately 0.3 %), routine determination of hematocrit and hemoglobin is not necessary if the results of studies performed previously as part of well-child care have been normal. A selective hemoglobin determination should be performed in children with a chronic medical illness, those with acute blood loss (trauma, GI

bleeding), and those about to undergo procedures with the potential for significant blood loss. Infants younger than 6 months should have hemoglobin measured because of the nadir. In addition, in premature infants, hemoglobin levels of less than 10 g/dL have been associated with an increased incidence of postoperative apnea. Children of African ethnicity who have not been screened for sickle cell disease and have not had a hemoglobin determination after 6 months of age should have such measurements performed before undergoing a major surgical procedure.

Anemia results in a decrease in oxygen-carrying capacity and an increase in cardiac output. Most children with chronic anemia are in a well-compensated state. However, intraoperative blood loss can lead to decompensation in the face of surgical stress, systemic vasodilation, and myocardial depression caused by anesthetic agents. Further, the child with preoperative anemia is more likely to require a transfusion in the setting of moderate blood loss than children without anemia. Although the hemoglobin value at which individual anesthesiologists choose to transfuse varies greatly, most anesthesiologists allow a healthy child's hemoglobin to decline to the range of 7–8 g/dL before recommending a blood transfusion.

Sickle Cell Disease

Sickle cell anemia results from a single-base mutation in the β-globin gene. Under conditions of hypoxia, acidosis, dehydration, hypothermia, or the use of a tourniquet, HgbS can polymerize, causing sickling of red blood cells, resulting in microvascular occlusion, tissue ischemia, pain ("crisis"), and, when it occurs in the lung, impaired pulmonary function (acute chest syndrome). This is most common in children homozygous for the mutation but can also occur with one HgbS gene combined with another abnormal gene such as $HgbO_{Arab}$ or HgbC. The optimum hemoglobin level in patients with sickle cell disease is unknown, but recent studies indicate that simple transfusion to 10 g/dL is associated with morbidity no greater than that in patients treated with aggressive exchange transfusion to reduce the HgbS concentration to less than 30 %, which was the standard recommendation for many years. That is not to say that the rate of morbidity is low; in fact, it is around 20–30 % in both groups. These patients require (1) pre- and postoperative hydration, (2) careful attention to maintenance of normothermia, (3) avoidance of tourniquets whenever possible, (4) supplemental oxygen to avoid hypoxemia, and (5) good analgesia. Patients with sickle cell trait (Hgb AS) have no apparent perioperative risk of sickling or acute chest syndrome, except rarely in conditions associated with extreme dehydration and electrolyte depletion such as uncorrected GI losses from bowel obstruction.

Coagulation Disorders

Von Willebrand disease (vWD) is the most common congenital bleeding disorder. Most patients with vWD have type I disease, which is a quantitative deficiency of von Willebrand factor (vWF). Ninety percent of patients with type I vWD will respond to DDAVP with a two- to threefold increase in vWF. The DDAVP is administered intravenously, intranasally, or subcutaneously 30 min before the procedure. Because 10 % of patients with type 1 vWD do not respond to DDAVP, advance determination of the quality of the response is fundamental to the preoperative evaluation of a patient with vWD. Type 1 nonresponders, as well as patients with type 2 and type 3 vWD, require preoperative administration of plasma-derived factor VIII concentrate (Humate-P), which has a high concentration of vWF. All patients with vWD undergoing major surgical procedures require factor replacement preoperatively.

Hemophilia A, B, and C are inherited deficiencies of factors VIII, IX, and XI, respectively. Perioperative management of these patients depends on the procedure planned. Patients undergoing major surgical procedures require factor VIII and factor IX levels that approximate 100 % of normal from 30 min before the procedure through the first postoperative week. Factor administered to patients with hemophilia A can be plasma derived or recombinant, and the regimen should be discussed with the child's hematologist ahead of time. Recombinant factor VIII products have become available but are not necessarily associated with a lower rate of inhibitor or antibody formation. Patients undergoing minor procedures are usually fine with factor levels that are 50 % of normal for the first 2–3 postoperative days. Some patients with mild hemophilia A have a sufficient response to DDAVP to provide adequate protection for minor procedures. The coagulopathy of patients with hemophilia C does not directly correlate with factor levels. The need for fresh-frozen plasma transfusion in these patients should be determined by a pediatric hematologist.

Malignancy

Children with cancer frequently receive medications that have the potential to cause profound perianesthetic complications. Some receive prolonged doses of corticosteroids as part of their chemotherapy, which places them at risk for adrenal suppression. The anthracycline drugs, doxorubicin and daunorubicin, can cause myocardial dysfunction, whereas mithramycin, carmustine (BCNU), and bleomycin can cause pulmonary fibrosis, especially when combined with radiation therapy. The fact that this pulmonary damage can be exacerbated by supplemental oxygen is of concern to the anesthesiologist. The effects of these drugs are not always

apparent at the time of treatment and can present later in life or are unmasked by the additive effects of anesthetic agents (myocardial dysfunction) or oxygen exposure. As many protocols include serial echocardiographic evaluations, the most recent echocardiographic report should be included in the preoperative evaluation.

In addition to complications from chemotherapy and radiation, these children and their families frequently have psychological sequelae from prolonged treatment and the side effects associated with malignancy and bone marrow transplantation. They deserve careful evaluation and gentle treatment in the perioperative environment.

Anterior Mediastinal Mass

Patients presenting with an anterior mediastinal mass (especially lymphoma) are at particularly high risk of airway compromise and cardiovascular collapse with the induction of general anesthesia due to compression of the trachea or great vessels when intrinsic muscle tone is lost and spontaneous respiration ceases. Preoperative evaluation should begin with a careful history to elicit any respiratory symptoms, including dyspnea, orthopnea, stridor, or wheezing. A chest X-ray and complete echocardiogram must be performed, including evaluation of the great vessels with respect to compression of inflow or outflow tracts, the pericardium for direct infiltration or effusion, and the atria and ventricles with attention to degree of filling and the presence of atrial diastolic collapse. If it can be done safely, computed tomography should be obtained to assess the degree of tracheal and bronchial compression. Pulmonary function studies do not predict outcome or help to guide management and are no longer considered useful. Whenever possible, percutaneous biopsy of the mass or surgical cervical lymph node biopsy using local anesthesia with minimal sedation is preferred over a procedure performed under general anesthesia because it poses the least risk to the patient. If general anesthesia is required and airway or vascular compression exists, having rigid bronchoscopy or even ECMO capability on standby is strongly recommended.

Cerebral Palsy

Cerebral palsy is a polymorphic set of motor disorders with a wide spectrum of severity. Children with CP frequently require surgery to treat GERD or orthopedic problems. Many have increased oral secretions, dysfunctional swallowing, and chronic pulmonary aspiration of both oral and gastric contents. Together with an ineffective gag and inadequate cough, these commonly result in the development of reactive airway disease and recurrent pneumonitis. Up to one third of children with CP also have a seizure disorder. They are often taking several medications, including anticonvulsants, muscle relaxants, proton pump inhibitors, or H_2 blockers and drugs for reactive airway disease. Communication is important so that these essential medications are continued in the perioperative period. Confirmation of recent determination of adequate anticonvulsant blood level within the previous 6 months is helpful, although some patients have poorly controlled seizures and are expected to have seizures in the perioperative period despite adequate blood levels.

Preoperative assessment should include evaluation of room air oxygen saturation and the degree of underlying reactive airway disease, as well as the presence of snoring and other obstructive symptoms suggestive of inadequate airway tone. In the most severely affected patients, scheduling elective procedures between episodic exacerbations of reactive airway disease and aspiration pneumonia is challenging. Since many of these children have ongoing increased airway reactivity, preoperative evaluation and preparation should be directed to ensuring that the child's pulmonary status is as good as it can be. Chest radiographs are helpful in the child who has had frequent pneumonitis.

Hypotonia

Children with generalized hypotonia often present for definitive diagnosis by muscle biopsy under general anesthesia and should be considered at risk for malignant hyperthermia. Malignant hyperthermia precautions are commonly taken, consisting of avoidance of succinylcholine and potent volatile anesthetics. Patients with muscular dystrophy or myotonia are also at risk for MH and MH-like events with exposure to triggering agents. Succinylcholine should always be avoided in patients with Duchenne muscular dystrophy due to the risk of rhabdomyolysis.

Developmental Disorders

An increasing number of children are receiving pharmacotherapy with stimulant medications for attention deficit disorder. Although the American Heart Association recommends that an electrocardiogram be performed prior to initiation of stimulant therapy to identify significant cardiac conditions (LQTS, hypertrophic cardiomyopathy, Wolff–Parkinson–White syndrome), the American Academy of Pediatrics does not agree with this recommendation. There is no evidence to suggest that patients with these diagnoses are at higher risk of sudden cardiac death with stimulant medications than the general population. Therefore, in the absence of a personal history, family history, or physical exam findings suggestive of cardiac disease, no additional testing or evaluation is required prior to anesthesia and surgery.

Children with pervasive developmental disorder or autism require special patience and care because of communication difficulty, emotional lability, possible aggressive behavior, and sensory hypersensitivity. Some of the medications used to treat the maladaptive behaviors in children with autism (atypical antipsychotic drugs) can cause LQTS, placing the patient at risk for torsade de pointes.

Prematurity

Infants born prematurely (<37 weeks gestation) may have sequelae such as bronchopulmonary dysplasia, GERD, intraventricular hemorrhage, hypoxic encephalopathy, laryngomalacia, or tracheal stenosis from prolonged intubation and are at increased risk for postoperative apnea after exposure to anesthetic and analgesic agents. Preoperative assessment of prematures should therefore take these conditions into consideration.

Bronchopulmonary dysplasia is the most common form of chronic lung disease in infants and significantly complicates the perioperative management of infants born prematurely. The incidence of BPD has fallen, probably as a result of the widespread use of surfactant over the past two decades. It is associated with airway hyperreactivity, bronchoconstriction, airway inflammation, pulmonary edema, and chronic lung injury. Corticosteroids are frequently used in an attempt to reduce inflammation and mitigate the extent of evolving BPD. Many infants with BPD also have pulmonary hypertension. Several effects of anesthesia, together or separately, may have life-threatening consequences. Pulmonary vasoconstriction after anesthetic induction can aggravate ventilation–perfusion mismatch and lead to profound hypoxemia. Anesthetic effects on myocardial contractility can result in impairment of right ventricular function, reduced cardiac output, and pulmonary blood flow, and profound cardiovascular compromise with hypoxemia, resembling acute cor pulmonale. Increased airway reactivity during anesthetic induction or emergence from anesthesia can result in severe bronchoconstriction, impairing ventilation and pulmonary blood flow. Increased oral and bronchial secretions induced by the anesthetic can further compromise airflow and lead to plugging of the airway or endotracheal tube, which, because of their diminished respiratory reserves, can quickly cause profound hypoxia and acute right-sided heart strain, arrhythmias, or death.

The pulmonary status of these children must be evaluated and their condition optimized to minimize perioperative risks of bronchospasm, atelectasis, pneumonia, respiratory, and cardiac failure. Bronchodilators, antibiotics, diuretics, corticosteroid therapy, and nutritional therapy should be considered in these children. Children with bronchospasm and pulmonary hypertension may benefit from preoperative treatment with elevated FiO_2 to decrease pulmonary vasoreactivity and improve cardiovascular function. The possibility of associated right ventricular dysfunction should always be considered and, when indicated, evaluated with electrocardiography and echocardiography. Many children take diuretics such as furosemide and spironolactone on a long-term basis, which may cause electrolyte abnormalities that should be assessed preoperatively. Corticosteroids administered for 48–72 h might reduce the risk of perioperative bronchospasm. Infants with severe BPD require continuous postoperative monitoring and intensive pulmonary therapy for 24–48 h postoperatively. Risks of general anesthesia and intubation in these children can sometimes be avoided with the judicious use of either a laryngeal mask airway or a regional anesthetic.

If an infant was intubated for a prolonged period after birth, subglottic stenosis, granuloma, or tracheomalacia may be associated with stridor but can be asymptomatic. A range of smaller uncuffed endotracheal tubes should be available at the time of surgery in the event that the initial size chosen is too large.

The risk of apnea is increased in premature infants because of immaturity of central and peripheral chemoreceptors with blunted responses to hypoxia and hypercapnia, even without the additional burden of drug-induced depression. In addition, anesthetic agents decrease muscle tone in the upper airway, chest wall, and diaphragm, thereby depressing the ventilatory response to hypoxia and hypercapnia further. Although postanesthetic apnea is often brief and frequently resolves spontaneously or with minor stimulation, even brief apnea in premature infants can result in significant hypoxia. Although most apneic episodes occur within the first 2 h after anesthesia, apnea can be seen up to 12 h postoperatively.

This increased risk of apnea affects the postanesthetic care of infants born prematurely, mandating that those at risk be admitted for cardiorespiratory monitoring, including ECG, plethysmography, and pulse oximetry. This increased risk persists until infants born at less than 37 weeks gestation reach 56–60 weeks postconceptual age. A hemoglobin concentration of less than 10 g/dL increases the risk above the mean for all premature infants. Infants undergoing surgery with regional (caudal or spinal) anesthesia alone are at less risk of postoperative apnea. Former premature infants who receive prophylactic caffeine intravenously also have a lower incidence of postoperative apnea and bradycardia, but the long half-life of caffeine may delay the appearance of apnea rather than prevent it. Regardless of the anesthetic technique used, our preference is to admit all prematures with a postconceptual age less than 60 weeks to a monitored, high-surveillance inpatient unit for 24 h after surgery. Similarly, because postanesthetic apnea has been reported in full-term infants up to 44 weeks postconceptual age, infants born at

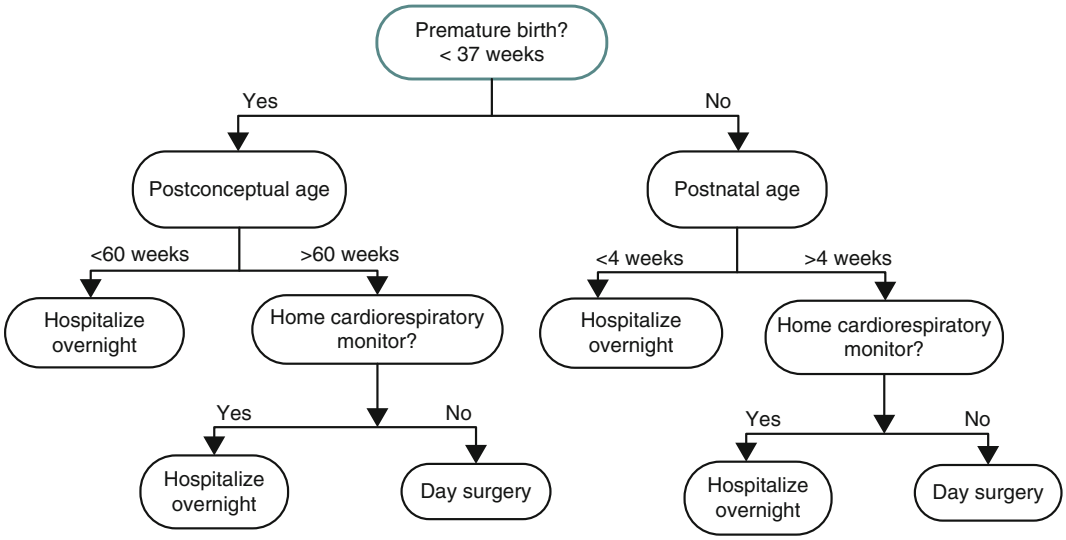

Fig. 1.1 Algorithm for eligibility for day surgery in young infants (Reprinted from Galinkin JL, Kurth CD. Neonatal and pediatric apnea syndromes. *Problems Anesth* 10:444–54, 1998, with permission)

Table 1.4 Treatment of malignant hyperthermia: "**S**ome **H**ot **D**ude **B**etter **G**ive **I**ced **F**luids **F**ast!"

Stop all triggering agents, administer 100 % oxygen
Hyperventilate: treat **h**ypercarbia
Dantrolene (2.5 mg/kg) immediately
Bicarbonate: treat acidosis (1 mEq/kg)
Glucose (0.5 g/kg) and **I**nsulin (0.15 U/kg): treat hyperkalemia
Iced intravenous fluids and cooling blanket
Fluid output: ensure adequate urine output, **f**urosemide and/or mannitol as needed
Fast heart rate: be prepared to treat ventricular tachycardia

Source: Reprinted with permission from Zuckerberg AL. A hot mnemonic for the treatment of malignant hyperthermia. *Anesth Analg* 77:1077, 1993

term must be at least 4 weeks of age to be candidates for outpatient surgery (Fig. 1.1).

Malignant Hyperthermia

Malignant hyperthermia is an inherited disorder of skeletal muscle calcium channels, triggered in affected individuals by exposure to inhalational anesthetic agents (isoflurane, desflurane, sevoflurane) or succinylcholine, resulting in an elevation of intracellular calcium. The incidence of MH in children is 1:15,000 general anesthetics, but it is important to note that nearly half of patients who have an MH episode have undergone a prior general anesthetic without complication. The resulting MH crisis is characterized by a hypermetabolic state (fever, hypercarbia, acidosis), electrolyte derangement (hyperkalemia), arrhythmias, and skeletal muscle damage (elevated CPK). This constellation of events can be lethal if unrecognized or untreated. Dantrolene reduces the release of calcium from muscle sarcoplasmic reticulum and when given early in the course of an MH crisis significantly improves patient outcomes. With early and appropriate treatment, the mortality is now less than 10 %. Current suggested therapy can be remembered using the mnemonic "Some Hot Dude Better Give Iced Fluids Fast!" (Table 1.4). It should be noted that dantrolene must be prepared at the time of use by dissolving in sterile water. It is notoriously difficult to get into solution and the surgeon may be asked to help with this process.

Patients traditionally thought to be susceptible are patients with certain muscle diseases, (Table 1.5) but many patients who develop MH have a normal history and physical examination but have a specific genetic susceptibility. In the past, patients with mitochondrial disorders have been thought to be at risk, but recent case series have concluded that anesthetic gases are safe in this population. Nevertheless, it is still recommend that succinylcholine be avoided. An occasional patient will demonstrate signs of rhabdomyolysis (elevated CPK, hyperkalemia, myoglobinuria) without having true malignant hyperthermia.

Trisomy 21

Several common attributes of patients with trisomy 21 have potential perianesthetic implications. Perioperative complications occur in 10 % of patients who undergo noncardiac surgery. Complications include severe bradycardia, airway obstruction, difficult intubation, post-intubation croup, and bronchospasm.

The risk of airway obstruction is increased by a large tongue and midface hypoplasia. The incidence of obstruc-

Table 1.5 Conditions associated with MH susceptibility

Previous episode of MH in patient or first-degree relative
Central core myopathy
King–Denborough syndrome
Other muscle diseases (Duchenne muscular dystrophy, myotonic dystrophy)—associated with MH-like episodes

tive sleep apnea exceeds 50 % in these patients and can worsen after anesthesia and surgery. Obstruction can persist even after adenotonsillectomy. Many patients with trisomy 21 have a smaller caliber trachea than children of similar age and size; therefore, a smaller endotracheal tube may be required.

Nearly half children with trisomy 21 have congenital heart disease, typically an ASD, VSD, and AV canal, and if congenital heart disease is present, they should have a cardiology consultation and recent echocardiogram.

Patients with trisomy 21 have laxity of the ligament that holds the odontoid process of C2 against the posterior arch of C1, resulting in atlantoaxial instability in 15 %. Cervical spine instability can lead to spinal cord injury in the perianesthetic period. Preoperative X-ray screening for this condition is controversial, but in the absence of an X-ray exam (sometimes performed as part of routine pediatric care or pre-participation sports physical examination), care should be taken perioperatively to keep the neck in as neutral a position possible, avoiding extreme flexion, extension, or rotation. Any patient with trisomy 21 who has neurologic symptoms such as sensory or motor changes or loss of bladder or bowel control must have preoperative neurosurgical consultation to rule out cervical cord compression.

Allergies

Documentation of allergy status is an essential part of the preoperative evaluation. Prophylactic antibiotics are frequently administered prior to incision. Antibiotic allergies, especially penicillin, ampicillin, and cephalosporins, are the most common medication allergies in children presenting for surgery. Although severe allergic reactions and anaphylaxis are rare in patients undergoing surgery, latex is still a common trigger. Such reactions can be life threatening if not diagnosed and treated promptly. Children with spina bifida (myelomeningocele), bladder exstrophy, and those who have undergone multiple surgical procedures (ventriculoperitoneal shunts) are at greatest risk for such reactions. Although the etiology is unknown, these patients may be at higher risk because of repeated exposure to latex rubber products during repeated surgeries or other procedures, such as bladder catheterization. In 1991, the FDA recommended that all patients be questioned about symptoms of latex allergy prior to surgery. The general consensus among the pediatric anesthesia community is that children in the high-risk groups should never be exposed to latex-containing products. Since 1997, the FDA has mandated that all latex-containing medical products be labeled as such. Latex-free alternatives should be used instead. It has been well documented that prophylactic medications (steroids, histamine blockers) are ineffective in preventing anaphylaxis in susceptible patients. If anaphylaxis occurs (hypotension, urticaria or flushing, bronchospasm), the mainstays of treatment are (1) stopping the latex exposure by aborting the operation, changing to non-latex gloves, and removing any other sources of latex and (2) resuscitation with fluids, intravenous epinephrine (bolus and infusion), corticosteroids, diphenhydramine, and ranitidine. Blood should be drawn within 4 h for measurement of tryptase levels, which can confirm whether anaphylaxis took place but does not identify the inciting agent. Patients should be referred to an allergist for definitive testing to identify the antigen.

Prior to Admission Medications

Children are frequently taking medications for various illnesses, both chronic and acute. Dosing of some (anticonvulsants) is adjusted to ensure adequate therapeutic levels both by serum determination and clinical end point. Administration of most medications is continued at customary doses up to and including the day of surgery as long as excessive volume or co-ingestion of solid food is not involved. An increasing number of children are being treated for behavioral and depressive disorders with selective serotonin reuptake inhibitors (SSRI) such as fluoxetine (Prozac). Due to the possibility of severe withdrawal symptoms such as severe anxiety and agitation, they should not be stopped abruptly in the perioperative period. Most of these drugs have such long elimination half-lives that unless prolonged fasting periods are contemplated; withdrawal is unlikely if only one dose is omitted. Anesthesiologists must be aware that patients are taking an SSRI because they are potent inhibitors of hepatic CYP 450 enzymes, which can result in prolonged or exaggerated effects of other drugs metabolized by the same enzyme system.

NSAIDs and Aspirin

Contrary to most other drugs, NSAIDs and aspirin should be stopped preoperatively because of their effects on platelets. Because of aspirin's irreversible binding, it should be stopped at least 10 days prior to surgery. Ibuprofen and naproxen are reversibly bound and can probably safely be continued until 2–3 days prior to surgery.

Herbal Medications

An increasing number of children are taking herbal or homeopathic medications, some of which can interact with anesthetic and analgesic drugs (St. John's Wort, kava kava, valerian) or increase the risk of bleeding (*Ginkgo*, ginseng). Many anesthesiologists advise stopping all herbal supplements for 2 weeks before a surgical procedure. Melatonin is often used to ameliorate sleep derangements associated with behavioral disorders, and many practitioners will allow it to be continued throughout the perioperative period as there are no apparent interactions with anesthetic or analgesic drugs.

Preoperative Fasting

Aside from upper respiratory infections or other acute illnesses, violation of fasting guidelines is one of the most common causes for cancelation or delay of surgeries. Preoperative fasting is required to minimize the risk of vomiting and aspiration of particulate matter and acidic liquid during the induction of anesthesia. Research done at the authors' institution has demonstrated that intake of clear liquids up until 2 h prior to the induction of anesthesia does not increase the volume or acidity of gastric contents. Our policy is to recommend clear liquids up until 2 h prior to the patient's scheduled arrival time. Breast milk is allowed up until 3 h before arrival, and infant formula is allowed until 4 h before arrival in infants less than 6 months of age and until 6 h before arrival in babies between 6 and 12 months of age. All other liquids (including milk), solid food, candy, and gum are not allowed <8 h before induction of anesthesia. In order to minimize "NPO violations," we developed a color flyer with clear rules that is provided to families at their preanesthetic visit (Fig. 1.2).

Laboratory Testing and Diagnostic Studies

For most procedures in healthy children, preoperative laboratory testing and/or diagnostic studies are not necessary. Patients with underlying diseases should have appropriate testing to ensure that they are in optimal health at the time of anesthesia:

Hemoglobin/hematocrit. At our institution, all neonates and infants less than 6 months of age must have their hemoglobin checked prior to surgery. For any procedure associated with the potential for significant blood loss and need for transfusion (tonsillectomy, craniotomy, spinal fusion), a complete blood count should be performed in the preoperative period.

Pregnancy testing. Routine screening for pregnancy in all girls who have passed menarche is strongly recommended. An age-based guideline (any girl 11 years of age or older) might be preferable. Although it is easiest to perform a point-of-care test for HCG in urine, if a patient cannot provide a urine sample, blood is drawn and sent for serum testing. Institutional policy may allow the attending anesthesiologist to waive pregnancy testing at their discretion.

Other studies. The nature of the planned surgical procedure may dictate additional studies. It is important to note that the results of any testing must be reviewed and interpreted before proceeding with surgery. Patients at risk for an occult mediastinal mass include those who are scheduled for cervical or supraclavicular lymph node biopsy due to a high index of suspicion for lymphoma and should have a preoperative chest X-ray.

Editor's Comment

We are fortunate to live in an era in which general anesthesia, especially for healthy children, is extraordinarily safe. In fact, because it involves more secure control of the airway, it is probably associated with fewer serious complications than moderate or deep sedation. Nevertheless, we should not be complacent and should instead take every case involving general anesthesia very seriously. This means a meticulous and systematic approach to preoperative preparation based on evidence-based protocols and strict attention to detail. Many institutions utilize physician extenders to perform the preoperative assessment of every patient according to strict guidelines. Children at our institution are evaluated by nurse practitioners, unless they have significant risk factors for an anesthetic or surgical complication, in which case they are also seen in the Anesthesiology Department by specially trained nurse practitioners or an anesthesiologist. Healthy children should not be subjected to phlebotomy or medical imaging unless absolutely necessary. It is useful to have very specific guidelines with clear triggers for various proposed tests. To avoid a delay or last-minute cancelation, consider obtaining a formal consultation with an anesthesiologist well in advance of the scheduled date of the operation.

Allergies are obviously important to document, but it is also clear that the majority of reported allergies are erroneous or exaggerated. This is partly due to overly anxious parents who are quick to label their children with an allergy and clinicians who are afraid of hurting a child or being held liable for inducing an allergic reaction. Falsely reported reactions prevent some patients from getting the medications they need or force clinicians to administer inferior alternatives. Moreover, the science of allergy immunology is clearly still inadequate to help us sort out

Fig. 1.2 Fasting instructions given to families at the preoperative visit

The Children's Hospital *of* Philadelphia

Pre-operative Information

Procedure date:_____ Arrival time on day of procedure: _____

IMPORTANT RULES

about Eating and Drinking before Anesthesia or Sedation

Eating and drinking before anesthesia can cause problems such as choking or vomiting during the procedure. Follow these rules exactly or the procedure will be delayed or cancelled. Supervise your children closely as many will "sneak" food. Check cars and car seats for food that may be in your child's reach.

NO Food, milk, drink, candy, or gum, after 11 pm the evening before your

YES **Clear Liquids**

Your child may drink water, Pedialyte, or clear liquids until **2 hours** before your arrival time

YES **Breast milk**

Babies may be breastfed until **3 hours** before your arrival time.

YES **Infant**

Heal thy babies less than 6 months old on day of procedure may have formula until 4 hours before your arrival time.

Healthy babies 6 to 12 months old on day of procedure may have formula until 6 hours before your arrival time.

DO NOT ADD CEREAL

these very important questions. Until better tests or preventive medications become available, we have no choice but to continue taking a careful history and using the current approach, albeit characterized by somewhat excessive caution.

When considered on purely statistical grounds, preoperative fasting guidelines are admittedly excessive and sometimes extremely frustrating (is chewing gum really equivalent to eating solid food?), but they probably need to be to avoid even a single preventable episode of aspiration and hypoxemia. This is especially true in infants with obstruction, which explains the seemingly excessive measures experienced anesthesiologists take when evacuating the gastric contents of babies with pyloric stenosis. The result of being cavalier in these situations can be the rare but horribly tragic case of a neurologically devastated child.

Suggested Reading

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Prenatal Diagnosis and Genetic Counseling

2

R. Douglas Wilson

Birth defects are increasingly being identified prenatally, allowing the pediatric surgeon to become involved before presentation in the neonatal intensive care unit. Congenital malformations are the most frequent cause of mortality during the first year of life, accounting for approximately 20 % of all infant deaths in the USA. The overall risk of birth defects for any couple undertaking a pregnancy is estimated at 3–5 %, with 2–3 % of those infants having major structural abnormalities identified prenatally and requiring evaluation and treatment as a newborn (Table 2.1). More functional birth defects and developmental changes, not recognizable as structural anomalies, can make up the additional 2–3 % by the end of the first year of life. Minor birth defects are estimated at 8–10 % but generally are not associated with significant morbidity.

The principal causes of birth anomalies are (1) chromosome abnormalities, such as microdeletion and microduplication syndromes, (2) single-gene disorders, (3) multifactorial disorders involving both genetic and environmental factors, (4) teratogenic exposure, and (5) idiopathic.

The most common prenatal diagnosis procedure is ultrasound (US), which is recommended as a routine evaluation for all pregnancies in the 18–22 weeks' gestational age range. First trimester US is becoming more common for screening of pregnancies to identify early risks for aneuploidy and structural defects, but this is not as frequently utilized as the second trimester US. The classification of fetal and birth defects has developed over the years with the Royal College of Obstetricians and Gynaecologists in the United Kingdom looking at four specific subgroups: (1) lethal anomalies, (2) anomalies associated with possible survival and long-term morbidity, (3) anomalies that may be amenable to intrauterine therapy, and (4) anomalies associated with possible immediate or short-term morbidity.

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Genetic Inheritance Mechanisms and Other Etiologies

Autosomal recessive inheritance is common as all individuals are carriers for up to five recessive genetic conditions. For common recessive conditions, the survival advantage conferred by being heterozygous is usually much more important than incidence of new mutations for maintaining the diseased gene at high frequency, the most obvious example being sickle cell disease, in which carriers are less susceptible to malaria. Heterozygotes do not usually manifest a phenotype or, if they do, it is a mild form of the disease. Affected siblings often follow a similar clinical course—more similar in fact than for many autosomal dominant disorders. Once a diagnosis of a recessive disorder is made, the parents are considered obligate carriers, and the risk of another affected child is 25 %. The healthy siblings of the affected individuals have a two-thirds risk of recessive carrier status.

Autosomal dominant diseases require a single mutant allele to be manifested and are characterized by significant clinical variability. Factors influencing this variability include penetrance, expressivity, somatic mosaicism, germline mosaicism, reproductive ability of the affected individual, new mutation rate, paternal age effect (new mutations occur with age greater than 50), and anticipation (worsening of the disease severity in successive generations). Carriers of autosomal dominant conditions have a 50 % chance of passing the condition on to their offspring.

X-linked recessive disorders usually manifest in males who are hemizygous for the X chromosome but generally not in carrier females. The exception is the rare situation in which, rather than the usual 50–50 inactivation pattern, the inactivation of one X chromosome predominates, allowing an X-linked recessive condition to be clinically expressed. Mosaicism may also occur, as in Duchenne muscular dystrophy and androgen insensitivity syndrome. When a female X-linked recessive carrier has a pregnancy, there are four possible outcomes that occur in equal proportion: normal

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Table 2.1 Congenital anomalies: classification and frequency

Classification		Frequency (per 1000)	
		Isolated	Multiple
A	Major malformations (mortality; severe morbidity)	30	7
B	Deformations (mechanical; intrinsic or extrinsic)	14	6
C	Minor malformations (limited or mild morbidity)	140	5

Source: Data from Connor and Ferguson-Smith (1993), p. 193

daughter, carrier daughter, normal son, and affected son. When an affected male initiates a pregnancy, all of his daughters will be X-linked carriers and none of his sons will be affected.

X-linked dominant disorders affect males more severely and often lead to pregnancy loss or neonatal death. When a heterozygous affected female has an offspring, there are four equally likely possibilities: normal daughter, affected daughter, normal son, and severely affected son. When an affected male has a child, the daughters will inherit the mutation with some clinical features while none of the sons will be affected.

Multifactorial inheritance is the result of environmental interactions with genetic alleles at many loci and is the cause of a large number of common birth defects, such as cleft lip and palate, congenital dislocation of the hip, congenital heart disease, and neural tube defects. The risk of the specific defect is greatest among close relatives and decreases with increasing distance of relationship. The risk is also higher when the proband is severely affected and if two or more close relatives demonstrate the defect. When there are several affected close relatives, the possibility of an autosomal dominant disorder with incomplete penetrance should be considered.

Genomic imprinting is when one allele is inactivated in utero by an epigenetic mechanism such as histone modification or DNA methylation. The imprint is maintained throughout the life of the organism. Imprints previously established are removed during the early development of male and female germ cells and thus reset prior to germ cell maturation. About 50 genes are known to be imprinted, and these genes have important roles in growth and development as well as in tumor suppression. One additional aspect of imprinting is inheritance by uniparental disomy, in which one of the chromosome pairs has been inherited exclusively from one parent. If two identical homologues are inherited, this is called isodisomy; if nonidentical homologues are inherited, this is called heterodisomy.

A trisomic zygote is then formed at fertilization and trisomic rescue with loss of the "paired" chromosome from the other parent. If uniparental disomy occurs in an imprinted region of the chromosome, this could determine a specific disease. Some diseases that are a result of an imprinting effect are transient neonatal diabetes, Russell–Silver syndrome, Beckwith–Wiedemann syndrome, Prader–Willi syndrome, Angelman syndrome, and Albright hereditary osteodystrophy.

Chromosomal mosaicism is the presence of two or more cell populations derived from the same conceptus that are genetically disparate. Mosaicism can occur prenatally or postnatally, due to mitotic nondisjunction, trisomy rescue, or a new mutation. Prenatal chromosomal mosaicism is increasingly identified by invasive prenatal diagnostic studies and is found in 0.3 % of amniocentesis specimens and approximately 2 % of chorionic villi specimens. In chorionic villi, this is usually confined to the placenta with true fetal mosaicism occurring in less than 10 % of cases. The morbidity from mosaicism is difficult to predict and may require analysis of more than one cell source from the fetus, such as amniocytes or fetal blood.

When evaluating a child with an anomaly, it is important that the appropriate terms be used so that a clear understanding of the etiology will be conveyed (Table 2.1). The causes of birth defects include multifactorial inheritance in 25 %, familial disorders in 15 %, chromosomal defects in 10 %, teratogens in 3 %, single mutant genes in 3 %, uterine factors in 2.5 %, twinning in 0.4 %, and unknown in 40 %.

The four defined terms that should be used to describe birth anomalies are malformation, deformation, disruption, and dysplasia. The term *malformation* is used for intrinsic abnormalities caused by an abnormal completion of one or more of the embryonic processes. These anomalies are usually limited to a single anatomical region, involve an entire organ, or produce a syndrome affecting a number of different body systems. *Deformations* are secondary events that can be extrinsic or intrinsic to the fetus, such as mechanical forces that alter the shape or position of a normally formed body structure. Deformations usually occur during the fetal period. Intrinsic deformations are secondary to other malformations or neuromuscular disorders. *Disruption* is a structural defect of an organ, part of an organ, or larger region of the body that is caused by an interference with or an actual destruction of a previously normally developing organ or tissue. Disruptions result from mechanical forces as well as events such as ischemia, hemorrhage, or adhesion of denuded tissues. Disruption anomalies are commonly involved with teratogen exposure. *Dysplasia* occurs when structural changes are caused by abnormal cellular organization or function within a specific tissue type throughout the body. Except for hamartomatous tumor development (hemangioma, nevi), this is usually caused by a primary defect caused by a major mutation.

Additional terms used in describing birth defects include syndrome, sequence, and association. A *syndrome* is a particular set of developmental anomalies occurring together in a recognizable and consistent pattern and known or assumed to be the result of a single etiology. A *sequence* is a pattern of devel-

opmental anomalies consistent with a primary defect but often with a heterogeneous etiology (oligohydramnios sequence). An *association* is a nonrandom collection of developmental anomalies not known to represent a sequence or syndrome that are seen together more frequently than would be expected by chance, such as the VACTERL association.

When evaluating a fetus or child, parents will want to know several things about the anomaly: the etiology, the genetics, the prognosis, the risk of recurrence in subsequent pregnancies, and what further studies might be available to better answer these questions. The history is very important and includes the family history for at least three generations, pregnancy history and exposures, neonatal history, and, if the child is older, developmental milestones and current school level. The physical examination will allow classification of the birth anomalies into the descriptive terms of malformation (multiple or isolated), deformation, and disruption. The pattern of the birth defects, both major and minor, will assist in syndrome identification as well as considering the possibilities of a sequence or an association pattern. This type of evaluation will assist in the investigations and directed diagnostic testing required (Table 2.2).

Genetic Analysis and Techniques

The screening and diagnostic techniques to evaluate the genetic status of the fetus are changing rapidly (Tables 2.3 and 2.4). Appropriate pretest counseling and maternal informed consent are required. Prenatal/genetic assessment can be considered as:

1. Screening (ultrasound; noninvasive maternal plasma cell-free fetal DNA (cffDNA))
2. Diagnostic (detailed fetal ultrasound assessment (fetal echocardiography/Doppler), MRI, invasive needle-based fetal diagnostic techniques amniocentesis/chorionic villus sampling/cordocentesis)

National guidelines/recommendations for screening and diagnosis by ultrasound have been published in 2014 by National Institute od Child Health and Disease (NICHD), Society of Maternal Fetal Medicine (SMFM), American Institute of Ultrasound in Medicine (AIUM), American College od Obstetrics and Gynecology (ACOG), American College od Radiology (ACR), Socirty of Perinatal Research (SPT), Society of Radology (SR). The practices reviewed are fetal US (first trimester, second trimester, ultrasonographic aneuploidy or structural "soft markers" in the second trimester), US in specific subgroups and conditions (obese women, twin gestation, placenta previa, placenta accreta, amniotic fluid volume), safety of ultrasound in pregnancy, and fetal MRI.

Noninvasive prenatal screening (NIPS) using maternal plasma cell-free fetal DNA (cffDNA) is becoming the primary screen or used as a secondary screen tool (after traditional aneuploidy screening by ultrasound and maternal serum analyses but before invasive testing) for fetal aneuploidy screening/assessment for trisomy 13, 18, and 21. National Societies are summarizing the use of NIPS and the precautions:

1. NIPS is not a diagnostic test and requires confirmatory needle-based invasive testing.
2. The positive predictive value of NIPS is better in high-risk populations rather than general "all risk" populations.
3. Accuracy for twin pregnancies (dichorionic twins) requires further investigation.
4. Pretest counseling for screening and subsequent diagnosis is very important (Table 2.4).

The traditional tissues required for the invasive/definitive/diagnostic analysis have not changed (amniocytes, chorionic tissue, fetal lymphocytes), but the methods to analyze the cells have become more sophisticated and detailed (Table 2.4).

Diagnostic fetal chromosome analysis is commonly performed for prenatal diagnosis when there is increased genetic risk due to screening risk, ethnicity, birth defects, multiple malformations, familial disorders, risk of neonatal mental retardation, infertility, or a history of recurrent miscarriages (Table 2.3). Cytogenetic testing requires the cells that are replicating, including blood lymphocytes, bone marrow cells, skin fibroblasts, amniocytes, chorionic villus, or solid tumor cells.

Standard chromosome analysis using staining methods (G-banding, Q-banding, C-banding) is being replaced by molecular chromosomal analysis techniques. G-banding combines the use of trypsin to denature associated proteins and a green dye. This produces the characteristic dark and light bands as seen on a standard karyotype. Q-banding uses fluorescent microscopy, while C-banding is used to enhance the centromeric regions and areas containing heterochromatin. Standard chromosome analysis can identify fetuses with trisomy 21 (1 in 800), trisomy 18 (1 in 5000), and trisomy 13 (1 in 15,000), as well as sex chromosome abnormalities such as Klinefelter syndrome 46XXY (1 in 700 males), 47XYY syndrome (1 in 800 males), 47XXX syndrome (1 in 1000 females), and Turner's syndrome 45X or mosaics (1 in 1500 females).

While still in use for chromosomal deletion and duplication screening/diagnosis, fluorescence in situ hybridization (FISH) is a sensitive and relatively rapid method for direct visualization of specific nucleotide sequences. Single-stranded DNA is annealed with specific complementary probes tagged with fluorescent markers. One of the major advantages of FISH over the standard cytogenetic techniques is the ability to recognize subtle chromosomal changes such as deletions or duplications. FISH probes are used to recognize specific microdeletions that may be suspected due to the pattern of congenital anomalies. An example of this is the 22q deletion sequence (DiGeorge syndrome or velocardiofacial syndrome).

Table 2.2 Differential diagnosis of congenital anomalies based on results of screening studies

Neck
Cystic hygroma
Isolated (sporadic)
Trisomies 21 or 18
45X
Noonan's syndrome (AR)
Hemangioma
Isolated (sporadic)
Klippel–Trenaunay–Weber syndrome
Proteus syndrome (somatic mosaicism)
Teratoma
Isolated (sporadic)
Chest
CCAM
Isolated (sporadic)
Genetic mutations reported for growth control
CPL
AR associated with pleural effusions
CDH
Isolated (60 %)
Trisomy 18, 21; tetrasomy 12p
Chromosomal deletions (15q, 8p, 8q, 4p, 1q)
Cornelia de Lange syndrome (AD, XL); craniofrontonasal dysplasia (XL)
Donnai–Barrow syndrome (AR); Fryns syndrome (AR); Matthew–Wood syndrome (AR)
Multiple vertebral segmentation defects (AR)
Jarcho–Levin syndrome (AD); Simpson–Golabi–Behmel syndrome (XL)
WT1 mutations
TEF/EA
Trisomy 18, 21
del22q11; 17qdel
VATER/VACTERL (sporadic)
Goldenhar syndrome (sporadic)
CHARGE sequence (sporadic)
OEIS (sporadic)
Feingold syndrome (AD)
Opitz syndrome (XL, AD)
AEG syndrome (SOX2 mutation)
Martinez–Frias syndrome (AR)
CHARGE sequence (sporadic)
OEIS syndrome (sporadic)
Feingold syndrome (AD)
Opitz syndrome (XL, AD)
AEG syndrome (SOX2 mutation)
Martinez–Frias syndrome (AR)
Abdomen
Gastroschisis
Isolated (sporadic)
Omphalocele
Trisomy 13 or 18
Beckwith–Wiedemann syndrome
OEIS syndrome
Cloacal exstrophy
OEIS syndrome
Bowel obstruction
Miller–Dieker syndrome; duodenal atresia; deletion 17p
Short rib-polydactyly syndrome (Type I, III—AR)
Trisomy 21 or 22
Cystic fibrosis (AR)
Fryns syndrome (AR)
Feingold syndrome (AD)
Martinez–Frias syndrome
Ascites
Perlman syndrome (AR); Fraser syndrome (AR)
Trisomy 21; 45X; alpha-thalassemia (AR)
OEIS syndrome
CHAOS syndrome
Cystic fibrosis (AR)
Infection (CMV, parvovirus, toxoplasmosis, syphilis)
Hyperechogenic bowel
Intra-amniotic bleeding
IUGR
Trisomy 21
Cystic fibrosis (AR)
Alpha-thalassemia (AR)
Infections (rubella, CMV, varicella)
Absent stomach
CDH
Trisomy 9 or 18
Tetrasomy 12p
Deletion 4p (Wolf–Hirschhorn syndrome)
VATER/VACTERL sequence
Tracheoesophageal fistula
Distended bladder
Cloacal exstrophy sequence
Megacystis-microcolon-intestinal hypoperistalsis syndrome (AR)
PLUTO (posterior urethra valves, urethral hypoplasia/atresia)
Bladder hypotonia

AR autosomal recessive, *AD* autosomal dominant, *XL* X-linked

Another advantage of FISH is that it can be applied to interphase nuclei of nondividing cells, thereby minimizing the need for cell culture. A disadvantage of FISH is that certain structural chromosome abnormalities cannot be detected with this technique.

In addition to FISH, other molecular genetic methods are used for rapid aneuploidy detection and include quantitative fluorescence polymerase chain reaction (QF-PCR) and multiplex ligation-dependent probe amplification (MLPA), which is replacing standard cytogenetics due to their sensitivity, specificity, and cost saving compared to the full karyotype if aneuploidy (large chromosome defect) testing is the primary reason for the prenatal diagnosis.

Table 2.3 Informed consent (benefit/risk) for ultrasound-guided invasive acquisition of fetal tissue for genetic and other fetal laboratory investigations

Benefit: diagnosis, possible treatment, prognosis		
Risk: spontaneous loss with no procedure; loss (added or total) for invasive acquisition technique		
1. Spontaneous fetal death (FD)/loss rate after 10 gestational weeks		
Evidence-based etiology/cause		
(a) Fetal	25–40 %	(Chromosomal; birth defect NTD/CNS, cardiac, immune/nonimmune hydrops, infection)
(b) Placental	25–35 %	(Abruption, PROM, implantation/growth issues, chorioamnionitis)
(c) Maternal	5–10 %	(Diabetes, hypertension, obesity, thyroid, renal, APA, thrombophilia)
(d) Unexplained	15–35 %	
2. Amniocentesis	Estimated total singleton procedure loss risk is 0.5–1.0 % (range 0.17–1.5 %)	
Risk of miscarriage above the estimated background rate or as the loss rate (total or at a specific GA beyond procedural related affect)		
(Related to maternal age, gestational age at procedure, indication for procedure, provider experience)		
3. CVS (TC/TA)	Estimated added postprocedure loss rate of 0.5–1.0 %	
Risk of miscarriage above the estimated background rate or as the loss rate (total or at a specific GA beyond procedural related affects)	(Total spontaneous and procedure loss rate of 1.9–2.0 %)	
(Related to maternal age, gestational age at procedure, indication for procedure, provider experience)	Total fetal loss rate for TA CVS = second trimester amniocentesis rate RR 0.9 (0.66–1.23)	
	TA 1–2 %	
	TC 2–6 %	
	(TC increased fetal loss OR 1.40 (1.09–1.81)	
4. Cordocentesis	18–24 weeks increased risk	
Total risk of miscarriage	No anomalies 1 %	
	Anomalies 7 %	
	IUGR 14 %	
	Hydrops 25 %	

Source: Reprinted with permission from Wilson RD. Fetal Hydrops: An Evidenced Based Triage, Diagnosis, and Treatment Approach. In: *High-Risk Pregnancy*: *Management Options*, *5th Edition*, ed. David James et al. Cambridge: Cambridge University Press. Forthcoming 2016

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Table 2.4 Checklist for depth of genetic analysis/information available based on techniques, infectious, and body cavity fluid analysis *Source*: Reprinted from Wilson RD et al. Prenatal Diagnosis Procedures and Techniques to Obtain a Diagnostic Fetal Specimen or Tissue: Maternal and Fetal Risks and Benefits J Obstet Gynaecol Can 2015;37(7):656–668, by permission of the Society of Obstetricians and Gynaecologists

Indication for Invasive Prenatal Testing

- ❑ *Past obstetrical history (fetal chromosomal anomaly / genetic syndrome) specify:* _____
- ❑ *Positive family history (translocation carrier; genetic carrier AR/AD/XL) specify:* _____
- ❑ *+ aneuploidy screening test (first +NT/second trimester; maternal age>35) specify:* _____
- ❑ ***Fetal anomalies identified by ultrasound imaging specify: NIFH***

_____

Depth / Complexity of Fetal Testing: Patient informed consent counselling

Genetic Complexity Level I-V

- ❑ *I. Fetal karyotype only*: for the number of chromosomes / chromosome pairs and large chromosome re-arrangements / large deletion / duplication detection

- ❑ *II. Fetal karyotype plus selected molecular deletion / duplication testing*
  Specify molecular del /dup test:
  Deletion interstitial p or q chromosome arm location
  Deletion terminal or subtelomeric location
  Duplication interstitial direct 'abab' or inverted 'abba'
  Duplication terminal or subtelomeric location

- ❑ *III. Fetal karyotype plus array CGH (comparative genomic hybridization)*
  CGH analysis with fetal anomalies identifies 6% more genetic pathology not seen by karyotype alone (additional findings vary based on anomalies)

- ❑ *IV. Fetal karyotype plus whole genome sequencing*(genome and exome sequencing)
  Recurrence of anomalies; Limited use to date for prenatal assessment but increasing neonatal use

- ❑ *V. Fetal sexing only (molecular / ultrasound)* FISH or QF-PCR for sexing

- ❑ *Other* *amniotic fluid testing*
  Genetic DNA storage (future); FISH or QF-PCR trisomy only
  Infection culture; PCR (CMV, ParvoB12, toxoplasmosis) RPR syyphilis
  Fetal lung maturity (dependent on GA)
  fetal blood testing CBC , platelets, TORCH, liver, Hb electro
  cavity aspiration lymphocyte count, albumin, culture

The whole genome can be evaluated for copy number variation (CNV), indicating that there is too much or too little of a portion of a chromosome. This is known as array-based comparative genomic hybridization (array CGH) and is able to detect small changes in the amount of chromosomal material in the fetus but with the advantage of significant less analysis time than a standard karyotype. Studies that compare chromosomal microarray with standard karyotyping for prenatal diagnosis suggest that the microarray technology identifies an additional 6 % of clinically relevant deletions and duplications in fetuses with structural abnormalities and a standard normal karyotype. The microarray does not typically identify fetal-balanced translocations or triploidy. In prenatal diagnostic cases where fetal anomalies (isolated or multiple) are identified, the prenatal diagnostic standard of care is moving to the diagnostic molecular technology.

The limitations of array CGH are that it cannot detect chromosomal defects in which the total amount of chromosome material is unchanged. Therefore, it cannot be used to identify balanced rearrangements such as reciprocal translocations, Robertsonian translocations, or inversions.

Other molecular technology such as whole genome/exome sequencing is required for certain genetic diagnostic circumstances as array CGH cannot detect point mutations or small changes in the genes as it is designed to detect syndromes caused by duplications or deletions of large amounts of chromosome material.

Chromosomal mosaicism may or may not be more identifiable depending on the level of the mosaicism. The level of the mosaicism needs to be higher than 15–30 % of the cells. The array CGH analysis will also identify "normal variants" that are not associated with pathological changes. For this reason, when prenatal or neonatal array CGH testing is undertaken, parental bloods are used to compare for the presence of these "normal" variants. Other pediatric surgery issues are important to identify and include the appropriate evaluation of prenatally diagnosed structural congenital anomalies and the need for informed consent and recommendation for fetal and perinatal autopsy in prenatally diagnosed fetal abnormalities with normal karyotype.

A good understanding of prenatal diagnosis techniques, genetic counseling issues, and birth defect terminology and etiologies will assist pediatric surgical specialists in their daily role of caring for fetuses, newborns, and children with birth defects.

Editor's Comment

Prenatal testing continues to evolve as newer and less invasive technologies are developed. Many women in the USA undergo a quadruple screen (or "quad" screen, which has replaced the triple screen) in the second trimester, a test that measures serum levels of alpha-feto=protein (AFP), unconjugated estriol, human chorionic gonadotropin (hCG), and inhibin. It is more than 80 % sensitive for neural tube defects and certain chromosomal abnormalities (trisomies 18 and 21), but has a 5 % incidence of false-positive results. A positive screen is usually followed by more detailed imaging or, in some cases, amniocentesis or chorionic villus sampling (CVS). Imaging modalities, including 3-D ultrasound and fetal MRI, have also continued to improve significantly, allowing the prenatal characterization of complex structural anomalies such as heart defects and gastrointestinal abnormalities. There are now a number of fetal diagnostic and therapeutic specialty centers where the care of the high-risk pregnant woman and fetuses with congenital anomalies can be coordinated and planned, sometimes allowing in utero intervention.

What defines a pregnancy as high risk for birth defects is somewhat variable, but usually includes women who are over 35 years of age, women who have a history of miscarriages or premature births or have given birth to a child with cardiac defects or genetic abnormalities, parents with an ethnic background associated with a high risk of certain genetic syndromes, multiple fetuses, and women with certain medical conditions (diabetes, systemic lupus erythematosus, seizure disorder). Regardless of the calculated risk of a birth defect, national groups like the American College of Obstetricians and Gynecology often recommend that all pregnant women be made aware of the prenatal screening tests that are available to them.

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Epidural and Regional Anesthesia

3

Harshad G. Gurnaney and Arjunan Ganesh

The management of postoperative pain in children has evolved into a multimodal approach, including newer drugs and advances in regional anesthetic techniques. In addition, the changes in the attitudes of physicians, nurses, patients, and families, coupled with increased pressure from external regulatory agencies and hospital administrators mandating the adequate assessment and effective treatment of pain in children, have led to the incorporation of these advances into clinical practice. It can no longer be debated whether infants and children have the capacity to feel pain or whether the experience of pain by a child can result in negative consequences. In fact, evidence is mounting that inadequately treated pain can result in harmful physiological and behavioral consequences as well as delay return to a regular diet, activity, and hospital discharge.

Although systemic opioids have long been the mainstay of treatment for postoperative pain management in children, a very important advance in pediatric pain management over the last few decades has been the recognition that the harmful side effects of systemic opiate (nausea, vomiting, constipation, ileus, sedation, respiratory depression, pruritus) can be minimized by the use of other analgesic agents and techniques that act at other targets in pain pathways. Furthermore, one of the most effective methods for reducing opiate consumption in any patient population including children, and therefore the unwanted opiate-related side effects, is the judicious use of an appropriate regional anesthetic technique whenever possible.

Advantages of regional anesthesia include site-specific analgesia, decrease in the use of opioids, superior analgesia, lowering of the hormonal stress response, and improved patient and family satisfaction. The importance and advantages of providing adequate perioperative analgesia in infants and neonates have been well described. These include minimizing the endocrine and metabolic responses associated with surgical stress and decreasing the risk of neurobehavioral changes later in childhood.

Regional anesthetic techniques used in children undergoing general surgical procedures include epidural analgesia (single injection or continuous infusion), intrathecal (spinal) analgesia, penile block, ilioinguinal/iliohypogastric blocks, and rectus sheath blocks. Most techniques used in pediatric regional anesthesia are similar to the ones used in adults. However, drug doses used have to be adjusted to body weight and pharmacokinetic differences, particularly in neonates and young infants. Also, unlike adults, most regional anesthetic techniques in children are performed under general anesthesia. Although this could increase the risk of these procedures, large prospective observational studies have demonstrated that trained anesthesiologists can safely perform these techniques. The addition of ultrasound guidance increases the precision and success rate and lowers the volumes of local anesthetic used, potentially reducing the risk of toxicity.

Based mostly on experiments in animals, there has recently been increasing concern among clinicians and parents regarding the potential risk of neurotoxicity in neonates and young infants exposed to general anesthesia. Although clinical data are currently inconclusive, there are several ongoing multicenter studies to address this issue. This has led to a renewed interest in the role of regional anesthesia as the primary anesthetic for surgery when feasible. Some of these techniques include spinal anesthesia and epidural anesthesia for procedures below the umbilicus and peripheral nerve blocks for extremity surgery.

Epidural Analgesia

In neonates, the spinal cord usually extends to the level of L3 and the dural sac to the level of S3, but they gradually recede to the adult levels of L1 and S1 during the first year of life.

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It is therefore recommended that dural punctures for intrathecal (spinal) injections be performed below the level of L3 in infants.

The epidural space is a potential space located outside the dura and contains blood vessels, fat, and lymphatics. In infants and young children, the epidural space is accessed via the sacral hiatus, which is usually easily identified and allows for single-shot injections or for continuous infusions through an indwelling catheter. The single-shot technique provides effective analgesia for surgical procedures below the level of T10.

The caudal approach to the epidural space is usually obtained with the patient in the lateral decubitus position. Using strict sterile technique, the needle is advanced cephalad through the skin at the level of the coccyx; one can appreciate crossing the sacrococcygeal membrane by a sudden loss of resistance. In case of a single injection technique, aspiration is performed to rule out intravascular or intrathecal position of the needle tip, and then a small test dose of local anesthetic combined with epinephrine 1:200,000 is injected, while the patient's EKG is monitored continuously. Abrupt changes in heart rate and ST segments or T-wave morphology suggest intravascular injection. Once proper epidural needle placement is confirmed, a larger dose of long-acting local anesthetic such as ropivacaine or bupivacaine is administered in incremental doses and can provide postoperative analgesia for over 4 h.

Continuous infusions of local anesthetics into the epidural space can be used to provide intra- and postoperative analgesia after surgical procedures performed below the level of T4. Catheters may be placed in the epidural space using the caudal, lumbar, or thoracic route. Ideally, the tip of the epidural catheter is positioned in the center of the involved dermatomes. In infants, thoracic and lumbar dermatomal analgesia may be obtained by advancing a styletted epidural catheter to the thoracic and lumbar epidural level via the caudal approach. Although this technique may be potentially safer than placing a catheter by the thoracic approach, incorrect dermatomal placement can occur. When a catheter is advanced from a caudal entry, radiographic confirmation of the catheter tip by injection of contrast through the catheter should be performed. Radiopaque epidural catheters that are now available and should help in documenting the catheter tip location without the use of contrast.

When direct access to the lumbar or thoracic epidural space is desired, the epidural space is usually identified by a loss-of-resistance technique with saline as the epidural needle is advanced gradually, usually in the midline. A catheter is then advanced via the needle up to a distance of 3–5 cm beyond the tip of the needle within the epidural space.

After a catheter is placed in the epidural space, a test dose of local anesthetic with epinephrine is administered to rule out an intravascular injection. Epidural infusions are typically started following a bolus injection in the operating room. The infusate may consist of a single agent (usually a local anesthetic) or a combination of local anesthetic and opioid or clonidine. Inpatients with continuous epidural infusions are followed closely by the pain management service, who are consulted soon after the epidural is placed in the OR. A full report including the patient's medical history, surgical procedure, location of the epidural insertion site, and medications administered via the epidural catheter needs to be communicated to the pain management service.

Postoperative monitoring of these patients includes continuous EKG monitoring, hourly respiratory rate, and 4-hourly recording of blood pressure, heart rate, mental status, and pain scores. These patients also need to be followed by a team of physicians and nurses with expertise in continuous epidural analgesia, in order that adequate analgesia is provided and complications like nausea, vomiting, pruritus, motor block, and infection at epidural site are detected and treated appropriately. When opioids are administered into the epidural space, continuous intravenous infusions of opioids should be avoided. However, additional intermittent intravenous opioids may be administered after consultation with the pain management service.

The most common problem noted with continuous epidural analgesia is inadequate analgesia due to incorrect dermatomal location and inappropriate infusion rate or solution. Mechanical problems include kinking and obstruction of the catheter, leakage, accidental displacement of catheter, and pump failure. Side effects related to opioids in the epidural infusion like nausea/vomiting, pruritus, and sedation with respiratory depression are managed with ondansetron, nalbuphine, and naloxone, respectively. Another rare but potentially serious complication is local anesthetic toxicity related to systemic absorption or accidental placement or migration of the catheter into a blood vessel. Strict adherence to epidural analgesia dosing protocols is required to avoid excessive administration of local anesthetics. The pain management team should inspect all epidural infusions and infusion pumps regularly to confirm that the correct solutions and dosages are being administered. Neonates have a higher risk of developing local anesthetic toxicity related to immature hepatic and renal function and thus decreasing the metabolism and excretion of local anesthetics. A functioning intravenous line is required in patients with continuous epidural infusions. In addition, a breathing circuit, oxygen source, and suction should be immediately available at the bedside to deal with respiratory complications.

Other complications of epidural catheter placement include epidural hematoma, epidural abscess, nerve injury, post-dural puncture headache, chronic back pain, and unintentional intrathecal injection resulting in a "high spinal." A high spinal can cause severe respiratory depression and is managed by providing supportive cardiorespiratory measures

until the effect of the local anesthetic wears off. Any suspicion of an epidural hematoma/abscess including back pain or neurological deficit should generate an immediate neurosurgical consult while concurrently performing neuroimaging studies. Post-dural puncture headache is often successfully treated using conservative measures that include rest, fluids, and caffeine. An epidural blood patch is the definitive treatment when conservative measures fail.

Spinal Anesthesia and Analgesia

Although used sparingly, a spinal anesthetic technique is useful in premature infants who are less than 60 weeks postconception and full-term infants less than 44 weeks postconception and who are having surgery below the level of T10 and decreases the incidence of postoperative apnea when no additional opioids, sedatives, or hypnotics are used. Most infants do fairly well with this technique. Also, the recent increase in concern of potential neurotoxic effects of inhalational anesthetics has resulted in a resurgence of this technique as the sole anesthetic in neonates and infants for brief procedures below the level of the umbilicus. The technique is limited by the duration, which is usually in the range of 60–90 min. Spinal anesthesia is also a useful technique in children undergoing muscle biopsy, particularly in those having a higher risk of developing malignant hyperthermia.

Spinal analgesia using intrathecal morphine can be used for operations of the lower extremities, abdomen, and thorax. A single intrathecal injection of morphine 5 μg/kg can provide analgesia for about 12–24 h. Although respiratory depression with this dose is rare, other side effects like pruritus and nausea or vomiting are more common. These side effects are dealt with in the same manner as those seen with epidural opioids.

Penile Block

Penile nerve blocks can be effective as the sole anesthetic technique for circumcision or to provide postoperative analgesia following circumcision or distal hypospadias surgery. Several techniques have been employed. The simplest technique is to perform a ring block around the base of the penis while taking care to avoid the subcutaneous veins. The penile nerves may also be blocked in the subpubic area using the technique described by Dalens. Using a long-acting local anesthetic like bupivacaine or ropivacaine helps to prolong the period of postoperative analgesia. Complications from penile blocks include hematoma formation and intravascular injection.

Ilioinguinal and Iliohypogastric Block

Ilioinguinal and iliohypogastric nerve block is commonly performed for inguinal hernia repair. The nerves lie between the internal oblique and the transversus abdominis muscle about 1–2 cm medial and cephalad to the anterior superior iliac spine. Although the block is still performed using the double-pop technique (representing the popping of the needle through the external oblique aponeurosis and the internal oblique muscle), ultrasound increases the success of the block and allows the use of smaller quantities of local anesthetic compared to the double-pop technique. Complications of this block include hematoma and intraperitoneal or intravascular injection.

Rectus Sheath Block

The rectus sheath block provides effective intra- and postoperative analgesia following umbilical hernia repair and other midline abdominal procedures. The 9th, 10th, and 11th thoracic nerves are blocked bilaterally by infiltrating local anesthetic between the posterior rectus sheath and the rectus abdominis muscle. This technique is usually done using a short bevel or a blunt-tipped needle and feeling the pop through the anterior rectus sheath and advancing the needle further until the resistance of the posterior rectus sheath is met. At this point local anesthetic is infiltrated. Ultrasound guidance is being used more and more to precisely guide the needle to the target to ensure a higher level of success and also to accomplish the block with a smaller amount of local anesthetic.

Editor's Comment

The vast majority of surgical procedures performed in children are performed under general anesthesia. Properly performed regional techniques, such as epidural analgesia and regional blocks, can be very effective and reduce the need for systemic narcotics, decrease the physiologic stress response, and provide lasting postoperative pain relief in these patients. The key, however, is accurate placement. This can be difficult to achieve, especially given that these procedures are technically demanding, require a great deal of experience, and are often placed when the child is already under general anesthesia, removing an element of feedback that is usually available when placed in adults.

When used as part of a postoperative enhanced recovery protocol after major bowel surgery, thoracic epidural catheters through which local anesthetics are infused instead of

opioids postoperative pain relief probably reduce postoperative ileus and shorten hospital stay. Children with lumbar epidural catheters not only can have a prolonged ileus, but they usually require a Foley catheter and often have lower extremity weakness, which delays ambulation. In addition, the success rate of epidural analgesia is variable and disappointing. When they fail, the children suffer and the parents become frustrated and angry. There needs to be an aggressive and rapidly instituted back-up plan, including the use of intravenous narcotics or anxiolytics.

It might be true that a well-placed and expertly managed epidural catheter can help avoid some of the negative sequelae of systemic opioids as traditionally administered, but it is probably also true that most children can be safely and effectively managed with patient-controlled or intermittent intravenous opioids administered as needed. This is only possible, however, if we use intravenous narcotics in the dosage and frequency necessary to keep the patient comfortable (most tend to use doses that are too small at intervals that are too long): continuously monitor vital signs; avoid continuous intravenous infusions, which tend to prolong the ileus and cause excessive sedation and respiratory depression; use intravenous acetaminophen, nalbuphine, or ketorolac starting on POD 1 or sooner; and advance diets early to allow rapid transition to oral narcotic analgesic medications, which provide much longer and more uniform pain relief with fewer side effects. If an epidural catheter is in place, weaning it should start on POD 1 and the catheter removed by POD 2 or 3 to avoid side effects that tend to prolong recovery.

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Enteral Nutrition and Access

4

Daniel P. Doody and Allan M. Goldstein

Pediatric surgeons play an important role in managing the nutritional needs of their patients, working collaboratively with the nutritionist, neonatologist, intensivist, and gastroenterologist to ensure that the specific needs of the surgical infant or child are met. Although the clinician has the opportunity to provide nutrition intravenously when needed, enteral access is always preferred when possible. Enteral nutrition is more physiologic, is associated with lower cost, and avoids the complications associated with parenteral nutrition, including local and systemic infection, hepatic dysfunction, vascular complications including thrombosis and septic thrombophlebitis, and mechanical complications of intravenous access devices. Simple enteral access, particularly if indicated for a short period of time (<4 weeks), can be provided by feeding tubes passed through the nose or mouth. Placement of these tubes is generally straightforward and easily performed. Moreover, the gastric reservoir will tolerate bolus feedings and stimulate the pancreatico-hepatobiliary axis. If the stomach is not an appropriate site for enteral feedings, transpyloric tubes (nasoduodenal or nasojejunal) may be used. These are often indicated in the setting of gastroparesis, significant gastroesophageal reflux, or poor airway protection. Placement can be challenging and sometimes requires endoscopic or radiographic assistance. Transpyloric tubes are not ideal long-term solutions as the tip frequently migrates back into the stomach. Surgical approaches for neonates or children requiring chronic enteral access may also be needed.

Nutritional Requirements

Breast milk and standard infant formula are designed to provide sufficient calories, protein, and fat for normal growth and development. A well-balanced formula contains approximately 50 % of calories as carbohydrate, 35 % as fat, and 15 % protein. The younger the child, the greater are the energy requirements to maintain normal growth (Table 4.1). Basic caloric requirements are estimated to be 2.5–3-fold greater in young children as compared to adults. Weight gain, which represents a simplistic global assessment of adequate caloric intake, should be between 20 and 30 g daily for full-term infants and 10–20 g daily for preterm infants. However, it is important to remember that while underfeeding is undesirable, overfeeding also has adverse sequelae. Too much carbohydrate intake can lead to osmotic diarrhea and overproduction of CO_2, complicating ventilator management. Therefore understanding a child's nutritional needs is critically important to maintaining proper growth and development and optimizing substrate availability in the hospitalized and critically ill child.

The protein in standard infant formulas is most commonly derived from cow's milk. These formulas typically contain more casein protein than whey protein, which is the predominant protein in breast milk. While lactose intolerance is rare in children under the age of 4 years, cow's milk protein allergy is common, usually presenting with irritability, abdominal distention, vomiting, hematochezia, or diarrhea 30–120 min after feeding. If the clinician is concerned about a cow's milk protein allergy, changing to a soy protein-based formula would not be appropriate. Rather, protein hydrolysate formula and elemental formula would be better. Soy formula is indicated for infants and children with galactosemia (1:30,000–60,000 births). The carbohydrate source is sucrose and corn syrup, which are tolerated in patients with galactose-1-phosphate uridylyltransferase (GALT) deficiency. Soy-based formula can also be used if the parents prefer a vegan diet, but not in preterm infants as osteopenia can occur.

Specialized formulas are available for specific clinical settings (Table 4.2). Infants and children with chylous ascites, chylothorax, or long-chain 3-hydroxyacyl-coenzyme A dehydrogenase (LCHAD) deficiency benefit from a formula enriched in medium-chain triglycerides (MCT). These formulas, which contain 80–87 % MCT as the fat source, are beneficial because MCTs are absorbed across the brush border and transported to the liver through the portal circulation, without requiring transport in the lymphatics. Some MCT-enriched formulas are specifically designed for infants, while others are nutritionally more appropriate for older children and adults based on vitamin and protein content. Patients with pancreatic insufficiency, cystic fibrosis, fat malabsorption, or short bowel syndrome might also benefit from a MCT-enriched diet.

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Table 4.1 Calorie and protein requirements

	Calories (kcal/kg/day)	Protein (g/kg/day)
Premature infants	120	3.0–4.0
Infants (0–1 year)	100–110	2.0–3.0
Children (1–10 years)	70–100	1.0–1.3
Adolescents (>10 years)	40–55	0.8–1.0

Table 4.2 Choosing the right formula for infants

Infant formulas	Trade names[a]	Protein	Carbohydrate	Indications
Standard	Similac Advance	Cow's milk	Lactose	
	Enfamil Premium			
Soy	Abbott Isomil	Soy	Sucrose	Galactosemia
	Enfamil ProSobee		Corn syrup solids	Vegan diet
	Gerber Good Start Gentle Plus			Congenital lactase deficiency (rare)
				Severe diarrheal illness
Predigested	Enfamil Nutramigen Lipil Abbott Alimentum Advance Enfamil Pregestimil Lipil	Oligomeric	Sucrose	Milk protein allergy
Elemental	Abbott EleCare	Amino acids	Corn syrup solids	Milk protein allergy
	Nutricia Neocate			
	Enfamil Nutramigen			
MCT-enriched	Mead Johnson Enfaport	Cow's milk	Corn syrup solids	Chylothorax
				Chylous ascites
				LCHAD deficiency

[a]Formulas listed represent selected examples only. Other formula options are available

LCHAD long-chain 3-hydroxyacyl-CoA dehydrogenase, *MCT* medium-chain triglycerides

Premature Infants

Breast milk is the ideal food for newborns. Not only does it provide sufficient macronutrients and electrolytes for normal growth, but it has also been shown to be beneficial for immune function and neurodevelopment. In premature infants, the use of breast milk lowers the incidence of necrotizing enterocolitis. Mothers of premature infants should be encouraged to store their milk and to maintain their supply. When maternal breast milk is not available, donor breast milk should be considered. This exceptional nutrient source can be fortified if necessary with powdered formulas to increase caloric density.

When breast milk is unavailable, one needs to consider that premature infants have different nutritional requirements than term infants. Preterm formulas have a greater concentration of calories, protein, calcium, and phosphorus. Preterm infants are relatively deficient in bone density compared to term infants and the supplemental nutrients help to diminish the risk of osteopenia and osteomalacia. Standard premature infant formula preparations provide 22–24 kcal/oz, as compared to standard infant formulas, which provide 20 kcal/oz. A greater portion of fat provided in the preterm formula is comprised of MCTs to compensate for a limited bile salt pool.

At our center, we introduce intermittent trophic feedings within 24 h of life, even in extremely premature infants (24–26 weeks gestational age), if they are otherwise stable. Contraindications to starting trophic feedings include severe acidosis or hemodynamic instability requiring vasopressor support. The presence of an umbilical arterial or venous line, mechanical ventilation, or a hemodynamically insignificant patent ductus arteriosus does not preclude initiation of trophic feeding. Depending on the weight of the infant, we start with 10–30 mL/kg/day (10 mL/kg/day if weight <1250 g; 20 mL/kg/day if weight 1250–1800 g; 30 mL/kg/day if weight >1800 g) given as bolus feedings every 3 h. This small quantity of nutrition in the GI tract is considered trophic, but could more aptly be referred to as "medication for the gut" as it minimizes villous atrophy, stimulates release of enteric hormones, promotes intestinal perfusion, enhances the mucosal barrier, and improves overall gut function. We continue trophic feedings for the first few days of life before slowly advancing the rate, depending on the infant's weight and clinical condition. Feedings in preterm infants are not rapidly advanced to full feedings but rather are gradually

increased in volume over the first 7–10 days of life, remaining vigilant for signs of ileus or necrotizing enterocolitis.

Oral feeding is the goal for all infants. However, premature infants less than 34 weeks gestation do not generally have a mature and coordinated suck and swallow. Feedings must therefore be provided enterally by gavage, either as bolus feedings every 2–3 h or continuously by feeding pump. We favor the nasogastric route unless the infant is on nasal CPAP. Most infants develop an ability to feed orally by 34 weeks gestational age, and gavage feeding is almost invariably necessary to provide enteral nutrition in the extremely premature infant. Oral aversion can be a late consequence, characterized by thrusting the tongue, turning the head away, or pooling milk in the mouth. The prolonged absence of oral stimulation in infants who are unable to be fed orally or excessive oral stimulation such as occurs with mechanical ventilation can lead to an orally averse child. Encouraging oral stimulation is important even if the infant relies on tube feedings. Early involvement of a speech therapist or feeding team is often helpful in interrupting what can be a long-term feeding problem.

Short Bowel Syndrome

Pediatric short bowel syndrome, defined as insufficient intestinal length to achieve adequate nutrient absorption, can be a catastrophic consequence of necrotizing enterocolitis, midgut volvulus, extensive inflammatory bowel disease, jejunoileal atresia, gastroschisis, or very long-segment intestinal aganglionosis. A combination of parenteral and enteral nutrition is used in the treatment of patients with short bowel syndrome. Unfortunately, infants are particularly susceptible to parenteral nutrition-associated liver disease (PNALD), which may be ameliorated by transition to enteral feedings. Unfortunately, the injury associated with the cholestasis created by long-term parental nutrition can lead to chronic, progressive liver disease and hepatic failure.

Early enteral nutrition promotes intestinal adaptation in patients with short bowel syndrome. It is unlikely that hepatic dysfunction will be completely avoided, as liver injury can be identified with even short courses of parenteral nutrition (>14 days). Nonetheless, intestinal adaptation is the ultimate goal, with eventual transition to full enteral feeding when possible. Trophic feedings should be initiated within 24–48 h of surgical treatment. Initially, continuous feedings in infants and children with short bowel syndrome are better tolerated than bolus feedings, although transition to bolus feedings is appropriate when 50 % of daily nutrition can be tolerated enterally. Feedings should advance if the patient is not experiencing vomiting (>3 times/day) and stool volume remains less than 50 mL/kg/day.

With initiation of enteral feedings, watery diarrhea in excess of the enterally administered volume is a common complication. Gastric hypersecretion is an early physiologic response to extensive small bowel resection and treatment of this complication of short bowel syndrome includes H_2 antagonists or proton pump inhibitors. Antimotility agents, including loperamide, diphenoxylate with atropine, and even opioid-based drugs (codeine, morphine, paregoric tincture of opium), can be used to slow the intestinal hypermotility associated with the increased osmotic load, likely fat malabsorption, and gastric hypersecretion. Choleretic diarrhea may be seen after extensive resection of the ileum as bile salts enter and irritate the colonic mucosa. This diarrhea may be lessened by the addition of abile salt-binding agent such as cholestyramine.

The clinician needs to be aware of the long-term problems associated with vitamin, particularly fat-soluble vitamin, malabsorption in infants, and children with chronic short bowel syndrome. Supplemental vitamins and trace elements may need to be provided enterally or parenterally if enteral supplementation is insufficient. Even with aggressive medical management of short bowel syndrome, introduction of enteral feeding requires strict measurement of input and output, adjustments of feeding schedules, and frequent formula modifications, as some children may need a component-based formula with amino acid substrate and a higher concentration of MCT as a fat source.

The Critically Ill Child

The resting energy expenditure of the otherwise healthy child with surgical or medical illness approximates the energy expenditure of the healthy active child. The normal calorie, protein, and fat requirements are not significantly changed. However, certain injuries and metabolic states do increase the catabolic response and energy requirements in children. Children with severe burns, sepsis, or closed head injury with traumatic brain injury have especially higher energy requirements. In those instances, the basal metabolic rate may be increased by 150–200 % of predicted and the clinician needs to deliver this additional energy either parenterally or enterally.

The malnourished child is also at increased risk for morbidity during acute illness. In critically ill children, malnutrition is associated with increased risk-adjusted mortality as well as prolonged ICU length of stay. With the goal of initiating enteral nutrition early in the ICU, the clinician frequently finds that the ideal way of judging a patient's ability to tolerate feedings is an uncertain science. Gastric residual volume is a common variable used to determine tolerance of enteral nutrition. It should be stressed that a single high gastric residual volume is not a reason to stop enteral feedings, while repeated high residuals may indicate delayed gastric

emptying. Specific residual volumes (>5 mL/kg or >50 % of the volume fed) have not been rigorously shown to place the patient at increased risk of vomiting or aspiration. Evidence suggests that the risk of aspiration is similar with small or moderate residuals and therefore holding feedings unnecessarily interrupts enteral nutrition support. While a potentially important variable, gastric residual volume by itself should not stop feeding without additional clinical information. In some centers, gastric residuals are felt to be such an impediment to continuing enteral feeding that some authors argue they should not even be measured. While many intensivists favor holding feedings based on gastric residual volume, others feel that continued feeding in the face of a high gastric aspirate is tolerated, does not significantly increase aspiration risk, and may shorten hospital stay.

We prefer to use gastric residual volume data in combination with clinical signs and symptoms (vomiting, abdominal distention, diarrhea, evidence of aspiration) to determine if enteral nutrition should be adjusted. If the measured gastric residual volume remains consistently high, we consider adding a prokinetic agent or passing a transpyloric tube. Without evidence-based data, it is difficult to determine which approach is best. However, it appears that a protocolized approach to enteral nutrition in the ICU results in more consistent care of critically ill infants and children and leads to better outcomes.

Enteral Access

When the oral route is unable to be used for enteral nutrition, alternate methods of access need to be considered. Which method is best depends on the child's clinical condition, the underlying disease process, and the anticipated duration of need. Choosing the best mode of enteral access for a given patient requires an understanding of the risks and benefits of each approach (Table 4.3). Temporary access is most easily achieved with an NG or transpyloric feeding tube. These tubes are easily placed and can be used for up to 1–2 months. However, they carry the risk of irritation or even erosion of the nostril, sinusitis, and gastroesophageal (GE) reflux. While bolus feedings can be administered through a NG tube, transpyloric tubes require continuous feedings but may benefit patients with severely delayed gastric emptying, gastroesophageal reflux disease (GERD), or poor airway protection.

The surgeon is consulted when reliable long-term enteral access is needed for nutrition or administration of medications. The need for chronic enteral access may be due to underlying diseases such as congenital heart disease, chronic newborn lung disease, cystic fibrosis, or chronic renal failure. Children requiring specialized diets that are unpalatable may also benefit from feeding access. Severe dysphagia or oropharyngeal discoordination in a neurologically impaired child or in a child with a severe craniofacial anomaly may greatly complicate oral feeding and be an indication for surgical enteral access. There are occasional pediatric patients with such profound gastric dysmotility or severe refractory GE reflux that jejunal access may need to be considered. Children who have failed multiple fundoplications, usually children with severe neurological impairment, could also benefit from jejunal feeding. Finally, children with chronic failure to thrive, often without an identified etiology, often need definitive enteral access.

4.1.1 Gastrostomy

Long-term enteral access can be achieved by a gastrostomy tube (GT), jejunostomy tube (JT), or gastrojejunostomy (GJ) tube. Feeding the stomach, as opposed to the small intestine, has several advantages. Gastric feeding is more physiologic and thus leads to normal stimulation of pancreatic and biliary secretions. Additionally, bolus feedings can be administered into the stomach, whereas continuous feedings must be used in the small bowel, leaving a child attached to a pump for most of the day. Prior to placing a GT, one should consider whether a fundoplication is indicated. In the neurologically impaired child with reflux and poor airway protection, surgeons have traditionally advocated for concomitant fundoplication. Based on recent data and our own experience, we do not routinely perform a fundoplication in these patients,

Table 4.3 Choosing the best route for enteral access

	Benefits	Risks
Nasal route (NG/NJ)	Bedside procedure	Sinusitis
	Anesthesia not required	Nasal septum erosion
		Limited to <4 weeks duration
Gastric access (NG/GT)	Ability to bolus feed	Exacerbation of GERD
	More physiologic	Not effective with severe gastroparesis
		Aspiration pneumonia
Jejunal access (NJ/GJ/JT)	Okay with severe GERD or DGE	Tube displacement (NJ and GJ)
		Requires continuous feedings

DGE delayed gastric emptying, *GERD* gastroesophageal reflux disease, *GJ* gastro-jejunal, *GT* gastrostomy tube, *NG* nasogastric, *NJ* nasojejunal, *JT* jejunostomy tube

although we explain to the family that a fundoplication may become necessary in the future. In children with significant GE reflux based on symptoms or objective testing, a fundoplication should be seriously considered at the time of GT insertion. Many pediatric surgeons routinely obtain a preoperative upper GI contrast study prior to GT placement. Recent evidence does not support this practice and we no longer recommend it.

GTs can be placed open, laparoscopically, endoscopically (percutaenous endoscopic gastrotomy (PEG), or percutaneously under fluoroscopic guidance. All of these approaches are acceptable, although we favor the laparoscopic technique as it allows safe and precise placement of the tube through the anterior gastric antrum along the greater curve, avoiding the occasional overlying transverse colon. This position minimizes distortion of the angle of His and permits future fundoplication if needed usually without the need to reposition the gastrostomy. While PEGs are generally safe and minimally invasive, they are associated with a 1–2 % risk of colon or liver injury, particularly in older children and young adults, in whom the abdominal wall is thicker and visualization of the liver border may be more difficult. The position of the tube on the stomach wall is also less predictable, potentially exacerbating reflux and chronic discomfort at the site.

In the laparoscopic approach, we place two ports, with the camera at the umbilicus and a grasper at the site of the planned GT. The anterior stomach wall is grasped with 2-0 PDS sutures on either side of the future GT site. These sutures are passed through the anterior abdominal wall, anterior wall of the stomach close to the junction of the body and antrum of the stomach, and back out through the anterior abdominal wall. In larger children with thicker abdominal walls, T-fasteners can be used.

Next, after the anesthesiologist has insufflated the stomach with air via an orogastric tube, a Cook Dilator Set (Model G10397) is used to place a needle and wire into the stomach. The tract is sequentially dilated over the wire until the 20 Fr. dilator is passed. The gastrostomy appliance is placed over the wire. If practical, we prefer to use a gastrostomy button, with the length based on measuring the thickness of the abdominal wall. The 8 Fr Cook dilator is placed through the gastrostomy device to stiffen it and allow it to be advanced over the wire. The PDS sutures are tied down over the GT button. Feedings can be initiated 6 h after the procedure and the "holding stitches" removed the following day. We typically do not use endoscopy for this procedure, but this can be added as an adjunct to facilitate gastric insufflation and visualization. In children <2.5 kg, we prefer to do an open gastrostomy, placing a Malecot tube, which can be replaced with a low-profile gastrostomy button once the tract is mature and the infant or child is large enough to accommodate the balloon in the gastric lumen.

The most common complications of gastrostomy devices include the development of granulation tissue and accidental tube dislodgement. Granulation tissue is very common and can lead to discomfort at the site, drainage, and bleeding. The granulation tissue can be treated with chemical cauterization using silver nitrate. Alternatively, triamcinolone cream can be applied to the tissue 2–3 times daily for 10–14 days. If the tube falls out, it needs to be replaced immediately, as the opening can close quickly and require dilation of the tract. Following replacement of the tube, especially if it falls out within the first few weeks of placement, proper position should be confirmed either by aspirating gastric contents or by performing a contrast study through the tube.

4.1.2 Jejunostomy

Jejunal feedings are generally reserved for children who have failed gastric feeding, often because of severe GERD or markedly delayed gastric emptying. Jejunal feeding is less physiologic than gastric feeding and does not allow for bolus administration of feedings. Two options exist for jejunal feeding, JT or GJ tube. A GJ tube can be positioned through an existing gastrostomy site either endoscopically by a surgeon or gastroenterologist or fluoroscopically by an interventional radiologist. Primary placement of a GJ with laparoscopy alone is difficult, as navigating a thin tube through the pylorus, around the C-loop of the duodenum, and into the proximal jejunum is not easily performed with this technique. Primary GJ tube placement therefore usually needs to be performed as an open procedure or with an adjunct like fluoroscopy or endoscopy.

The benefits of a GJ tube include the ability to position it without requiring general anesthesia and the potential to decompress the stomach while simultaneously feeding the jejunum. Common drawbacks, however, include the risk of clogging the lumen of the long jejunal limb and the frequent migration of the jejunal portion of the tube back into the stomach, necessitating replacement.

We favor placement of a primary JT in those patients who cannot tolerate GT feedings and will require prolonged enteral access with the expectation that gastric function will not recover for some time. Several operative techniques exist, including the standard Witzel tube, direct insertion into the small bowel, or a Roux-en-Y jejunostomy (Fig. 4.1). These are associated with multiple risks, including narrowing of the intestinal lumen, intussusception, volvulus, leakage, and anastomotic dehiscence.

In order to limit the potential complications associated with traditional JT procedures, our preferred approach is to create a "chimney" jejunostomy (Fig. 4.2). The procedure starts laparoscopically, with an umbilical port for the laparoscope and two additional ports, one in the right mid-

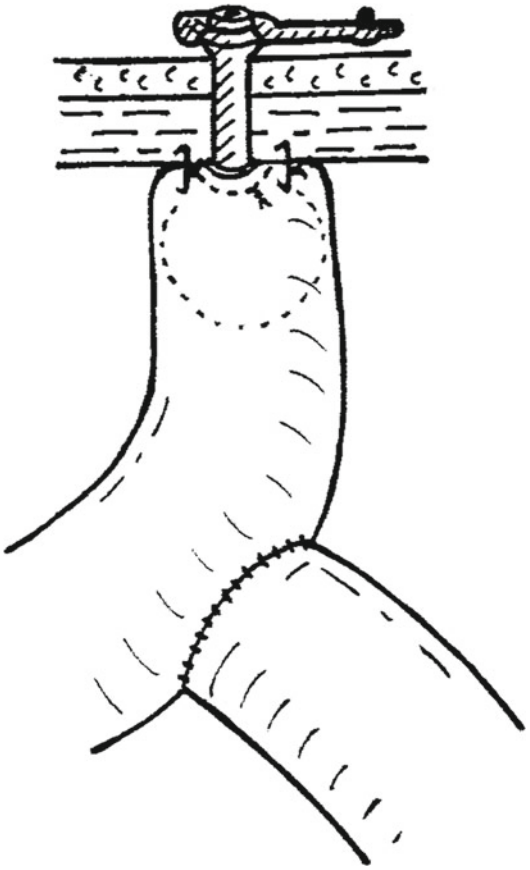

Fig. 4.1 Roux-en-Y feeding jejunostomy. After dividing the proximal jejunum, the proximal end is sewn end to side to the distal limb, and a low-profile gastrostomy button is placed into the open distal limb of the jejunum (Courtesy of Lily Cheng, MD, University of California San Francisco, Department of Surgery)

abdomen (at the site of the planned JT) and the other in the mid-epigastrium. A segment of proximal jejunum is selected and a marking stitch placed. The epigastric port site is extended to a 2 cm vertical incision and the marked segment of bowel folded on itself. An antimesenteric enterotomy is made and a stapler is used to join together the two limbs into a common reservoir which can accommodate the JT balloon without obstructing the flow of enteral contents. After a purse-string suture is placed, the proper size button device is introduced through the right-sided port site and advanced into the enterostomy. The balloon is inflated and the purse string secured. The jejunal limb is secured to the anterior abdominal wall and the midline fascia is closed. Feedings are started the following day.

Summary

Pediatric surgeons must have a solid understanding of the nutritional needs of their young patients and how those needs change based on the child's age and their overall condition. The importance of maintaining adequate enteral nutrition in children cannot be overestimated.

Meeting the nutritional requirements of surgical patients with unique needs, such as short bowel syndrome, critical illness, or chylous ascites/chylothorax, is critical and the pediatric surgeon also plays an especially important role in managing these conditions. Finally, the pediatric surgeon plays a central role in determining the optimal means of accessing the gastrointestinal tract in children unable to achieve adequate enteral nutrition orally.

Editor's Comment

Ensuring that your patients are adequately nourished is critical to maintaining good surgical outcomes. It is critical that institutions develop evidence-based protocols to ensure minimal disruption and variation. A PEG is an acceptable option when done under laparoscopic guidance. There is no reason to do a PEG blindly and risk a liver or colon injury. PEGs are less appealing for most families because there is a long-stemmed, stiff tube present on the abdominal wall for 2–3 months. And removal of a PEG at the first tube change is traumatic for the child. The Malecot tube is not stable because it does not have a balloon and is thus prone to dislodgement. If an open G-tube is necessary, a long-stemmed, balloon-tipped G-tube is a much better alternative.

The child with functional intestine who needs supplemental nutrition should be given enteral feedings. This can be by nasogastric, nasoduodenal (post-pyloric), or nasojejunal tube or by gastrostomy, gastrojejunostomy, or jejunostomy tube. This is preferable to parenteral nutrition because of the lower risk of hepatic dysfunction, DVT, and line sepsis. Feedings are usually given as gastric boluses, which are thought to be more physiologic, though children tolerate continuous feedings well and can be more practical. Giving bolus feedings during the day and continuous at night is often more convenient for parents, and the night feedings allow more calories to be given. The disadvantages of continuous feedings include the need for a pump, being tethered by the feeding tube, and the risk of formula spoilage.

Some like to overcomplicate the process of advancing feedings with elaborate rules and restrictions that border on superstitions (gastric residuals, abdominal girth). Enteral feedings are usually advanced very gradually in preemies because rapid feeding advancement might provoke NEC. For most other children, feedings can be advanced as tolerated, meaning without pain, reflux, or diarrhea. Which formula, how much, and by what route should be agreed upon and then feedings started at one quarter to one half of the goal rate. Some prefer to start with a glucose-electrolyte solution or diluted formula, but these should be switched to an appropriate full-strength formula as soon as possible. Advancing

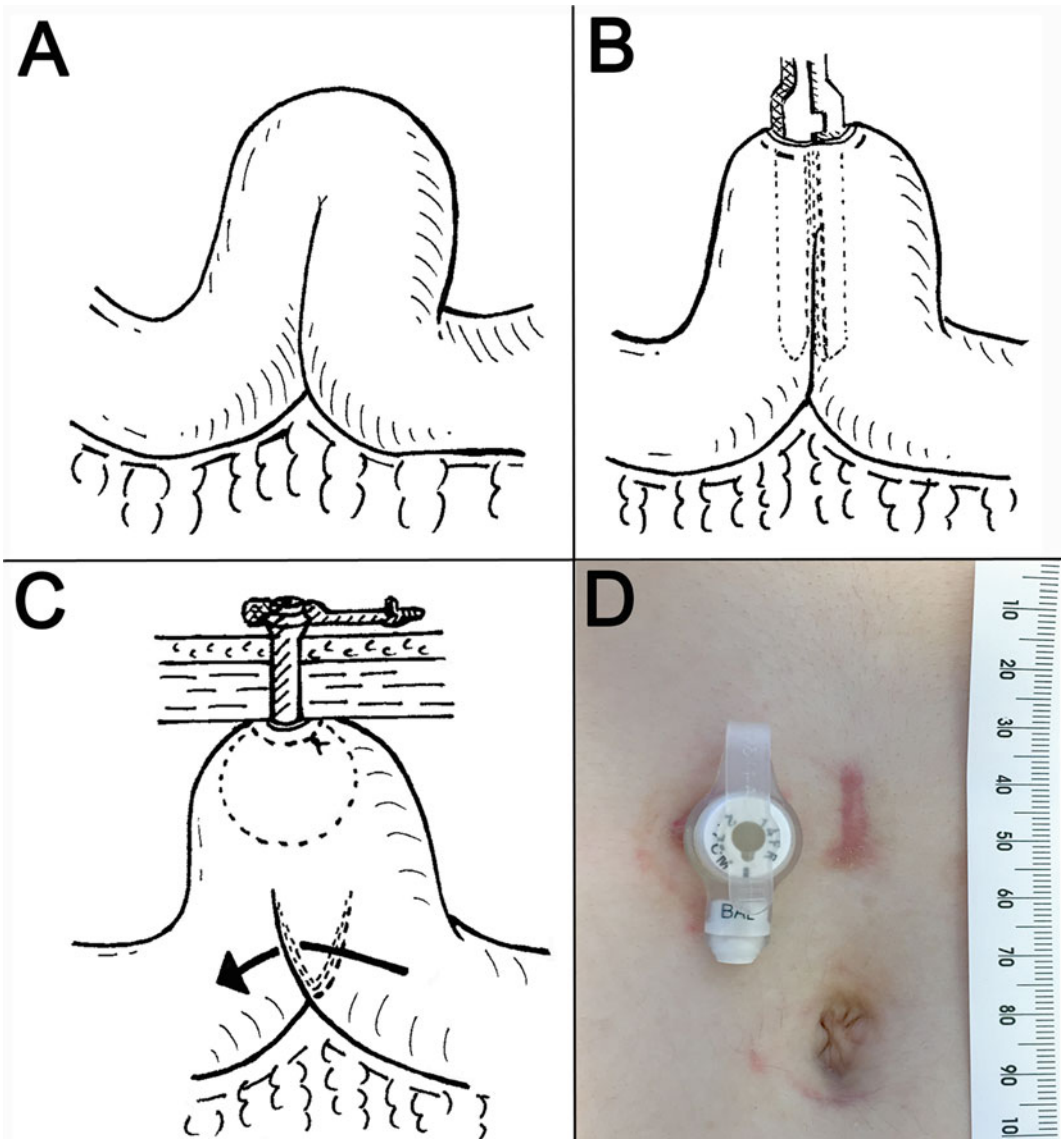

Fig. 4.2 "Chimney" jejunostomy. A portion of proximal jejunum is selected (**a**) and a stapler deployed through an antimesenteric enterotomy (**b**), creating a reservoir that can accommodate a balloon-type button and allow easy passage of enteral contents (**c**). The procedure is performed with laparoscopic assistance and a short vertical midline incision, as shown in this teenage patient (**d**, ruler on right in centimeters) (Courtesy of Lily Cheng, MD, University of California San Francisco, Department of Surgery)

all the way to goal volume with anything other than formula makes little sense, except perhaps in the rare case of the child who is at risk for dehydration and has no intravenous access. In infants, the goal rate for hydration is about two thirds of the goal for calories. A reasonable regimen is to start with one third volume feedings and then advance to two thirds and then full feedings every 8, 12, or 24 h, depending on how quickly the child is expected to tolerate it.

About half of goal volume can be given at night as continuous feedings. The key is that the child must be assessed for reflux, discomfort, abdominal distension, and watery diarrhea at every step. It is dangerous to put the schedule on autopilot. Gastric residuals and abdominal girths are generally not very useful in assessing feeding tolerance. Children with intestinal failure or gastroschisis are at risk for malabsorption and do not tolerate rapid feeding advancement. It is useful to start with continuous feedings and then gradually consolidate the feedings into boluses after full volume is achieved. Many start with a very small rate (5 mL/h or less) and then advance by 1 mL/h/day, as long as stool output is less than 15 mL/kg/shift (45 mL/kg/day). More than this and fluid and electrolyte abnormalities become difficult to manage. If there is profuse diarrhea, feedings should be stopped for at least 8 h and then restarted at the last rate that was tolerated. Children with proximal high-output stomas can be re-fed the effluent through a mucous fistula, in which case the only output that matters is

the actual (more distal) stool output, but this can be extremely difficult and labor intensive for bedside providers.

Suggested Reading

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Parenteral Nutrition

5

Amy Hood and Susan S. Luskin

Parenteral nutrition (PN) is an important tool for the pediatric surgeon and should be considered only when the enteral or oral routes are not available. For a malnourished, undernourished, or at-risk patient (many neonates), PN should be initiated in as soon as 2–3 days without food intake; in contrast, one may wait as long as 7 days in a well-nourished teenager or older child. For the malnourished patient, PN may be considered for 1–2 weeks in preparation for elective surgery since a well-nourished patient is less likely to have fewer complications and infections and more likely to recover without negative surgical outcomes. The goal of perioperative PN is to minimize the adverse effects of catabolism, which is a natural reaction to stress and inflammation, and to promote wound healing. The goal of long-term PN is to promote proper growth and development and to avoid or minimize complications. PN is optimally delivered in consultation with a multidisciplinary team, including nutritionists, nurses, pharmacists, and physicians.

Nutrition Assessment

Historically, pediatric malnutrition was thought to be a problem only in developing countries. In recent years, it is being recognized among hospitalized infants and children in developed nations as a consequence of acute and chronic illness. Malnutrition or poor nutritional status may lead to complications such as poor healing, wound dehiscence, and increased length of hospital stay. As there is no universally accepted definition of pediatric malnutrition, prevalence is difficult to define but has been cited as occurring in up to 60 % of hospitalized children.

As underlying nutritional status plays a role in determining the timeframe for initiation and advancement of nutrition support, it is imperative that the patient be assessed by or in conjunction with a registered dietitian who has neonatal or pediatric experience. This includes a thorough review of growth history, including length- or height-for-age, weight-for-age, weight-for-length or body mass index (BMI)-for-age, and head circumference (for those less than 36 months of age). Current recommendations suggest using weight gain velocity, weight loss, actual *z*-scores, change in *z*-scores over time, and the degree of deviation from population median (negative *z*-score) to define pediatric malnutrition. With the exception of prematurity, in which Fenton or Olsen charts are routinely used to document growth, current recommendations are to use the World Health Organization growth charts for infants and children <2 years of age and the Centers for Disease Control and Prevention charts for children and adolescents 2–20 years of age. Mid-upper arm circumference may also be a useful tool for determining nutritional status, particularly in patients for whom an extensive growth history is unavailable or when weight may not be a reliable indicator (liver failure, renal failure, edema, steroid use).

Nutrition Requirements

The determination of nutrition requirements for neonatal and pediatric patients should be individualized. This includes evaluation of the patient's current anthropometrics, growth history, age, clinical status, and overall goals as defined by a multidisciplinary team. An experienced pediatric registered dietitian is instrumental in helping the team determine appropriate calorie, protein, and fluid goals.

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Table 5.1 Potential candidates for indirect calorimetry

Parameter	Specific indicator
Weight	Underweight: BMI-for-age or weight-for-length <5th percentile
	Overweight/obese: BMI-for-age >85th percentile
	Weight change: gain or loss of >10 %
Respiratory	Failure to wean or need to escalate respiratory therapy, requires mechanical ventilation for >7 days
Hypermetabolism	Status epilepticus, dysautonomic storms, SIRS, hyperthermia
Hypometabolism	Pentobarbital/midazolam coma, vecuronium, hypothermia
Diagnosis	Burns/thermal injury, oncologic diagnosis (including bone marrow transplantation or BMT), neurologic trauma (traumatic, hypoxic and/or ischemic)

Adapted from: From Mehta NM, Compher C and A.S.P.E.N. Board of Directors. A.S.P.E.N. Clinical Guidelines: Nutrition Support of the Critically Ill Child. JPEN J Parenter Enteral Nutr. 2009; 33: 260–276, reprinted with permission

Calories

In general, calories (energy) from PN should be approximately 10 % less than from enteral nutrition (EN) in order to account for the calories required for digestion and absorption. In order to avoid complications from overfeeding or underfeeding, astute attention to energy needs throughout the course of illness is required. The most accurate method for determining energy requirements and thus optimizing nutrition, especially during acute illness, is indirect calorimetry. Indirect calorimetry can be particularly helpful for determining energy needs among specific patient populations (Table 5.1). When indirect calorimetry is not available or not feasible (weight <8–10 kg, chest tube in place with air leak, oscillating ventilator), equations to determine estimated resting energy expenditure (REE) or basal metabolic rate (BMR) may be used. The WHO and Schofield equations are the most widely used to calculate REE or BMR, respectively. An exception to this is for preterm and term neonates for whom the initial goal is to provide 90–110 kcal/kg/day from PN.

Table 5.2 Parenteral protein requirements in pediatric patients

Pediatric classification	Protein
Premature infant	3–4 g/kg/day
0–2 years	2–3.5 g/kg/day
2–13 years	1.5–2.5 g/kg/day
13–18 years	1.5–2 g/kg/day

Protein

Current literature suggests that administration of amino acids (AA) should be initiated at goal on day 1 of PN (Table 5.2), unless limited by fluid restriction or significant azotemia (BUN >80 g/dL) associated with acute renal failure or acute kidney injury. Early administration of AA approximating 3 g/kg/day in very low birth weight (VLBW) preterm infants has been associated with improved growth at 36 weeks gestation, and it is common to aim for a goal of 3–4 g/kg protein (or approximately 15 % total calories) daily in the surgical neonate, particularly if born prematurely. A minimum of 1.1 g/kg/day protein is recommended to prevent catabolism in neonates.

Crystalline amino acids are the primary parenteral protein source. TrophAmine® (B. Braun Medical) is recommended to meet the specific amino acid requirements from birth to 12 months of age. It mimics the amino acid profile of human milk for a healthy, term infant. Cysteine is not a routine component of amino acid solutions, but may be added at a dose of 30–40 mg per gram of AA for preterm infants and term infants up to 6 months of age as it is conditionally essential for these populations; of note, its addition limits the ability to administer intravenous fat emulsion (IVFE) through the same line, due to its acidity and propensity to break down the fat emulsion.

Carbohydrate

Dextrose monohydrate is the primary source of calories in PN. Formulas generally provide 50–55 % of total calories from carbohydrate. Initiation, advancement, and maximum glucose infusion rate (GIR) are dictated by the patient's age, weight, and clinical status. Neonates may be initiated at a GIR of 6–8 mg/kg/min (or as needed to maintain an age-appropriate blood glucose, avoiding hypo- and hyperglycemia) and advanced daily by a GIR of approximately 2 mg/kg/min, as tolerated, until goal is reached. For older infants and children, one may regularly start with dextrose 10 % and advance by dextrose 2.5–5 %, or a GIR of approximately

2–2.5 mg/kg/min, until goal is achieved. It is imperative to avoid overfeeding and hyperglycemia, which impairs wound healing, increases the risk of wound infections, and lengthens the ICU stay. Recent studies suggest serum glucose levels between 80 and 150 mg/dL as an optimal target. Insulin is rarely added to pediatric PN, but may be provided as a separate infusion to optimize blood glucose levels while avoiding hypoglycemia.

Fat

Unless severely limited by volume and the need to provide an adequate GIR for the pediatric patient, IVFE may be initiated on the first day of PN administration. The goal of IVFE administration is to provide a source of calories as well as essential fatty acids to avoid essential fatty acid deficiency (EFAD). The only commercially available lipid product in the USA is a soybean oil-based product (Intralipid). It is typically administered as a separate infusion starting with 1 g/kg/day and advancing by 1 g/kg/day, as tolerated, to goal lipid dosage, which is generally 30 % (25–35 %) of total calories. The maximal infusion rate for lipids in neonates is 0.17 g/kg/h and for older infants and children 0.15 g/kg/h. (Many institutions filter IVFE with a 1.2 μm filter to remove particulates.) A mixture of olive oil and soybean oil emulsions (Clinolipid®) in a 4:1 ratio is also available in the USA but is not indicated for use in children. SMOFlipid® (a mixture of soybean oil, medium chain triglycerides, olive oil, and fish oil) is in clinical trials in the USA. In addition, Omegaven® is available for special circumstances.

Levocarnitine, an amino acid required for transporting fatty acids into the mitochondria for oxidation, is added to neonatal PN at a low dose (5 mg/kg/day). It may be started on the first day of PN, if no enteral source is provided. If blood triglycerides (TG) exceed 200 mg/dL in an infant or young child or 400 mg/dL in an older child or adolescent, the levocarnitine dose may be increased to 10–20 mg/kg/day (or higher) to improve lipid tolerance. In some cases, IVFE may be discontinued temporarily if TG levels continue to be elevated; lipid restriction to approximately 1 g/kg/day in the setting of cholestatic jaundice is common practice and considered the standard of care at this time. In general, EFAD develops in approximately 1–2 weeks if lipids are not administered, but can manifest sooner (3–5 days) in neonates. In order to prevent EFAD, IVFE 0.5–1 g/kg/day should be provided.

Fluids

When determining daily maintenance fluid requirements for a pediatric patient, one may use the Holliday-Segar method: 100 mL/kg for the first 10 kg of weight, followed by 50 mL/kg for the next 10 kg (10–20 kg), and 20 mL/kg for every kg over 20 kg. The exception is preterm neonates who will likely require 140–150 mL/kg/day by day of life 5 in order to meet fluid requirements. One must also take into consideration ongoing losses (NG suction, diarrhea, frequent emesis, large amount of secretions) when establishing fluid goals. It is also imperative to take into account all sources of fluid. Patients in the ICU setting may receive a large percentage of their daily fluid goals from medications (fentanyl, midazolam, IV antibiotics); these must be taken into account when recommending PN fluid goal. In addition, certain patients, such as those with congenital heart disease in the immediate postoperative period, may require significant fluid restriction. In this case, optimize nutrition support within the fluid allocation and maximally concentrate or eliminate medications or lines as clinically warranted.

Electrolytes

When dealing with neonates or infants, initial PN should mimic human milk as much as possible. For the teenager, PNs are similar to adult PNs in terms of composition. For children, the evidence is less clear and one may start with additives that resemble both an infant and adult PN. Most institutions will dose electrolytes based on weight (mEq/kg) until the child's weight is between 30 and 40 kg; once this weight is attained, adult doses are used. When trying to estimate initial requirements, using the current intravenous fluids as an initial guide is reasonable. For example, if a patient is receiving 1.5 L daily of D 5 %, NaCl 0.45 % with KCl 20 mEq/L, and the basic metabolic profile (blood chemistries) is within normal limits, it is reasonable to start the PN with the equivalent of NaCl 0.45 % with potassium 30 mEq/L, assuming the PN dextrose concentration will be greater than dextrose 5 %. After the initial PN, additives are adjusted according to lab results (Table 5.3).

With neonates and infants, it is critical to remember that sodium is essential for growth, and maintaining blood levels within the normal range is very important. The initial sodium in a neonatal or infant PN should be approximately 2 mEq/kg/day, or higher if the patient is requiring extra sodium in current intravenous fluids, and is likely to advance to a total of 4–5 mEq/kg/day to promote adequate growth and maintain normal serum sodium. NaCl 0.2 % is a good starting point for infants or children without sodium losses (no significant diarrhea, emesis, or gastric suction); older pediatric patients should receive NaCl 0.45 % or higher. For patients with a chylothorax, especially if chest tube placement is required for drainage, the sodium requirement may approach NaCl 0.9 % (154 mEq/L), depending on amount of output and comorbidities. Once started, sodium in the PN is adjusted to keep serum levels within the normal range, and,

Table 5.3 Daily PN electrolyte requirements in the pediatric patient

Electrolyte	Preterm neonates	Infants/children	Adolescents and children >50 kg
Sodium	2–5 mEq/kg	2–5 mEq/kg	1–2 mEq/kg
Potassium	2–4 mEq/kg	2–4 mEq/kg	1–2 mEq/kg
Calcium	2–4 mEq/kg	0.5–4 mEq/kg	10–20 mEq/day
Phosphorus	1–2 mmol/kg	0.5–2 mmol/kg	10–40 mmol/day
Magnesium	0.3–0.5 mEq/kg	0.3–0.5 mEq/kg	10–30 mEq/day
Acetate	As need to maintain acid-base balance		
Chloride	As need to maintain acid-base balance		

Source: Adapted from Task Force for the Revision of Safe Practices for Parenteral Nutrition, Mirtallo J, Canada T, Johnson D, et al. Safe practices for parenteral nutrition. Journal of Parenteral and Enteral Nutrition, Vol. 28, Issue 6, pp. 39S–70S, © 2004. Reprinted by permission of SAGE Publications

with occasional exceptions, low serum sodium levels are due to lack of sodium as opposed to fluid overload. Changes in sodium in the PN should reflect total sodium concentration (e.g., NaCl 0.2 % to NaCl 0.45 %), with the exception of neonates, infants, and small children, where 1–2 mEq/kg/day changes in sodium content are reasonable.

A good starting point for potassium is 1–2 mEq/kg for neonates (once urine output is established) and infants and 30 mEq/L (between 1 and 2 mEq/kg/day) for older children, unless they are already requiring additional potassium or have significant losses (GI suction, emesis, hyperglycemia exceeding renal threshold, furosemide therapy). Changes in potassium content should be in 0.5–1 mEq/kg/day increments for younger children and 10–20 mEq/day increments for older children to avoid hyperkalemia; the changes will depend on the rate and degree of changes in serum levels, the child's weight, and the need for supplementation outside the PN. For adult-sized children who are not obese, a general rule of thumb is that for every 10 mEq of potassium administered, the blood level will increase by 0.1. It is important to remember that hospitalized, well-monitored children do not die of hypokalemia, but they may die due to arrhythmias associated with hyperkalemia.

Regarding calcium, neonates and infants require at least 2 mEq/kg/day for adequate bone accretion. Older children and adolescents should receive calcium gluconate 10–20 mEq/day. Calcium content may be limited by physical compatibility with phosphate in the PN, particularly if PN volume is limited. PN formulations are made with calcium gluconate, which requires de-conjugation in the liver; it is chosen over calcium chloride because it is less reactive (much less likely to form calcium-phosphate precipitates) in the PN solution. Many institutions will not administer calcium peripherally, but dilute concentrations such as those in PN may safely be administered.

For magnesium, a good starting place is 0.3 mEq/kg/day for nearly all patients. In neonates and young children, changes of 0.1 mEq/kg/day are reasonable. For older patients, doses should generally be rounded to the nearest ½ gram and changed in ½–1 g (4–8 mEq) increments. With the exception of the cardiac patient, hypomagnesemia does not pose significant risk in the short term, and the primary problem is its association with hypokalemia (without adequate magnesium, the renal tubule will not resorb potassium).

A reasonable initial dose for phosphate is 0.5–1 mMol/kg/day (or, if dosing on volume, 15 mMol/L). Changes of 0.3 mMol/kg/day are suggested if more or less phosphate is needed to keep blood levels within normal levels; for older patients, changes of 7.5–15 mMol/day are reasonable. Phosphate is essential for energy metabolism and bone formation.

For the anions, most pediatric patients will receive chloride salts, including patients with pyloric stenosis, frequent emesis, or NG tubes to suction. Patients with diarrhea or lower gastrointestinal losses (Crohn's disease, ulcerative colitis, fistulas, ostomies, short gut syndrome), those in the immediate postoperative period, or those with renal dysfunction will require some, if not all, acetate in the PN. In general, acetate and chloride are added to the PN in amounts to balance the cations. In other words, the amount of cations the patient will require is calculated and then divided among the anions (chloride, acetate, and phosphate) according to the estimated needs. If providing "base" or "buffer," most patients will require acetate 1–2 mEq/kg/day, with exceptions as noted above. Keep in mind that a secondary hyperaldosteronism due to the adrenal aldosterone response to dehydration and fluid loss will also influence fluid choice and makes the selection of chloride-containing fluids more likely.

Formulation (Calculations, Physical Traits, and Limitations)

Creating an initial PN formulation requires knowledge of the available components for PN. For the neonate and children up to 6 months of age (and potentially up to 12 months corrected age), TrophAmine® or another amino acid product that is similar to human milk is the preferred protein source. It comes as a 10 % (10 g/100 mL) solution. For older children, most pharmacies use either a 15 % (15 g/100 mL) or

Table 5.4 Parenteral trace element requirements according to age

Trace element	Premature neonates (μg/kg/day)	Term infants (μg/kg/day)	Children (μg/kg/day)
Zinc	400–500	250 (<3 months old)	50 (max = 5 mg/day)
		50 (>3 months old)	
Copper	20	20	20 (max = 500 μg/day)
Manganese	1	1	1 (max = 50 μg/day)
Chromium	0.05–0.2	0.2 (max = 5 μg/day)	0.2 (max = 5 μg/day)
Selenium	1.5–3	1–3	1–3 (max = 100 μg/day)
Iodine	1 μg/day	1 μg/day	1 μg/day

Source: Data from Vanek VW, Borum P, Buchman A, et al. A.S.P.E.N. Position Paper: Recommendations for Changes in Commercially Available Parenteral Multivitamin and Multi–Trace Element Products. Nutr Clin Prac. 2012; 20(5): 1–52

10 % (10 g/100 mL) amino acid solution. Dextrose is available as a 70 or 50 % solution. Most institutions use IVFE 20 % (20 g/100 mL).

To calculate calories, each gram of protein (amino acids) provides 4 kcal; for dextrose, it is 3.4 kcal/g; for fat (IVFE or lipids), IVFE 20 % (in the USA, Intralipid 20 %) is most commonly used in the pediatric population, and it provides 10 kcal/g or 2 kcal/mL; if the lipid is a 10 % solution, it is 11 kcal/g or 1.1 kcal/mL due to the glycerol (just as with propofol).

For total nutrient admixtures (TNA or 3-in-1 PNs, indicating that the IVFE or lipid is added to the bag), the product should contain at least AA 4 %, dextrose 10 % and fat 2 % in the final concentration to ensure stability of the PN.

To make the formulation, the first decision is dosing weight, which should be a "dry weight," admission weight, or usual body weight. For neonates, the dosing weight should be their birth weight for at least the first 7–10 days of life.

The second decision is how much energy and protein the neonate, infant, or child will need. (Again, this is best done in consultation with a registered dietitian or nutritionist qualified to evaluate the patient.)

The third decision is the total daily volume. The majority of patients may receive maintenance fluids through the PN, and some may receive 1.2–1.5 times maintenance, if needed, to keep blood pressure at desired levels or to replace ongoing losses. For situations in which fluid restriction is required, most PN solutions can be concentrated.

Finally, vitamin and trace elements should be provided. For infants and children less than 2.5 kg, 2 mL/kg of pediatric multivitamin is provided. For those >2.5 kg, 5 mL/day will be added to the PN solution. Once the patient is 11 years old, an adult multivitamin (MVI-12) may be used. Given recent significant shortages, if a child is able to tolerate a multivitamin supplement enterally, this should be the clinician's preference. Recently, trace element dosages for neonates, infants, and children were updated by the American Society for Parenteral and Enteral Nutrition (Table 5.4). Significant shortages have required the use of single trace elements or the use of imported products from Europe in order to meet patient needs.

For patients receiving peripheral PN solutions, the osmolality should be less than 900 mOsm/L, unless institutional policy allows for higher osmolalities (Table 5.5). IVFE (lipids) are essentially iso-osmolar (260–308 mOsm/L) and should be administered to help decrease the osmolarity that the vein is exposed to. To calculate osmolality: (1) Every gram of amino acids is 10 mOsm; (2) Every gram of dextrose is 5 mOsm; (3) The sodium and potassium chloride and acetate salts contain 2 mOsm/mEq (1 for the cation and 1 for the anion); (4) Calcium gluconate 1 g is 4.67 mEq or ~7 mOsm; (5) For phosphate, the potassium salt is 1 mMol = 2.467 mOsm and the sodium salt is 1 mMol = 2.33 mOsm; (6) For magnesium sulfate, 1 mEq = 1 mOsm.

Another important calculation is the GIR. For most patients, especially neonates or those who have been NPO for several days, start with a lower GIR and work up to the goal GIR over 2–3 days. If the patient was eating or on enteral nutrition and tolerating it within the prior 24–72 h, they may be gradually ramped up to goal PN over a 24-h period of time, assuming the blood glucose is within the normal range. To calculate GIR, the units are mg/kg/min and one should take the amount of dextrose being administered divided by the time period of administration and patient weight in kg. Two examples follow:

$$\text{Glucose infusion rate}\left(\text{mg/kg/min}\right) = \frac{\text{dextrose grams/kg/day} \times 1000\,\text{mg/g}}{\left(24\,\text{h/day}\right) \times \left(60\,\text{min/h}\right)}.$$

Example If administering dextrose 10 g/kg/day, the GIR for administration over a day is 6.9 mg/kg/min.

Table 5.5 Calculating osmolarity in peripheral parenteral nutrition

Electrolyte	mEq/mL	mOsm/mL
NaCl	4	8
Na acetate	2	4
KCl	2	4
K acetate	2	4
Na Phos	4	7
Na Phos	3 mMol	
K Phos	4.3	7.4
K Phos	3 mMol	
Ca	0.465	0.68
Mg	4	4.06

Maintain total mOsm/L of PPN less than 900 mOsm/L
1. Dextrose grams/L × 5 = mOsm/L
2. Protein grams/L × 10 = mOsm/L
3. Convert mEq/L of electrolytes in PN to mOsm/L

If, however, the same amount of dextrose (10 g/kg/day) in a volume of 520 mL is cycled over 18 h, with a 1-h ramp-up and 1-h ramp-down in rate, the cycle is 15 mL/h × 1 h, 30 mL/h × 16 h, and 15 mL/h × 1 h:

$$\text{Maximal Glucose infusion rate}\left(\text{mg/kg/min}\right) = \frac{10\,\text{g/kg/day} \times 1000\,\text{mg/g} \times 30\,\text{mL/h}}{520\,\text{mL/day} \times \left(60\,\text{min/h}\right)} = 9.6\,\text{mg/kg/min}$$

Administration

Most PN solutions should be administered centrally as it is difficult to meet a patient's nutritional and electrolyte needs with a peripheral solution. The pediatric surgeon has a critical role to play in choice of access and type of catheter. In general, a central venous catheter or a percutaneously inserted central catheter (PICC) should be placed if PN will be administered longer than 72 h or if the peripheral venous catheter would be replaced should it infiltrate within 48 h. Ports may also be used for PN administration, although the reason for placement is still usually limited to those requiring intravenous anticancer therapy. In general, the fewest lumens necessary should be inserted to minimize risk of central line infections.

Solutions with an osmolality of <900 mOsm/L may be administered peripherally. Such solutions generally contain dextrose 10–12.5 % (10–12.5 g/100 mL) with amino acids 1–2 g/kg/day (usually AA 3 % or less). When salts are added, the simplest way to decrease the osmolality is to decrease the amount of protein. However, if the solution cannot provide at least 1 g/kg/day protein, consider infusing dextrose-containing fluids until central access is obtained, which allows the PN to be administered centrally to avoid the limitations of peripheral administration (not being able to provide sufficient calories to meet needs, risk of phlebitis).

When first starting PN, it is usually administered continuously. Continuous administration is the standard for neonates until they are at an age where they can maintain their blood glucoses with the PN infusion discontinued for 2–4 h. For older patients, once they are stable on a goal PN formula, it may be cycled over 12–20 h, depending on the patient and ability to tolerate being off PN (usually determined by the amount of time the patient can go between feedings, whether they are on enteral feedings, line time needed for administration of medications, desire for time off for ambulation, and, for home PN patients, lifestyle of patient and family). The advantages of cycling are that the body, specifically the liver, gets a break from metabolizing nutrients, similar to the individual who is eating; and the patient is better able to ambulate without being tied to an IV.

Complications

The use of PN carries the possibility of complications, including central line infection, thrombosis, thrombophlebitis, hyperglycemia, hypoglycemia, electrolyte disturbances, intestinal failure-associated liver disease (IFALD, also known as parenteral nutrition-associated liver disease or PNALD, or TPN-associated cholestasis), and secondary nutrient deficiencies.

To avoid infection, the catheter should be inserted aseptically and catheter care should include careful, thorough preparation of the hub prior to administration of PN or medications or taking blood samples for laboratory monitoring. In addition, sterile dressing changes should be done per hospital protocol. Instilling an alcohol (EtOH) dwell into the catheter (note that the catheter must be silicone) when not in use inhibits the growth of bacteria. The use of a 0.22 μm inline filter will remove bacteria and fungi but may not be used with IVFE (breaks the emulsion; for IVFE, a 1.2 μm filter may be used to filter particulates).

Thrombosis is a common complication, especially with multi-lumen catheters. To avoid this, appropriate selection of catheter size and avoidance of multiple lumens, if possible, are important means to limit risk. In the neonatal population, heparin is often added to the PN in a dose based on final PN volume (0.5 units/mL), but the evidence that this prevents or decreases thrombosis is equivocal. Rate of flow (at least 1–10 mL/h, depending on catheter size), routine catheter flushing, and the use of heparin or saline lock solutions

when the catheter is not in use will limit thrombus formation. Should a clot occur, the use of alteplase (1–2 mL dwells, depending on volume of the catheter) will usually dissolve the clot.

Hyperglycemia may occur during periods of stress or inflammation (immediately postoperatively or with infection), and giving large doses of dextrose worsens this. It is reasonable to limit the amount of dextrose during periods of stress to decrease the negative sequelae of hyperglycemia (blood glucose >180 mg/dL which is the renal threshold for glucose: glucosuria, dehydration, loss of electrolytes). The same is true in the immature neonate. For most pediatric patients, starting with the equivalent of dextrose 10 % infusing at an appropriate GIR and advancing by an appropriate rate over 2–3 days will avoid this complication.

Hypoglycemia (BG <60 mg/dL or symptomatic) may also occur, although this usually occurs when a patient is abruptly withdrawn from PN and dextrose is not administered at an appropriate GIR to prevent the rapid decline in blood glucose. This can be avoided by decreasing the PN rate over 1–2 h (cycling off) or by substituting dextrose-containing fluids (usually 10 % dextrose) at a GIR that is at least half the GIR that the PN was providing.

Adjustments in PN additives will correct the majority of electrolyte abnormalities. For acid-base disorders, an increase in the acetate in the PN will provide more "base." In general, the manipulation is best done to keep the cations at their current levels; in other words, do not manipulate the cations to provide more chloride or acetate.

Intestinal Failure Associated Liver Disease

Pediatric patients on long-term PN (at least 2–4 weeks) without enteral intake are at the highest risk for developing IFALD. The clinician must recognize those patients that are most likely to require long-term PN (intestinal atresia, gastroschisis s/p bowel resection, severe prematurity, necrotizing enterocolitis) and tailor the nutrition support plan accordingly. There is a fine balance between providing PN substrates for growth and minimizing complications. In children, should the direct bilirubin rise above 2 mg/dL, the current standard of practice is to limit IVFE to 1–2 g/kg daily to twice weekly, in order to limit or halt the rate of rise in direct bilirubin. Cycling the PN as soon as clinically feasible should also be considered. In addition, ursodiol may be administered. Ultimately, the optimal way to avoid IFALD is to feed the patient orally or enterally. Daily consideration should be given to the initiation of trophic EN with advancement as clinically able given the patient's tolerance and clinical course.

Summary

The timeframe for initiation of PN should consider the patient's age, underlying nutritional status, and anticipated duration of NPO or lack of enteral feeding. Parenteral AA provision can and should be initiated at goal protein level. In order to prevent EFAD, IVFE (lipids) 0.5–1 g/kg/day should be provided. Avoid overfeeding: Calorie needs should be individualized and are best determined by indirect calorimetry; if this is not feasible, predictive equations such as WHO or Schofield should be utilized. For a patient with or at risk for IFALD, start EN as soon as clinically able, consider cycling PN and limiting IVFE (lipids) to 1 g/kg/day (or adding a fat emulsion that contains omega-3 fatty acids) if the bilirubin increases.

Editor's Comment

Aside from checklists and protocols around wound care, there is perhaps no variable more important in reducing the risks of complications in pediatric surgical patients that ensure that patients are appropriately nourished prior to surgery. Parenteral nutrition and nutrition assessment are critical tools that the pediatric surgical team can utilize to minimize the risk of postoperative complications. What makes pediatric nutrition support particularly challenging are both age- and disease-dependent variability in nutrition requirements. Ideally, PN in surgical patients is best managed by a team led by a pediatric surgeon composed of pharmacists and dieticians with specific training in pediatric nutrition support. Training is provided through the American Society of Parenteral and Enteral Nutrition (ASPEN) and individuals are certified through a computerized exam that is offered annually.

Advances in the science of parenteral nutrition have saved lives; however, until the mystery of parenteral nutrition-associated cholestasis is solved, it will continue to be simply a bridge to enteral nutrition. As a result, the goal for every patient receiving parenteral nutrition is to transition to enteral feedings as soon as possible. Peripheral nutrition rarely provides enough nutrition to make a real difference and tends to require daily replacement of peripheral intravenous catheters, which can be torturous for the patient.

It is incumbent on the surgeon or interventionalist who places central venous catheters in patients who will need long-term parenteral nutrition to do everything possible to preserve the central veins. This means placing only the smallest single-lumen catheter needed to meet the child's needs, having protocols and support staff available to help

families avoid catheter dislodgement and line infections, and monitoring patients closely for catheter-associated vein thrombosis so that the catheter can be removed and treatment started early. Some of these patients will benefit from a work up for a hypercoagulable state.

Suggested Reading

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Enhanced Recovery Protocols

6

Peter Mattei

It is increasingly clear that when we apply systematic and evidence-based perioperative protocols, we can make patients more comfortable and hasten their recovery. Patient care should also be streamlined, and patients should not be subjected to the discomfort and indignity of unnecessary procedures, worthless rituals, and therapies that are not supported by scientific evidence. "Fast-track" protocols have been renamed "enhanced recovery" protocols as they aim to address all aspects of postoperative care—return of bowel function, early resumption of physical activity, maximizing patient comfort, and eliminating superfluous maneuvers—all ideally evidence-based and designed to improve the recovery rather than simply just shorten the hospital stay.

Traditional surgical teaching, passed on by generations of surgery residents, emphasized the idea that after an abdominal procedure or bowel surgery, the postoperative ileus is a mandatory and presumably beneficial period of bowel inactivity that should not be hastened or otherwise manipulated. For many decades standard therapy mandated strict bowel rest and nasogastric decompression. Although an enlightened few would allow removal of the nasogastric tube and resumption of diet upon the passage of flatus or when the gastric drainage was no longer green, most would forbid patients from eating or drinking until their first bowel movement, which was thought to herald the return of bowel function. As a result, the typical length of time before resumption of regular diet could be anywhere between 3 and 10 days. Those brave enough to remove a nasogastric tube prematurely, allow the patient to ingest ice chips or sip water, or induce a bowel movement with a laxative or suppository were accused of placing the patient at risk for bowel obstruction, anastomotic dehiscence, peritonitis, and sepsis.

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Finally, a few brave pioneers in the 1990s began to question this dogma and renounced these firmly held beliefs. They found that not only did their patients survive, but they also got better faster, went home sooner, and were more comfortable throughout their postoperative course. They originally developed and tested these regimens for elective colorectal operations, but since then, a few pockets of stubborn resistance notwithstanding these concepts have been expanded and refined and widely accepted as standard for nearly every type of surgery. For some inexplicable reason, pediatric surgeons were initially reluctant to adopt similar measures in the care of children.

Basic Principles

There should be a sound scientific basis for every specific step of and enhanced recovery protocol as well as to the program as a whole, which bundles several concepts within a single comprehensive clinical pathway. But they are not meant to be one size fits all—it is also important that the protocol be flexible and carefully designed to address the needs of the individual patient.

Children stand to benefit as much or more than adults and, in fact, similar protocols have been used in the care of children safely for many years. Most likely to benefit from application of an enhanced recovery program is the healthy child who has undergone an elective and uncomplicated procedure and who is comfortable, neurologically intact, and spontaneously breathing. The absence of any of these components is not an absolute contraindication but the critically ill, heavily sedated, mechanically ventilated patient with chemical peritonitis is not a good candidate. Although after a minimally invasive procedure one would naturally expect the patient to recover more quickly, children who have undergone an extensive operation through a more traditional open incision also benefit from these measures.

Safe application of an enhanced recovery protocol requires good judgment. Relative contraindications include

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age less than 6 months; weight less than 10 kg; respiratory status that might be compromised by a distended abdomen; the presence of an esophageal, gastric, or duodenal suture line; an inability to protect the airway in the event of emesis; positive-pressure ventilation, including BiPAP or CPAP; and any condition expected to cause a profound ileus such as high-grade bowel obstruction, fecal contamination of the peritoneum, or massive ascites. Nevertheless, we have safely utilized the protocol or a slightly modified version in patients with perforated appendicitis, partial SBO, jejunal resection with primary anastomosis, hepatic resection, Meckel's diverticulectomy, resection of extensive retroperitoneal tumor, nephrectomy, or creation of an ostomy.

The basic tenets of the protocol for abdominal surgery include no routine nasogastric tube, early diet advancement, minimization of narcotic analgesics, and early ambulation/physical rehabilitation (Table 6.1). Naturally, the protocol is modified according to the patient population, the procedure, and the clinical judgment. The common theme is that each component should be supported by evidence.

Preoperative Preparation

It all starts at the surgical pre-visit and includes informing the patient and family about the details of the operation and managing expectations around their child's anticipated recovery. We explain that discharge is determined by how the patient progresses and is therefore inherently unpredictable. It is reasonable to give them some idea of a typical length of stay, but it is important to emphasize that it is not the calendar but the achievement of specific milestones that determine the discharge date. We tend to underestimate the length of stay a bit because parents often feel rushed if their child does well enough to go home sooner than projected but are somewhat more accepting of the child who needs a little more time to recover. It is also important to consider the cultural and psychological state of the patient and family to help manage their anxiety around their child's care.

Mechanical bowel preparation, standard for patients preparing for elective bowel surgery for decades, in most cases is unnecessary and may actually do more harm than good in

Table 6.1 Concepts of a typical enhanced recovery protocol in pediatric surgery: laparoscopic ileocecectomy for Crohn's ileitis

Preoperative	• No mechanical bowel preparation (clear liquids for 24 h)
	• Detailed explanation of operation, risks, benefits
	• Concept of post-op milestones, criteria for discharge
	• Anticipate discharge to home by POD 2–3[a]
Intraoperative	• Laparoscopic or transverse incision
	• Optimize IV fluids, avoid overhydration
	• Optimize body temperature, glucose control
	• Prophylactic antiemetics
NO nasogastric tube	Except:
	(a) After esophageal, gastric, or duodenal surgery
	(b) Infants <6 months of age or <10 kg body weight
	(c) Placed post-op as needed for comfort[b]
Diet	• Clear liquid diet immediately
	• Advance to regular diet as tolerated[c]
Intravenous fluids	• 0.75 of calculated "maintenance" rate[d]
	• Crystalloid boluses as needed for low urine output
Pain management	• Minimize narcotics
	• Ketorolac, nalbuphine, and/or acetaminophen
	• If IV PCA, basal infusion rate should be **zero**
	• Thoracic epidural with local anesthetic[e]
Physical rehabilitation	• OOB to chair/ambulate within first 12–24 h
Bowel regimen	• Bisacodyl suppository on POD 2, BID until first stool

[a]This is standard for an uncomplicated bowel resection but will vary depending on the procedure being performed
[b]Intractable emesis, extreme distension, gas bloat; should be necessary <5 % of cases
[c]In the absence of symptoms (fullness, nausea, emesis) or abdominal distension
[d]Maximum rate, 84 mL/h (=2 L per day)
[e]Lumbar epidural administration of narcotics is known to prolong postoperative ileus
POD postoperative day, *PCA* patient-controlled analgesia, *OOB* out of bed, *BID* twice daily

terms of surgical site infection and anastomotic complications. It is also unpleasant for patients and their families, causes discomfort and dehydration, and can result in significant metabolic derangement. We therefore generally avoid traditional mechanical bowel preparation in most cases. For elective colorectal operations, we ask the patient to adhere to a clear-liquid diet for 24 h prior to admission. This reduces the stool burden somewhat and promotes the intake of fluids prior to the preoperative fast. Patients who are malnourished and whose operations can be safely delayed may benefit from a period of enteral or even parenteral nutritional rehabilitation for 2–4 weeks before the scheduled date of surgery. Adults often receive an enema in the preoperative area before elective distal colorectal procedures but in children we avoid this and instead perform a fecal disimpaction and rectal washout with dilute betadine in the OR after induction of anesthesia.

Gastric Decompression

Nasogastric tubes were once thought to improve patient comfort by preventing postoperative emesis and shortening the postoperative ileus by reducing bowel distension caused by secretions and swallowed air. It turns out that very few patients are at risk of excessive distension or intractable vomiting and there is no evidence that gastric decompression itself shortens the postoperative ileus. The tubes themselves are extremely uncomfortable and increase the risk of certain infectious complications such as sinusitis and possibly pneumonia.

We do not routinely place nasogastric tubes after most abdominal operations. We consider using them after operations in which gastric distension might disrupt a suture line or compromise respiration. We will offer to place an NGT postoperatively for intractable vomiting, early postoperative small bowel obstruction, or severe symptomatic distension. We also tend to still use them in small infants because even a moderate amount of gastric or abdominal distension can compromise their respiratory status.

Diet

Even after bowel resection or extensive abdominal operations, early (day of surgery) intake of moderate amounts of clear liquids provides comfort, hastens recovery of bowel function, and appears to be safe for most patients. In addition, contrary to prior teaching, early oral intake does not increase the risk of complications or anastomotic dehiscence.

As soon as the patient is coherent enough to drink safely, we let our patients take small amounts of clear liquids and then advance to more substantive intake, as long as they are not feeling full or nauseated and if there is only minimal abdominal distension on physical examination. Though patients generally limit their intake appropriately, we always monitor them closely for worsening abdominal distension or nausea at least two or three times daily.

Intravenous Hydration

Most patients receive large amounts of intravenous fluid, especially during long and difficult operations, despite little evidence that it is beneficial or necessary. However, excessive fluid seems to prolong the postoperative ileus perhaps by increasing bowel wall edema. We therefore try to limit the amount of intravenous fluid, both in the operating room and in the postoperative period, to only what is necessary to maintain adequate tissue perfusion and renal function. Even the traditional pediatric "maintenance" fluid formula is empirically based and designed to err on the side of giving too much fluid. It is also increasingly clear that children can tolerate a degree of permissive oliguria in the postoperative period, especially close to the time when they are expected to mobilize extra fluid and begin the postoperative diuresis, typically 36–48 h postoperatively. Assuming the child is otherwise stable and comfortable, a urine output of approximately 0.8 mL/kg/h is probably adequate.

In the immediate postoperative period, we generally administer 75–80 % of the calculated maintenance rate, and then if a patient demonstrates a need for more fluid (low urine output, tachycardia), we give a bolus of crystalloid solution (10–20 mL/kg) rather than just increasing the maintenance rate. We also rarely, even for children who weigh more than 45 kg, administer more than 84 mL/h since few patients need more than 2 L of "maintenance" intravenous fluids in a 24-h period. If a patient requires more fluid due to third-space losses or loss of secretions, it is probably better to replace these losses with crystalloid rather than the usual dilute fluids used for maintenance.

Opioids

Narcotics have a well-documented detrimental effect on bowel motility. They also induce nausea and their sedative effects make it difficult for some patients to participate in a postoperative physical rehabilitation program. We minimize the administration of narcotics while still making sure the patient is comfortable.

We will use the combined agonist–antagonist narcotic drug *nalbuphine* (0.1 mg/kg IV every 3 h, as needed for pain), which has good analgesic properties and seems to have less of a detrimental effect on bowel motility than morphine or hydromorphone. We also typically use *ketorolac*

(0.5 mg/kg IV every 6 h, maximum dose 30 mg, around the clock), which has excellent analgesic properties and none of the adverse effects associated with opiates. Intravenous *acetaminophen* is another useful adjunct in patients who have a contraindication to ketorolac. *Patient-controlled analgesia* is also an excellent option for postoperative pain relief, but we have found it best to avoid a basal continuous opiate infusion as this causes excessive sedation and prolongs the postoperative ileus. Finally, narcotics delivered through a lumbar epidural catheter prolong the postoperative ileus, while local anesthetics administered by a *thoracic epidural* catheter have little such effect and provide excellent analgesia.

Ambulation

Patients who get out of bed early and often after a major operation tend to recover more quickly and have fewer complications. While being completely immobile probably prolongs the ileus, making patients take more than two or three long walks per day is probably excessive, at least as far as the ileus is concerned. We encourage patients to get out of bed and walk to the bathroom for the first time on the day of surgery or, if they cannot do so safely, then certainly no later than the morning of the first postoperative day.

Bowel Function

The traditional recommendations of gastric decompression and *nil per os* until the patient passed stool or flatus were based on the belief that the colon was the last segment of the intestine to recover from the postoperative ileus. In retrospect it seems more likely that this purported final phase of the postoperative ileus should simply have been called constipation. There are many factors that promote constipation in postoperative patients: general anesthetic agents, opiates, diminished activity, fluid shifts, and poor oral intake.

We actively anticipate and take measures to prevent constipation, if possible, in the postoperative period. In fact, inducing a bowel movement on the second or third postoperative day in patients who are otherwise recovering nicely from their operation makes them feel better, relieves abdominal distension, improves their appetite, and appears to be safe. While some routinely give their adult patients oral laxatives in the immediate postoperative period, we have been reluctant to use purgatives or osmotic agents due to the cramping and distension that we sometimes see in children. On the other hand, we have for years routinely offered our patients a bisacodyl suppository (some will refuse) on POD 2 even after bowel surgery and have had excellent results, high patient and parental satisfaction, and no complications associated with their use.

Minimally Invasive Surgery

It is well established that minimally invasive surgical techniques are associated with less postoperative pain and faster recovery. When the only option is a laparotomy, many have found that incisions that are oriented transversely, avoid cutting across muscle fibers, or both are less painful and heal better than a midline incision. These include the Pfannenstiel, Maylard, Cherney, and Rockey–Davis incisions. When appropriate we also prefer to use transverse incisions placed lateral to the rectus sheath to allow an extraperitoneal dissection for exposure of retroperitoneal structures such as certain adrenal masses or iliac or ureteral lesions. We have also avoided the routine use of intra-abdominal drains as these have been shown to be ineffective and unnecessary but also painful, dangerous, and costly.

Regional Analgesia

Lumbar epidural infusions are associated with unpleasant sequelae and may impede recovery: they prolong the postoperative ileus; frequently cause urinary retention and the need for bladder catheterization; affect the muscular tone of the lower extremities and proprioception, preventing some patients from ambulating; and may contribute to postoperative constipation. On the other hand, thoracic epidural catheters, especially when used to administer local anesthetics, appear to be more effective and have fewer adverse effects on the natural course of postoperative recovery; however, they are more difficult to insert and have been associated with complications related to the spinal cord.

Discharge Criteria

Barring a postoperative complication, patients are considered ready for discharge to home when they are afebrile (<38.5 °C for 12 h), tolerate a regular diet, able to ambulate reasonably well, and are reasonably comfortable taking just oral analgesics. We prefer that patients after bowel surgery have at least one bowel movement. If they have not stooled by POD 2, we encourage them to take a bisacodyl suppository. It is very important that parents feel comfortable taking their child home, and this is where the preoperative education to anticipate a timely discharge is vital.

Future Considerations

Enhanced recovery protocols have been very well established to be safe and effective for many types of surgery. These concepts should be embraced and advocated by surgeons and nurses who take care of patients after major operations. And these caregivers should work to develop similar regimens to improve the care of their patients at their institution. Naturally, it is important to consider the specific needs on your unit and to educate and inform everyone involved, including patients and their families, as to the philosophical tenets of the program and the reasons why every step of the process is considered important.

Preoperative fasting and the physiologic stress of surgery produce significant metabolic derangements that can delay recovery and increase risk. To counteract the catabolic effects of fasting and cellular injury, some advocate a shorter period of fasting and the intake of clear liquids supplemented with complex carbohydrates up to 2 h before induction of anesthesia. We are considering adding this to our regimen but have been prevented from doing so by the lack of a suitable commercially available carbohydrate-rich drink in the USA and the more stringent NPO guidelines proposed by our anesthesiologists.

Although mechanical bowel preparation seems to have little benefit for elective colorectal procedures, there is increasing evidence that oral antibiotics may decrease SSI rates and therefore should probably be used routinely in these patients. However, in the USA at this time, it is difficult to find safe and effective oral antibiotics for use in children. Neomycin and erythromycin are rarely used due to concerns about toxicity and side effects. We hope to find a suitable drug combination that is minimally absorbed and safe.

Early reports suggest alvimopan, a μ-receptor opioid antagonist that blocks the effects of narcotics on the intestine but not in the brain, might hasten return of bowel function and shorten hospital stay after surgery. It appears to be safe but the reduction in time to diet and discharge seems to be modest at best. Nevertheless, we suspect these or similar drugs will someday become a standard part of our regimen.

Finally, the short history and impressive success of enhanced recovery protocols should be a clear lesson that empiric methods, superstitious practices, and traditional dogma can be dangerously wrong and, despite our technical skill, attention to detail, and good intentions, we can cause unnecessary suffering and actual harm to our patients by stubbornly adhering to unproven traditional methods. It is far better for our patients that we view traditional teaching and conventional wisdom with skepticism, keep an open mind about concepts that might seem at first to be heretical, and insist every action we take in the care of our patients be justified and based on sound scientific principles.

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Quality Improvement, Education, and Outcomes Research

7

Steven Teich and Marc P. Michalsky

Historically, there has been a great disparity in the advancement of pediatric clinical services and the development of pediatric quality and safety indicators. The development and expansion of pediatric care in the USA began with the opening of the Children's Hospital of Philadelphia in 1855. Despite this major advancement in the organization and administration of medical care for the pediatric population, a formalized mechanism to specifically address medical errors, quality of care, quality improvement, and longitudinal outcomes analysis did not take form until the middle of the twentieth century. In 1934 Ernest Codman, an orthopedic surgeon, advocated that every hospital should follow patients to determine if their treatment had been successful. Over the past half-century, pediatric hospitals have become highly specialized facilities for delivering state-of-the-art medical care. The progression of medical specialization into pediatric subspecialties has led to a commitment to provide the best care possible for pediatric patients.

Medical Injuries

Patient safety events for hospitalized children occur at a comparable rate to hospitalized adults. This has led to increased scrutiny regarding the accurate assessment and prevention of pediatric medical errors. Serious safety events are associated with a two- to sixfold increase in length of stay and up to a 20-fold increase in total hospital charges. Furthermore, specific medical injuries have up to 50–60 % excess adjusted mean LOS and more than $5000 excess mean adjusted hospital charges.

There are also many safety issues that are unique to children's health care. These relate to the four Ds of childhood: developmental change, dependence on adults for accessing care, different disease epidemiology from adults, and demographic characteristics unique to childhood. The enhanced susceptibility of newborns to infections and the detection of life-threatening cardiac anomalies within the first few days of life are examples of developmental change. Children are dependent on adults for accessing medical care since they usually cannot be the primary historian for their medical complaints, they are not capable of questioning their medical care, and usually do not administer their own medications. Children also have unique illnesses, such as birth trauma and metabolic abnormalities that do not occur de novo in adults. Pediatric outcomes research is hampered by the low association between parental and child perspectives, the need for developmentally appropriate measures, low rates of medical conditions, long intervals necessary to detect treatment effects, and the need for case-mix adjustment.

Medication errors are the most common adverse events in hospitalized patients, accounting for nearly 20 % of all events. One third of all adverse drug events are associated with medication errors and are therefore preventable. In adults, ADEs occur at a rate of 5 % of medication orders. Although a similar overall medication error rate occurs in the pediatric population, the nature of associated errors has several unique characteristics when compared to the adult population. Specifically, routine weight-based dosing in the pediatric population results in children being more likely to experience dosing errors as a result of simple mathematical errors. Such errors result in the inadvertent administration of medications at doses 10- or 100-fold higher than the prescribed amounts. Other unique factors to be considered include the errors associated with off-label drug usage and preparation. In addition, pediatric patients have a limited reserve to tolerate a dosing error and limited ability to communicate with health-care personnel that an error has

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occurred or is about to occur. Academic pediatric hospitals demonstrate a medication error rate of 5–6 % and 50–90 % of ADEs are preventable, since medication errors occur frequently during drug order entry and may be corrected if the error is detected early in the ordering process.

Analysis of medication error causality on a pediatric surgical service concluded that the majority of medication errors are associated with the presence of rotating general surgery residents, who while often still in the process of familiarizing themselves with routine "adult" dosing guidelines are often less familiar with pediatric dosing and therefore more likely to commit an error. Some have demonstrated that an incorrect dose of medication accounts for the largest number of errors, followed by dosage form, omission of information necessary to complete an order, and missed allergies. Most medication errors are identified by the pharmacy, go no further, and result in no harm to the patient. Medication orders should always include the milligram-per-kilogram dosing information, the patient's weight in kilograms, as well as the total dose requested. This allows the pharmacy to efficiently check medication orders. Computerized physician order entry (CPOE) is an important tool in this regard since it is designed to flag and to refuse to accept a medication order without these critical parameters.

On the pediatric surgery service at the Nationwide Children's Hospital, like most pediatric surgical services, the attendings and fellows are most experienced at writing pediatric medication orders, yet the majority of orders are written by inexperienced rotating general surgery house officers. Therefore, we have initiated standardized order sets for many pediatric surgical conditions including hypertrophic pyloric stenosis, acute appendicitis, and Nissen fundoplication. In addition to reducing the potential for medication error, we have demonstrated that the use of routine perioperative order sets reduces overall hospital charges as well as length of stay.

Other strategies to decrease medication errors can also be useful. Pharmacy auditing and clinical pharmacist review are critical to identify medication errors involving drug interactions, incorrect drug doses, incorrect solutions, and inappropriate infusion rates. Adding a pharmacist to the ward team has been shown to decrease ADEs by 66 % and has been widely adopted in both the pediatric and adult setting. Handheld PDAs with a drug prescribing reference can help reduce medication errors. However, not all commercially available drug-dosing references have pediatric dosing information, and many drugs are used off label for pediatric patients.

Within our CPOE at the Nationwide Children's Hospital, common dosages for prescribed drugs are listed to help guide physicians. In an effort to reduce errors on the pediatric surgery service, we also provide the house staff with a pediatric surgery pocket manual, which lists the common drugs used on the pediatric surgery service with the correct dosages. In addition, we highlight several specific services, such as pediatric burn surgery and trauma surgery, with supplemental pocket cards, which allow for immediate access to important information on drug dosing in the acute care setting.

Morbidity and Mortality Conferences

Surgical morbidity and mortality (M&M) conference has been the most important meeting for surgical education and quality assurance in the surgery department at teaching institutions ever since Ernest Codman developed his "End Results" system at the Massachusetts General Hospital in the early 1900s. The structure of M&M conference has remained essentially unchanged from Codman's description of a system, which details the patient's history and outcome, along with adverse events and their causative errors.

Teaching at M&M conferences is based on the idea that analysis of our errors is a powerful educational tool. In national surveys, 80 % of respondents state that they would attend M&M conference even if it were not mandatory. This survey reflects the strong belief among surgical residents and attendings of the value of M&M conferences as an educational tool. M&M conferences are also an important tool for quality assurance since many surgeons demonstrate a willingness to change their clinical practice based on knowledge acquired at M&M conferences.

Over the past decade, surgical education has been strained by reduced resident work hours, the economic needs of the hospital, and further specialization within general surgery. In 2001, the Accreditation Council for Graduate Medical Education (ACGME) mandated US residencies to implement a curriculum and evaluation process based on six general competencies: patient care, medical knowledge, practice-based learning and improvement, interpersonal and communication skills, professionalism, and system-based practice. In response to these challenges, surgical residencies have instituted a number of innovative changes including a night float system and a daily general surgery morning report. However, a well-run M&M conference remains the cornerstone to fulfilling many of the ACGME competencies, especially practice-based learning and improvement.

We have sought to increase the educational value of the surgical M&M conference through several proven techniques: direct questioning of the audience, more thorough explanation of cases, questions directed to attending surgeons, use of radiographic images, and teaching points specifically made for the medical students in attendance. Moreover, this weekly conference requires coordinated participation from an attending radiologist and pathologist, as well as other pediatric subspecialists as dictated by the case under discussion. The result is a multidisciplinary discussion with maximal educational content.

Evidence-Based Practice

Evidence-based medicine (EBM) defines best practice based on the weight of best available evidence. It has been demonstrated in the adult medical literature that among different practice groups, significant variations can exist in rates of hospitalization, medical therapy, and surgical procedures for the same medical conditions with no significant variation in quality or outcomes. Therefore, all specialties are seeking to define optimal care practices to reduce inappropriate utilization through the use of objective clinical data studies.

Evidence-based practice derives its data from the scientific literature. However, the pediatric surgery literature is replete with retrospective single-institutional series, often focusing on narrow surgical problems. There are many descriptions of surgical techniques, personal experiences, and unique cases. These observational studies do not provide strong support for defining best practices in pediatric surgery. Several studies have shown that among original articles published in the pediatric surgery literature in recent years, less than 1 % can be classified as prospective, randomized, controlled studies. Thus, the need for better outcomes research in pediatric surgery is obvious.

Several studies in children have suggested an association between hospital and surgeon volumes and outcome, yielding data similar to adult volume-outcome studies. This has been clearly shown for pyloromyotomy for hypertrophic pyloric stenosis and portoenterostomy for biliary atresia. Europeans have demonstrated that centralized systems for certain low-volume high-risk procedures such as portoenterostomy have the distinct clinical advantage of creating a seamless transition from rapid evaluation of neonatal obstructive jaundice to prompt Kasai portoenterostomy by an established, multidisciplinary team at a single center.

The opportunity for evidence-based practice in minimal access pediatric surgery is evident. Pediatric surgeons were initially slow to embrace minimal access surgery until the 1990s when advances in technology allowed the creation of smaller instrumentation and camera systems suitable for children and infants. Nevertheless, less than 2 % of articles on minimal access pediatric surgery can be classified as level 1 randomized controlled studies or systematic reviews of randomized controlled studies, while 70 % are classified as level 4 case series. Any new surgical technique should be equal or superior to the conventional method that it is trying to replace but the quality of evidence for minimal access pediatric surgery remains extremely poor.

The nonoperative management of blunt spleen and liver injuries in children serves as a model for the creation of evidence-based guidelines in pediatric surgery. In 1998, the American Pediatric Surgical Association (APSA) Trauma Committee devised evidence-based guidelines for resource utilization based on a retrospective review of 832 children with isolated liver or spleen injuries. Stylianos and the APSA Liver/Spleen Trauma Study Group then conducted a prospective study at 16 centers to apply these evidence-based guidelines to children with isolated spleen or liver injuries. Compared with the patients in the retrospective study, the prospectively treated patients had a significant reduction in ICU stay, hospital stay, follow-up imaging, and interval of physical activity restriction within each grade of injury with no adverse sequelae. With validation, these guidelines have had direct economic impact while enhancing patient and family satisfaction.

Pediatric surgeons, like other health-care providers, are being challenged to optimize utilization of resources while providing maximum patient safety. We now have the opportunity and need to apply evidence-based practice to define optimal care for our pediatric surgical patients on a prospective basis.

Surgical Outcomes Research

The assessment of surgical outcomes had its beginnings in the pioneering work of Ernest Codman at the Massachusetts General Hospital in the early 1900s. Among his many accomplishments were the development of the intraoperative anesthesia record, the first tumor registry, and the routine collection and reporting of individual surgeons' operative outcomes. His adverse operative outcome system is still in use today. The M&M conference and audits of physician performance were widely adopted by the surgical specialties but largely ignored by other branches of medicine. In the 1960s and 1970s, computer programs made it possible to audit large institutional surgical volumes as well as surgeon-specific outcomes. However, data collection was not uniform, there was no risk stratification, comorbidities were not well assessed, and incomplete follow-up gave rise to inaccurate morbidity and mortality data.

In 1991, the National Surgical Quality Improvement Program (NSQIP) was initiated by the US Department of Veterans Affairs and was subsequently adopted in a staged fashion by academic medical centers throughout the USA. Designed to measure the quality of adult surgical care within an institution utilizing prospective entry of patient risk and outcome data and the determination of risk-adjusted 30-day outcomes, initial NSQIP results from the VA system demonstrated a 47 % reduction in overall 30-day postoperative mortality and a 43 % reduction in overall 30-day postoperative morbidity.

Due to the great need for risk-adjusted and outcomes-driven quality improvement programs in pediatric surgery, the American College of Surgeons and the APSA codeveloped NSQIP Pediatric. However, there are marked differences in children's surgery that do not allow for direct adaptation of the NSQIP model. Most complicated general pediatric procedures are performed infrequently and have a low

perioperative mortality rate. Also, because of age-related cognitive limitations, preoperative comorbidities, postoperative outcomes, and quality of life assessments must be obtained through parents or caregivers for neonates, infants, and preschoolers.

The philosophy of the children's NSQIP, like the adult version, is to provide pediatric surgeons with highly reliable data that they can use to make quality improvements. The aim is to not only provide a highly reliable data system to compare risk-adjusted outcomes among pediatric surgical programs and individual pediatric surgeons but also to provide robust data to permit intensive quality improvement efforts at the local hospital level.

Editor's Comment

It is hard to believe that a focus on the issue of patient safety as it relates to the care of children has taken so long to take root in this country, especially when one considers the staggering number of preventable injuries that occur every day. At many children's medical centers, the boards of trustees have taken ownership of the problem, and this has helped to increase awareness and spark entire institutions to action. Every children's hospital should have a patient safety officer and deputies in every department and division. Meanwhile, the science of patient safety, though still in its early development, is being developed by pioneers who are applying many of the same techniques that have proved successful in other fields such as aviation and industry.

A major advance is the concept that although some medical errors are due to human factors and the technological complexity of the medicine, the majority actually appear to be due to predictable and therefore preventable system failures. Analysis of errors and near misses through root cause analyses and multidisciplinary M&M conferences, without using traditional personal blame tactics, has helped to identify system modifications that should help to prevent similar errors. There are also efforts to make use of available technology such as computer-based medical entry to improve efficiency and minimize errors. Finally, it is clear that improving quality and patient safety follows naturally when medical care is evidence-based and standardized.

These modern concepts have been difficult to institute due to the traditional health-care culture that values physician autonomy, a rigid hierarchy in which the physician is "captain of the ship," and learning by trial and error. The M&M conference is a hallowed tradition in most surgery departments. Modifications in the traditional approach are long overdue and should result in vast improvements in the value of the conference without compromising its traditional usefulness. These modifications include:

1. Making it a multidisciplinary conference
2. Adopting a no-blame format
3. Distinguishing between known and expected complications from true patient safety issues, which should be forwarded to the department patient safety officer for systematic review
4. Discussing near misses in addition to true complications
5. Discussing cases in the context of the available scientific evidence

Finally, there should be a concerted effort to gather data prospectively rather than discuss each case individually and therefore out of context. Though much is to be learned by studying individual data points in depth, it is through the analysis of outcomes data and trends that improvements in the quality and safety of patient care can be realized more quickly and effectively.

A major hindrance is the culture of arrogance, machismo, and stubborn individualism seemingly inherent in many surgical departments. We fail to take into account our own biases, especially confirmation bias, in our decision-making process and tend to have higher opinions of our own intelligence and abilities than is usually warranted. We speak glowingly of those who are team players, but in the end it is my way or the highway. We pretend that we only have the patient's best interest in mind but deep down we are overly competitive and seem to prefer to appear to be the smartest or coolest and, ultimately, to win the argument, the battle or the war. We can only hope that as the older generations retire and fade, the newer generation of young surgeons will be: better team players who truly respect the opinions and skill of others; better and more respectful citizens of the medical community; less dogmatic and beholden to silly rituals and superstitious beliefs; more aware that everything we do to a patient should have a basis in the scientific evidence; more humble, introspective, and self-critical; and more professional in the modern sense of the term.

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Part II

Critical Care

Shock

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Michael Wilhelm

The recognition and treatment of shock supersedes all other priorities because it is fatal when untreated. Inadequate oxygen delivery results in increased oxygen extraction, lower mixed venous oxygen saturation, and, due to anaerobic metabolism at the cellular level, increased serum lactate levels. The resultant acidosis can lead to increased minute ventilation and notable tachypnea, particularly in younger patients. A number of physiologic compensations occur in the setting of impaired systemic oxygen delivery in an effort to protect perfusion of the most vital organs (the brain, heart, kidneys). Activation of the sympathetic nervous system promotes tachycardia and increased systemic vascular resistance as evidenced by embarrassment of distal perfusion (increased peripheral-to-core temperature gradient, prolonged capillary refill, narrow pulse pressure). The same mechanisms divert blood from the splanchnic circulation promoting ileus and decreased urine output. Diaphoresis is another potential sign of catecholamine activation. Finally, because physiologic compensations aim to preserve cerebral perfusion at the expense of other organs, altered mental status strongly suggests significant malperfusion. Combinations of each of these signs can occur in patients with various forms of shock and the presence of two (and definitely three) should raise suspicion that the patient requires urgent resuscitation. In any patient in shock, therapies to reduce metabolic demands (from hyperthermia, agitation, or seizures) can improve the metabolic supply-demand balance even without improving substrate delivery.

Very frequently one or more compensatory mechanisms fail, directly contributing to the shock state. Recognizing that a patient is in shock (altered mental status, high lactate, oliguria) and yet lacks one or more compensatory mechanisms (still has warm extremities) strongly suggests the mechanism of shock (low SVR suggestive of sepsis). Shock will frequently be refractory to other therapies until these failed mechanisms have been identified and addressed—profound volume resuscitation will be required to normalize perfusion in vasodilatory shock until vasoconstrictive medications are initiated.

While pediatric surgeons will encounter children with shock from a variety of causes, hypovolemia (whether absolute or effective) will be a contributing factor in nearly all patients. If the patient exhibits signs of high filling pressures (hepatomegaly, jugular venous distention, elevated CVP), early investigation of cardiac function and possible pericardial tamponade should be considered. In all other cases, fluid resuscitation with isotonic fluids remains the mainstay of initial therapy. In the setting of hemorrhagic shock, replacement of blood products should occur as soon as possible, though initial therapy may by necessity be crystalloid and other colloids. For other shock states in children, there is a paucity of data to determine whether crystalloid or colloid is the preferred therapy. Presently, the only non-plasma colloid in routine use in children is 5 % albumin. Many studies have attempted to determine whether crystalloid or colloid resuscitation improves outcomes in specific forms of shock, but this remains unclear. Given the additional cost and theoretical downsides of albumin, isotonic saline is therefore generally used in initial resuscitation and up to 60 mL/kg should be given in the first 30 min if shock persists.

General Principles

It is important to monitor signs and symptoms of adequate oxygen delivery as well as filling pressures and compensatory mechanisms throughout the period of resuscitation. Vital signs and mental status should improve with resuscitation as should urine output as a marker of renal perfusion. Regional oximetry using near-infrared spectroscopy (NIRS) can approximate the venous saturation (and hence extraction) in specific tissues and is typically measured over the

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forehead and flank to measure cerebral and renal perfusion, respectively. Central venous access permits measurement of CVP as well as venous saturation. It is important to remember that all of these numbers are relative and indirect measurements—no absolute number is "optimal" for any given physiology. However, they provide useful information, particularly when interpreted together as a composite data set, and they should improve as therapy of shock progresses.

Laboratory assessment is also critically important in shock. *Glucose* must be measured immediately and normalized to ensure adequate metabolic substrate delivery. This is particularly important in infants as they are more prone to hypoglycemia than older children and adults. Anemia will impair oxygen delivery by reducing oxygen content and in certain cases a *hemoglobin* greater than the age-based norm may be targeted if cardiac output cannot be normalized without excessive therapies. Serial measurements of *lactate* will help determine if oxygen delivery is adequate, though there may be an initial increase in lactate with improved distal perfusion and washout of lactate from the microcirculation. *Hypocalcemia* commonly occurs in shock and also contributes to impaired cardiovascular function. Neonates and infants are particularly sensitive to hypocalcemia as their sarcoplasmic reticulum is immature and they are therefore more reliant on extracellular calcium for cardiac contractility. Finally, sequential blood gas analysis is also important. In general, a *pH* greater than 7.2 need not be specifically treated, but certain circumstances (pulmonary hypertension, malignant arrhythmias, intracranial hypertension) dictate more aggressive normalization of pH with increased ventilation or intravenous administration of bicarbonate or other bases.

In addition to fluid resuscitation, a variety of medications are used to support the circulation. The apparent physiology determined by examination (SVR, myocardial function) dictates the category of drug used. Drugs can exert inotropic, vasopressor, or vasodilatory effects and combinations thereof. For patients with high SVR after fluid resuscitation, combined inotropes and vasodilators are used. Milrinone is typically used for myocardial support unless the blood pressure is low. If blood pressure is low, low-dose epinephrine (0.02–0.1 μg/kg/min) will provide inotropic support and some afterload reduction but better preservation of blood pressure than milrinone. Dopamine is frequently used in sepsis in children, as titration of its dose can lead to different effects on SVR and myocardial function.

Drugs that are not primarily considered vasoactive medications can also have profound effects on cardiovascular function in children in shock. Again, calcium has beneficial effects on myocardial and vasomotor function and can be given as a rescue medication in refractory shock even if ionized calcium is normal. Steroids also raise blood pressure, but their impact on outcome in various forms of shock is controversial. Recent steroid use, metabolic evidence of hypoadrenalism (hypoglycemia, hyponatremia, hyperkalemia), and shock refractory to multiple vasopressors are common indications for empiric administration of corticosteroids. Ideally, serum cortisol is measured prior to initiation of steroids to help determine further steroid management. Importantly, weaning of steroids should begin as soon as the patient is stable, as their side effects are both dose and duration dependent. Many other medications that target inflammation and microvascular function have been tried in shock in adults, and these may find utility in pediatrics as well, but thus far no adjunctive medications have proven useful.

These general management principles, serial examination, and laboratory analysis will permit the recognition and early intervention for shock required to optimize outcome. In addition, specific etiologies of shock have unique characteristics that require specific evaluation and management.

Hypovolemic Shock

Profound hypovolemia can be caused by either loss from the body (hemorrhage, diarrhea), losses from the vascular space (capillary leak, hypoproteinemia), or increased venous capacitance (as in distributive shock). In all cases, the filling pressures by examination (liver size, jugular venous distention) and monitoring (CVP) should be low. Patients will also have evidence of increased systemic vascular resistance (cool extremities, delayed capillary refill, and narrow pulse pressure).

Aggressive isotonic crystalloid resuscitation is the mainstay of therapy, and in pediatrics normal saline has traditionally been used. This can lead to hyperchloremic acidosis, and a resultant increased load on the respiratory system. Lactated Ringer's solution can be substituted if hyperkalemia and liver function are not concerns and acetate or bicarbonate can be used as needed. It is important to avoid vasodilatory drugs in this setting as they can cause acute hypotension.

Cardiogenic Shock

Cardiogenic and obstructive shock will similarly have evidence of high SVR, but will have evidence of increased filling pressures (JVD, hepatomegaly, increased CVP). The major distinction to make is whether there is truly myocardial pump failure or impaired filling (decreased compliance) of the ventricles. The mechanism of impaired filling is sometimes suggested by the history and physical examination. The patient with acute shock on high ventilator settings could have a tension pneumothorax, while the patient with uremia and distant heart sounds might have pericardial tamponade. In the absence of myocardial dysfunction, initial fluid resuscitation will help to overcome the deficit in

compliance of the heart. Tension pneumothorax and pericardial tamponade require tube drainage.

If myocardial failure is suspected, fluid therapy should be in small aliquots with careful reassessment, as excessive fluid can make cardiac output worse. With impaired filling of the heart, pure vasoconstrictors are beneficial as they keep the blood pressure up without increasing heart rate, which would lead to further decreases in diastolic filling time. In the setting of myocardial failure, combined inotropes and vasodilators will improve the cardiac function and reduce the work the heart must do. However, if the patient has borderline blood pressure, this can result in frank hypotension. In this case, an inotrope in combination with a vasopressor (milrinone plus vasopressin) or a drug with combined effects (low-dose epinephrine) is a safer choice.

Distributive Shock

Distributive shock is classically due to sepsis, though spinal shock, anaphylaxis, and many intoxications also cause vasodilation that impairs perfusion of vital organs. In addition to fluid therapy, these patients commonly need vasoconstrictors to restore normal blood pressure. Unlike adults, children with sepsis typically do not have measurably impaired myocardial function, though this can be unmasked with vasoconstrictors. Therefore, if the peripheral perfusion deteriorates but other markers of shock fail to abate, reinvestigation of volume status and myocardial function is warranted. In this setting and in others, echocardiography can be used to assess cardiac function. Given the global impact of septic shock on mortality, the Surviving Sepsis Campaign regularly updates the evidence for specific therapies in sepsis and septic shock. These guidelines also outline considerations that are unique or specific to children.

It is important to remember that progressive, untreated shock of any kind can progress to a profound vasodilatory state with cold extremities and impaired myocardial function. In this setting, it can be extremely difficult to determine whether additional fluids, vasoconstrictors, or inotropes are required. And frequently all three are needed in addition to improving the metabolic milieu (particularly pH and ionized calcium). In adults, vasopressin has some theoretical advantages in late shock compared to other vasoconstrictors, though there are no data specific to children. Ultimately patients may be refractory to medical support and require ECMO to restore systemic oxygen delivery in this setting.

Neurogenic shock occurs after a traumatic spinal cord injury above the level of T6. This a specific type of distributive shock in which there is an acute loss of sympathetic innervation, which results in global venous and arterial vasodilation, classically accompanied by bradycardia, caused by unopposed vagal stimulation of the heart.

Future Considerations

Supportive therapy for shock remains the mainstay of therapy, but future studies will hopefully identify specific mediators of specific shock states and mechanisms to improve microcirculatory function. Future studies will hopefully resolve controversies such as type of resuscitation fluid to use in specific shock states and the appropriate indications of adjunctive medications such as steroids. With continued improvements in outcomes from pediatric shock, the long-term consequences in shock survivors will require additional study.

Editor's Comment

Shock is a multidisciplinary disease that demands a calm and systematic approach to assessment and treatment. One of the challenging things about shock in children is that the parameters for normal and abnormal vital signs vary with age. Furthermore, children can be in a compensated state of shock and therefore "not look that bad." A number of institutions have implemented the use of a shock tool to recognize shock based on age-specific vital signs. For experienced clinicians, the most sensitive indicator of shock in a child is often persistent tachycardia. If resuscitation has not begun in earnest but the heart rate starts to rapidly fall back to normal, this is an ominous sign that cardiovascular collapse is imminent and that CPR will need to be initiated within minutes to seconds.

All accepted critical care protocols (ACLS, ATLS, PALS) explicitly address the patient in shock. The ABCs should always be assessed first, although in reality multiple issues are addressed simultaneously. Most children in shock, unless they respond rapidly to initial fluid boluses, should be intubated and mechanically ventilated. After securing the airway and establishing adequate ventilation, fluid resuscitation should always be initiated aggressively but judiciously to avoid fluid overload and pulmonary edema. If clinical parameters fail to improve despite seemingly adequate fluid resuscitation, pressors should be considered next, but always remember that the goal of therapy is to restore tissue perfusion—any intervention that increases central pressure at the expense of peripheral tissue perfusion is counterproductive. This is why the use of drugs that induce intense peripheral vasoconstriction (norepinephrine) should be considered only as a last resort, if ever.

Given their characteristic clinical presentations, the common causes of shock (sepsis, hypovolemia, anaphylaxis) and even the less common causes (cardiogenic, neurogenic) are usually fairly easy to spot, especially when the history is known. However, there are rare causes of shock that should be considered when the presentation is not so

clear-cut. Spontaneous pneumothorax, typically occurring in tall, thin teenagers who smoke, can occasionally result in tension pneumothorax and shock. Careful physical examination and immediate thoracostomy can be life-saving (there is no time for a chest X-ray). Pericardial tamponade is also quite rare but should be considered in the child who presents with what otherwise appears to be cardiogenic shock. Physical examination (muffled heart sounds, pulsus paradoxus) and US should be used to confirm the diagnosis. Occult bleeding can cause hypovolemic shock after traumatic injury (scalp laceration, femur fracture, hemothorax), or in association with a GI source (esophageal varices) or massive hemolysis (toxins, rare infections). It is also easy to underestimate the ability of severe dehydration to cause shock in a child.

ECMO is increasingly considered a final option in children with refractory but otherwise potentially reversible shock. Though still somewhat controversial and certainly in need of evidence-based protocols to streamline the process, we have used it with some success in children with cardiogenic shock, septic shock, and idiopathic cardiovascular collapse, especially when triggered or accompanied by concomitant respiratory failure.

Suggested Reading

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Electrolyte Abnormalities

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Adam Szadkowski and Michael Wilhelm

Maintenance of adequate circulating volume is the mainstay of fluid therapy, and children are at increased risk of hypovolemia for multiple reasons. Total body water (TBW) makes up a greater percentage of body weight in neonates and infants. Approximately 2/3 of the TBW is in the intracellular space, while the remaining 1/3 is in the extracellular space. These calculations are important when considering how drugs and electrolytes distribute between the spaces and determining appropriate doses. Sodium, for example, predominantly distributes in the extracellular space, while potassium is predominantly an intracellular cation.

When circulating volume is rapidly expanded with isotonic fluids (crystalloid or colloid), it is important to recall that the tonicity of administered fluid must be considered. The fluid should not be hypotonic as this can cause hemolysis. To prevent excess sodium (and chloride) administration at the relatively high fluid rates required by children, dextrose is often used to increase the tonicity of administered fluid. This can cause hyperglycemia, particularly if supranormal fluid rates are required for any reason. As the body metabolizes the dextrose, there is also the risk of making the patient hyponatremic if fluids with a lower sodium concentration are used. Given the increasing occurrences of hospital-acquired hyponatremia resulting in volume overload, cerebral edema, seizures, and even death, we typically administer no less than 0.45 % sodium chloride ("1/2 normal" saline) as maintenance fluid.

Apart from resuscitation, fluid therapy can generally be broken down into maintenance fluids and replacement of losses. Weight-based maintenance fluids were originally described as a way to approximate basal free water and electrolyte requirements. However, the idea that this amount of fluid is *required* is imprecise. This fluid rate will promote a moderate amount of nearly isosthenuric urine output if renal function is normal. In actuality, a maintenance rate includes replacement of measurable losses (urine and others) and insensible (unmeasurable) losses. Unmeasurable losses due to humidification of inspired air and evaporative losses from the skin typically approximate 400 mL/m^2/day. This can change significantly by humidification of inspired air, fever, or loss of skin integrity. But, to truly "maintain" the patient's volume status, the most accurate method is to provide this basal fluid rate and replace losses. In addition to urine, important sources of measurable losses are blood, drain output, and diarrheal stools.

Practically speaking, in the majority of cases, however, we start with the standard maintenance calculations: each hour give 4 mL/kg for the first 10 kg + 2 mL/kg for 10–20 kg and 1 mL/kg of weight over 20 kg. Thus, a 34 kg child would receive ($4 \times 10 + 2 \times 10 + 1 \times 14 = 74$ mL/h). Our practice has been to avoid very hypotonic fluids, so our default is 0.45 % NaCl. When patients are at high risk of developing hypoosmolality or significant morbidity if they become hypoosmolar (intracranial hypertension, diabetic ketoacidosis), we use normal saline. Lactated Ringer solution is used far less commonly in pediatrics outside the OR as children frequently tolerate the hyperchloremic acidosis induced by large volumes of saline. However, as long as the patient has adequate clearance of lactate, LR is a reasonable replacement or resuscitation fluid, particularly if large bicarbonate losses are occurring.

For dehydrated patients, the volume deficit must be replaced—maintenance fluids as well as replacement of ongoing losses. With isonatremic dehydration, ½ of the fluid deficit is replaced in the first 8 h followed by replacement of the second ½ over the subsequent 16 h. In order to avoid significant shifts in sodium concentrations, we typically replace the fluid deficit more slowly in either hyponatremic or hypernatremic dehydration. As long as the patient is not in shock, the deficit can be replaced over 48 h in most patients.

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Colloid solutions are used infrequently in pediatrics, but 5 % albumin can be used to replace albumin losses when highly proteinaceous fluids (ascites) are being lost. The rate of replacement depends on the volume of losses as well as the concentration of albumin in the fluid.

In addition to fluid requirements and derangements, children are similarly at higher risk for electrolyte disturbances.

Sodium

Sodium is the main osmole in serum under normal conditions. It regulates the size of the extracellular fluid (ECF) space and is responsible for the depolarization of neurons and other excitable cells. Acute significant changes in serum sodium can therefore have life-threatening consequences. Gradual changes in sodium concentration are often well tolerated because the body can adapt through a variety of mechanisms. This in turn requires slower correction to allow the reversal of these adaptive responses; a good general rule is to correct over the same time period that the abnormality occurred. Because sodium is the major electrolyte in the ECF, abnormalities can be due either to primary sodium or water abnormalities or both. Therefore, the patient's volume status is critical to understanding the mechanism, and appropriate treatment, of sodium derangements.

Hyponatremia is defined as a serum sodium of less than 130 mEq/L and is the result of having an overall deficit of sodium *relative to free water*. This drops extracellular osmolality and promotes fluid shifts into cells, as well as easier depolarization of neurons. As sodium levels continue to decrease to around 120–130 mEq/L, clinical symptoms including headache, restlessness, disorientation, lethargy, and even seizures may appear. With changes occurring slowly (many hours to days), adaptive responses may limit symptoms by the reduction of intracellular "idiogenic" osmoles, thereby preventing excessive intracellular edema. Acute, symptomatic hyponatremia should be corrected quickly to levels that eliminate symptoms, but then correction should be slowed to prevent osmotic demyelination syndrome. Correction rates of 0.5–1 mEq/h have been reported without morbidity or mortality. An acute increase in sodium by 3–5 mEq/L is often enough to reverse symptoms and can be achieved with 5 mL/kg of 3 % NaCl (hypertonic saline).

Hyponatremia can be broken down into causes with increased salt loss and those with exaggerated water retention. With salt loss from vomiting, diarrhea, abnormal skin losses (extensive burns, cystic fibrosis), or renal salt losses (cerebral salt wasting, certain drugs), antidiuretic hormone (ADH) levels are elevated because of decreased effective arterial volume (*hypovolemic hyponatremia*). Treatment is replacement of the sodium deficit and ongoing losses and, when possible, treatment of the underlying cause. The sodium deficit can be estimated as total body water × (goal sodium − current sodium). This amount of sodium can be replaced over 48 h by increasing the amount of sodium in the fluid volume provide over that time.

ADH levels are appropriately elevated in many causes of *hypervolemic hyponatremia*. Congestive heart failure, hypoalbuminemia (liver failure, nephrotic syndrome), and sepsis all cause decreased effective circulating volume. Treatment consists of correcting dangerously low sodium, though typically the hyponatremia is milder and treating the underlying cause is sufficient. In all cases, serial measurement of serum sodium is imperative as any approach to treatment is merely an estimate and many patients have ongoing salt and water losses that are not accounted for.

The syndrome of inappropriate ADH release (SIADH) deserves special mention. The vast majority of ICU patients with hyponatremia have appropriate ADH in response to effective hypovolemia. However, in patients who are euvolemic or hypervolemic without decreased effective circulating volume, the ADH release may be primary and inappropriate. Retention of free water causes volume expansion; this in turn causes increased natriuresis that exacerbates hyponatremia. Patients will have higher urine osmolality than their low plasma osmolality and be either euvolemic or hypervolemic. Primary treatment consists of fluid restriction, which is usually significantly lower than maintenance amounts. Hypertonic saline is given for acute, symptomatic hyponatremia.

Finally, hyponatremia also occurs when other osmotically active substances are in excess such as hyperglycemia or certain intoxications. In these settings, sodium level should increase as the other osmole is cleared. Failure of sodium to increase as the other osmole decreases may herald impending cerebral edema and should be aggressively monitored and treated. *Pseudohyponatremia* is uncommon in pediatrics and occurs with hyperlipidemia (and hypoproteinemia) due to expansion of the lipid phase of blood, which does not contain sodium.

Hypernatremia (greater than 160 mEq/L) results from net water loss or, much less commonly, increased total body sodium in excess of water. Symptoms of hypernatremia include but are not limited to muscle weakness, nausea, vomiting, and altered mental status. Severe elevations can cause subdural hemorrhage due to brain shrinkage and rupture of bridging veins. And, if acute, patients are at risk for the osmotic demyelination syndrome. Infants are at particularly high risk given an inability to augment oral intake, risk for dehydration, and immature renal water retention. Because treatment promotes falling serum osmolality, caution must be used to prevent intracellular water shifts and specifically cerebral edema, particularly if the hypernatremia has been prolonged (more than 24–48 h). In this case, sodium levels should be dropped by no more than 0.5 mEq/L per hour.

Free water deficit can be calculated as [total body water × (serum sodium − 140)/140]. When patients are dehydrated, they also have a salt and water deficit that must be corrected, as must ongoing losses. As with hyponatremia, this merely provides an estimate (and ideally a conservative estimate to promote slow correction in chronic cases). Therefore, serial sodium measurements are imperative in all cases.

The source of free water loss is typically identifiable by history and examination. In most cases, the patient will have a low volume of concentrated urine due to increased ADH levels. In the setting of osmotic diuresis, as occurs in diabetes mellitus, the urine may appear dilute, but will have a high osmolality (and specific gravity). On the other hand, high volume of truly dilute urine in the setting of hypernatremia suggests diabetes insipidus (DI). DI can be central or nephrogenic and both can be genetic or acquired. In addition to volume restoration and gradual lowering of serum sodium, patients with central DI will require vasopressin replacement. Vasopressin is typically given as an infusion and titrated to urine output and appropriate rate of sodium decline. Once a stable regimen can be established, patients are transitioned to longer-acting dDAVP. Nephrogenic DI is much more difficult to treat as the kidneys do not respond to vasopressin. Thiazide diuretics and replacement of urine output may be required.

Potassium

Unlike sodium, potassium is predominantly intracellular, but serum levels greatly affect the activity of electrically active cells. Therefore, potassium must remain in a narrow range to avoid life-threatening arrhythmias and neuromuscular compromise. Due to its intracellular predominance, large changes in serum potassium can occur quickly due to intracellular (or extracellular) shifts. This can be used therapeutically, but also makes the differential diagnosis a bit more complicated.

Hypokalemia is defined as having a serum potassium level of less than 3.5 mEq/L. Symptoms are predominantly cardiovascular (T-wave flattening or inversion, ST depression, U waves) and neuromuscular (ileus, skeletal muscle weakness). When extreme, hypokalemia may cause respiratory failure and life-threatening arrhythmias. However, mild and even moderate hypokalemia is often well tolerated unless patients are on digoxin or have underlying arrhythmias. When rapid correction is needed, IV potassium replacement is required, though in general enteral replacement is preferred when possible because it more stably and safely increases serum potassium. Doses range from 0.25 to 1 mEq/kg and should be given over an hour or more when IV. Concentrated potassium infusions (more than 40 mEq/L) should be given centrally to avoid risk of soft tissue necrosis in the case of extravasation. Careful monitoring of potassium levels and ECG should be performed, particularly with IV replacement. In some institutions, this must by policy be performed in an ICU or other monitored setting.

Hypokalemia can be due to lower total body potassium or intracellular shift. Insulin, alkalosis, and beta-agonists (exogenous or endogenous) all cause intracellular shifts of potassium and lower serum potassium levels despite normal total body levels. Loss of potassium typically occurs in the kidney. Increased aldosterone causes sodium retention and potassium excretion. Aldosterone release is stimulated by effective hypovolemia (CHF, hypoalbuminemia) as well as actual dehydration. Other causes of high aldosterone levels include endocrine tumors (Wilms' tumor), malignant hypertension, and renal artery stenosis. Diuretics (especially loop diuretics) and other drugs can cause renal potassium wasting. Renal potassium wasting is also enhanced when patients are polyuric, particularly if they are acidotic, which promotes extracellular shift of potassium. For this reason, patients with diabetic ketoacidosis are often profoundly total-body-potassium deficient and will have marked drops in serum potassium with the initiation of insulin if not given supplemental potassium.

Hyperkalemia (>6.5 mEq/L) results from excessive potassium intake (usually iatrogenic), a shift of potassium from the intracellular to the extracellular space, or impaired excretion of potassium. Renal insufficiency, even mild, can dramatically worsen hyperkalemia in the setting of an increased load. Hyperkalemia is a medical emergency as it affects the action potential in cardiac myocytes and can cause life-threatening arrhythmias. Hyperkalemia can be artifactual if the sample is hemolyzed, so the quality of the sample should be verified. At the same time, hemolysis and other significant tissue injury (burn, ischemia) can cause marked hyperkalemia especially if there is concomitant renal insufficiency. Other causes include acidemia, impaired renal function, aldosterone deficiency (congenital adrenal hyperplasia), and drugs like spironolactone that inhibit tubular secretion. Finally, exogenous potassium from supplementation (especially IV), red cell transfusion (especially after prolonged storage), and TPN all can cause hyperkalemia.

For mild cases (asymptomatic and without ECG changes), treatment consists of stopping *all* exogenous potassium intake and, if renal insufficiency is present, considering enteral (or rectal) sodium polystyrene sulfonate (Kayexalate). As levels reach 6.5 mEq/L or ECG changes develop, urgent treatment focuses on (1) electrically stabilizing the myocardium, (2) promoting intracellular shift of potassium, and (3) enhancing potassium excretion. Calcium stabilizes the myocardium through complex mechanisms. Initial dosing is 10 mg/kg of calcium chloride if central access is available or an equivalent dose of calcium gluconate. Additional doses may be needed if the ECG deteriorates again and patients may end up with supernormal calcium levels.

Rapid intracellular shift occurs with alkalosis (hyperventilate, bicarbonate 1 mEq/kg) and beta-agonism (nebulized albuterol). Less rapid redistribution occurs with glucose (0.5 g/kg) and insulin (0.1 U/kg). In patients who make urine, furosemide can promote rapid elimination of potassium, while Kayexalate causes ongoing, but much slower, removal. However, with significant renal dysfunction or for refractory, severe, or life-threatening hyperkalemia, dialysis may be required. In all cases, continuous ECG and hemodynamic monitoring and frequent measurement of blood pH, glucose, potassium, and ionized calcium levels are required.

Calcium

Calcium is critical for many cellular functions, particularly in cardiac muscle and vascular smooth muscle. Thus *hypocalcemia* can cause severe cardiovascular compromise. Cytoplasmic calcium comes from intracellular stores (sarcoplasmic reticulum) as well as extracellular sources to exert its effects. Therefore, because neonates have an immature sarcoplasmic reticulum, they are particularly dependent on normal extracellular calcium levels. Also, calcium is highly protein bound (in serum mostly to albumin), but it is the ionized form that exerts its physiologic effects. Therefore, with hypoproteinemia, the total calcium may be low, yet the patient may have adequate ionized calcium. Similarly, pH dramatically affects the binding of calcium to albumin: alkalosis promotes increased binding and a drop in the ionized calcium. Therefore, with coexisting acidosis and hypocalcemia, as commonly occurs in neonates, we routinely replace calcium prior to administering bicarbonate as a bolus.

Summary

Volume and electrolyte requirements can vary significantly between pediatric patients and can change rapidly. Serial assessment and measurements of electrolytes are critical, particularly when actively correcting abnormalities. Initial calculations merely provide estimates, and therapy often must be tailored to meet the individual patient's needs. With acute changes in electrolytes, or when life-threatening symptoms exist, rapid correction is needed; otherwise gradual correction is often safer and well tolerated.

Editor's Comment

Surgeons who take care of children should be aware of the electrolyte abnormalities commonly seen in children in the postoperative period. Since most are mild and self-correcting, it is rarely necessary to even check electrolytes after an uncomplicated procedure in a healthy patient who resumes normal oral intake within 2–3 days of the operation. But patients who are NPO for many days, have high GI fluid losses, are being provided parenteral nutrition, or have another specific risk factor should have a basic metabolic panel checked periodically. Rarely do they need to have labs checked more than twice weekly unless there is a dangerous value that is being aggressively corrected. It is still common to see daily or twice daily labs being drawn, especially in the ICU, despite the values being entirely normal for days—this is wasteful and should be abandoned.

Mild hyponatremia is common in the postoperative period due to a combination of GI losses, over-resuscitation with hypotonic solutions and a physiologic stress-induced SIADH. Our current protocols for fluid resuscitation provide excess free water, which contributes to hyponatremia, dilutional anemia, and bowel edema. Some enhanced recovery protocols recommend a slightly lower rate of maintenance fluids, crystalloid boluses for patients who need extra fluid, and early reliance on oral intake and thirst to guide fluid management. It is also common for surgical residents to mistakenly use the fluid replacement strategy recommended for gastric fluid losses (mL-per-mL of D_5 ½NS + 20 mEq/L KCl) for all GI losses (ileostomy, diarrhea, biliary drainage), which are all isotonic and have higher concentrations of potassium. Hypernatremia is less common and the cause is usually more obvious, though insensible losses are always more than anticipated, especially in infants. The most serious cases of hypernatremia (>200 mEq/L!) have occurred when parents are instructed to supplement their infant's formula with a pinch of salt. Regardless of the cause, correction of hypo- and hypernatremia should be gradual to prevent brain injury related to cerebral edema or demyelination.

Hyperkalemia can be dangerous but is almost unheard of in patients with normal renal function. It is almost always spurious, especially in infants, due to hemolysis of the specimen. Nevertheless, having to prove that it is normal is time-consuming (delays induction of anesthesia) and potentially dangerous because potassium is withheld from an infant who more likely has hypokalemia. This occurs in more than a third of babies with pyloric stenosis. Hypokalemia must be profound to have clinical effects but is dangerous because of the excitement it causes for healthcare providers, who tend to overreact by giving large amounts of potassium either intravenously, which is dangerous, or orally, which induces vomiting, making the problem worse. Calmly correcting acid-base imbalances, replacing potassium losses in GI fluids, and providing moderate concentrations of potassium in the maintenance fluids or parenteral nutrition solutions are usually all that is required.

Mild hypocalcemia is relatively common but is more often spurious in patients with hypoalbuminemia. Patients who are risk (thyroidectomy) and symptomatic should

be treated with oral calcium carbonate and calciferol. Rarely, intravenous calcium gluconate or calcium chloride is needed and should be administered according to institutional guidelines for rate and cardiac monitoring. Hypomagnesemia can be seen in patients with malnutrition or excessive GI fluid losses, often in conjunction with hypocalcemia. Oral magnesium supplements usually work best but intravenous replacement is occasionally necessary. Hypophosphatemia occurs commonly after massive hepatic resection and is due to a transient hyperphosphaturia rather than consumption by the regenerating liver. It typically peaks on postoperative day 2 and resolves by day 5. Supplementation is necessary to prevent life-threatening hypophosphatemia but will not prevent the underlying parathyroid hormone spike that is the likely cause.

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Vascular Access

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Peter Mattei

Securing vascular access for a child is always very gratifying but can also be challenging to the point of severe frustration. Pediatric surgeons should strive to be the best vascular access experts available anywhere in the hospital or clinic. Children who need a lifeline in an emergency, for comfort, for nutrition, or for long-term care, depend on us to make sure the access is placed safely and that it works reliably and painlessly. Any surgically created line should be inserted under general anesthesia or deep sedation while peripheral lines, depending on the age and maturity of the child, usually require only mild sedation. Sterile precautions should be followed with meticulous attention to detail and the safety of the patient should always be monitored and optimized. Complications from central access procedures can be very serious and in some cases potentially lethal.

Short-Term Access

Peripheral venous access should be considered first for most children who need intravenous access, and surgeons should be skilled in their placement. In the current era of "IV teams," it is unfortunately fast becoming a lost art for surgeons, but it need not be. Surgical residents should learn how to place PIVs and practice placing them in the OR every chance they get, not only because it is a valuable skill to have but because it teaches them a great deal about the handling of tissue and is another way to achieve the manual dexterity useful in many other maneuvers surgeons are called upon to perform.

One cannot learn to place a PIV by reading about it; hours of practice are really the only way. However there are a fewer pearls to pass along: learn to do it with gloves on; don't apply the tourniquet too tightly; be patient when looking for a suitable vein; wipe with alcohol from proximal to distal (toward the patient's fingertips) to avoid pushing blood up past the tourniquet; stretch the skin by pulling it distally with your nondominant hand; when you get a flash of blood, push the entire needle-catheter unit in a little bit deeper before trying to slide the catheter over the needle; learn how to gauge the depth of the vein (which is more difficult than it seems); and have the line to attach to the catheter ready, primed, and close at hand. One should also develop a short list of favorite sites—the vein on the ulnar aspect of the back of the hand and the saphenous vein at the ankle (just superior and anterior to the medial malleolus) are excellent choices. Always place a catheter of sufficient size for the child and its intended use, typically one size larger than you think of first. Except in times of desperation, one should generally avoid the misleadingly named "interns' vein" as it is very difficult to access and painful for the patient. Likewise, the antecubital location should be avoided—it is difficult to secure it properly as it lies so close to the elbow joint, it should be preserved for other purposes (phlebotomy), and its use is considered the mark of the inexperienced and insecure practitioner.

In the heavily sedated or critically ill child with very difficult access, a saphenous vein cut down at the ankle is an excellent option. A small transverse incision anterior and superior to the medial malleolus using sterile technique and a fine mosquito clamp should allow isolation and control of the saphenous vein. I prefer to place the catheter itself through a separate skin puncture just distal to the incision so that the incision can be sutured neatly without having to accommodate the catheter coming through it. Traditionally, the vein was ligated distally, but this is not always necessary if the vein can be accessed using the needle (rather than by venotomy) and if bleeding is minimal.

Percutaneous non-tunneled central venous catheters are useful alternatives in patients who are seriously ill and have either very poor peripheral access or who need short-term (<5–7 days) central access for central venous monitoring, parenteral nutrition, or vasoactive drugs. Most are made of relatively stiff polyurethane and are therefore prone to infection, breakage, and complications. Antibiotic-coated catheters

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seem to be less prone to infection. They are usually placed using the Seldinger technique under circumstances that are less than ideal. The three most accessible sites are internal jugular, subclavian, and femoral. The right internal jugular vein is ideal for most critical care needs given its ease of access and straight course. Ultrasound should be used whenever available (surgeons should be trained and practiced in its proper use), though one should also be prepared to gain access to the RIJ vein using only anatomic landmarks for those rare situations when a US is not available. I prefer an anterior approach between the two heads of the sternocleidomastoid muscle. Insert the needle almost perpendicular to the neck and above the level of subclavian artery, which in most children arches slightly above the level of the clavicle and is more at risk than the carotid artery. The pressure needed to puncture the skin can be significant, but the subsequent "overshoot" usually results in the tip of the needle residing within the lumen of the vein, which becomes obvious when the needle is lifted to tent up the anterior wall of the vein. Common complications include arterial puncture, hematoma, and vein thrombosis; rare complications include pneumothorax, Horner syndrome, and phrenic nerve injury.

Percutaneous access to the subclavian vein is also a fading art as more institutions mandate open access at the deltopectoral groove or internal jugular vein, presumably out of fear of litigation for pneumothorax and other complications. Nevertheless, it is a very useful and safe technique when performed properly. A small rolled towel between the scapulae is all that is necessary to slightly exaggerate the normal angulation of the clavicles—a large roll is not necessary and can allow the patient to rock back and forth. Live fluoroscopy is critical when available. I prefer to access the vein within the middle third of the clavicle in the sulcus that is palpable just lateral to the first rib. Here, the vein is very superficial (1–3 cm deep), and the risk of inadvertent arterial puncture is lower than the more lateral approach we were taught to use in adults. Trendelenburg position probably helps very little to distend the subclavian vein, but it doesn't hurt. We also routinely ask the anesthetist to hold positive pressure ventilation while we try to access the vein as this might minimize the risk of injury to an inflated lung. One needs to angle the needle along an imaginary line that intersects the cricoid cartilage rather than the sternal notch. I place my nondominant middle finger in the sternal notch and use my thumb to push the shaft of the needle downward so that the needle is always parallel to the chest wall, never angled sharply downward in a way that places the apex of the lung at risk. Except perhaps in children who are the size of a large adult, the vein will be entered just under the clavicle—it is almost never necessary to bury the full length of the needle, which can cause puncture of the subclavian or carotid artery, the internal jugular vein, trachea, or the endotracheal tube balloon. The entry of the lumen of the vein might not be obvious until the needle itself is withdrawn slowly. There must be a robust flash and good blood flow or the wire will not pass easily. Once the vein is entered, turn the needle slightly so the beveled end is facing proximally, hold the needle extremely still, and pass the wire until cardiac ectopy is noted or most of the length of the wire has passed.

It is very common in children for the wire to travel up the internal jugular vein or opposite subclavian, the first clue usually being the fact that only a third or half of the length of the wire passes until an obstruction is encountered. A standard IV catheter (18 or 16 gauge) can be used as a sheath while the wire is manipulated under fluoroscopy. The right brachiocephalic vein origin can be gently compressed by pressing down on the head of the right clavicle while passing the wire from the left subclavian side. Likewise, one can use a finger to compress the internal jugular vein, which prevents the J-tip from passing cephalad and allows a loop of wire to go down into the atrium, dragging the tip with it.

The femoral vein should always be considered the central venous access of last resort. It is difficult to access because of its proximity to the femoral artery and the fact that it is not directly medial to but rather also slightly posterior to it. Catheters in this location are also prone to infection and kinking.

Surgeons should be trained and certified experts in the use of ultrasound guidance for the placement of central venous lines. It has been shown to reduce the incidence of complications and improve the accuracy of placement of catheters in the internal jugular vein. It is considered the standard of care in most institutions but is probably of little benefit for subclavian vein access. A more practical reason to become experienced in US guidance is that due to work-hour restrictions and the widespread use of PICC lines, the modern resident is not placing thousands of central lines during their training as those of us from prior generations did, and therefore the art of using external anatomic landmarks and the "feel" for just knowing where that vein is hiding developed over years of experience have been lost and are unlikely to be brought back in any meaningful way. The residents simply need to learn how to use US to place central lines percutaneously and we need to teach them.

Percutaneous central venous catheters come in many sizes and varieties. They are single, double, or triple lumen and typically come in 5, 8, 12, and 15 cm lengths and 4-, 5-, 6-, and 7-French (circumference in mm) sizes. The number of lumens is based on the intended use of the line (antibiotics, parenteral nutrition, pressors, blood draws). The caliber of the line is based on weight and age of the child. As a general rule of thumb, one might use 4 Fr in infants and toddlers, 5 Fr in some toddlers and most children, 6 Fr in some children and most adolescents, and 7 Fr in large adolescents and adults. The length of the catheter is chosen based on the size of the patient and the site of insertion so that the tip of the catheter ends up in the right location, preferably at the SVC-right atrial junction or upper right atrium. With experi-

ence, one eventually learns which catheter is best at any given site: 8 cm from the right subclavian vein, 8 or 12 cm from the right internal jugular vein, 12 or 15 cm from the left subclavian vein, and so forth.

In most institutions, peripherally inserted central catheters (PICC) are inserted not by surgeons but by radiologists, neonatologists, and nurse practitioners. They are generally well tolerated and are useful in situations in which a central line is needed for 2–6 weeks. However, they are fraught with complications, including thrombosis, infection, dislodgement, phlebitis, breakage, and unplanned return to the ED. They are also expensive to place and maintain, are occasionally used by patients for injection of illegal drugs, and are probably overused. One should consider an alternative such as peripheral IVs, highly bioavailable oral antibiotics, or nasogastric feedings rather than being quick to recommend a PICC line.

Long-Term Access

Catheters that are needed for more than a few weeks are tunneled and generally made of silastic polymer. In most institutions these include the Broviac (Hickman) catheter and the subcutaneous venous access port. Ports are generally preferred for patients who need intermittent infusions but not for those who need continuous infusions (parenteral nutrition) because of the risk of infection and skin breakdown (due to being accessed with a needle for long periods of time) or for drugs that are sclerosants due to the risk of local soft-tissue necrosis in the event of inadvertent needle dislodgement. They are preferred in general because when not in use, the child may bathe and swim and there is no external portion of catheter that might become snagged or cause annoyance. Downsides include the need for a larger incision, the need to access it by passing a needle through the skin, and the fact that when infected they are usually more likely needed to be removed. Ports are also prone to complications and difficult access in children with morbid obesity, large breasts, and skin diseases (especially graft-versus-host disease) or who are emaciated and malnourished. They should always be placed below Scarpa's fascia and secured to the pectoralis fascia rather than have only skin covering them.

Ports can theoretically be left in place for years; however, it has been our experience, especially with the smallest ports, that ports that have been in place for more than 3 years tend to be very difficult to remove: the silastic polymer tends to dry out and crack, creating tiny crevices for scar tissue to intercalate, and we have had several that have broken off, creating a retained foreign body situation or, in some cases, an actual pulmonary embolus. Although the best advice is probably to plan to remove or replace the port every 2–3 years, there are a few tricks when removing the port to help avoid this scenario (and the subsequent and obligatory road trip to interventional radiology): gentle tugging on the catheter, prolonged steady traction without increasing the tension excessively and just being patient until it starts to slip; opening the incision in the neck or subclavian region so that the catheter can be pulled out straight rather than creating a tissue-pulley situation by trying to pull it out from below; passing a guide wire through the lumen and using the outer sheath of a peel-away introducer to slide over the outer surface of the stuck catheter; theoretically shearing off the fibrous tendrils holding it in place (the risk of course is pushing it into the body even further); and cutting down on the catheter practically into the vein, though many of these have been incorporated into the endothelial wall of the vessel itself. When they break off, they are usually stuck to the wall of the vein, having been wallpapered over by the neointima. As such, while they likely pose little if any danger to the patient, the anxiety it creates for parents can be extreme.

Choosing the appropriate size of catheter is important. The catheter needs to be big enough to be used for blood draws and resist clotting but small enough to minimize the likelihood of vein thrombosis. Single-lumen Broviac catheters usually come in 2.7 Fr for preemies, 4.2 Fr for infants, 6.6 Fr for children weighing more than 10 kg, and 9.6 Fr or larger for adult-size patients who for some reason need a larger catheter (most teenagers do well with 6.6 Fr). Double-lumen Broviac catheters come in 5 Fr, 7 Fr, and 10 Fr. The 7 Fr catheter is a standard and very reliable catheter in most patients between 10 and about 80 kg. Because the smaller lumen has a tendency to clot off early, the 5 Fr double-lumen catheter is very unreliable and should be avoided. Ports come in 5 Fr for infants, 6.6 Fr for those who weigh more than about 10 kg, and 9.6 Fr for children who are morbidly obese or who have very large breasts. Double-lumen ports are more difficult to place (the tip cannot be cut to length because the catheter needs to be placed over the hub of the port itself; they are often of an awkward shape and are difficult to handle) and usually come in 7 Fr or 10 Fr sizes.

Placement of a Broviac (pediatric Hickman) catheter, port, or permanent hemodialysis catheter can be very difficult and demands patience, an absolutely meticulous approach and sometimes ingenuity to do it well. These lines are lifelines for these kids, and we owe it to them to place a line that is functional but also easy to maintain, safe, and durable for the length of their treatment. Even a meticulous surgeon needs to be even more fastidious than usual when placing these lines. Except in the most exceptional and truly desperate situations, these are never placed in a femoral vein. Likewise, general anesthesia is strongly preferred. I place a very small rolled blue surgical towel between the shoulder blades to slightly exaggerate the posterior inclination of the clavicles and to expose the anterior aspect of the neck somewhat. I always sterilely prepare the entire neck and chest so as to have access to all four traditional sites of access. Everyone has their preferred sites and for me the order of preference is RIJ, LSC, RSC, and LIJ. Some believe subcla-

vian vein access results in thrombosis that can affect a child throughout life (especially if they ever need to have a shunt placed for hemodialysis) and therefore prefer to use an internal jugular vein whenever possible. I also always prefer a percutaneous approach rather than a cutdown mostly for cosmetic reasons and to try to avoid having to sacrifice the vein by ligation or thrombosis. The external jugular vein, though often tempting us with its deceptive prominence, is very unreliable, and its attachment at the central veins is often weirdly angled, making central passage of the catheter frustrating or impossible.

Once the wire has been placed centrally and secured (only so that it is not snagged by the inattentive operator, they do not get sucked in), a site is chosen for the Broviac or port to be placed on the chest. For Broviacs I prefer a paramedian location near the lower sternum, though large breasts can make this impractical. I avoid the upper chest whenever possible for cosmetic reasons and the axilla, lateral chest, or abdomen for practical and infectious reasons. Once a small incision has been made, create a small subcutaneous pocket for placement of the cuff, preferably below Scarpa's fascia, directly cephalad to the incision, and tunnel the catheter using any of several tools (silver probe, tunneler provided in the manufacturer's kit, tendon passer) around the breast tissue and in such a way that the catheter travels in smooth arcs without kinking and arrives at the venous puncture site below the platysma so that it does not end up directly against the skin incision of the insertion site. The cuff should be 1–2 cm above the incision but should be pulled up farther at first so that one can feel the cuff being held back by one of Cooper's ligaments when gentle traction is placed on the catheter. This prevents the cuff from working itself out without having to place it a long distance from the incision. The tip of the catheter, cut straight across, should be at the SVC-RA junction, which on AP chest fluoroscopy is at the point where it appears to be just entering the atrium (the SVC enters on the posterior wall of the atrium) or just below the visible lucency of the right mainstem bronchus (Fig. 10.1). A little deeper than this is ok too, but the lower half of the atrium is where the tricuspid valve is and should be considered too deep. The catheter must be pointing caudad in all projections, must not be flicking excessively during the cardiac cycle, and must draw back and flush with no resistance. Achieving this ideal position can be difficult and requires experience and patience. I keep the peel-away sheath in place until I have trimmed the catheter to size, sometimes pulling out and replacing the catheter several times. Others use external landmarks or a mathematical formula based on the length of the wire, but regardless it is absolutely critical that the catheter tip be in the best position possible when the child leaves the OR, even if that means removing it and placing a brand new one, whatever it takes to make it as close to perfect as possible. It also cannot be sim-

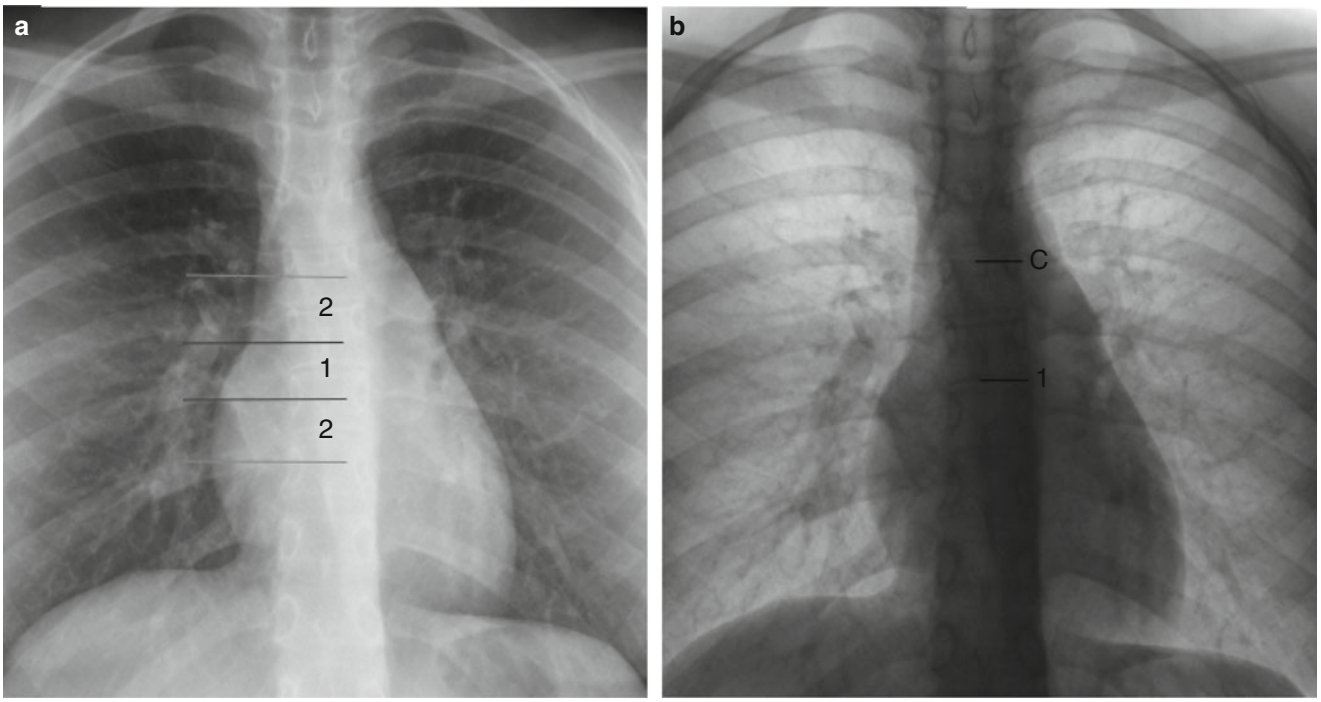

Fig. 10.1 Ideal placement of the catheter tip for central venous lines placed in the internal jugular or subclavian vein. (**a**) The zone delineated by the *gray lines* and labeled "1" is the RA-SVC junction and is the ideal location for the catheter tip. The zones labeled 2 are usually also acceptable though not ideal locations. Wherever the catheter tip resides, it must be pointing straight down, away from the wall of the SVC or atrium, in both AP and lateral projections. (**b**) Some prefer to use the carina as a guide, in which case the RA-SVC junction ("1") has identified two vertebral body units below the level of the carina ("C")

ply left in the mid- or upper SVC as it will have a tendency to flip up into the more proximal veins with movement or when forcibly flushed with a syringe under pressure (a trick that can also be used to force an errant catheter tip out of the subclavian or jugular vein and back into the atrium). Once in place and flushed, it should be stitched to the skin near the entry site with two fine monofilament sutures using a Romansandal technique and a dry sterile dressing applied according to institutional protocols.

The best place on the chest for a port in a boy is in the upper chest lateral to the manubrio-sternal joint, and in a girl in a more lateral infraclavicular location closer to the shoulder for aesthetic reasons or even very close to the clavicle in girls with large breasts. In rare cases an unusual location such as the inner arm, lateral chest, or abdomen is requested, though these are fraught with significant logistical problems and access-related issues. I prefer a transverse incision with creation of a subcutaneous pocket between the Scarpa's fascia and the pectoralis fascia inferior to the incision. I use two monofilament sutures to tack the port to the pectoralis fascia and then tunnel and insert the catheter as per usual. Passing the dilator or peel-away sheath should be considered a potentially dangerous maneuver as the SVC or right atrium can be punctured if not done with deliberate caution and smooth precision. The port incision is closed in layers with interrupted absorbable sutures and cyanoacrylate glue. If it is to be used within a few days, it should be accessed with a right-angle Huber needle, flushed, and dressed.

Tunneled hemodialysis catheters are placed like Broviac catheters except that they are stiffer and larger and needle to be tunneled with even larger arcs and smoother bends than the more pliable and forgiving Broviac catheter. This usually means bringing it out near the axilla or lateral chest wall. They can also not be cut to size, and therefore it takes planning to make sure the cuff sits an appropriate distance from the skin insertion site and the tip of the catheter is in an appropriate location. The distal tip should usually sit in the mid-atrium so that the proximal tip is at the VC-RA junction. I usually make the skin incision longitudinal and err on the side of making it too close so that it can be extended and the Scarpa's fascia and skin can be closed over the cuff if it has to be pulled back somewhat. These need to function flawlessly for however long the child needs it, often many months.

Removing a Broviac catheter should be straightforward and though in older children it can be done under sedation, it is usually best done under deep sedation or general anesthesia. The cuff is dissected free and the catheter removed. I routinely close the skin incision with skin glue and sometimes a stitch and have never had an infection. Alternatively, ointment can be applied and the wound allowed to close by secondary intention. Ports can usually be removed by opening the prior incision. I do not routinely excise the pseudocapsule and instead close the wound in layers and skin glue while holding pressure at the vein entry site.

Cutdown Techniques for Central Access

For those uncommon situations when percutaneous access is not an option, the surgeon should be able to access the femoral vein via the saphenous vein in the thigh, the subclavian vein via the cephalic vein at the deltopectoral groove, and internal jugular vein by way of the external jugular or facial vein in the neck. These skills are only obtained by practice but frequent review of a good surgical atlas is useful. Though not a cutdown, intraosseous access is underrated and underutilized. It is used most often in the trauma bay but is very safe and extremely versatile—another skill with which a pediatric surgeon should be very familiar.

The facial vein is especially useful in small preemies. The patient should be properly anesthetized and the arms pulled down gently with tape to expose the right side of the neck. A small transverse incision is made just anterior to the sternocleidomastoid muscle below the angle of the mandible. I make the incision directly over where I think the IJ lives so that if the facial vein is absent or too small, direct entry to the IJ is an excellent plan B. The facial vein usually resides just below the platysma and can be ligated and entered through a small venotomy. These are usually small infants so a 2.7 Fr or 4.2 Fr catheter is used and tunneled after the vein is controlled with sutures. If the IJ is used instead, it is better not to ligate it distally and instead pass the tip of the catheter which has been cut at a sharp angle through a venotomy created with a 20-gauge needle, allowing a watertight seal around the catheter and obviating ligation or a purse-string suture, which is near impossible in such a small vein anyway. You still need to control the proximal and distal IJ with ties but ligation should be rarely necessary. Making sure the tip is in a good position is much more difficult given that fluoroscopy is rarely available in the NICU but takes practice to get right based on external landmarks. The nipple line is usually a good guess in most infants.

Radial arterial lines are often useful though probably overused in the PICU and in the OR. Pediatric surgeons should become experts in the percutaneous approach, which should always include the use of sterile technique, a guide wire, and the option of using US guidance. Cutdowns for arterial access should also be in the armamentarium but only used when absolutely necessary. It is important to have good lighting, magnification, and delicate instruments. The artery in children is always very small, prone to spasm, and easily confused with nerves and tendons in the wrist. I never ligate the artery and prefer to place the catheter through a separate skin puncture so the incision can be closed neatly with absorbable sutures without having a catheter coming through it.

Complications

If a line is placed without difficulty and the tip position is confirmed by fluoroscopy or CXR in the OR, then a postoperative radiograph is unnecessary. Pneumothorax is rare and can usually be observed unless symptomatic or enlarging. Hemothorax is also rare but can be difficult to manage if caused by injury to the inferior aspect of the subclavian artery in the chest and can be life threatening if caused by puncture of the sidewall of the SVC with a dilator. Catheters that are left deep in the atrium can perforate the atrium and create pericardial tamponade. This can occur with hyperosmolar solutions or parenteral nutrition and is potentially life threatening. If recognized in time, the catheter can often be simply removed but contingencies need to be made for possible bypass, thoracotomy, and repair of the injury. Catheter tips situated deep in the atrium can also cause arrhythmias, especially SVT. These should almost always be replaced and pulled back a few centimeters to avoid the conduction pathways of the heart. Infection can often be treated effectively with antibiotics alone, but if bacteremia persists the catheter will need to be removed and then replaced, preferably more than 24 h after removal rather than at the same operation. This is especially true for infections caused by encapsulated organisms or fungus. Although these are typically endovascular infections, the old skin entry site can apparently harbor organisms for weeks or months and therefore it is usually advisable to use a completely different skin site for the new catheter. Small catheter-associated thrombi are probably much more common than we appreciate, especially with PICC lines. Although it is unclear if they are always clinically significant, when identified, even incidentally, they tend to induce significant anxiety and frequent recommendations for therapy with anticoagulants.

Lines whose tips have flipped back into the subclavian vein or jugular vein can sometimes be repositioned by forcibly injecting saline under high pressure with a 10 mL syringe, which can cause the tip to be propelled into the SVC by action of the jet created, similar to what happens on a large scale with a fire hose. This is usually best done under real-time visualization with fluoroscopy. When the cuff of a Broviac catheter becomes extruded, it is at high risk for infection and dislodgement and should therefore usually be replaced somewhat urgently.

Ports can be difficult to access if they are too small and too deep or if they have flipped upside down. This is especially a problem in morbidly obese patients and in girls with very large breasts. Some will place the port between the skin and the breast tissue or cut away breast tissue to minimize the amount that obscures the port. Some place the port near or practically on the clavicle with some success. Regardless, it is important to place a very large port in these circumstances.

Breakdown of the skin overlying a port is a concern in patients who are emaciated, have skin diseases (especially graft-versus-host disease), have ports that have been placed too superficially (covered only by skin), or have frequent or continuous needle access. If the port is visible through the skin, it cannot be salvaged and it needs to be removed and moved to a completely new site. Many extravasations and hematomas can be managed with port rest but frankly purulent fluid bathing, the port requires port removal in every case. Every institution should have guidelines for who can safely receive a port and who should be recommended for a Broviac catheter. Relative contraindications to use of a port include morbid obesity, large breasts, malnutrition or emaciation, osteogenesis imperfecta (rib fracture), graft-versus-host disease, and other dermatologic conditions associated with open sores or poor wound healing, severe neutropenia, or thrombocytopenia, some connective tissue disorders and certain cognitive or psychiatric disorders that would prevent safe handling or maintenance of an imbedded access needle for long periods.

Summary

In any hospital that takes care of children, pediatric surgeons should be the experts in all forms of vascular access, especially when a child needs a well-placed and well-functioning long-term access or for critical access in an emergency. We are also the go-to folks when a line is malfunctioning, becomes infected, or needs to be replaced, even if the line is "someone else's" and especially when the stakes are high. Most importantly, all access procedures demand meticulous attention to detail and careful precision.

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Acute Kidney Injury

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AKI historically has been poorly characterized, but recent algorithms have defined it using changes in serum creatinine (or estimated creatinine clearance) and oliguria or anuria. These are often late signs of decreased renal function and are relatively inaccurate markers of AKI. Moreover, serum creatinine often varies with age, sex, muscle mass, muscle metabolism, exercise, and hydration status. Nevertheless, these methods are in widespread use both for bedside assessment and clinical investigation. Over the past decade, several AKI biomarkers have been identified though their value in predicting AKI remains under investigation. The risk injury failure loss end-stage (RIFLE), pediatric RIFLE (pRIFLE), and acute kidney injury network (AKIN) criteria are similar categorical scoring systems for stages of AKI and have been evaluated in pediatric patients yielding similar associations with poorer prognosis as AKI stage increases. In 2012, the Kidney Disease Improving Global Outcomes (KDIGO) group integrated the RIFLE and AKIN criteria into a single standardized definition (Table 11.1). The KDIGO AKI guidelines provide a stage-based management scheme for AKI that incorporates risk assessment in the model.

Due to the lack of consensus in previous definitions, reported incidence rates of AKI in hospitalized pediatric patients can vary from less than 1 % in some US studies to about a third in pooled worldwide studies. Children most commonly develop AKI as a consequence of systemic disease, particularly sepsis (40–50 %), drug-induced nephropathy, and injury to other organ systems rather than primary renal disease (<20 %) or hemolytic uremic syndrome (<2 %). Seventy percent of hospitalized patients with AKI not requiring dialysis survive. Long-term results are excellent with over two-thirds of children with AKI going on to full recovery of renal function. Nevertheless, the morbidity and mortality of children with severe AKI is high. In the perioperative setting, the most important predictors of mortality include hemodynamic instability, underlying systemic illness severity, and degree of fluid overload. Survival is better in patients with primary renal disease, whereas the mortality can be over 50 % in patients with multiple organ dysfunctions, requiring renal replacement therapy. In patients who survive severe AKI, there is an increased risk of chronic renal insufficiency, with about a third of survivors progressing to end-stage renal disease.

Etiology and Pathophysiology

AKI is categorized functionally as *prerenal*, *intrinsic renal*, and *post-renal*. AKI can also be classified based on the amount of urine output into *non-oliguric*, *oliguric*, and *anuric* (Table 11.2).

In prerenal AKI, a decrease in circulatory volume stimulates the baroreceptors in the carotid sinus and aortic arch, which leads to the activation of the sympathetic nervous system and release of angiotensin II and antidiuretic hormone (ADH). This results in renal vasoconstriction and increased sodium and waster reabsorption from the proximal tubule and collecting duct. Hence patients present with a decrease in GFR and oliguria and have a low fractional excretion of sodium (FE_{Na}). In an attempt to maintain glomerular filtration, the kidney compensates by increasing vasodilatory prostaglandins and angiotensin II autoregulation, which cause dilation of the afferent arteriole and constriction of the

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Table 11.1 Diagnostic criteria for AKI

pRIFLE criteria			AKIN criteria			KDIGO criteria		
Stage	Creatinine clearance	Urine output	Stage	Serum creatinine	Urine output	Stage	Serum creatinine	Urine output
Risk	>25 % eCCL decreased	<0.5 mL/kg/h for 8 h	**I**	SCr inc >0.3	<0.5 mL/kg/h for 8 h	**I**	SCr inc >0.3 in 48 h	<0.5 mL/kg/h for 6–12 h
				(OR)			(OR)	
				150–200 % in <48 h			1.5–1.9 times	
Injury	>50 % eCCL decreased	<0.5 mL/kg/h for 16 h	**II**	SCr inc 200–300 %	<0.5 mL/kg/h for 16 h	**II**	SCr inc 2.0–2.9 times	<0.5 mL/kg/h for 12 h
Failure	>75 % eCCL decreased	<0.5 mL/kg/h for 24 h	**III**	SCr inc 200–300 %	<0.5 mL/kg/h for 24 h	**III**	SCr >3.0 inc	<0.5 mL/kg/h for 24 h
	(OR)	(OR)		(OR)	(OR)		(OR)	(OR)
	eCCL	<0.3 mL/kg/h for 12 h		SCr >4.0 mg/dL	<0.3 mL/kg/h for 12 h		SCr >4	<0.3 mL/kg/h for 12 h
	<35 mL/min/1.73 m^2						(OR)	
							If <18 years of age then eCCl	
							<35 mL/min/1.73 m^2	

pRIFLE pediatric risk of renal dysfunction, injury to the kidney, failure of kidney function, loss of kidney function, and end-stage renal disease; *AKIN* acute kidney injury network; *KDIGO* kidney disease: improving global outcomes; *eCCL* estimated creatinine clearance; *SCr* serum creatinine

Table 11.2 A differential for AKI

Prerenal	Intrinsic renal	Post-renal
Volume related	Glomerular	Urinary tract obstruction
Intravascular depletion	Hemolytic uremic syndrome	Posterior urethral valves
GI losses	Acute glomerulonephritis	Bilateral UPJ obstruction
Blood loss	Hereditary	Bilateral nephrolithiasis
Burns, hyperthermia	Polycystic kidney disease	Neoplasm
Renal losses (e.g., diabetes insipidus.)	Alport syndrome	Retroperitoneal fibrosis
Ineffective circulation	Sickle cell nephropathy	Trauma
Ischemic/thrombotic	Juvenile nephronophthisis	
Abdominal compartment syndrome	Vasculitis	
Nephrotic syndrome	Lupus nephritis	
Myocardial dysfunction		
Sepsis		
Renovascular	Goodpasture syndrome	
Renal vein thrombosis	Wegener's syndrome	
Renal artery stenosis	ANCA associated	
Neurohumoral signaling dysfunction	Vascular	
Hepatorenal syndrome	Hemolytic uremic syndrome	
Medications	Malignant hypertension	
Calcineurin inhibitor	Renal artery/vein thrombosis	
Radiocontrast agents	Cortical necrosis	
ACEI and ARB	Tubular/interstitial	
	Uncorrected pre- or post-AKI	
	Hypoxic ischemic injury	
	Medications	
	Aminoglycosides/vancomycin	
	Amphotericin B	
	Poisons	
	Crystals (acyclovir and methotrexate)	
	Endogenous toxins	
	Rhabdo/hemolysis: pigment nephropathy	
	Exogenous toxins	
	Ethylene glycol	
	Methanol	
	Tumor lysis/urate nephropathy	

ACEI angiotensin-converting enzyme inhibitors, *ARB* angiotensin receptor blockers, *ANCA* anti-neutrophil cytoplasmic antibodies, *UPJ* ureteropelvic junction

efferent arteriole in the glomerulus. Any interference in this pathway can affect GFR.

Intrinsic renal AKI is due to acute tubular necrosis (ATN) or renal vascular, interstitial, or glomerular diseases. ATN usually occurs from prolonged ischemia and exposure to nephrotoxic medications. These lead to damage of the tubules, especially the proximal tubule and the thick ascending limb of the loop of Henle (tubular segments with high energy requirements). ATN progresses through several phases: initiation, extension, maintenance, and recovery (Figs. 11.1 and 11.2). The initiation phase starts when reduction in blood flow further reduces GFR and results in damage to the tubular cells. This phase can be subtle and oliguria might be the only sign. Prompt recognition is essential because early intervention can limit the degree of injury. Vascular and inflammatory changes occur in the extension phase, associated with a further decline in renal function. In the maintenance phase, GFR reaches its nadir and patients have persistent oliguria and progressive azotemia. The cellular processes in this phase permit repair. The recovery phase is also known as the "polyuric phase" in which renal function begins to improve, but the tubular cells still have poor concentrating abilities. Careful monitoring of fluid balance in the recovery phase is essential as excess fluid loss can lead to fluid and electrolyte depletion.

Post-renal AKI is caused by congenital or acquired obstruction to the urinary outflow tract bilaterally. Management is prompt relief of the obstruction.

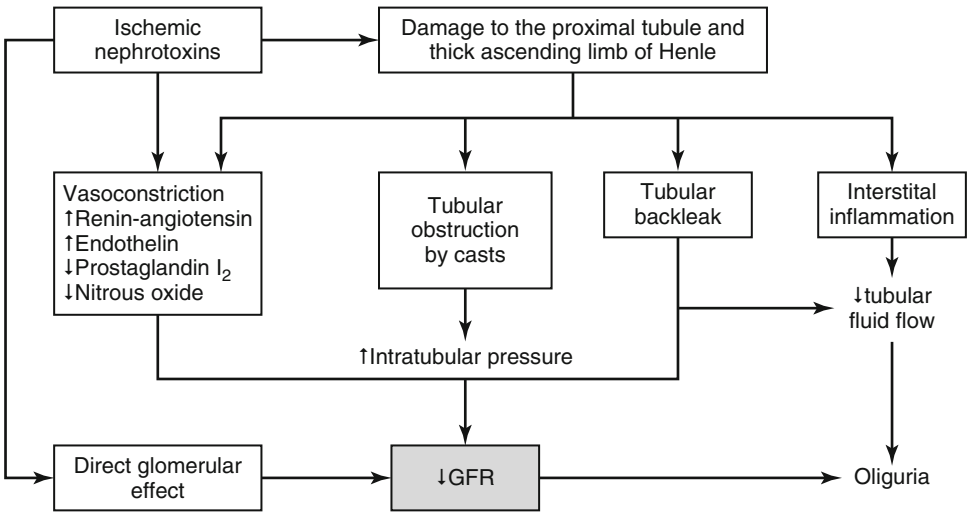

Fig. 11.1 Pathophysiology of intrinsic AKI

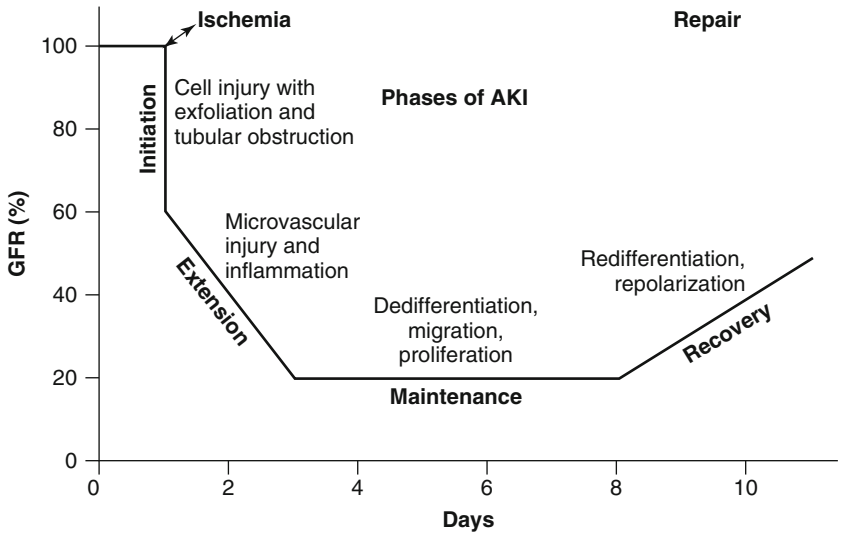

Fig. 11.2 Relationship between clinical phases and the cellular phases of ischemic acute kidney injury (AKI) (data from Basile DP, Anderson MD, Sutton TA. Pathophysiology of acute kidney injury. *Compr Physiol*. 2012;2(2):1303–1353)

Part of the usual stress response to surgery is an increased secretion of ADH and an upregulation of the renin–angiotensin–aldosterone system, resulting in avid salt and water retention. It is part of the normal postoperative recovery to have decreased urine output and free water clearance in the first 12–24 h following surgery. However it is important to remember that impaired renal function decreases the clearance of many medications commonly used in the perioperative setting, such as antibiotics, anticonvulsants, paralytics, and H_2 blockers. Dose adjustments need to be made based on the GFR and serum drug levels.

Workup

A detailed history is essential. Patients with prerenal AKI may have a history of fluid loss from vomiting, diarrhea, fevers, and decreased oral intake. A history of headaches and blurry vision suggests hypertension. Weight gain and swelling suggest fluid overload. Obtaining a detailed list of potentially nephrotoxic medications including nonsteroidal antiinflammatory drugs (NSAIDs), ACEI, aminoglycoside antibiotics, and vancomycin among others is integral. Recent exposure to nephrotoxic agents including contrast media can also result in ATN. Concurrent upper respiratory infection (IgA nephropathy), epistaxis (granulomatosis with polyangiitis), hemoptysis (Goodpasture disease), recent streptococcal infection (postinfectious glomerulonephritis), bloody diarrhea (hemolytic uremic syndrome, HUS), or joint pains and rash (vasculitis) may suggest glomerular pathology. A search for sources of emboli, a history of umbilical lines in the neonatal period, and a family history of renal disease should be included. Anuria and a poor urinary stream may suggest outflow tract obstruction.

A thorough physical examination should include assessment of overall fluid status by checking weight and looking for edema. Blood pressure, jugular venous distension,

Table 11.3 Creatinine: normal values by age

Age	Normal creatinine
Newborn	0.3–1.0 mg/dL (27–88 μmol/L)
Infant	0.2–0.5 mg/dL (18–13 μmol/L)
Child	0.3–0.7 mg/dL (27–62 μmol/L)
Adolescent	0.5–1.0 mg/dL (44–88 μmol/L)

Table 11.4 Interpretation of FE_{Na} in children and newborn

	FE_{Na} in children	FE_{Na} in newborn	Urine sodium in children
Prerenal disease	<1 %	<2.5 %	<20 mEq/L
Intrinsic renal disease	>2 %	2.5–3.5 %	>40 mEq/L

Table 11.5 Urinalysis and urine microscopy in the evaluation of AKI

Finding on urinalysis/urine microscopy	Diagnosis
Nearly normal or minimal proteinuria, few hyaline casts, and/or fine granular casts	Prerenal AKI
Heme-positive dipstick, no RBC on microscopy	Hemolysis/ rhabdomyolysis
Heme and protein positive on dipstick. Dysmorphic RBCs and red cell casts on microscopy	Glomerular disease
Muddy brown granular casts and epithelial cells	Ischemic/toxic AKI
WBC and WBC casts on urine microscopy	Pyelonephritis/ interstitial nephritis

hepatomegaly, and respiratory sounds will help to assess intravascular fluid volume. A thorough examination of mucous membranes, joints, and skin is essential in patients with suspected glomerular disease. Abdominal examination might reveal a mass or palpable bladder.

Laboratory studies are often useful. A pre-illness baseline serum creatinine is helpful in classifying the degree of AKI using the KDIGO criteria (Table 11.3). A high fractional excretion of sodium (FE_{Na}) suggests a significant prerenal component: $FE_{Na} = [(\text{urine Na/plasma Na})/ (\text{urine Cr/plasma Cr})] \times 100$, where Na = sodium and Cr = creatinine (Table 11.4). Loss of concentrating ability is an early finding in ATN: *urine osmolarity* greater than 500 mOsm/kg usually indicates prerenal AKI; however, lower values are of little value in differentiating prerenal from intrinsic renal AKI. Similarly, *urine specific gravity* is not very useful as it is affected by the maturity of the kidney and by the presence of colloids including protein, glucose, and mannitol. *Urinalysis* and *urine microscopies* are important noninvasive tests in the evaluation of AKI (Table 11.5).

A renal ultrasound is utilized to determine kidney size and shape and echogenicity of the parenchyma. In AKI, the kidneys are usually normal or enlarged in size with increased echogenicity. In patients with chronic kidney disease, the kidneys are small and shrunken. Renal ultrasound also helps to exclude urinary tract obstruction, and a Doppler-enhanced study can detect vascular occlusion.

Renal biopsy is helpful in the diagnosis of glomerular disease. In patients with ATN it is rarely required prior to the initiation of supportive therapy. Caution should be used in considering renal biopsy in the critically ill, coagulopathic patient.

AKI biomarkers provide insight into molecular mechanisms and can be used to direct clinical intervention; however, because the pathophysiology is so often multifactorial, a single biomarker may fail to provide a troponin-like diagnostic value for early detection. For predicting AKI, a combination of functional and tubular damage biomarkers is more useful than just the change in serum creatinine. These include cystatin C, neutrophil-associated lipocalin (NGAL), kidney injury molecule 1 (KIM-1), interleukin-18 (IL-18), liver-type fatty acid-binding protein (L-FABP), tissue inhibitor of metalloproteinase 2 (TIMP-2), and insulin-like growth factor-binding protein 7 (IGFBP7). Urine and plasma NGAL are emerging as powerful biomarkers for the early detection of AKI and prediction of adverse clinical outcomes.

Management

Regardless of the cause, initial management should be directed at mitigating the progression of AKI. The priority in prerenal AKI is clearly to improve perfusion of the glomerulus. This can be achieved by optimizing intravascular volume and, as long as cardiac output is not compromised as a consequence, weaning vasoconstrictive medications. With intrinsic renal disease it is important to minimize or eliminate nephrotoxic medications and treat any underlying renal disease process. Management of post-renal AKI is usually invasive and involves endoscopically placed stents or percutaneously placed nephrostomy drains. Unfortunately, despite best attempts, progression to renal insufficiency with fluid overload, electrolyte abnormalities, and ongoing impairment in drug metabolism can still occur.

Controlling fluid balance is key. It is not uncommon to have intravascular depletion even in the setting of total body fluid overload. Alternatively, reduced GFR or inability to excrete fluids together with ongoing intake or administration of further fluids can lead to increased plasma volume, which in turn can lead to pulmonary edema and cardiac failure. Determination of volume status is crucial because, depending on the situation, administration of isotonic fluids, careful use of diuretics, or both could be appropriate. If addressing intravascular depletion, there is no clear evidence that any one isotonic fluid is better than another, but emerging evidence seems to favor balanced fluids rather than high-chloride solutions such as 0.9 % saline. Blood products are more likely to remain intravascular and should also be used when clinically indicated. There is increasing evidence for worsening risk of AKI with synthetic colloids.

In the case of fluid overload, diuretics can be utilized. Loop diuretics inhibit sodium, potassium, and chloride ion transport mechanisms in the ascending loop of Henle, which is responsible for 20–30 % of the total reabsorption of sodium and chloride in the renal medulla. A continuous infusion can help to avoid the toxicity that occurs with bolus use at high peak serum concentrations. Loop diuretics also increase venous capacitance, which can relieve symptoms of volume overload before their effect on total fluid volume. Thiazide and thiazide-like diuretics can also be used as an adjunct to inhibit sodium and chloride reabsorption at the distal convoluted tubule. Caution is advised in severe AKI when diuretic use is less effective and more likely to cause toxicity. If hypertension occurs in spite of fluid management, calcium channel antagonists or beta-blockers can be used cautiously. Despite the fact that the hypertension might in part be due to dysfunction at the renin–angiotensin–aldosterone axis, ACE inhibitors should be avoided in the acute phase.

Once euvolemia is achieved, strict fluid management is essential. Fluid administration should match urine output plus insensible losses, which are approximately one third of calculated "maintenance" requirements. In patients who are mechanically ventilated, humidification of inspired gases decreases the insensible losses to approximately one-quarter maintenance.

Although low-dose infusion of dopamine (0.5–2 μg/kg/min) has been shown in the laboratory to increase renal blood flow, on meta-analysis it has not been shown to improve outcomes in clinical practice. Some studies using the selective dopamine receptor-1 agonist fenoldopam mesylate have found that it might decrease the incidence of AKI, the need for renal replacement therapy, length of ICU stay, and mortality, but further studies are required in children. Although free radicals are thought to contribute in kidney injury, long-term clinical trials do not uniformly confirm this, so antioxidant therapy cannot be recommended at this time.

Classic electrolyte abnormalities of AKI include hyponatremia, hyperkalemia, hyperphosphatemia, hypocalcemia, metabolic acidosis, and elevated creatinine and blood urea nitrogen. Limiting additional administration of potassium and phosphorus may not be sufficient to stop ongoing elevation. As such, orally administered binding resins, such sodium polystyrene sulfonate (Kayexalate®) and sevelamer hydrochloride (Renagel®) may need to be used. Hyperkalemia can rapidly become life threatening and additional potassium must be removed from all IV fluids and parenteral nutrition. Electrocardiographic findings associated with severe hyperkalemia include peaked T waves, prolonged PR interval, flattened P waves, widened QRS complex, bradycardia, and, eventually, ventricular fibrillation. Treatment with IV calcium, dextrose and insulin, sodium bicarbonate, and loop diuretics might be necessary to prevent cardiac arrest. Hypocalcemia is usually the result of hyperphosphatemia and usually resolves with treatment of the elevated phosphorus. Calcium supplementation is not usually required unless the patient is symptomatic. Metabolic acidosis can be temporarily corrected with sodium bicarbonate, which should be considered if acidosis is causing hemodynamic changes even though there are no randomized control trials to support this recommendation. Refractory electrolyte disturbances and acidosis sometimes require renal replacement therapy.

Renal Replacement Therapy

Indications for renal replacement therapy include (a) fluid overload that is interfering with ventilation and provision of adequate nutrition, (b) severe acidosis or hyperkalemia refractory to medical therapy, and (c) symptomatic uremia including pericarditis and mental status changes.

Modalities include peritoneal dialysis (PD), intermittent hemodialysis (HD), and continuous renal replacement therapy (CRRT). Intermittent HD and CRRT require vascular access, specialized equipment, trained personnel, and systemic anticoagulation. CRRT is slow and gentle and is useful in patients with multi-organ dysfunction or hemodynamic instability. Intermittent hemodialysis is often not well tolerated in critically ill patients due to rapid fluid shifts and the large extracorporeal volume. Peritoneal dialysis is the preferred modality of dialysis in neonates and small infants. It has the advantage of requiring less specialized equipment and personnel and does not require systemic anticoagulation. All forms of renal replacement therapy require some form of vascular access or surgical intervention.

Peritoneal Dialysis

Placement of a peritoneal dialysis catheter is a surgical procedure. A curled catheter is usually preferred over a straight catheter as it has more side holes, is less likely to migrate out of the pelvis and to be occluded by the omentum or bowel, and is less painful with fills. Some prefer a double-cuff catheter, with one cuff adjacent to the peritoneum and one in the subcutaneous tissues. A swan-neck configuration of the catheter enables a downward-pointing exit site with a long subcutaneous tunnel. Single-cuff catheters are associated with an increased risk of exit site infections and peritonitis. These should only be used in neonates and small children for anatomical reasons or when PD is being used for shorter durations, as in AKI. The cuff is placed between the rectus muscle and posterior rectus sheath. The exit site should be located as remote as possible from other stomas (vesicostomy, colostomy) and should be pointing downward to avoid accumulation of dirt. In infants, it should be placed outside the diaper area to prevent contamination. Lateral placement of the catheter helps prevent leaks. Partial or extensive omentectomy at the time of catheter placement helps prevent catheter obstruction.

Intermittent HD and CRRT

Well-functioning vascular access is probably the most important aspect contributing to successful provision of HD or CRRT. A free-flowing catheter allows for efficient therapy and less circuit clotting. The KDIGO recommends that the catheter size should be matched to patient size with the goal of minimizing intraluminal trauma and obstruction to blood flow while allowing sufficient blood flow for adequate HD. An acute non-tunneled catheter can be placed at the patient's bedside, or a tunneled catheter can be placed by a surgeon or interventional radiologist. A double- or triple-lumen catheter should be placed depending on the anticoagulation used. Circuits running with heparin as the anticoagulant need only two lumens. Citrate circuits require a third lumen for calcium replacement. Alternatively, a separate catheter can be placed for this purpose. Catheters should be placed preferably in the internal jugular veins, though this might not be feasible in patients requiring high-frequency oscillatory ventilation because of the risk of pneumothorax. Subclavian stenosis occurs in more than 80 % of patients in children who have subclavian catheters. Although femoral catheters are associated with decreased risk at the time of placement, they have increased risk of infection and kinking.

Cardiac Surgery

AKI occurs in up to 50 % of infants who undergo cardiac surgery and is associated with increased morbidity and mortality. Patients at highest risk are those with low cardiac output, vasodilatory shock, or bleeding, though cardiopulmonary bypass itself is an independent risk factor. There is no definitive evidence that the use of diuretics, vasodilators, bicarbonate, *N*-acetyl cysteine, dopamine, fenoldopam, or even early CRRT prevents or alters the course of AKI after cardiac surgery. Aminophylline is potentially useful but further prospective trials are underway.

Radiocontrast Nephropathy

Radiocontrast administration is associated with renal injury in children. Contrast medium leads to renal medullary hypoxia, direct cytotoxicity, or tubular injury secondary to generation of reactive oxygen radicals. Patients with underlying renal impairment, heart failure, diabetes mellitus, or volume depletion and those receiving concomitant nephrotoxins, a high volume of contrast, or multiple sequential procedures are at increased risk. The incidence of renal injury has decreased since the use of low-osmolar agents has increased. Prior to the procedure, medications like NSAIDs and metformin should be withheld, and patients must be adequately hydrated. The use of bicarbonate and N-acetyl cysteine in preventing contrast-induced AKI has not proven to be beneficial.

Drug-Related AKI

Antimicrobials, antiinflammatories, antiepileptics, and many chemotherapeutic agents have been implicated in pediatric medication-associated AKI (Table 11.6). Infants, children with chronic kidney disease, and children on multiple medications are at increased risk. The effect is usually mild and self-limited but only if recognized early and administration of the drug *and all other nephrotoxins* are stopped or at least renally dosed. The indications, alternatives, pharmacokinetics, and potential for drug interactions need to be considered for each potentially nephrotoxic medication administered in the perioperative setting.

Acute Interstitial Nephritis

Acute interstitial nephritis (AIN) refers to inflammation of the renal interstitium and tubular cells. Although the majority of cases are drug related, about 15 % are due to infection (Table 11.7). Besides viral infections, bacterial (streptococcal, legionella, and leptospirosis), parasitic (schistosomiasis and malaria), and fungal infections are known to cause AIN. Autoimmune disorders, metabolic diseases, and heavy metal ingestion can also result in AIN. The clinical presentation of AIN consists of nonspecific constitutional symptoms. The classical triad of fever, rash, and eosinophilia occurs in less than 10 % of patients. Patients with AIN have sterile pyuria (specifically eosinophilia), non-nephrotic range proteinuria, and electrolyte abnormalities (hypokalemia, metabolic acidosis) suggestive of tubular injury. Renal ultrasound will show diffusely enlarged kidneys with increased echogenicity. A renal biopsy remains the gold standard for diagnosis. Removal of the offending agent, treatment of the infectious organism or underlying disease along with supportive therapy, and close observation are all that is required. Most patients improve after 3–5 days of appropriate treatment.

HUS and TTP

Hemolytic uremic syndrome is characterized by a triad of microangiopathic hemolytic anemia, thrombocytopenia, and renal dysfunction. Ninety percent of cases of HUS are secondary to Shiga toxin-producing *E. coli* (O157:H7). The course is severe in less than 10 % of children but can be fatal due to neurologic (seizures, coma), gastrointestinal (gangrenous colitis), renal, or cardiorespiratory complications.

Table 11.6 Nephrotoxic drugs

Analgesics	Calcineurin inhibitors
Acetaminophen, aspirin	Cyclosporine
Nonsteroidal antiinflammatory drugs	Tacrolimus
Antacids	Cardiovascular agents
Lansoprazole, omeprazole, pantoprazole	Angiotensin-converting enzyme inhibitors
Ranitidine	Angiotensin receptor blockers
Antidepressants/psychiatric medications	Clopidogrel, ticlopidine
Amitriptyline, doxepin, fluoxetine	Statins
Lithium	Chemotherapeutics
Haloperidol	Carmustine, semustine
Antihistamines	Cisplatin
Diphenhydramine, doxylamine	Interferon alfa
Antimicrobials	Methotrexate
Acyclovir	Mitomycin-C
Aminoglycosides	Contrast dye
Amphotericin B	Diuretics
Beta lactams (penicillins, cephalosporins)	Loops, thiazides
Foscarnet	Triamterene
Ganciclovir	Drugs of abuse
Pentamidine	Cocaine, heroin
Quinolones	Ketamine, methadone
Rifampin	Methamphetamine
Sulfonamides	Others
Vancomycin	Allopurinol
Antiretrovirals	Pamidronate
Adefovir, cidofovir, tenofovir	Quinine
Indinavir	Zoledronate
Antiepileptic	
Benzodiazepines	
Phenytoin	

Table 11.7 Common viral infections associated with acute interstitial nephritis

Epstein–Barr virus (EBV)
Adenovirus
Human Immunodeficiency virus (HIV)
Cytomegalovirus (CMV)
Polyomavirus (BK)
Rubeola
Hepatitis viruses
Hantavirus

Management of HUS is mostly supportive. Careful monitoring of fluid balance is necessary to prevent fluid overload. Patients often require renal replacement therapy. Peritoneal dialysis is usually the modality of choice for patients with HUS. Due to the risk of fluid overload in patients with oliguria, red cell transfusions should be given slowly and in small aliquots. Platelet transfusion should only be given if patient has acute bleeding or at the time of a surgical procedure.

HUS is also known to occur secondary to pneumococcal infections, pregnancy, and medications including oral contraceptives and calcineurin inhibitors. Genetic causes of atypical HUS lead to unregulated activation of the alternate complement pathway. These include mutations in genes encoding factor H, factor I, or membrane-cofactor protein and production of factor H antibodies. These are best treated with plasma replacement therapy and eculizumab, a human monoclonal anti-C5 antibody that blocks activation of the terminal complement pathway. Patients started on eculizumab must receive meningococcal vaccine and be started on penicillin prophylaxis to prevent invasive meningococcal disease. A rare form of HUS is seen in infants with inborn errors of cobalamin metabolism.

Thrombotic thrombocytopenic purpura is often described as a pentad of microangiopathic hemolytic anemia, thrombocytopenia, fever, neurological signs, and renal dysfunction. There are hereditary and acquired forms of TTP. The acquired form is more common and is secondary to antibodies to ADAMTS13 (von Willebrand factor-cleaving protease).

The hereditary form (Upshaw–Schulman syndrome) is due to inherited deficiency of ADAMTS13. AKI is much less common in patients with TTP, while neurological symptoms predominate.

Rhabdomyolysis

Rhabdomyolysis refers to the destruction of skeletal muscle, leading to leakage of their contents including myoglobin and creatine kinase. In adults, the risk of developing AKI ranges from 5 to 50 % but much lower in children. Viral myositis (40 %) and trauma, including crush injuries, (25 %) make up the majority of cases in children. Less common causes include extreme exertion, heat-related illness, status epilepticus, mitochondrial and metabolic disorders, and malignant hyperthermia. Drugs of abuse known to cause rhabdomyolysis include alcohol, heroin, cocaine, amphetamines, methadone, and LSD. Prescription medications to be aware of include antipsychotics, statins, selective serotonin reuptake inhibitors, zidovudine, colchicine, lithium, and antihistamines. Rhabdomyolysis is thought to cause AKI by the direct renal tubular toxicity of myoglobin, intrarenal vasoconstriction, and tubular obstruction, as well as secondary injury associated with volume depletion and renal ischemia. Treatment involves aggressive fluid administration to offset the fluid sequestration occurring in the damaged muscle tissue, thus reducing secondary renal ischemia, and is thought to help eliminate urinary myoglobin. Despite never having been rigorously tested, sodium bicarbonate is often used to "alkalize" the urine, reduce cast formation, and act as an antioxidant. Mannitol has also historically been used as an osmotic agent, but its use is falling out of favor as it lacks evidence and is not without side effects. It is important to watch carefully for hyperkalemia and treat it rapidly if it occurs.

Abdominal Compartment Syndrome

Normal intra-abdominal pressure (IAP) ranges from below zero to 0 mmHg in healthy individuals and from 1 to 8 mmHg in critically ill children. Abdominal compartment syndrome (ACS) is a condition caused by intra-abdominal hypertension. It is defined currently as an IAP >20 mmHg *with new or worsening organ dysfunction*, although ACS can occur at lower pressures and IAP >12 mmHg is still pathologic. More than 60 % of pediatric cases are associated with massive fluid resuscitation. IAP measurement by bladder pressure through a special Foley catheter has been considered the gold standard, but in cases of bladder trauma, a monitor can be placed in the stomach, rectum, or the peritoneum itself. Renal dysfunction results from a decrease in cardiac output, compression of renal vessels and decreased renal blood flow, increased renal vascular resistance, and redistribution of renal blood flow from the cortex to the medulla. Oliguria is often seen at an IAP of 15–20 mmHg and anuria at 30 mmHg. Medical management includes patient positioning flat and supine, with gastric and rectal decompression. Diuretics and CRRT can be adjunctive. Drainage of ascites or surgical decompression of the abdomen may be necessary when medical management fails. Marked improvement in renal function is commonly observed within hours following decompression; however, mortality remains about 50 % usually due to the inciting pathology.

Hepatorenal Syndrome

AKI occurs in almost 20 % of patients with cirrhosis. This is due to dysregulation of circulatory and neurohormonal balance. A subset of patients will have a form of functional renal failure called hepatorenal syndrome (HRS). The underlying pathogenesis is incompletely understood, but the peripheral arterial vasodilation theory is the most widely accepted, leading to lower effective arterial blood volume, which in turn activates neurohumoral vasoconstrictors (renin–angiotensin–aldosterone system, ADH) which will lead to renal vasoconstriction together with salt and water retention. Prognosis is dismal with survival measured in weeks to months. There have been few proven effective treatments in clinical studies in children, but vasoconstrictors remain a viable temporary option (noradrenaline, midodrine, and octreotide). A transjugular intrahepatic portosystemic shunt (TIPS) can be useful but is often unavailable to patients with HRS due to one or more contraindications (INR >2). Renal replacement therapy can be used as a bridge to liver transplantation, which remains the only definitive cure.

HIV/AIDS

There can be numerous etiologies of AKI in patients with HIV/AIDS. The chronic condition known as HIV-associated nephropathy (HIVAN), which is similar in pathology to focal segmental glomerulosclerosis (FSGS), is seen particularly in patients of African descent and places them at a much higher risk of developing concomitant AKI. Although modern more effective therapy for HIV has resulted in a decreased incidence of HIVAN, up to two-thirds of HIV positive admissions to the ICU for any reason will develop AKI. The most common causes are opportunistic infections (50 %), toxicity from medications (30 %), and liver failure (10 %). Also seen with increased frequency in this group of patients are HUS/TTP, rhabdomyolysis, and AIN. The protease inhibitor indinavir causes nephrolithiasis,

crystal-induced AKI, and tubulo-interstitial nephritis. The nucleotide reverse transcriptase inhibitors tenofovir, adefovir, and cidofovir cause AKI with proximal tubular injury and a Fanconi syndrome. AKI seen in hospitalized patients with HIV is often due to concomitant administration of other nephrotoxic drugs with most cases being associated with beta-lactam and aminoglycoside antibiotics. Dose adjustments of all medications, including antiretroviral drugs, are required with renal impairment.

Malignancy

Malignancy-associated AKI is often multifactorial. The etiology can be divided into prerenal, intrinsic renal, and postrenal. Tumor lysis syndrome is a condition that results from massive lysis of tumor cells in tumors with a high proliferative rate, a relatively large mass, and a high sensitivity to cytotoxic agents. In pediatrics this is most commonly seen in lymphomas (up to 10 %), acute leukemias (5 %), central nervous system tumors, and neuroblastoma. After the initiation of therapy, there is a rapid release of intracellular electrolytes and proteins that can cause AKI by decreasing GFR through prerenal mechanisms and by increasing solute load, which impairs tubular function. Additional symptoms include gastrointestinal disturbances, neuromuscular effects, cardiovascular complications, and ultimately death. The syndrome is characterized by hyperkalemia, hyperphosphatemia, hyperuricemia, and metabolic acidosis. In the setting of acidic urine, uric acid crystallizes in the tubules. A urine uric acid-to-creatinine ratio of greater than 1 is suggestive of uric acid nephropathy. Prevention centers on massive volume expansion, prevention of hyperuricemia with allopurinol, and administration of urate oxidase (Rasburicase®), an enzyme that converts uric acid to allantoin, which is five times more soluble in the urine than uric acid. Care must be taken with administration of urate oxidase in the setting of confirmed or potential glucose-6-phosphate dehydrogenase deficiency. Oliguric AKI due to tumor lysis syndrome invariably requires institution of renal replacement therapy.

The Future

There is ongoing research in the field of AKI evaluating the use of biomarkers in the early diagnosis of AKI. Multiple therapeutic agents are under investigation, including atrial natriuretic peptide, thyroid hormone, calcium channel blockers, oxygen radical scavengers, and adenine nucleotides. It is likely that with earlier detection and newer treatment options and early intervention, prevention and management of AKI in children will continue to improve.

Editor's Comment

In the past, acute kidney injury could be seen even in healthy children after major surgery, especially when nephrotoxic IV contrast and drugs like gentamicin were in more widespread use. Today transient renal dysfunction might occasionally be seen after prolonged exposure to or excessive dosing of ketorolac or in patients with a predisposition such as sickle cell trait who are allowed to become extremely dehydrated. Since routine daily blood draws have for the most part been eliminated, the clinician needs to be vigilant for the subtle signs of renal dysfunction: nausea, prolonged ileus, or nonspecific malaise. Urine output is usually within normal limits, or consistent with the usual fluctuations observed in the postoperative period, and is therefore not a reliable sign. Ultimately, any patient whose postoperative progress seems to have stalled or taken a step back for no apparent reason (sepsis, obstruction, and hemorrhage have been ruled out) should raise the question of AKI. Electrolytes with BUN and creatinine should be drawn, fluid status should be assessed, and a urinalysis with specific gravity and urine sodium and creatinine (for calculation of fractional excretion of sodium) should be ordered. If AKI is confirmed, all potential nephrotoxins should be discontinued, fluid intake should be decreased, and if the patient is oliguric, potassium should be removed from all intravenous solutions. The vast majority of these children will recover uneventfully without specific therapy or need for dialysis.

Infants and children with AKI will sometimes need dialysis or hemofiltration. The indication is usually fluid overload, hyperkalemia, or, in the case of a prolonged recovery from ATN, azotemia. Options include peritoneal dialysis, standard hemodialysis, or CRRT, usually in the form of continuous venovenous hemofiltration (CVVH). Peritoneal dialysis is more often used in infants due to their limited vascular access for hemodialysis. Peritoneal dialysis catheters are almost always placed under general anesthesia but in most cases dialysis itself is well tolerated. Hemodialysis is sometimes considered in older children and requires placement of a large-bore double-lumen hemodialysis catheter in the jugular vein. These can be percutaneous or tunneled, depending on how long dialysis is likely to be needed. CVVH is generally used only in patients admitted to the ICU who are critically ill. Hemofiltration differs from hemodialysis in that water and solutes from the blood are forced through a semipermeable membrane by hydrostatic pressure generated by a pump (convection), rather than across a gradient generated by the presence of dialysate on the other side of the membrane (diffusion). It is slower than dialysis and requires daily sessions lasting 12–16 h. It has less of an effect on systemic blood pressure and is usually better tolerated than hemodialysis in patients who are hypotensive.

Continuous arteriovenous hemofiltration, in which the patient's blood pressure provides the hydrostatic pressure needed to create the ultrafiltrate, is sometimes used in adults but is rarely an option for children. The pediatric surgeon is often asked to provide the vascular access required by these various therapies and must therefore be familiar with the equipment available and the flow rates needed. Subclavian vein catheters should be avoided in children at risk for chronic renal failure—in the event they need to have a graft or arteriovenous fistula created in the future—it is important to avoid subclavian vein stenosis or thrombosis.

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Ventilation

12

Mohammed Hamzah and Michael Wilhelm

Much pediatric respiratory management in the ICU is extrapolated from the adult literature, as there is paucity of pediatric specific research. At the same time, a number of critical differences exist between adult and pediatric respiratory physiology that predispose children to respiratory failure. Apneic episodes (central or obstructive) are much more common in children than adults, in part due to the immature respiratory control center that continues to develop for months even after term birth. This immaturity can impair the normal ventilatory response to hypoxia and hypercapnia. Infection (particularly certain viral infections) or neurologic insults (trauma, medications, infection) can impair respiratory control even in older infants. Infants are therefore particularly sensitive to the respiratory depressant effects of anesthetics and sedatives as well as metabolic alkalosis.

Respiratory mechanics are also different in infants and young children. A relatively larger anatomical dead space with larger and more compliant upper airway structures that collapse easily during forceful inspiration predisposes to obstructive apnea. A higher airway resistance, highly compliant (easily deformable) chest wall that will move inward paradoxically during inspiration, and less efficient, more easily fatigable intercostal muscles and diaphragm with fewer type 1 muscle fibers predispose children to respiratory failure when illness strikes. These differences in physiologic parameters require early recognition of respiratory distress and prompt institution of appropriate respiratory support to prevent frank respiratory failure.

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Respiratory Distress and Failure

While respiratory distress (the use of accessory muscles and increased respiratory work) and respiratory failure (inadequate gas exchange) can occur in the same patient, they are not synonymous. Accessory muscle use (retractions, nasal flaring) occurs when more negative intrathoracic pressures are being generated in an effort to increase tidal volume. With restrictive lung disease (pneumonia, ARDS, abdominal distention), patients become tachypneic, with normal respiratory rates varying by age. On the other hand, with obstructive disease (asthma, upper airway obstruction), retractions tend to be more severe than the tachypnea as slower breathing is more mechanically advantageous. Furthermore, the phase of respiration that is obstructed will be prolonged. It is important to remember that infants have intrinsic restrictive and obstructive physiology, so many disease processes present with a mixed picture. As respiratory insufficiency progresses, children will begin to grunt ("auto-PEEP") to prevent collapse of alveoli. With further reduction in effective air movement, they develop a thoracoabdominal paradox. More concerning still is the development of respiratory pauses—brief pauses during marked tachypnea that signify impending respiratory arrest. Respiratory pauses and altered mental status in the setting of respiratory distress strongly suggest that the patient should be electively intubated.

Respiratory failure is defined by the degree of hypoxemia or hypercarbia. Hypoxemia is easily identified by pulse oximetry, though patients can have significant unrecognized alveolar-arterial (A-a) oxygen gradient if on supplemental oxygen. There are several formulas used to measure the degree of hypoxemia based on the arterial oxygen level (P_aO_2) including A-a gradient, the P_aO_2/F_IO_2 (P/F) ratio, and the oxygenation index (OI). These quantities are important for clinical studies, but also for determining when a patient requires increased respiratory support. On the other hand, hypercarbia can **only** be confirmed by obtaining an arterial (or venous) blood gas. Clinical symptoms that suggest hypercarbia

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include depressed mental status (narcotic effect of CO_2) and signs of sympathetic activation such as diaphoresis, tachycardia, and hypertension.

Several situations deserve specific comment. First, patients who lack muscle strength might show limited respiratory distress prior to frank respiratory failure, as they are unable to significantly increase negative intrathoracic pressure. Tachypnea and thoracoabdominal paradox are often more prominent in these patients than retractions. Even harder to identify are patients who have diminished respiratory drive for any reason as they may not even develop tachypnea en route to frank hypercarbic respiratory failure. (A classic at-risk surgical patient is the infant with pyloric stenosis and a high serum bicarbonate level after anesthesia.) On the other hand, patients with increased respiratory load due to hyperthermia (increased CO_2 production) or metabolic acidosis (decreased pH) will augment their minute ventilation by Kussmaul respirations (deep and labored) if their respiratory compliance is normal. However, with restrictive lung disease (pneumonia, chronic lung disease, underlying restrictive physiology typical of infants), this can generate a significant amount of respiratory distress and tachypnea. Therefore, in a patient who appears to have significant restrictive lung physiology but good air entry throughout, one should consider checking electrolyte in a blood gas to look for metabolic acidosis.

Principles of Respiratory Support

Several fundamental principles dictate the approach to ventilatory support of children and are largely extrapolated from data in adults. Perhaps the most important overarching principle is that *adequate* ventilation and oxygenation should be the goal as opposed to pushing harder to achieve *normal* levels of ventilation and oxygenation. Once respiratory support is initiated (especially invasive ventilation), minimizing ventilator-induced lung injury is imperative. Therefore, because of the inflammatory response induced by mechanical ventilation, due to high pressures and oxygen concentrations, permissive hypercapnia and mild hypoxemia are the typical goals. A pH over 7.3 is usually adequate, and even a pH of 7.25 (or even 7.2) is tolerated if on high ventilatory support. Similarly, as long as the patient is not notably anemic and they have good cardiac output, they will usually tolerate an oxygen saturation of 88 % or greater. However, several specific situations require more normal blood gas targets. Patients with pulmonary hypertension and intracranial hypertension or patients in shock may all require blood gasses that are closer to or even completely normal.

The plateau pressure, which essentially represents the alveolar pressure at end inflation, and the inspired oxygen are believed to be the most injurious aspects of mechanical ventilation. The plateau pressure is often less than the peak inspiratory pressure (and often considerably so in obstructive disease) as resistance contributes to the PIP when gas is flowing. The plateau pressure is measured in volume modes of ventilation after the breath is delivered by performing an inspiratory hold. In pressure-control modes, the plateau pressure is no greater than the absolute PIP, but cannot be directly measured.

Generally, the goal is to limit the F_IO_2 to 0.6 or less whenever possible. Increasing the mean airway pressure (MAP) will typically improve oxygenation, but the goal is to minimize the plateau pressure, which generally represents the alveolar pressure, usually less than 32. Therefore, increasing PEEP and lengthening the inspiratory time are often used sequentially during escalation of therapy. With restrictive lung disease (more common in pediatric surgery), patients will generally tolerate short expiratory times and therefore can even have an inspiratory to expiratory (I:E) ratio of >1 if necessary. Based on evidence showing improved outcome with smaller tidal volumes, initial goals in children are around 8 mL/kg ideal body weight. However, it is much more important to visually confirm appropriate chest rise as ideal body weight is more difficult to determine and the smaller total volumes make the ventilator's measurement less accurate. With worsening compliance, tidal volumes may be dropped as low as 5–6 mL/kg in order to limit plateau pressures. In these circumstances, higher rates are required to achieve adequate ventilation.

At this point, obstructive disease deserves specific comment. It is common for younger children to have mixed physiology, and specific surgical diseases promote expiratory obstructive disease due to tracheomalacia. With expiratory airflow obstruction, allowing adequate expiratory *time* is imperative (note that a normal I:E *ratio* has a short E-time at high rates). Low rates permit the greatest increase in expiratory time, and physical examination should confirm full exhalation between breaths. It is not uncommon to require neuromuscular blockade to prevent patients from breathing too quickly. In these situations, higher tidal volumes at lower rates might be required, and sometimes a higher PIP must be tolerated.

Finally, it is important to remember that adjusting the ventilator is not the only consideration in ventilated patients. Whenever making or considering changes to the ventilator, the patient must be examined to determine the respiratory rate, work of breathing, and air entry. Good blood gasses in the setting of a distressed patient may still indicate the need for increased support. Similarly, deteriorating gas exchange can occur due to patient-ventilator asynchrony, agitation or development of fever, and increased CO_2 production. Suctioning may be required if the patient has acute deterioration in gas exchange and air leak syndrome must also be considered, particularly if the patient is on high ventilator settings.

Methods of Respiratory Support

While invasive mechanical ventilation remains the definitive mode for respiratory support, noninvasive ventilation is used increasingly either to permit stabilization of hemodynamics prior to intubation or as the ultimate therapy for many patients. Noninvasive ventilation typically does not require sedation, which is a significant advantage over invasive ventilation. Continuous positive airway pressure (CPAP) has several benefits, including preventing dynamic airway collapse (in asthma or upper airway obstruction) and promoting increased lung volume (and therefore compliance) in restrictive lung diseases. BiPAP (biphasic airway pressure) adds the ability to augment tidal volume directly as well as providing a backup rate. Therefore, it can be used as an escalation from CPAP for patients who need additional support (persistent tachypnea or accessory muscle use).

Typically CPAP is used at levels from 3 to 10 cm H_2O, and BiPAP uses an additional inspiratory pressure of 5–15 cm H_2O above the expiratory pressure. Given the high flow rates and tight-fitting masks required, patients can be provided a higher F_IO_2, which means they can experience oxygen toxicity just as they can with invasive ventilation. The inability to achieve target oxygen saturation on more than 60–70 % oxygen for an extended period of time (1–2 h) warrants consideration of escalating noninvasive ventilation or electively intubating the patient.

Many modes of invasive ventilation exist, and new ones are being developed all the time in an effort to improve patient-ventilator interactions and to maximize ventilatory support while minimizing ventilator-associated lung injury. Conventional modes either use pressure or volume limits to dictate the size of the inspiratory volume the patient receives. It is important to pay attention to whichever variable is *not* being set on the ventilator. If a patient is receiving appropriate tidal volumes but requiring peak pressures over 32, they are at risk for barotrauma. Similarly, "normal" pressures generating very large tidal volumes are too high.

While many spontaneous modes of ventilation are used in adults, pressure support ventilation is the most commonly used in children (either alone or in combination with other modes of ventilation). Pressure support offers several advantages over other modes of ventilation. First, the patient can limit the size of the breath more effectively, enhancing comfort. Second, the patient is required to at least initiate the breath and therefore required to use some respiratory muscle effort. Therefore, pressure support is often used during ventilator weaning. Finally, ventilation-perfusion matching seems to be better with pressure support breaths as diaphragmatic movement causes better ventilation of dependent lung regions.

Newer modes of ventilation incorporate adaptive pressure in response to the volume of the previous breath. Other modes attempt to optimize inspiratory flow patterns to minimize airway pressures. Improved patient-ventilator interaction can sometimes be achieved by technologies such as neurally adjusted ventilatory assist (NAVA), which measures diaphragmatic depolarization to determine the degree and timing of pressure support. Knowing what modes are available and how they deliver each breath is imperative to managing pediatric patients with respiratory failure.

Advanced Respiratory Support

HFOV

High-frequency oscillatory ventilation is the most common rescue therapy for refractory hypoxemia (and less commonly hypercarbia). Some centers use this mode as primary therapy as a gentler mode of ventilation, but this is not our practice given the need for more sedation and more constant intrapleural pressure, which increases systemic venous pressure. (For this reason, patients often require fluid resuscitation with the initiation of HFOV.) However, because the majority of the pressure change is dampened before it reaches the alveoli, we use this mode for patients with toxic ventilator settings or significant air leak syndromes.

The MAP controls recruitment and hence oxygenation. Periodic chest X-rays are used to show lung expansion, with a target of ten ribs. The amplitude (AMP) of the oscillations and the frequency of the oscillations (Hz) determine the degree of CO_2 elimination. The initial target for the amplitude is to provide an adequate "wiggle" to the patient's pelvis. In general, higher frequencies are used in younger patients based on the theoretical resonance frequency of the respiratory system. Increasing the amplitude or *decreasing* the frequency typically enhances CO_2 elimination. The inverse relationship between the frequency and CO_2 elimination is likely due to enhanced bulk gas flow at lower frequencies. Deflating the endotracheal tube cuff (if present) can also increase CO_2 elimination.

Inhaled Nitric Oxide

Inhaled NO selectively dilates the pulmonary vasculature. NO treats pulmonary hypertension (PHTN) and can improve V/Q matching as only ventilated lung regions should have increased blood flow. Importantly, at high doses used for PHTN (>5 PPM), NO can actually *worsen* V/Q matching, though the improved global pulmonary blood flow usually predominates and improves oxygenation. In patient with ARDS, NO has been shown to improve oxygenation but not improve survival. However, it is our practice to initiate a trial

of NO in the setting of severe, refractory hypoxemia, particularly if there is evidence of PHTN on echocardiography.

Exogenous Surfactant

Surfactant clearly has a role in neonatal RDS, including in severe lung disease in the term infant (meconium aspiration syndrome, sepsis). Its role in ARDS in older infants and children remains less clear. As with NO for ARDS, trials showed improved oxygenation but not duration of ventilation, ICU, or hospital stay.

Prone Positioning

Prone positioning, though sometimes difficult, can acutely improve V/Q matching by converting open (anterior) lung regions to the dependent, more well-perfused position. However, there is also a risk of accidental displacement of lines and tubes, and studies have shown no improvement in mortality in pediatric populations. There is some evidence that longer durations of prone positioning may be more helpful, particularly in the sickest patients. Therefore, it is our practice to consider prone positioning when technically feasible in patients who are refractory to high levels of conventional therapies.

Airway Clearance

For patients who are unable to effectively cough (neuromuscular blockade or disease), secretion clearance can be markedly impaired. We routinely use intermittent percussive ventilation (IPV) and in-exsufflator therapies in these settings. They are particularly helpful in preventing intubation in patients with neuromuscular disease and helping to get these patients extubated. Therapists experienced with these techniques are invaluable in these situations.

Neuromuscular Blockade

With high ventilator settings, significant acidosis, or tachypnea in the setting of lower airway obstruction, neuromuscular blockade may be necessary. Recent data suggest that outcomes are improved with early NMB in ARDS. However, prolonged NMB can contribute to critical care neuromyopathy as well as impaired secretion clearance and should be used cautiously.

Many other adjunctive therapies are sometimes used in specific forms of respiratory failure. Corticosteroids, diuretics, beta-agonists, other bronchodilators, and many others may be used.

Additional Considerations

In ARDS, the main goal is to increase lung recruitment (by increasing MAP) while limiting peak pressure and oxygen toxicity. In this setting, pressure-control ventilation with longer inspiratory times and high PEEP can be very effective. This often requires NMB, which can also improve oxygenation by removing chest wall compliance from the equation. HFOV is our typical rescue if this approach fails. Patients should be as volume contracted as possible to enhance removal of lung water, as long as they are not in shock.

On the other hand, severe obstructive lung disease requires very low rates to allow full exhalation. To achieve CO_2 elimination, this requires large tidal volumes and often high peak pressures. Fortunately, the airway resistance limits the transmission of these pressures to the alveoli. Permissive hypercapnia is almost always required, and neuromuscular blockade is necessary to prevent the patient from spontaneously breathing and shortening their expiratory time. Extracorporeal membrane oxygenation (ECMO) remains the ultimate therapy for respiratory failure. However, recognition of when other therapies are failing and identification of appropriate candidates are important.

Future Considerations

Future studies may identify specific therapeutic targets to enhance recovery from lung diseases and reduce the impact of ventilator-associated lung injury. As different modes of ventilation become available, randomized controlled studies will need to be conducted to determine if they are more effective than current therapies. One particular area that may greatly benefit patients is the development of novel technologies and modes of ventilation that improve patient-ventilator synchrony and allow minimized sedation and improved V/Q matching.

Editor's Comment

For surgery residents, mastering the art of ventilator management is one of the most gratifying rites of passage we endure. Glance at the blood gas, make a subtle adjustment in the ventilatory rate or the PIP, and the patient weans, like magic—we have the power and the skill, and our patients are the beneficiaries. Nevertheless, we were slow to realize that, at least for our sickest patients, our treatment was sometimes

causing more harm than good. Ventilator-associated lung injury is a concept that has been around for a long time but is now finally accepted by clinicians on the front lines of critical care medicine, including surgeons. This concept posits that barotrauma, volutrauma, atelectrauma, oxygen toxicity, and biotrauma all contribute to lung injury and that minimizing the effects of these factors helps our patients recover more quickly and with fewer adverse sequelae.

When both conventional and advanced modes of ventilation fail, the next step for otherwise viable patients with reversible lung injury (influenza, aspiration pneumonitis) might be ECMO. There is now considerable experience with the use of ECMO in adolescents and even adults, and it appears to be a viable option in select cases. Every tertiary care children's center should have established criteria and an evidence-based algorithm for patients with severe respiratory failure so that this potentially lifesaving technology can be made available in a timely fashion. One of the most common problems with ECMO is that we too often wait too long to consider it. The patient with multiple pneumothoraces and chest tubes has probably already had irreversible lung injury due to barotrauma. The same is true for patients with ventilator-associated pneumonia, severe pulmonary edema, or multiple areas of refractory and severe atelectasis.

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Extracorporeal Life Support

13

Christopher S. Muratore

Extracorporeal life support (ECLS) most commonly referred to as extracorporeal membrane oxygenation (ECMO) is the use of prolonged, modified extracorporeal cardiopulmonary bypass for patients who are failing maximal conventional medical management for treatment of severe, acute, and reversible cardiac or respiratory failure. Initially designed with the goal of supporting adult patients with ARDS, the application was marginally successful at best. Early trials of ECMO for adults with severe acute respiratory failure and extracorporeal CO_2 removal ($ECCO_2R$) for severe ARDS showed no benefit. Conversely the use of ECMO to rescue pediatric and in particular neonatal patients with cardiopulmonary failure revolutionized extracorporeal support. First successfully used in 1972 to rescue a postoperative child in cardiac failure, the application of ECMO became more widespread after the successful use to support a newborn with respiratory failure in 1975. Since then, the indications have expanded, and the selection criteria improved such that patients are spared from the deleterious effects of futile aggressive management that would frequently cause barotrauma and organ dysfunction. The excess morbidity and mortality from viral pneumonia and ARDS observed in young people during the 2008–2009 H1N1 pandemic combined with substantial evolution of current ECLS circuits, technology, and ventilation strategies promoting lung rest revived the use of ECMO for adult respiratory failure. The technology of ECLS is similar for all applications, but the indications, management, and results are best considered separately for adults, children, and neonates.

The Circuit

A basic ECMO circuit is composed of a blood pump, a membrane oxygenator, a heat exchanger, interconnecting tubing, and the cannulas inserted in the patient. Depending on patient needs, cardiopulmonary support (venoarterial-ECMO) or pulmonary support (venovenous-ECMO) may be used. In a typical circuit, venous blood is drained from a major vein, pumped through a membrane lung for gas exchange, and returned as oxygenated blood through a major artery (VA-ECMO) or vein (VV-ECMO). Partial support can be achieved using an arterio-venous, AV or VV circuit and either a low-flow pump or the patient's own blood pressure to drive the blood across an oxygenator, effectively removing CO_2 ($ECCO_2R$).

Roller and centrifugal pumps are the two basic types of blood pumps used for ECLS. Many ECMO programs use a roller pump, but centrifugal pumps are gaining in popularity. There has been an evolution of circuit design toward simplification with minimal looping and bending of shorter tubing lengths to limit turbulent points, hemolysis, and thrombosis. A roller pump displaces blood through flexible tubing located inside a curved raceway to generate forward flow proportional to the pump speed and tubing size; this requires careful servo-regulation of pressures and a larger footprint is needed. Centrifugal pumps generate a pressure differential by spinning internal components and centrifugal force, creating negative pressure in the drainage tubing. The relationship between pump speed and blood flow is not directly related, making a flow meter necessary. Modern pumps use magnetically driven suspended impellers, which spin at the desired rate to create blood flow while minimizing heat and blood–surface contact, both of which contribute to hemolysis. Inlet pressure from the drainage limb and outlet pressure from the pump are monitored carefully to avoid excessive negative or positive-pressure swings. Additional shunts ("bridges" between drainage and return limbs for weaning trials) and other monitors (bub-

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ble detectors, oxygen saturation) can be added, but these introduce additional access points and complicate the circuit.

The membrane lung is responsible for gas exchange. There are diverse oxygenators in use, particularly since the classic silicone membrane is no longer manufactured, but most now use microporous hollow fiber or polymethylpentene (PMP) membranes. Oxygenation capacity is dependent on surface area of the membrane and contact with the blood. Oxygenator designs have evolved over time from flat sheets to hollow fiber (gas phase inside) membranes and from microporous to compressed microporous ("solid") designs such that gas exchange occurs entirely by diffusion. PMP hollow-fiber devices are best suited for longer ECMO runs and have lower rates of hemolysis, better durability with lower pressure differential, and less plasma leakage. Fresh gas ("sweep" gas) is introduced into the gas phase of the membrane (usually delivered as 100 % oxygen, oxygen-ambient air, or oxygen-CO_2 mixtures controlled by a blender), the flow of which is adjusted to optimize CO_2 levels.

Vascular Access Options

Cannulas and tubing size limit the flow rate achieved, which correlates directly with the length and inversely with the square of the radius of the conduits. For neonates, the smallest double-lumen cannula for VV-ECLS is 13 Fr, which can be challenging to place in the right internal jugular vein of a small infant. VA cannulation can be achieved with separate specific arterial return (8, 10, 12 Fr) and venous (10, 12, 14 Fr) drainage cannulas. Older children can similarly be cannulated in the right internal jugular vein in single-site VV fashion with double-lumen cannulas 15–23 Fr depending on the size of the patient and desired flow rates or double-site locations using single-lumen cannulas in combinations of femoral and jugular configuration. For adults, typical cannulas range from 23 to 29 Fr for venous drainage and 21–23 Fr for blood return (and as small as 17–19 Fr when in a VA configuration) with expected pressure flow characteristics available from the manufacturer.

Vascular access can be obtained in most patients with percutaneous cannulation using the Seldinger technique, although central cannulation and a cutdown approach are also used. Pure percutaneous access in neonates can be very difficult and risky. A semi-open technique to ensure safe passage of the percutaneously placed wire, dilator, and cannula is another option. In adults and children old enough to walk, the femoral vessels usually provide adequate access for double-site cannulation or if additional venous drainage is required. Frequently, a small distal arterial perfusion cannula or sheath is needed to perfuse the distal limb.

Arterial access has also been achieved in the subclavian and axillary arteries with adjunct or chimney synthetic PTFE grafts in adults. A bicaval double-lumen cannula (13–19 Fr with ¼-in. connectors for ¼-in. circuits and 20–31 Fr with 3/8-in. connectors for 3/8-in. circuits) with drainage ports in the IVC and SVC and a return port positioned in the right atrium that directs flow across the tricuspid valve is available for VV-ECMO and offers single-site internal jugular access (Avalon Elite; Maquet Cardiovascular, Wayne, NJ).

Goals of ECMO

The goal of ECMO is to support gas exchange and systemic metabolic demands by providing oxygen delivery to the tissues. The degree of support provided for native heart or lung function is mostly dependent on blood flow, but also on hemoglobin, oxygen saturation, and the properties of the membrane lung. There are significant differences in cardiac and pulmonary effects between VA- and VV-ECMO (Table 13.1). When primary cardiac support is the goal, drainage of blood from the patient to the circuit results in decreased right and left heart filling pressures, reduction in pulmonary blood flow, cardiac unloading, and an improvement in end-organ perfusion. In VA-ECMO, because left

Table 13.1 Comparison of the cardiac and pulmonary effects between VA- and VV-ECLS

	VA-ECLS	VV-ECLS
Cardiac support	Partial to complete	No direct support only indirect
LV effects	Decreased preload	No change
	Increased afterload	
	Possible cardiac stun	
RV effects	Decreased preload	No change
	Decreased afterload	
Coronary oxygenation	Native LV ejection	Improved
Pulmonary support	Decreased pulmonary blood flow	Maintained pulmonary blood flow
Unique issues	No recirculation	Recirculation
	Distal limb perfusion	
	Differential perfusion	

ventricular afterload is increased by retrograde aortic flow, additional interventions are sometimes needed to prevent or relieve left ventricular overdistension.

Targeted flow is usually 100–120 mL/kg/min for neonates, 80–100 mL/kg/min for older children, and 60–80 mL/kg/min for adults. Importantly, cannulas must be selected to support the desired flow rate. During cardiac support, mixed venous oxygen saturation is monitored from the venous drainage limb, and flow rates are adjusted to maintain adequate oxygen delivery. In the VV configuration, ventricular filling pressures and hemodynamics are unchanged in the steady state, but O_2 and CO_2 are exchanged through the membrane lung. Because both the drainage and return cannula are positioned in the venous system, mixing can occur. The native and membrane lungs are in series (supra-oxygenated blood is delivered back to the venous system or right atrium and then traverses the pulmonary circulation) so that expected arterial oxygen saturations are lower (85 %), depending on the patient's innate pulmonary function. In this setting, adequate oxygen delivery can be maintained provided cardiac output is sufficient and especially because limiting injurious positive-pressure ventilation augments cardiac output.

Recirculation is unique to VV-ECLS and is the immediate return of oxygenated blood from the circuit back into the circuit through the drainage lumen of the cannula. This limits oxygen delivery by limiting the effective ECMO flow seen by the patient. Some degree of recirculation is always present in VV-ECMO whether through a double-lumen cannula or dual-site configuration, but it is minimized by assuring optimal position of the cannulas, by providing appropriate volume to improve the venous compliance chamber and by temporarily lowering ECMO flow to restore effective flow.

Patient Selection

Any patient with severe, acute, and refractory but potentially reversible respiratory failure is a candidate for ECMO. Respiratory support can be considered while awaiting recovery from hypoxemic respiratory failure, hypercarbic respiratory failure, or massive air leak syndromes or as a way to bridge patients to lung transplantation. As a respiratory support modality, ECMO is most appealing in its potential to reduce (or eliminate) the injurious effects of positive-pressure ventilation. Ventilator-induced lung injury from overdistension of lung segments and cyclical recruitment–derecruitment exacerbates endothelial–epithelial barrier dysfunction, edema, and the release of inflammatory mediators in already injured lung. High concentrations of inspired oxygen can worsen cytotoxic damage. A low-volume/low-pressure ventilation strategy to reduce mechanical stretch improves outcomes in ARDS. ECMO can serve as an adjunct to or replacement of traditional mechanical ventilation, achieving gas exchange while allowing for lung rest by minimizing the volume, pressure, and fraction of inspired oxygen (FIO_2) delivered by the ventilator. Goal ventilator settings for a patient on ECMO typically include a respiratory rate of 6–10 breaths per minute, PIPs of 20–25 cm H_2O, PEEP of 10–15 cm H_2O, and FIO_2 of 0.3–0.4, although optimal ventilator settings are unknown and many variations exist. Tidal volumes are usually well under the protective 6 mL/kg of predicted body weight with this strategy.

Most patients should be considered candidates for ECMO if there are no absolute contraindications to systemic anticoagulation and a realistic expectation they will recover from the underlying cause of pulmonary failure. The family must be made aware of the possibility of significant morbidity and mortality with standard (failing) conventional management and understand the risks of ECMO. ECMO should be considered early as patient outcomes are far better than after prolonged mechanical ventilation with further pulmonary injury or signs of additional organ damage.

Mode of ECMO

We favor VV-ECMO for most patients who require respiratory support even if there are signs of global cardiac dysfunction. All children have a component of reversible pulmonary hypertension as part of the pathophysiology of their respiratory failure, which further adds to perceived cardiac dysfunction but is generally improved with the lung rest afforded by VV-ECMO. The return blood from the circuit with PaO_2 ~400 mmHg traverses the native cardiopulmonary circuit. Right atrial and ventricular filling are maintained, pulmonary blood flow is maintained, left atrial return and left ventricular ejection are maintained, and although significant mixing with poorly oxygenated blood from the injured lungs occurs, coronary oxygenation is improved with VV-ECLS compared to mechanical ventilation and massive V-Q mismatch. Furthermore, the deleterious effects of excessive mechanical support and high concentration of oxygen can be reduced, which lower intrathoracic pressure, augment ventricular filling, optimize cardiac output, and improve cardiac performance with less of a need for vasopressors. Moreover, oxygen delivery to the tissues can be assured even in the face of O_2 saturations of approximately 85 % and confirmed by the absence of metabolic acidosis, clearance of lactate, and spontaneous urine output.

Oftentimes the secondary cardiac dysfunction induced by respiratory failure, hypoxemia, or sepsis persists or progresses even after cannulation. It is important to remember that VV-ECLS requires intact, native cardiac output, and although VV-ECMO with improved coronary oxygenation can help restore hemodynamic stability, profound primary or secondary cardiac dysfunction is best addressed by VA-ECMO.

Cannulation

Cannulation in the neonate is usually straightforward but can be stressful, particularly when the patient is in extremis or receiving CPR. Right cervical cannulation is performed expeditiously through a small transverse incision situated over the bellies of the sternocleidomastoid muscles, which are preserved and separated with a hemostat, exposing the internal jugular vein. A small self-retaining retractor maximizes exposure and frees up hands. The carotid sheath is carefully dissected to gain proximal and distal control of the internal jugular vein and common carotid artery, taking care not to injure the vagus nerve. Heparin 50–100 units/kg is administered as an intravenous bolus, and 3 min later the vessels are ligated distally (cephalad). A venotomy is made and the cannula placed centrally to approximately the 6- or 7-cm mark so that the tip resides in the right atrium. This is followed by arteriotomy and cannulation to a distance of approximately 3 cm. VA-ECMO flow is initiated slowly ensuring venous drainage and inlet pressure are appropriate and ultimately increased to 120 mL/kg/min. Ventilator support is adjusted to lower FiO_2, respiratory rate, and driving pressure, and vasopressor support is weaned as tolerated. The cannulas are secured with silk ties over vessel-loop bolsters. Additionally, we routinely encircle the jugular vein with a blue vessel loop and the carotid artery with a red vessel loop and leave them in place in case of an emergency need to identify them later. Likewise, the neonate who needs to be converted from VV- to VA-ECMO can have the red vessel loop and carotid delivered into the incision more rapidly to allow arterial cannulation.

Neonatal VV cannulation with a double-lumen 13-Fr cannula proceeds in similar fashion. We do not use the bicaval 13 Fr cannula for neonates as the IVC portion of that cannula is short (compared to larger cannulas for bigger patients) and can slip back into the right atrium, causing excessive recirculation, poor flow, and, potentially, a cardiac injury. Repositioning the cannula is often challenging and potentially dangerous. A newer 13-Fr cannula (OriGen, Austin, Texas) is available that is flexible, wire reinforced, and meant to be positioned in the atrium.

The semi-open technique for VV cannulation in neonates provides a safe alternative to percutaneous cannulation. A small transverse right cervical incision is created, and the sternocleidomastoid muscles are separated to expose the jugular vein, which is left untouched so as not to disrupt it and its surrounding tissue attachments. Using the Seldinger technique, access to the vein is attained distal to the incision, preferably with US guidance. The passage of the wire, dilator, and cannula can be visualized within the jugular through the open incision. Cannula tip position in the atrium is best confirmed by fluoroscopy or x-ray.

Older children and adult patients who require ECMO are usually cannulated percutaneously using the Seldinger technique. We use US guidance for all percutaneous attempts and fluoroscopy or digital x-ray for confirmation of cannula position. We favor the right internal jugular vein for double-lumen cannulation for most patients beyond neonatal age. This approach, combined with a small centrifugal pump and a low-profile circuit, provides the opportunity for minimal sedation, early mobilization, and, in selected cases, awake and ambulatory ECMO.

It is usually best to use micropuncture access of the right internal jugular vein with placement of a 5-Fr sheath to manipulate the guide wire through under fluoroscopy into position deep within the IVC. The sheath provides secure vascular access and allows multiple wire or catheter exchanges. Often the wire will coil in the heart and not advance into the IVC. A 5-Fr angled catheter can be advanced over the wire under fluoroscopy to straighten the guide wire, and/or the catheter can be advanced into the IVC where the guide wire can then be deployed (Fig. 13.1). Once the guide wire is confirmed to be within the IVC and not in the hepatic veins, the sheath is removed, and the tract serially dilated to the appropriate cannula size. Periodic checks of wire position with fluoroscopy will ensure it has not migrated out of position. Finally, the cannula is advanced into position with the arterial return port positioned medially in the atrium for optimal flow across the tricuspid valve. The SVC and IVC drainage sites are also visible with fluoroscopy, and the IVC catheter tip location is noted with respect to the ribs and vertebral bodies, keeping in mind that once high ventilator settings are reduced, intrathoracic pressure will diminish and the diaphragms will rise, changing the position of the great vessels and heart.

When a double-lumen cannula becomes malpositioned, it needs to be repositioned. This can be accomplished using US-guided right common femoral vein access using a micropuncture needle and 6-Fr access sheath. Through the sheath, a guide wire is passed into the retrohepatic IVC, and a 5-Fr catheter is negotiated into the IVC under fluoroscopic guidance. Through this catheter, a 2.5-cm gooseneck loop snare is used to snare the tip of the malpositioned bicaval cannula, and together with manual manipulation of the exposed portion of the catheter at the neck, it is repositioned down into the IVC. There is usually immediate improvement in venous inlet pressure, patient saturation, and mixed venous inlet saturation (Fig. 13.2).

Occasionally, even the largest (31-Fr) double-lumen setup cannot provide adequate flow in a large patient, which is manifest by high negative venous pressures and is an indication for adding another venous drainage site. This can usually best be performed with percutaneous access of a femoral vein and placement of a single-lumen cannula into the retrohepatic IVC. This location is more stable and less prone

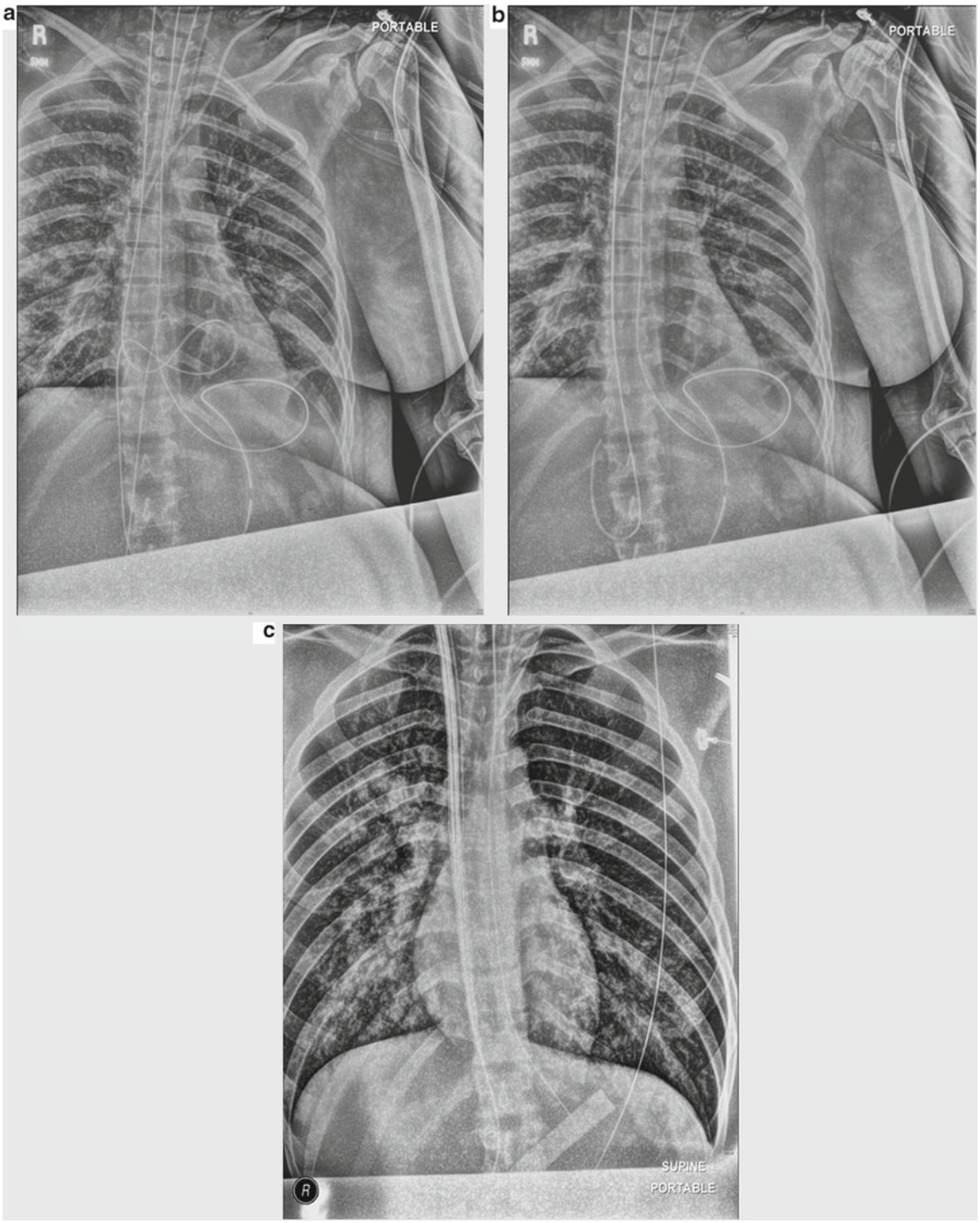

Fig. 13.1 Percutaneous access of the right internal jugular vein for venous cannula placement. (**a**) Guide wire coiled in the heart. (**b**) 5-Fr angled catheter over the guide wire to straighten the wire and advance into the IVC. (**c**) Dilator and proper guide wire position in the IVC

to collapse around the cannula than the intra-abdominal IVC or iliac veins. The drainage limb is saline primed and clamped, and the return limb is sterilized with Betadine, double-clamped, divided, and connected to the new femoral drainage limb with a Y-connector, restoring drainage continuity.

Worsening hemodynamics even after VV-ECMO is initiated is an indication for additional arterial support, usually best achieved with a femoral cannula. This is configured VV + A: venovenous respiratory support and arterial hemodynamic support. Often the patient will markedly improve with

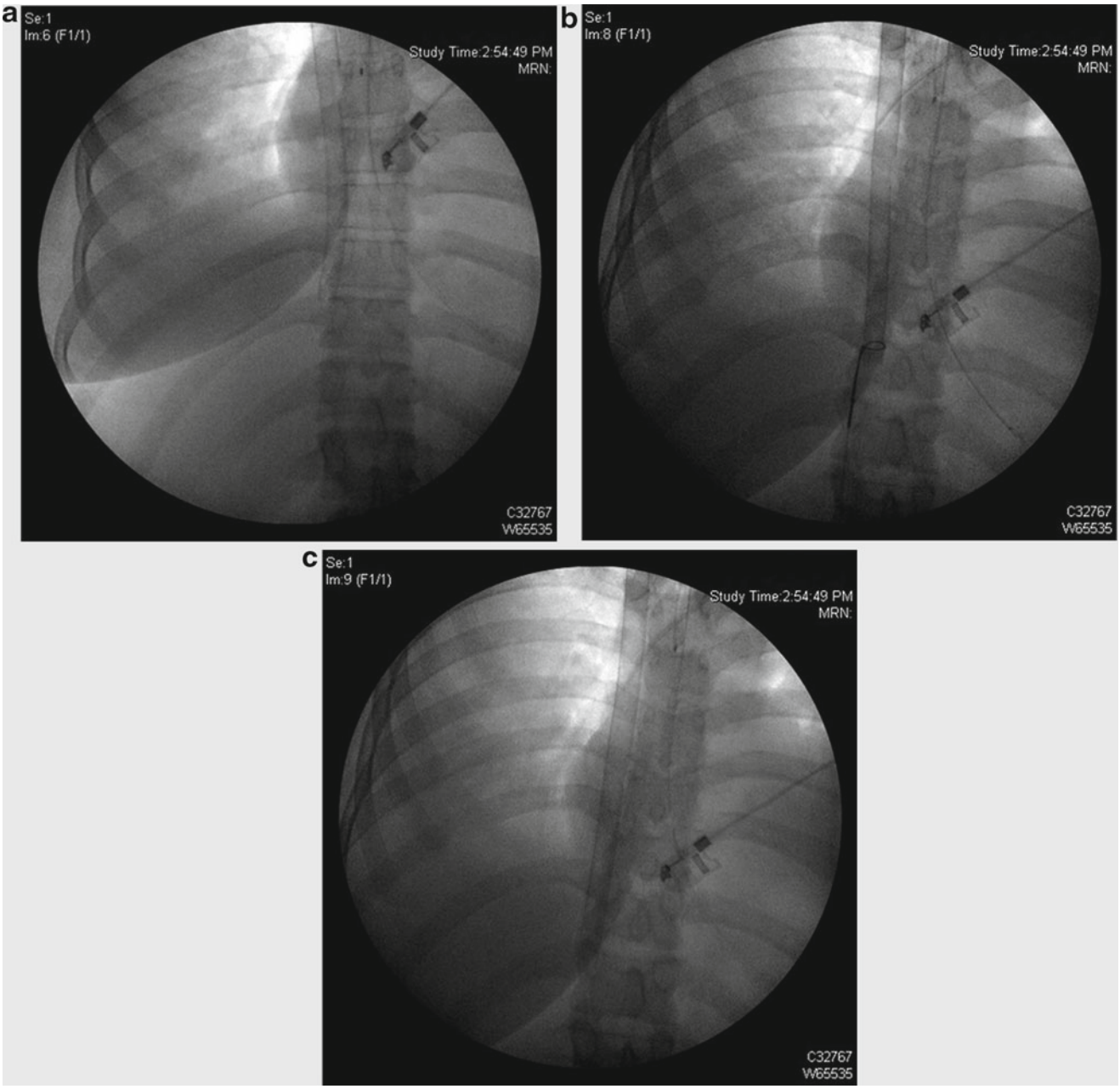

Fig. 13.2 (**a**) Malpositioned bicaval cannula with excessively high inlet pressure likely in the hepatic vein with suboptimal flow. (**b**) Snare placed using the femoral vein positioned around the tip of the cannula. (**c**) Repositioned bicaval cannula with the tip in the IVC and return of optimal flow, inlet pressure, and efficacy

minimal retrograde aortic support, which reverses systemic hypotension and provides afterload. The arterial limb is Y-connected to the arterial return limb from the circuit and can be removed once hemodynamic support is no longer needed.

A patient who is cannulated using the femoral vessels for VA-ECMO can develop significant differential perfusion due to the retrograde aortic arterial return perfusion, which results in excellent perfusion of the lower torso and extremities but sometimes striking cyanosis of the head and upper torso. If the lungs are not ready for conventional mechanical ventilation, this is an indication for the addition of a single-lumen arterial cannula in the right internal jugular vein. This VA + V configuration provides oxygenated blood from the circuit to be delivered to the SVC and right atrium, which then passes through the lungs, heart, and aorta to perfuse the upper body. Moreover, when the patient no longer requires arterial hemodynamic support, the VA + V can be reconfigured to VV until the patient can be decannulated.

At the time of VA cannulation using the femoral vessels, one must consider the risk of ischemia to the ipsilateral lower extremity since the common femoral artery is occluded by the arterial cannula. Some programs follow the physical examination and limb perfusion, choosing to address the issue when necessary with placement of a second more distal common femoral artery or the posterior tibial artery for retrograde perfusion. We prefer to be proactive and place an antegrade distal femoral cannula. With a cutdown approach, the femoral artery is cannulated with the appropriate-sized arterial cannula, which has a Luer-lock access point on the connector end. Using a modified Seldinger technique, we access the distal common femoral artery proximal to the profunda takeoff with a needle and short guide wire and place a 5- or 7-Fr sheath distally depending on patient size. The sheath is connected to saline- or blood-primed high-pressure arterial line tubing, which is then attached to the arterial infusion cannula via the Luer-lock connector. Alternatively, if a percutaneous approach is desired for VA cannulation, one should place the distal limb perfusion sheath first under US guidance, since once the arterial cannula is placed in the femoral artery, distal flow will be severely limited and percutaneous access is more difficult. Naturally, life comes before limb, and expeditious cannulation should be the priority with distal limb perfusion addressed as necessary.

Going on ECMO

Once stable on ECLS, all paralytic agents, vasoactive drugs, and sedating medications are weaned as tolerated. Muscle relaxation is discontinued, and sedation is titrated for comfort with the goal of a conscious and cooperative patient who is breathing spontaneously; this depends on the patient and naivety to narcotics and can be challenging in older patients. We avoid benzodiazepines if possible. Enteral nutrition is started and advanced as tolerated in all patients who are not receiving vasopressors, with the exception of patients with CDH, for whom distension of intrathoracic bowel can become an issue. In these patients, careful volume and caloric provision with TPN is more prudent. Diuretics or hemofiltration is used as necessary and titrated to normal baseline dry weight.

Point-of-care ACT is measured hourly to assure anticoagulation with goal ACT 180–200. However, we favor direct anti-Xa factor measurement in the prescribed therapeutic range and confirmed by thromboelastography (TEG) measurement, which is thought to be a better reflection of the real-time anticoagulation status. This is a crucial part of accurate anticoagulation management as individual patients of various ages and diagnoses have unique coagulation profiles and therefore deserve individualized treatment—one ACT range (180–200) doesn't fit all patients. Neonates will almost always require FFP within 6 h of initiation of ECMO due to factor dilution and often will also frequently need platelets. They can have an ACT >200 with an undetectable anti-Xa level and still require FFP and careful heparin dose correction.

Antithrombin III (AT-3) activity potentiates the effect of heparin and therefore must also be monitored. Some centers routinely give boluses or continuous infusions of AT-3 concentrate. This remains controversial and is an active area of investigation. Conversely, most of our adult patients rarely ever require routine FFP or AT-3 infusions. The ACT and PTT are reflections of heparin effect and can be monitored less often to assure the desired target range as predicted by the anti-Xa level and TEG analysis.

Coming Off ECMO

Once pulmonary function starts to improve and diuresis has been achieved, support can be modified, and blood flow and sweep gas are decreased. Patients can be trialed off VV-ECMO by lowering flow and eventually capping the sweep gas such that the patient remains on extracorporeal blood flow but without contribution of the oxygenator function. Patients on VA-ECMO are weaned and the cannulas clamped during a "clamp trial," at which point the patient is fully supported by the native cardiopulmonary system. It is useful to have an echocardiogram to demonstrate cardiac function recovery and residual pulmonary hypertension by septal position, tricuspid valve jet, and the patency or direction of flow through the ductus arteriosus.

Once the decision is reached, decannulation itself should be straightforward. Heparin is stopped for 30 min. Percutaneously placed venous cannulas are removed and pressure held for sometimes as long as 30–45 min to achieve hemostasis. Cannulas placed for neonatal VA-ECMO in the neck by cutdown require reopening of the incision and ligation of the jugular vein and carotid artery. Although some advocate repair of one or both, there is no proven benefit in doing so and it risks embolism or stenosis. We favor ligation, which historically has been very well tolerated. Removing femoral cannulas requires repair of the artery and can usually be accomplished with primary repair using standard vascular surgical techniques. Occasionally patch angioplasty will be required. In most cases, the femoral vein should be repaired.

Unique Situations

As of July 2015, over 69,000 cases have been voluntarily reported to the Extracorporeal Life Support Organization (ELSO) Registry since 1975. Of these, there have been more than 28,000 cases of neonatal respiratory failure, nearly 7000

cases of pediatric respiratory failure, 8000 cases of adult respiratory failure, 6000 cases of neonatal cardiac failure, 7500 cases of pediatric cardiac failure, and 6500 cases of adult cardiac failure. The overall survival for the aggregate is 70 % with 60 % survival to discharge. The best overall survival (85 %) and survival to discharge (75 %) are for neonatal respiratory failure with meconium aspiration syndrome diagnosis having 95 % survival, followed by respiratory distress of the newborn at 85 %, and persistent fetal circulation/pulmonary hypertension of the newborn and sepsis both at 75 %.

Congenital Diaphragmatic Hernia

There have been 7400 patients with CDH treated with ECMO, with only a 51 % survival. Patients with CDH continue to have the poorest survival among all patents that receive ECLS. The reasons for this are still unclear but likely due to the irreversible pulmonary hypoplasia and fixed, persistent pulmonary hypertension. Despite advances in prenatal imaging, stratification, and planning, the ability to accurately and reliably predict survival remains elusive. Moreover, CDH is a heterogeneous disease with multiple patient and iatrogenic factors that contribute to the failure of optimal medical management necessitating ECMO.

CDH is the most common indication for neonatal ECMO, and survivors have more morbidity than non-CDH ECLS survivors. Traditionally, many have favored VA-ECMO for CDH patients owing to the simultaneous hemodynamic effects of CDH. VA-ECMO adequately decompresses the right heart and can salvage or rescue a failing heart allowing it to recover from severe pulmonary hypertension, acidosis, hypercarbia, and hypoxemia. Recently however, there has been a gradual movement toward VV-ECLS with comparable survival noted. Regardless of mode, cannulation of the CDH patient presents unique challenges due to the severely shifted and often-rotated mediastinum and great vessels; this is true for both left and right CDH. One can easily find access to the jugular lumen only to find the cannula meets resistance in the chest or the ECMO flow is lower and inlet pressure higher (more negative) than anticipated due to inadvertent cannulation of the azygos vein. Image guidance, particularly with digital x-ray or fluoroscopy, can be very helpful and is encouraged.

Operative repair of CDH while on ECMO is preferred by many and discouraged by others in favor of repairing the CDH after decannulation. The ELSO database reports hemorrhage in 35–40 % of CDH patients repaired on ECMO. Anticoagulation strategies should be modified during an operation performed on ECMO. Heparin infusion can be lowered with goal ACT lowered to 160–180 s, the anti-factor Xa level reduced to sub-therapeutic levels and aminocaproic acid given, first as a bolus and then by continuous infusion during and for 24–72 h following repair. Although rare, heparin-induced thrombocytopenia (HIT) can occur, and argatroban or lepirudin may be used to provide systemic anticoagulation. False-positive testing for HIT is relatively high, and centers are urged to consult with hematology or the blood bank to develop alternative strategies to heparin if necessary.

Trauma, Infection, and ARDS

ECLS has been effective in many other clinical situations such as blunt trauma with lung injury in children and adults, with survival rates near 65 %. In select cases, ECLS has been successfully applied for lung injury and ARDS associated with traumatic brain injury with very careful attention to anticoagulation. ECLS has been applied to patients with tracheal anomalies requiring operative repair, mediastinal or other pulmonary tumors with airway compromise that need operative management where endotracheal intubation is contraindicated. ECLS has been very successfully applied to the management for pediatric and adult patients with H1N1 pneumonia.

Despite early randomized trials of ECMO for adults with severe acute respiratory failure and extracorporeal CO_2 removal ($ECCO_2R$) for severe ARDS that showed no benefit of ECLS, ventilation strategies, principally "lung rest" circuit configurations and new technology, particularly short circuits and centrifugal pumps, have evolved substantially, and a number of more recent studies from experienced ECLS centers reported survival rate of 50–75 % in adults with severe respiratory failure. The excess morbidity and mortality from viral pneumonia and ARDS observed in young persons during the H1N1 pandemic further prompted an increase in the use of ECMO for adult respiratory failure with better results of late. This further speaks to modern management strategies for critical respiratory failure with standardized protocols including low tidal volume ventilation, diuresis, and prone positioning used in many centers with a great deal of ECLS experience, who are also quite good at keeping patients off ECMO.

Hypercarbic respiratory failure and extracorporeal CO_2 removal ($ECCO_2R$) are exciting area of interest. CO_2 clearance is more efficient than oxygenation and depends largely on sweep flow and membrane characteristics, rather than blood flow. Although the use of $ECCO_2R$ has not been robustly studied in acute exacerbations of airway disease, it stands to reason that because the primary abnormality is ventilator failure, the potential for lower flow rates or pumpless configurations could offer more favorable side effect profiles as compared with VV-ECMO. $ECCO_2R$ may also allow for the minimization of sedation and promotion of early mobilization in certain patients.

There has been a renewed interest in the use of ECLS as a bridging strategy to lung transplantation as mechanically ventilated patients have a worse survival after lung transplant. The 1-year survival in patients bridged to lung transplantation from ECMO is approximately 60–75 % with the duration of mechanical support before transplant inversely related to outcomes. A strategy of "awake ECMO" for patients awaiting lung transplantation has been reported more frequently recently and offers the theoretical advantage of early mobilization, rehabilitation, and avoidance of endotracheal intubation and its associated complications. The most appropriate ECLS configuration for a given patient being bridged to lung transplant depends on the underlying disease process. Patients with significant right heart failure or hemodynamic compromise may require VA-ECMO support, whereas those with obstructive or restrictive lung disease can be supported with VV-ECMO or $ECCO_2R$.

CPR

Other applications of ECLS have been in the form of extracorporeal cardiopulmonary resuscitation (ECPR) in patients with cardiogenic shock, posttraumatic hypotension, hypothermia, cold-water near drownings, arrhythmias, and cardiac arrest with the ELSO Registry and literature demonstrating an overall survival near 40 %. Interestingly, many transplant programs are developing protocols to apply ECMO in the setting of organ donation after cardiac death to support organ function until organ procurement can be performed. This extracorporeal organ support has been used with reasonable success once institutional logistics and ethical considerations are resolved. Organs recovered and transplanted with this support strategy have functioned well and offer the promise of expanding the available organ donor pool for transplantation.

ECMO for septic shock remains controversial despite international guidelines recommending ECMO in certain cases. Survival outcomes vary widely (20–70 %) depending on the patient characteristics and associated diagnoses. Patient selection and cannulation strategy are critical. Recent experience suggests the survival rate could be close to 50 % for all patients with refractory septic shock but even higher (~75 %) in children.

Editor's Comment

ECMO is now considered for any patient of any age with severe respiratory distress that is potentially reversible and refractory to standard therapy. For patients at the extremes of age and size, technical issues still pose significant hurdles though absolute contraindications are difficult to define and continue to evolve. For larger patients, arterial access is limited by the implications of ligating the cannulated vessel, and venous return can be a significant issue, requiring sometimes two or three cannulas to support adequate flow. A distal internal jugular cannula ("brain drain") can provide substantial additional flow even in neonates and might relieve venous congestion of the head. Venovenous ECMO has become the preferred approach except when there is significant primary cardiac dysfunction (and most infants with CDH). Percutaneous VV cannulation is increasingly available and should be used whenever possible.

VV-ECMO is associated with transient cardiac dysfunction ("stun"), presumably due to cytokine release or electrolyte shifts, and can prompt conversion to VA-ECMO. We have found that stun is avoidable with a protocol that includes: low initial flows (10 mL/kg/min for 8 min), calcium gluconate 100 mg/kg IV (50 mg/kg in pediatric patients), and a slow increase in flow (10 mL/kg/min every 2–3 min).

Cannulation can be challenging in neonates and should not be taken lightly. The internal jugular vein tears easily, sometimes requiring ligation and a second or third more proximal attempt. One should use the smallest cannula that allows adequate flow. The right IJ vein is usually the only vein available in the neonate for safe cannulation and should therefore be preserved. A common problem is for the cannula to pass for a short distance and then meet resistance before it enters the atrium. Steady pressure might be sufficient, but perforation of the SVC or right atrium is a concern. Tricks include: using sterile water-soluble lubricant, gently spinning the cannula as it is being advanced, lifting the baby's thorax off the bed for a short distance, and changing the traction on the distal vein to straighten it (more traction) or to relieve the natural narrowing that occurs when a tubular structure is put on stretch (less traction). Rather than forcing it, it is usually best to remove the cannula and regroup and try again with a smaller cannula. In very rare cases, a portion of the clavicle must be resected to expose the vein in the chest, or a sternotomy with direct placement of a cannula in the atrium is required.

Arterial cannulation is usually more straightforward, but there is a risk of creating an intimal flap. The tip of the cannula must be within the true lumen. Some prefer to tack the intima down with fine polypropylene stitches prior to attempting cannulation. A common error is to position the tip of the cannula in the aortic arch, which can limit flow to the right arm and coronary arteries. The cannula should be advanced no more than about 2.5–3 cm, leaving the tip in the carotid artery rather than in the aorta.

Important considerations before agreeing to place a child on ECMO include: an assessment of the patient's candidacy in the context of available institutional resources, activation of the ECMO team, STAT echocardiography and head ultrasound, type and crossmatch for blood needed to prime the

ECMO circuit, and informed consent after a frank discussion of the indications, alternatives, anticipated benefits (it is a bridge, not a therapy), and potential risks of the procedure (especially bleeding and intracranial hemorrhage). The team should also agree on the goals of ECMO as well as how long it might be reasonable to continue in the absence of clinical improvement.

Ultimately the goal for any patient on ECMO is to get off ECMO, and every maneuver every day should be performed with that goal in mind. Minimize fluid overload and start a diuresis early. Gently increase ventilator settings to recruit native lung function as early as is practical. Wean vasopressors and unnecessary medications. Provide adequate intravenous nutrition throughout the run. Have frequent discussions with the family to review progress and discuss limitations. Finally, if the infant is not responding as expected, repeat the echocardiogram a second or third time—some congenital heart lesions can be very difficult to identify early on.

ECMO for children in the PICU with trauma, sepsis, or arrest of unknown etiology is somewhat controversial and always technically demanding, especially if the patient is actively receiving chest compressions. When in doubt, it is reasonable to offer ECMO if resources are available and the family and all team members understand its limitations. It is important to have as much of the decision-making protocolized by committee ahead of time to avoid the awkward and time-consuming back-and-forth among surgeons, intensivists, and perfusionists as to eligibility criteria, best access site to use, the type and number of cannulas to use, how long to hold CPR while dissecting out vessels, and the other details of initiating an ECMO run at a time when minutes count.

Suggested Reading

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Conjoined Twins

14

Gary E. Hartman

Conjoined twins are among the rarest developmental anomalies with incidence estimates ranging from 1 in 50,000 to 1 in 200,000 births. Most of the sets identified prenatally die either during pregnancy (25 %) or within 24 h of birth (50 %). While it is claimed that the incidence among stillborns is equal between boys and girls, girls predominate 3:1 among the live-born sets.

The twins are categorized by the location of the joining (thoraco-, omphalo-, cranio-) combined with the Greek term pagus ("that which is fixed") (Table 14.1). The attachment of an incompletely developed twin to the body of a fully developed twin is extremely rare and has been alternatively labeled heteropagus or parasitic or asymmetric conjoining. Twins joined at the chest and abdomen represent almost three quarters of the reported sets. There are two theories of the etiology of conjoined twins, the fission and the fusion theories. Historically, it has been assumed that conjoined twins resulted from incomplete separation of a monozygotic twin embryo between the 13th and 15th day after fertilization. An alternative theory (fusion) is that two embryos fuse after initially being separate. There is no association with previous conjoining, maternal age, or parity. While conjoined twins fit into the common classification categories with many similarities among them, it is best to consider each set a unique pair of individuals requiring careful anatomic evaluation and possessing separate moral and ethical identities.

Diagnosis

The diagnosis can be established by ultrasound as early as 12 weeks gestation by identifying constant relative positions of the fetuses, a single placenta with no separating membrane, or a single umbilical cord with more than three vessels. Follow-up scanning at 20 weeks provides reliable visceral detail and should include echocardiography. While fetal echocardiography is quite accurate, it tends to underestimate the degree of cardiac malformation and cannot reliably exclude myocardial fusion. Three-dimensional echocardiography provides greater detail. Since the chance of survival and separability are largely dependent on the extent of the cardiac anomalies, it is essential to obtain accurate cardiac imaging. In some instances, the imaging windows available are better prenatally than postnatally. If the pregnancy continues into the third trimester, a fetal MRI should be performed as it provides excellent soft tissue resolution and a larger field of view.

The frequency of associated anomalies and the site of fusion dictate the need for postnatal diagnostic studies. All sets should have plain radiographs of the chest and abdomen to identify associated anomalies such as diaphragmatic hernia, vertebral malformations, and cardiac lesions. Echocardiography and cranial ultrasound should also be performed in all cases. Additional studies are dictated by the location of the conjoining; the timing of these studies depends on their clinical condition. If the twins are stable, a few limited studies are obtained with the more complex imaging awaiting a period of transition and growth. If the twins' clinical condition is tenuous or discordant, suggesting that urgent separation might need to be considered, diagnostic studies should proceed with thoughtful multidisciplinary input.

In thoraco-omphalopagus twins, the bowel gas pattern might appear to be separate on plain radiographs but more specific studies such as GI contrast or CT with contrast should be obtained. Ultrasound of the liver, hepatic veins, and abdominal viscera can provide valuable information about separability and can be accomplished with portable equipment if the infants are unstable. CT (Fig. 14.1) and MRI of the head, chest, and abdomen are obtained under general anesthesia and should be planned with sequences and timing of contrast injections optimized to provide as much dynamic information as possible while limiting the duration of the studies.

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Table 14.1 Types of conjoined twins

Category	Fusion	Percentage (%)
Thoracopagus	Chest/abdomen	20–40
Omphalopagus	Abdomen	18–33
Pygopagus	Sacrum/buttocks	18–28
Ischiopagus	Pelvis	6–11
Craniopagus	Cranium	2
Parapagus	Ventrolateral	New term

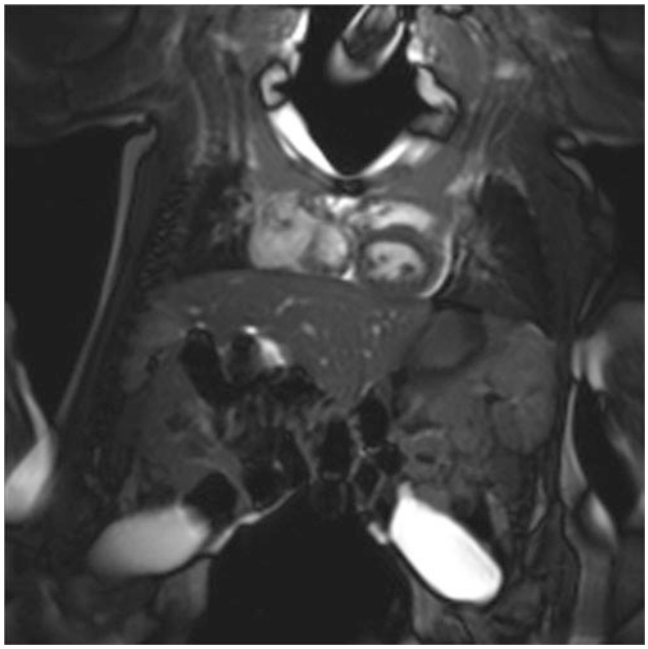

Fig. 14.1 Sagittal CT of thoraco-omphalopagus conjoined twins

Modern imaging software that allows three-dimensional reconstruction provides amazing detail and visualization of the proposed separation. The cross-sectional images of the viscera allow further planning both for the separation and the reconstruction and calculations of the anticipated defect in the body wall resulting from the separation. In addition, the imaging allows flow estimations about twin–twin shunting at the cardiac and visceral levels. In cases of possible separation with structural cardiac anomalies, cardiac catheterization should follow the same indications as those of a singleton infant and might also reveal pulmonary hypertension or substantiate cross-circulation. Imaging of the biliary trees should be accurate from the MRI but in some cases should be supplemented by nuclear imaging. Laboratory studies should include basic metabolic studies as well as oxygen saturations, arterial blood gases, and electrocardiograms. Twins with even small myocardial connections will usually have synchronous heart rates.

Twins joined at the pelvic (ischiopagus) and sacral (pygopagus) regions often have complex vertebral, orthopedic, and genitourinary abnormalities; CT and MRI are required to identify the bony and visceral anomalies as well as possible fusion of the spinal cord. Multiplanar MRI is helpful in cataloging the pelvic viscera (uterus, bladders, fallopian tubes). Cross-circulation is sometimes significant in these twins, and, as in thoraco-omphalopagus, the contrast injection is done in one twin only and the scanning timed to obtain arterial and venous information. Delayed images are helpful in determining renal function. Complementary information is obtained by performing contrast studies of the genitourinary and gastrointestinal tracts. Cloacal anomalies and single rectum are common and accurate definition of the anatomy that is critical to planning the surgical separation.

Twins joined at the head are classified as craniopagus or cephalopagus. Cephalopagus twins are usually also fused at the chest and have generally been thought to be nonviable, although a set of girls who are now 20 years old have chronicled their lives in short video clips on the Internet. Craniopagus twins account for approximately 2 % of all conjoining though they are more heavily reported in the lay press. Some cases have separate duras but most have significant connections of cerebral cortex and share at least a portion of the sagittal sinus.

Twins joined side to side (parapagus) can have extensive connections with complex pelvic anatomy. They usually have a shared leg, a single symphysis pubis, and one or two sacra. Unions that include the chest have complicated cardiac anomalies similar to the thoraco-omphalopagus twins and need extensive cardiac evaluation. The blood supply to the shared pelvis and lower extremity can be outlined with CT and MRI and rarely requires angiography.

Treatment

Multidisciplinary planning should begin prior to delivery. Counseling regarding viability and the possibility of separation should be accomplished with input from specialists with experience in the appropriate areas. Hospitalization is frequently indicated late in the pregnancy with a planned cesarean section although obstetrical complications are frequent and often necessitate an urgent delivery. Stabilization in the neonatal ICU should include standard neonatal care with multidisciplinary evaluation and attention to privacy. While in the NICU, public and media exposure is usually well controlled, but excessive or unnecessary examination by medical and hospital personnel is a risk and must be controlled. The optimal situation is stabilization of the infants such that they could be discharged home to return for further evaluation.

The optimal time for elective separation is undetermined but has been suggested at between 4 months and 2 years. We have noted that even with separation at 4 months of age, there are already significant musculoskeletal changes that require remodeling or physical therapy. On the other hand, larger size, more time for tissue expansion, and more “durability” of vessels and tissue are advantages of a delayed separation.

Emergency separation needs to be considered when one twin is unstable or if both physiologically deteriorate due to their connection. If one twin dies, the other will succumb within 4–6 h from disseminated intravascular coagulation. In the absence of complete preparation for separation, emergency separation should only be considered when the death of one twin is imminent and the goal is salvage of the healthier twin. The specific management of each set of twins will depend on their physiologic status and specific constellation of conjoining and associated anomalies.

Thoraco-omphalopagus is the most common type of conjoining. Twins joined at the pelvis will require involvement of orthopedic, urologic, and neurosurgical colleagues, and the operative plan will obviously be determined by the nature of their connections. The anesthetic and team coordination management of the twins begins with their diagnostic studies, as most will require general anesthesia. Experience with the twins' reaction to specific drugs, the degree of cross-circulation, and their recovery patterns are helpful in planning the separation procedure. We combine studies whenever possible, having obtained CT, MRI, and cardiac catheterization under a single anesthetic. Even with limiting of data acquisition, this can take 6–8 h.

Tissue expansion is usually required to obtain adequate skin coverage of the large body wall defect created by the separation. We have used tissue expanders in twins as young as 2 months of age and have placed the expanders either on the connecting bridge itself or parallel to it. The expanders can be filled fairly rapidly, with weekly injections, usually either with topical anesthetic or a brief general anesthetic. Care must be taken to avoid excessive pressure, as the expanders are placed on both lateral surfaces of the twins. The timing of the insertion and expected expansion needs to be coordinated with the separation date.

Younger twins or those requiring a preoperative bowel preparation should be admitted the day prior to separation, though we have admitted older twins with separate gastrointestinal tracts on the day of surgery. Some centers insert all monitoring lines under a separate anesthetic on the day prior to separation. The induction; insertion of central and peripheral venous, arterial, and urinary catheters; temperature probes; and positioning with careful padding of pressure points usually requires at least 2 h (Fig. 14.2).

The initial incision is centered at the midpoint of the connecting skin bridge, and the tissue expanders on the "up" side of the twins are removed. The abdomen is easily entered at the umbilicus, which frequently has a small omphalocele membrane that is usually epithelialized by the date of separation. The abdominal portion of the body wall connection is opened, and the peritoneal cavity of each twin is entered and the viscera inspected. The fused sternum on the "up" side is then carefully entered, which can be done without entering the common pericardium or separate pleural spaces. The pleurae of each twin can be bluntly dissected free of the sternal edges

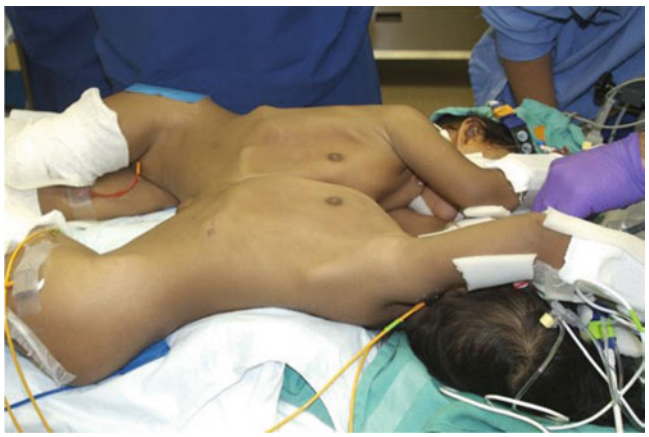

Fig. 14.2 Twins positioned with monitoring in place

to expose the pericardium, which is entered again at the midpoint of the connection. The degree of any cardiac connection can now be assessed, and preparation for potential cardiac bypass or pacing begun.

Opening of the abdomen and chest has thus allowed complete assessment of the visceral connections. Our strategy has then been to complete the separation of the abdominal viscera and the abdominal body wall of the "down" side prior to any cardiac procedures – although cannulation for bypass is possible in the lateral position, this would allow for expeditious separation of the "down" sternum should either twin deteriorate.

The majority of thoraco-omphalopagus twins have a fused liver, usually with separate biliary and vascular supply but with significant intraparenchymal vascular connections. On occasion, the livers are completely separate though touching. Bowel connections are separated with stapling devices and reconstruction deferred until separation is complete. Splitting of the diaphragm allows exposure to the contralateral surface of the liver connection, which can be encircled with umbilical tape or a Penrose drain. We have had good results dividing the liver with a variety of devices including the harmonic scalpel, hydro-dissector, bipolar and monopolar coagulators, and direct suture ligation. At the completion of the separation, the raw surface can be sealed with the argon beam coagulator with little risk of a bile leak.

Attention is then turned to the cardiac separation. The cardiovascular strategy depends on the degree of connection, structural integrity of each heart, and the physiologic status of each twin. Sometimes the hearts are completely separate within a common pericardium, in which case the posterior body wall is separated and tissue expanders on the "down" side removed. Myocardial connections can be small or large and are frequently atrial. A significant ventricular connection is usually identified preoperatively and precludes separation. The myocardial connections are test clamped to identify the physiologic consequences of their separation. While preparations for pacing or bypass are made ready prior to the division of the

connection, they have not been necessary. Once the myocardial connection is severed and closed, the posterior body wall is completed, and the twins rotated to the supine position. In the absence of structural cardiac anomalies, one twin is moved to a separate operating room with his or her entire team so that reconstruction of the body wall can proceed simultaneously.

Structural cardiac malformations can be repaired or deferred depending on the magnitude of the corrective surgery, the need for cardiopulmonary bypass, and the physiologic status of the twin. Our most recent separation outlines the cardiac options and strategies. The twins shared a large atrial connection approximately 6 cm in cranio-caudal dimension. One twin had double-outlet right ventricle, while the other had left main pulmonary artery stenosis with significant pulmonary hypertension. During test clamping of the atrial connection, both twins remained stable, and separation was uneventful. The twin with pulmonary artery stenosis underwent patch angioplasty and definitive body wall reconstruction and closure. The twin with double-outlet right ventricle underwent definitive closure of the abdomen with skin closure of the chest. She was stabilized for 48 h and then underwent cardiac repair with reconstruction and closure of the chest. While bypass was available, the ability to avoid its use immediately after the liver separation appears to have contributed to the uneventful recovery of both twins.

Following separation, the abdominal and thoracic viscera are inspected and repaired (Fig. 14.3). Hemostasis is ensured, and the abdomen is closed with minimal tension, which usually means placing a soft tissue patch in the upper fascial closure. Prosthetic material is used to provide a stable bridge between the sternal halves. We prefer sheets of material as opposed to struts and have had good experience with lactic acid polyglycolic acid copolymer products. The skin flaps are then generously mobilized and closed over drains placed in the mediastinal and subcutaneous spaces. If closure of both twins is completed at the same time, their return to the critical care area should be staggered.

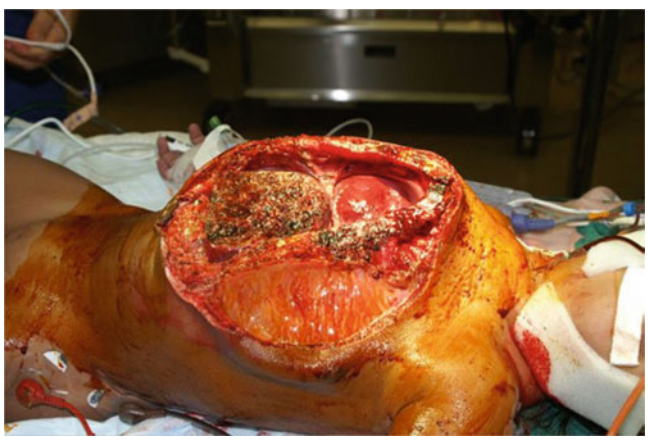

Fig. 14.3 One thoraco-omphalopagus twin after separation. The sternum is still split, revealing the heart and the cut edge of the divided liver bridge that is visible below the diaphragm

Postoperative Care

A written plan for the postoperative care with individuals from each discipline identified and specific responsibilities spelled out in detail minimizes confusion postoperatively. Preprinted order sets that have been reviewed and agreed upon by all relevant disciplines are also helpful. Initial care is directed at optimization of respiratory and hemodynamic status. Careful fluid and ventilator management predominates in the first days, but careful monitoring of liver function, fluid drainage, and the viability of skin flaps is also important. Early revision of any problems with the chest wall stabilization and skin flaps facilitates weaning from mechanical ventilation. Nutrition is critical, and a period of tube feeding should be anticipated. As recovery progresses, a physical therapist should address the musculoskeletal issues imposed by the conjoining and the separation. Hospitalizations of 2–4 weeks should be anticipated for relatively uncomplicated recoveries and longer if any complications intervene. Long-term care is directed at any underlying structural anomalies that required correction and the body wall reconstruction.

Planning Process

Almost every series or case report about conjoined twins stresses the need for careful and intense planning for a successful outcome. A strategy that we have employed is regularly scheduled (weekly or every other week) meetings including a representative from every involved medical and surgical discipline, hospital operational departments, and nursing and hospital leadership (Table 14.2). A flow diagram of each step of the process with a responsible individual identified is helpful. This working group anticipates all outcome scenarios and develops strategies for each with information gathered along the way from diagnostic studies and the twins' responses to anesthesia and the environment. Mock-ups of the operating room with a specified location for each individual and piece of equipment are done on paper and then tested in person with walk-throughs in the designated operating room (Fig. 14.4). All equipment should be

Table 14.2 Planning team—thoraco-omphalopagus

Anesthesia	Pediatric surgery
Cardiology	Cardiothoracic surgery
Radiology	Plastic surgery
Laboratory medicine	Critical care
Operating room director	Operating room nursing
Critical care nursing	Social services
Physical therapy	Admitting/registration
Medical records	Hospital administration
Security	Public relations/media

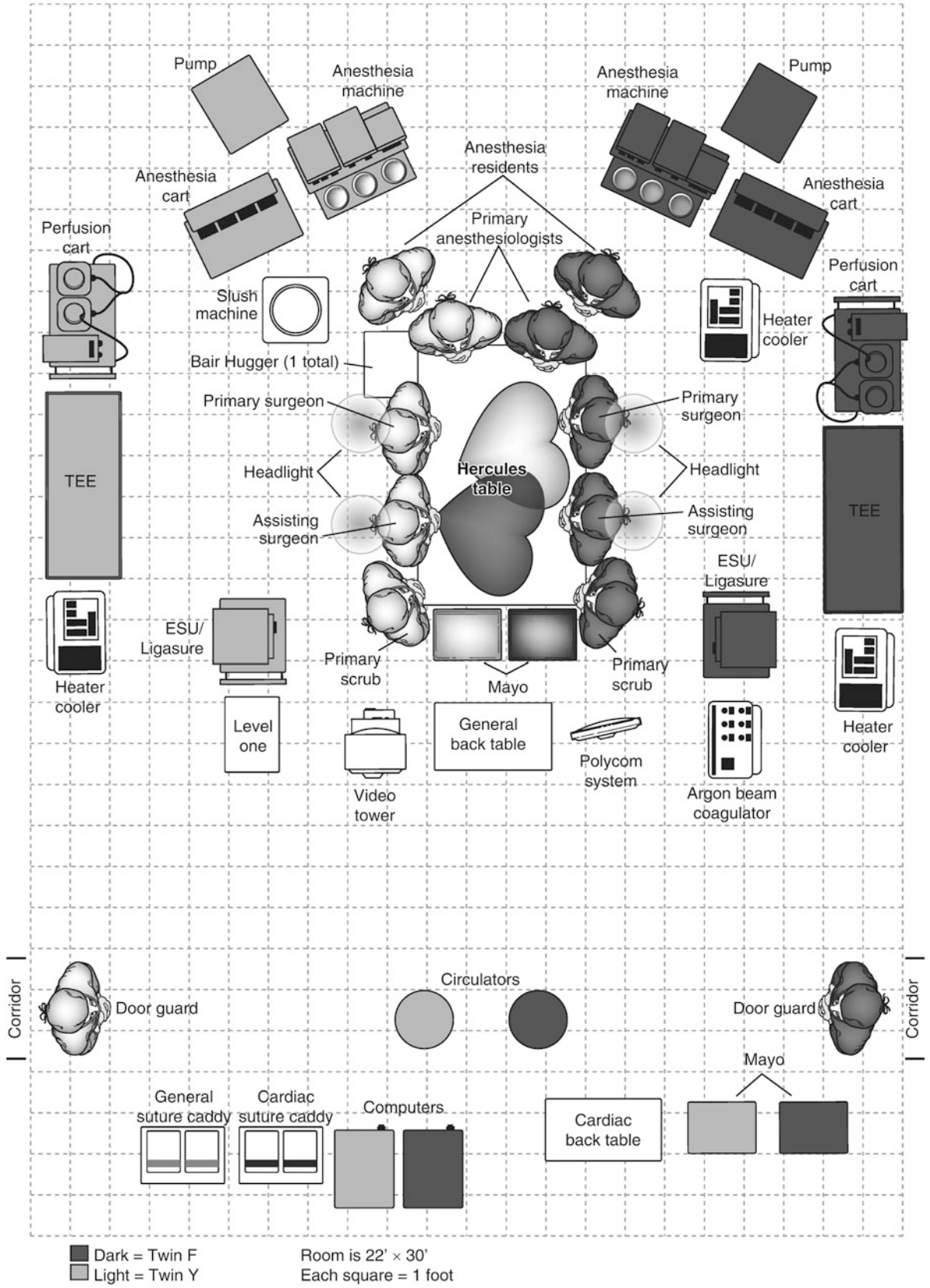

Fig. 14.4 Diagram of OR setup prior to separation

turned on to test the electrical capacity of the room, which frequently needs supplementation with temporary power (up to 100 Å or more).

On the day of separation, attention to security and crowd control is facilitated by having a room general who has no clinical responsibilities but has the authority to remove anyone from the room. Accommodations for legitimate educational and clinical interest can be accomplished with a video feed to designated secure viewing areas. For particularly lengthy procedures, planning should include rest periods for staff and a designated individual to relay progress reports to the family.

Editor's Comment

One still occasionally sees the obsolete and insensitive term "Siamese twins" in the lay press and in the medical literature (even from presidential candidates, who should know better). The proper term, for some time now, is "conjoined twins." Computer-enhanced three-dimensional imaging has allowed for much better preoperative planning for these often extremely difficult and tedious operations, but the assembling of a team of experts and meticulous planning of each minute detail, including contingency plans for every conceivable snag, is still the most important aspect of the care of these unique individuals. Given the intense societal interest in these cases, it is also advisable to involve a team of bioethicists, hospital administrators, and public relation experts from the very beginning so that medical personnel can concentrate on providing excellent care without being distracted.

Suggested Reading

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Part III

Trauma

Trauma Resuscitation

15

Nicholas E. Bruns and Anthony L. DeRoss

Unintentional injury is the leading cause of death in children older than 1 year. The most common types of injuries vary across subsets of pediatric age groups and include those related to motor vehicle crashes, drowning, fires, falls, homicide, and suicides. For infants, homicides tends to be from physical abuse; in adolescents it tends to be associated with firearms. For all ages, blunt trauma is seen at far greater frequency than penetrating trauma.

The care of a pediatric trauma patient differs from that of an adult in many ways. Children are less likely to have comorbid conditions or to take multiple medications. Children therefore have a greater physiologic reserve, allowing them to maintain hemodynamic stability in the setting of severe injury for some time. However, sudden deterioration with grave consequences can follow unless intervention is timely. Pediatric trauma providers must rapidly recognize and treat life-threatening injuries in the trauma bay before they become irreversible.

Developmentally children have bones that are less calcified and more pliable than those of adults. This difference may lead to internal organ injury without an overlying fracture, most commonly seen with pulmonary contusions and injuries to solid abdominal organs. Finally, children have relatively larger internal organs that are in close proximity, resulting in a higher incidence of multisystem injury. Given the additional difficult task of obtaining a reliable exam in younger patients, it is prudent to maintain a high level of suspicion for additional injuries.

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Intentional trauma is frequently encountered in pediatrics. Approximately half of deaths from child abuse involve victims of prior abuse that was not recognized or treated appropriately. It is imperative to be aware of the signs of child abuse and of the appropriate channels for involving legal authorities in each jurisdiction and institution.

Preparation

Prior to being on call for trauma, it is important to familiarize oneself with the emergency department and trauma facilities. It is essential that one knows where the airway cart, chest tubes, IV access, medications, and other equipment are located so that valuable time is not wasted searching for equipment after the patient has arrived. Extra consideration should be given for combined adult/pediatric hospitals where it may be more difficult to locate appropriately sized equipment.

Upon notification of a trauma patient's impending arrival, the trauma team should assemble, and each member's role should be clearly defined. The trauma attending, fellow, or chief resident is typically the team leader. The person with the most intubation experience, often an emergency medicine physician or anesthesiologist, should manage the airway. A junior fellow, resident, nurse practitioner, or physician assistant should perform the primary survey. Although the team leader could fill this or any other roles, if insufficient personnel were available, the team leader should ideally focus on running and supervising the trauma. Trauma nurses or medics should establish IV access and connect the patient to a cardiorespiratory monitor, pulse oximeter, and blood pressure cuff. In this way, the elements of the primary survey can be completed simultaneously, expediting treatment. Additional team members should include a radiology technician, a respiratory therapist, and a recorder to document progress and medications administered during the trauma resuscitation.

In order to provide the best care most efficiently, it is important to have some understanding of the normal vital signs for pediatric patients (Table 15.1). Beyond 12 years of

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Table 15.1 Normal vital signs by age

Age group (in months or years)	Weight range (in kg)	Heart rate (beats/min)	Blood pressure (mmHg)	Respiratory rate (breaths/min)	Urinary output (mL/kg/h)
Infant 0–12 months	0–10	<160	>60	<60	2.0
Toddler 1–2 years	10–14	<150	>70	<40	1.5
Preschool 3–5 years	14–18	<140	>75	<35	1.0
School age 6–12 years	18–36	<120	>80	<30	1.0
Adolescent ≥13 years	36–70	<100	>90	<30	0.5

Source: Reprinted with permission from Advanced Trauma Life Support, 9th Edition, American College of Surgeons, 2012

age, pediatric patients exhibit vital signs similar to those of adults. This information as well as equipment sizing and medication dosing is available on the Broselow® Pediatric Emergency Tape, an essential tool for any pediatric trauma center.

Primary Survey

Advanced Trauma Life Support® has established the primary survey as the first steps in the care of trauma patients. The primary survey consists of thorough but efficient evaluation of the following categories in order of priority: airway, breathing, circulation, disability, exposure/environment. Using this sequence, most life-threatening injuries can be identified, and interventions can be initiated.

Airway

Hypoxia is the most frequent cause of cardiac arrest in children. Ensuring that there is a patent airway is the first step in preventing hypoxia. The airway can be quickly assessed by asking the patient to speak. Crying is an indication of airway patency in infants as well as in older patients.

Airway anatomy in infants is unique due to their substantially larger occiputs, shorter tracheas, and increased amount of soft tissue in the oropharynx. A 1-in. roll may be positioned under the upper back of the supine infant to maintain neutral positioning. The crowded oropharynx and shorter trachea can make orotracheal intubation more challenging. Finally, the funnel-shaped subglottic entry of the pediatric airway may be a source of obstruction for a slightly large endotracheal tube even if that tube is able to pass through the vocal cords.

A suction catheter should be readily available to clear secretions, blood, or debris in a patient with airway obstruction. A jaw thrust can be useful in the event of an airway obstruction with care to maintain a neutral cervical spine position until a spinal injury has been ruled out. Bag-mask oxygenation should be used to achieve adequate oxygen saturation prior to intubation.

Oral airways may be used temporarily until a definitive airway is established, but they should not be used for long periods. They should only be considered in the unconscious patient as they can induce gagging and vomiting. Children are more susceptible to palatal trauma during insertion which can lead to hemorrhage. Thus, oral airways should not be rotated, which can cause additional trauma.

Orotracheal intubation is the preferred method for securing an airway. Although there are numerous algorithms in existence, it is important to know the medication dosing and steps for rapid sequence intubation in a particular institution. It is helpful to keep a copy for reference in the trauma room (Fig. 15.1). Pre-oxygenation is administered through bag-mask ventilation until adequate oxygen saturation is achieved. In infants, atropine is administered to prevent the bradycardia that often occurs with laryngeal stimulation. Sedation is achieved with etomidate or midazolam. Smaller doses are used in hypovolemic patients. Paralysis is induced with succinylcholine (preferred in patients without an obvious contraindication such as severe burn or crush injury), vecuronium, or rocuronium. This sequence should only be enacted by an experienced clinician in the company of a provider capable of providing a surgical airway.

In many institutions, uncuffed endotracheal tubes are preferred for use with premature infants and neonates. Cuffed tubes are used for most patients. The endotracheal tube size can be estimated by the size of the child's fifth finger or with the formula age in years/4 + 4. After intubation, it is important to verify with auscultation, end-tidal CO_2 (greater than 35 mmHg), and chest radiograph. Children have short tracheas, sometimes no more than 5 cm. This anatomy increases the risk of endotracheal tube migration, resulting in right mainstem intubation or extubation. A rule of thumb is that the tube should be placed to a depth measured from the lips of three times the diameter of the tube. The Broselow® tape also lists guidelines.

Although there must be a sense of urgency during any trauma resuscitation, especially if the airway is in jeopardy, it is important for the clinician to remain composed even in the face of adversity. Unless there has been severe injury to the face or airway, correctly executed bag-mask ventilation can in

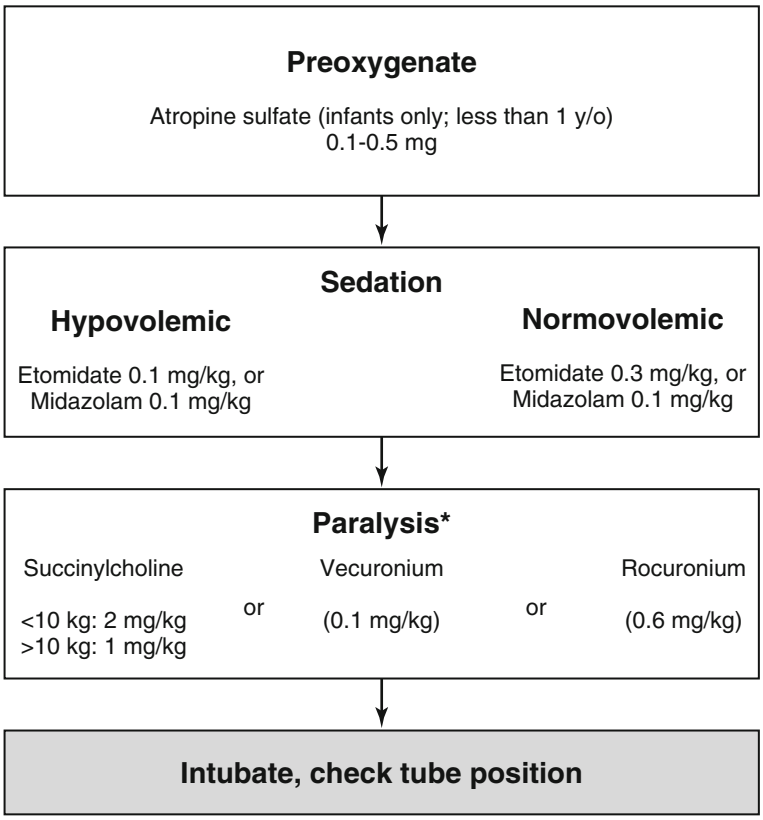

Fig. 15.1 Algorithm for rapid sequence intubation for pediatric patients (Reprinted with permission from the Advanced Trauma Life Support, 9th Edition, American College of Surgeons, 2012)

most cases be continued indefinitely, providing enough time to secure a more definitive airway. If orotracheal intubation is unsuccessful after three attempts, then a surgical airway should be strongly considered. A surgical cricothyroidotomy may be safely done in children 11 years or older, but in children under 11 years of age, cricothyroidotomy should be avoided due to the small size of the cricothyroid membrane and potential injury to the airway. In these younger patients, needle jet insufflation or needle cricothyroidotomy is preferred until the child can be transferred to the operating room for a formal tracheostomy.

Breathing

Even if a child's airway is intact, mechanical ventilation might be necessary if gas exchange is inadequate or if the patient cannot protect his or her airway. When evaluating a child's breathing, it is important to recall the normal respiratory rate (Table 15.1). Normal spontaneous tidal volume in children is 4–6 mL/kg. Vigorous ventilation can cause barotrauma. Pediatric bag-mask devices should be used in patients weighing less than 30 kg.

The pediatric patient has a more supple mediastinum, increasing the risk of tension physiology in the setting of a pneumothorax. The appropriately sized chest tube can be determined from the Broselow® tape. When deciding between sizes, we usually select the largest size able to fit through the intercostal space of the child. After placement of a chest tube, it is important to obtain a radiograph to confirm position as well as to assess the therapeutic benefit of the tube. In the setting of a large air leak or persistent pneumothorax, one needs to consider the possibility of a bronchial injury, which often necessitates placement of an additional chest tube in the trauma bay with plan for more definitive evaluation with bronchoscopy once the patient is stabilized. Chest tube output should be monitored closely in the trauma setting. Immediate output of 20 mL/kg or continuous output of >3 mL/kg/h suggest a major vascular injury and are indications for thoracotomy.

Circulation

Circulation is assessed by vital signs and by physical examination findings. A pulse exam should be performed, and the child assessed carefully for signs of hemorrhage.

Significant occult blood loss can occur internally in the chest, abdomen, pelvis, or extremities. Externally hemorrhage may transpire at the scene, in transit or in the trauma bay. In infants, significant bleeding can occur in the cranium due to the plasticity of the skull.

Signs of shock in children can be difficult to recognize for the inexperienced clinician. With blood loss of <30 %, they might maintain normal range of blood pressure with only mild tachycardia. In fact, many children will not exhibit hypotension until after blood loss of >45 % has occurred. Clinical signs such as lethargy and prolonged capillary refill can aid in the assessment of circulation. A high index of suspicion is critical.

Intravenous access may be obtained by many methods. We prefer placing two peripheral IVs in the upper extremities or saphenous vein at the ankle. If a peripheral IV cannot be secured in a timely fashion, intraosseous access is obtained at the anteromedial proximal tibia or distal femur. Large-bore introducer central lines may be placed percutaneously by Seldinger technique in the saphenofemoral region. Finally, venous cutdown may be performed at the saphenous vein at the ankle or in the groin. Venous access in the lower extremities is contraindicated if there is an obvious lower extremity injury or suspicion for internal hemorrhage from the pelvic vessels or inferior vena cava. Internal jugular or subclavian venous sites should be avoided unless absolutely necessary due to the physical impedance of the cervical spine collar and the potential for iatrogenic pneumothorax.

As soon as IV access is established, a 20-mL/kg bolus of isotonic fluid such as 0.9 % normal saline or lactated Ringer's solution is administered, especially if the patient exhibits hypotension, tachycardia, altered mental status, or other signs of significant blood loss. If the patient does not respond with improvement in vital signs, an additional 20-mL/kg bolus should be given. O-negative packed red blood cells should be administered, typically in 10-mL/kg increments, if there has not been an adequate response after two fluid boluses. When significant blood loss has been reported at the scene or if blood loss is ongoing, resuscitation may be started with blood transfusion instead with crystalloid solutions.

There is growing evidence that balanced transfusion with red blood cells, fresh frozen plasma, and platelets in a 1:1:1 ratio may be beneficial in the setting of massive transfusion. The aim of this approach is to return blood products in similar proportion to the blood lost. Most institutions have a massive transfusion protocol—the trauma surgeon and team must be aware of it and know how to activate it.

The trauma surgeon should be familiar with the concept of permissive hypotension in the setting of massive hemorrhage. Achieving a normal blood pressure before bleeding that can be definitively stopped can allow continued hemorrhage. Thus, IV fluids and transfusion to replace blood loss should be carefully titrated to maintain perfusion while trying to stop the hemorrhage. Urine output should be closely monitored with a goal of 2 mL/kg/h in infants and 1 mL/kg/h in older children. In the setting of hemorrhagic shock, urine output will not normalize until the source of hemorrhage is controlled.

Pediatric Advanced Life Support (PALS) should be initiated in case of cardiopulmonary arrest. In patients who have spontaneous return of circulation, there is up to a 50 % neurologically intact survival rate. Though emotionally taxing to contemplate, the outcome after prolonged loss of circulation is dismal. The entire team should make a unified decision when to deem resuscitation futile.

In a moribund patient with penetrating trauma to the chest, a resuscitative thoracotomy may be considered. However, in the setting of blunt trauma when loss of vital signs occurs prior to arrival in the trauma bay, the mortality rate is nearly 100 %, and resuscitative thoracotomy is not recommended. Providers should consider the risks to themselves as well as the resources involved prior to attempting thoracotomy. As always, personal protective attire and universal precautions should be standard for all members of the trauma team to minimize risk.

Disability

As part of the primary survey, a basic neurologic exam should be performed including cognitive, pupillary, and motor assessments. The Glasgow Coma Scale (GCS) should be calculated. The verbal score is modified for use with children such that a score of 5 corresponds with appropriate words or social smile. In patients with an impaired GCS, it is especially important to provide adequate resuscitation to prevent secondary injury to brain tissue due to hypoperfusion. In patients transferred from another facility, communication between the two hospitals is imperative to relay exam findings and interventions including medications administered.

The brain doubles in size during the first 6 months of life and reaches 80 % of adult size by 2 years of age. With a relatively larger brain-to-body ratio than in adults, cerebral blood flow is increased with a peak level twice that of an adult by age 5 years. This physiology increases the susceptibility of the pediatric brain to hypoxic injury. In addition, the arachnoid space is thinner, which leaves the parenchyma with less protective cushioning. In infants, bulging fontanelles can be a sign of severe intracranial injury. Seizures commonly occur in children with intracranial injuries. Persistent vomiting is another sign that should raise suspicion for a head injury. If there is any concern for intracranial injury, a non-contrast CT scan should be performed.

In the child with intracranial hypertension, a few therapeutic maneuvers can be performed in the trauma bay. The head of the bed should be elevated 30° by putting the patient into reverse Trendelenburg position while maintaining spinal precautions. Mannitol may be administered, but as with all

hyperosmolar therapy, care must be taken to prevent hypovolemia with the induction of diuresis. A Foley catheter should be placed to monitor urine output and to prevent rapid overdistension of the bladder. The use of hypertonic saline has been increasing among trauma centers with favorable outcomes. In contrast, recent theories on the use of hyperventilation have raised concern for increased risk of decreased cerebral blood flow and increased secondary ischemia. Hyperventilation has therefore fallen out of favor as a standard tactic in the trauma bay; if utilized, concomitant advanced neuromonitoring to rule out cerebral ischemia should be strongly considered. Finally, close communication with a pediatric neurosurgeon is paramount in the treatment of the trauma patient with neurologic injury.

Children have proportionally larger heads allowing greater angular momentum and increased risk for cervical spine injury. Children with a normal neurologic exam without cervical tenderness or a distracting injury are candidates for clinical cervical spine clearance. Clinical clearance should be done by an experienced physician at the senior resident level or above. If patients have pain, tenderness, altered mental status, positive neurologic findings, distracting injury, or other signs raising the possibility of cervical spine injury, a properly fitting collar should be placed until further evaluation is completed. Clinical clearance can be challenging in patients younger than 3 years old. Imaging should be considered if injury is suspected and a reliable exam cannot be obtained. Cervical spine precautions should be maintained if any concern for injury exists. In many cases, the cervical spine can be cleared clinically within the first 24 h after presentation once the anxious child has been calmed and other injuries have been addressed. Thoracic, lumbar, and sacral spine precautions should consist of maintaining the patient in the supine position and log rolling when necessary. Attention must be paid to removing the rigid spine backboard as soon as possible to prevent decubitus pressure injuries. Use of the backboard should be discontinued after 2 h and certainly before the patient leaves the trauma bay unless he or she is being transferred to another institution. A spinal service consultation should be initiated if the spine cannot be cleared. Most trauma centers have a spine protocol or set of guidelines for management with which involved personnel should be acquainted.

Exposure

All clothing should be removed from the patient to ensure that a comprehensive physical examination can be performed. Examination of the posterior aspects of the body must be included. Care must be taken by providers to prevent further injury to the patient or themselves as clothing may be wet or contain debris from the scene such as glass or chemicals.

Increased surface area-to-mass ratio in children places them at increased risk for hypothermia, worsened by them having less insulating fat and a higher basal metabolic rate. Some measures to combat hypothermia include increasing the ambient temperature in the trauma room, use of an active warming blanket, and infusion of warm IV fluids or blood products. More aggressive rewarming techniques such as peritoneal lavage and cardiopulmonary bypass should be considered in extreme cases. Failure to recognize hypothermia can be devastating, leading to secondary injury from hypocoagulability and ongoing blood loss.

Labs

For any patient with significant trauma, a complete blood count and type and cross match are usually routine. It is important to recall that in the setting of acute injury, hemoglobin and hematocrit levels may not accurately reflect the degree of blood loss. For patients with suspected abdominal injury, we recommend liver function tests, pancreatic enzymes, and a urinalysis to assess for hematuria. If cross-sectional abdominal imaging is planned, these labs may not be necessary. For the patient who is in shock or intubated, arterial blood gas samples can provide important information during resuscitation including the partial pressure of gases as well as the base deficit.

Catheters

For any patient in shock, unconscious or intubated, a urinary catheter should be placed for accurate urine measurement. If there is blood at the urethral meatus, a retrograde urethrogram or CT cystourethrogram should be performed prior to catheter insertion. If there is any injury to the urethra, a urologic consultation should be obtained.

Nasogastric or orogastric tubes are helpful in many cases. Children may be more prone to gastric distention from swallowing air while crying, but nasogastric tubes are usually not needed in the awake, neurologically normal patient. In intubated patients, orogastric tubes can help to prevent aspiration. Nasogastric or orogastric tubes can provide potential access later for feeding and medications, although a sump tube placed initially in the trauma bay should be replaced by a feeding tube for these more long-term uses. In the awake patient with vomiting or concern for bowel injury, insertion of a nasogastric tube is indicated. If there is significant facial trauma, an orogastric tube is preferred to avoid inadvertent penetration into the cranial vault.

Imaging

Pelvis and chest radiographs are obtained on most blunt trauma patients. In general, cross-sectional imaging such as CT or MRI is more sensitive and specific for internal injuries. With nonoperative management now the standard for low-grade solid organ injury, CT has become an integral tool. Although there is hesitancy to expose children to ionizing radiation, the consequences of missed injuries can be significant. Based on data from survivors of the atomic bomb attacks in Japan, it has been estimated that the lifetime risk of developing a radiation-induced cancer after a CT scan is approximately 1 in 1000. However, this estimate may be high. More recent studies in children who received CT scans suggest that the risk is more likely closer to 1 in 10,000 for development of a brain tumor or leukemia within 10 years. If imaging is considered necessary, the patient should be hemodynamically normal prior to transfer to the CT scanner. In addition, it is prudent to send a capable member of the trauma team with the patient in case of deterioration.

Focused assessment with sonography for trauma (FAST) exam may be helpful in certain situations. Perhaps the most useful application is in the multisystem blunt trauma patient with hemodynamic instability where a trip to the radiology department carries risk for decompensation. Other benefits of FAST exam are that it is low cost and easily repeatable. Some pitfalls of the FAST exam are that it is only moderately sensitive and nonspecific. In the era of nonoperative management for solid organ injury, FAST exam does not provide enough information to make an informed treatment decision; it can detect free fluid but offers little additional information regarding the source. However, assuming it does not delay care, there is little downside to performing a FAST exam. Further, regular practice by clinicians may be helpful in maintaining competency.

Diagnostic peritoneal lavage has become obsolete in most practices. It may still be of benefit if CT scan and ultrasound are unavailable or if there is a need to identify an intraperitoneal source of hemorrhage or bowel injury in an unstable patient.

Secondary Survey

After completion of the primary survey and its adjuncts, the secondary survey should be performed. This includes a head-to-toe physical exam and detailed history from the parents or caregivers. Tetanus immunization status should be obtained to determine the necessity for tetanus prophylaxis. Any areas with visible injury or tenderness should have plain radiographs to assess for fractures. If injuries are recognized during the primary survey, these images may be obtained at the same time of the pelvis and chest X-rays. However, if the patient is hemodynamically unstable, clinical judgment should be used to determine the appropriate timing of these additional x-rays.

If the institution where the child initially presented has insufficient resources to provide optimal care, then the patient should be transferred to the nearest facility that can provide definitive care. In general, diagnostic tests beyond the primary survey should be deferred as soon as the decision is made to transfer the patient. Additional studies may be appropriate if they influence the course of management, but they should not result in delay of transfer.

Special Considerations

Any patient with a seatbelt sign should be investigated for hollow viscous injury and lumbar spine injury. This phenomenon is caused by an ill-fitting seat belt that rests above the iliac crests leading to rapid deceleration and subsequent rectus lacerations, small bowel injuries, or Chance fractures. The presence of a seatbelt sign should prompt an abdominal CT scan with spinal reconstructions or plain films with plan for laparotomy or laparoscopy if the patient exhibits peritonitis or instability.

Penetrating abdominal trauma in the hemodynamically normal patient may be evaluated with local wound exploration. If there is no penetration of fascia, observation is appropriate. If the fascia is violated or local exploration is equivocal, CT or operative exploration is warranted. Most penetrating injuries to the abdomen require exploration in the operating room.

Due to the pliability of the chest wall, the force of impact may reach the pulmonary parenchyma resulting in pulmonary contusions, even without rib fractures. In fact, the presence of rib fractures indicates a high magnitude of energy transference to the thorax.

Child Abuse

Unfortunately, intentional trauma to children is not uncommon in our society. The following signs or symptoms should raise a flag that child abuse has occurred: inconsistent histories from caregivers; history that is not consistent with the child's developmental stage; delay in seeking treatment; history of

repeated trauma; bruising in various stages; multiple scars or old fractures; genital, perineal, or perianal injuries; multiple subdural hemorrhages; and retinal hemorrhages. Most states require that physicians report cases to local child-protective authorities when suspicion has been raised for child abuse.

Summary

Resuscitation in the trauma bay is perhaps the most critical portion of the entire hospital course for the pediatric trauma patient. Adherence to the principles of trauma resuscitation and mindfulness of the anatomical and physiologic distinctions of the pediatric patient facilitate optimal treatment. Pediatric trauma providers must remain vigilant so that life-threatening injuries are recognized efficiently and treated promptly.

Editor's Comment

The development of science-based protocols for the treatment of injured adults and children is one of the most significant advances in medicine. Modern pediatric trauma systems are examples of the benefits of teamwork and the practical application of evidence-based diagnostic and therapeutic guidelines. The trauma bay should have one recognized leader who welcomes input from any member of the team. The leader should use a gentle but firm voice without shouting or bullying. Every finding and intervention should be carefully recorded, and every resuscitation should be video recorded and reviewed in a systematic way as part of a formal quality improvement program. Parents should be allowed to be present and every aspect explained to them by an experienced liaison who stays at their side the whole time. The child should be kept warm and comfortable, with narcotics and anxiolytics as needed, and everything explained in an age-appropriate manner. All procedures should be done by experienced personnel or senior residents in training, but never by a "first-timer"—the stakes are too high and the teaching value overrated.

In pediatric trauma, there is a tendency for exaggerated personal emotional reaction and heavy-handedness in the delivery of care: over-hydration, overexposure to cold and radiation, overprotection (incomplete physical examination, tubes and catheters that are too small), superfluous laboratory studies, excessive concern about medical liability, and failure to use implements of appropriate size. In every aspect of the injured child's care, one should strive for a "just-right" approach based on scientific evidence and experience.

Emergency thoracotomy can be a controversial decision given how difficult it is to feel as though we have "given up" on a child who is gravely injured. Every institution should have a protocol as to when it should be considered so that team members are not made to feel as though they have to decide under duress. Data support the use of emergency thoracotomy in children after penetrating trauma and only a short period of lack of vital signs. It should never be done for teaching purposes or when it is clear that the likelihood of a reasonable neurocognitive result is clearly minimal.

Suggested Reading

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Concussion

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Christopher B. Renjilian and Matthew F. Grady

Concussion is increasingly recognized as a common and clinically significant form of traumatic brain injury (TBI). According to the Centers for Disease Control and Prevention, 1.6–3.8 million concussions occur annually in the United States, many of whom are children or adolescents. Although in most cases the clinical signs of concussion eventually fully resolve, the symptomatic period is often marked by significant impairment. There is also now greater awareness by both the medical profession and the general public that repeated or complicated concussions can increase the risk of long-term disability.

Surgeons and their team members are likely to encounter patients with concussion in the emergency department, in the office, or on the sidelines of sporting events. In many cases, surgeons are the first to diagnose and care for the child with concussion. The pathophysiology of concussion is increasingly well understood, and the evidence basis for treatment in both straightforward and complicated cases has grown. It is important to understand concussion in clinically meaningful terms, to appreciate the features of concussion pathophysiology that inform clinical management, to have a well-thought-out strategy for recognition and diagnosis, to be able to describe evidence-based and expert recommendations for initial management, to understand key features of both typical and atypical recovery, and to understand follow-up evaluation, management, and indications for expert referral.

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Pathophysiology

A concussion is an acute brain injury caused by an impact to the head or body that transmits impulsive forces to the brain, resulting in the rapid onset of clinically apparent neurologic impairment. The first signs and symptoms usually appear within minutes but may present at any point within 24 h following impact. Concussion is strictly classified as a functional injury—neurologic impairment in the absence of clear evidence of damage to the structure of the brain. This differentiates concussion from more severe forms of TBI, when gross structural injury can be documented by imaging studies. Nevertheless, it is well recognized that concussion is the result of structural injury and dysfunction at the cellular level.

Major advances in the understanding of the pathophysiology of concussion over the past few decades are due in large part to the development of animal models of TBI. The laboratory construct that is most widely referenced in the literature is known as the "lateral fluid percussion" (LFP) model. Evidence from both animal models and clinical research has helped explain concussion as a two-step process: the initial injury caused by the transmission of forces to the brain followed by a recognizable pattern of injury responses. Each of these phases contributes to the pathology observed.

When a concussive injury is applied to the brain, neurons and surrounding support cells are affected. The oscillatory and rotational forces involved are powerful enough to disrupt cytoskeletal elements. Cell membranes sustain damage that leads to altered permeability and, in some cases, cell rupture; axons are stretched and potentially sheared; synapses are disrupted. Alterations in cell membrane permeability result in a stereotyped sequence of events. The electrochemical gradient maintained across the cell membrane is disrupted, and potassium ions leave the cell across a leaky cell membrane and into the extracellular space, while sodium and calcium ions flood inward. This derangement leads to widespread, unregulated depolarization and the pathologic release of excitatory neurotransmitters, further altering the state of

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neurons downstream. As the injury cascade unfolds, alterations in cellular pH and ion concentration can lead to delayed swelling, apoptosis, or necrosis.

The body's response to these derangements represents the second phase of injury. Affected cells release cytokines that promote inflammation, further changing the permeability of blood vessels, increasing edema, and recruiting white blood cells. Injured tissues also begin an intensive process of self-repair. Cells increase production of the structural proteins and enzymes required to rebuild the cell membrane, replace damaged organelles, and restore the physiologic state. A key component of this process is restoration of the neuron's electrochemical gradient, a function that requires the energy-dependent action of a Na^+/K^+ ATPase to pump ions across the cell membrane. The greatly increased demand for substrates and energy to carry out cellular repair makes it a metabolically expensive process. Healing is complicated by a global restriction in cerebral blood flow and a simultaneous disruption of regional blood flow by direct microvasculature injury, reactive vasospasm, and alterations in the vascular response to local tissue signaling. As such, the supply of fuel and substrates to injured tissues is restricted and uncoupled from metabolic demands. This "metabolic mismatch"—increased metabolic demand and diminished supply—explains many of the clinical features of concussion and informs the approach to therapy.

Diagnosis

Concussion is suspected whenever a person has experienced a traumatic injury and demonstrates signs or symptoms of neurologic impairment within 24 h of impact (Table 16.1). Patients at risk for concussion should always be evaluated for other clinically significant injuries per standard protocols. The primary survey should include an assessment of the airway, breathing, and circulation. Addressing the integrity of these functions takes precedence over an evaluation for concussion. Priority should then be on evaluating the patient for cervical spine injury and more severe forms of TBI.

Loss of consciousness occurs in approximately 10 % of concussions. Very brief loss of consciousness (a few seconds) is not believed to be a specific risk factor for more significant injury, but loss of consciousness for more than a minute should prompt further evaluation. Other red flags include persistent alterations in consciousness, signs of a basilar skull fracture, focal neurologic deficits, vomiting, severe headache, and a severe mechanism of injury, especially an unexpected blow or a blow to the side of the head. The patient who initially appears well but shows signs of clinical deterioration is also at high risk. Any of these conditions should prompt immediate transfer to an emergency department by emergency medical services and evaluation with head imaging.

The signs and symptoms of concussion are varied. The evaluation for a suspected concussion should include a multifaceted assessment of symptoms, cognition, memory, balance, coordination, and visual tracking abilities, which can be performed quickly and minimizes the likelihood that the diagnosis will be missed. Amnesia can be due to a loss of consciousness or disruption of short-term memory consolidation from the trauma itself.

A brief review of past medical history is also warranted. A history of bleeding disorders or ongoing treatment with anticoagulant or antiplatelet therapies increases the concern for intracranial bleeding. A history of multiple concussions, prior TBI, a recent injury, or prolonged recovery portends a more difficult recovery. Patients with a history of headaches, vision problems, motion sickness, cognitive differences (learning disabilities, dyslexia, attention-deficit disorder, dementia), and mood disturbances (depression, anxiety, bipolar disorder, suicidal ideation) are more likely to experience worsening or recurrence of their symptoms during the concussion recovery process.

Physical examination should include standard assessment of cranial nerve function, muscle strength, sensation, and deep tendon reflexes. These can reveal gross neurologic impairment, but focal deficits are not expected in concussion and warrant further evaluation. Because concussion is defined as a functional impairment, standard tests of neurologic function are generally not sufficient and must include more challenging maneuvers, specifically to look for signs of impairment of cognitive function, balance and coordination, and vision.

Signs of cognitive impairment are sometimes quite obvious and enough to establish the diagnosis: the patient may appear dazed, be slow to respond to questions, forget a series

Table 16.1 Signs and symptoms of concussion

Physical	Cognitive	Emotional	Sleep	Visual
Headache	Poor concentration	Emotional	Fatigue	Light sensitivity
Dizziness	Poor memory	Irritable	Drowsiness	Eyestrain
Poor balance	Inattention	Sad	Sleepy	Blurry vision
Poor coordination	Slowed thinking	Anxious	Insomnia	Poor tracking
Sound sensitivity	Easily confused			Near objects blurry
Nausea	Feeling dazed			Eye movements slow or poorly coordinated

of instructions, or repeat statements as if saying them for the first time. Orientation to person, place, and time should be assessed by asking specific questions that require some knowledge of detail. An athlete might be asked about the name of the sporting venue, the affiliation or name of the other team, which team scored the most recent goal, and the time of day (within an hour). Concentration, attention, and working memory can be evaluated by asking the patient to repeat a series of five randomly selected words or to repeat a series of three, then four, and then five digits in the reverse order that they are presented. Similarly, patients may be asked to repeat the months of the year in reverse order. Delayed recall can be tested by asking the patient to again repeat the five randomly selected words that were used to test working memory a few minutes later. Healthy adolescent subjects can typically complete these tasks without errors.

Paper- and computer-based neurocognitive tests are being developed that can assist in the diagnosis and management of concussion. These testing batteries measure performance in several cognitive realms (visual memory, verbal memory, reaction time). Though the range of normal performance by healthy subjects on these tests is quite broad, healthy individuals tend to demonstrate stable performance over time. These assays are therefore most useful if baseline testing has been performed, so performance after concussion can be evaluated against performance in the uninjured state rather than against population norms. Although the majority of concussions can be diagnosed and managed without these tools, popular interest in neurocognitive testing has led many schools and sports leagues to conduct universal baseline testing. This information can be especially useful in cases of complicated or prolonged concussion. Interpretation of formal neurocognitive testing should generally be deferred to clinicians who are specifically trained in that area.

An individual with concussion may be observed to stumble or sway and will often report feeling dizzy. Maintaining balance is a complex function that requires integration of input from the vestibular, somatosensory, and visual systems. Impairment in any of these systems or the neural networks that connect them can result in clinically evident balance impairment. During the physical examination, balance testing should be standardized and made progressively more challenging to help reveal subtle deficits.

A modified version of the Balance Error Scoring System (BESS) test is commonly used in the evaluation of concussion. This clinical test involves asking an individual to maintain his or her balance for 20 s while standing, with the eyes closed and the hands resting on the hips, in each of three stances: (1) feet together, (2) on the nondominant foot only, and (3) heel to toe with the nondominant foot in the back. The test is scored based on the number of errors that occur in each stance. A reasonable alternative is to observe the individual as he or she executes a tandem (heel-to-toe) gait along a straight line. We ask patients to do this forward and then make the test more challenging by asking them to do it backward and finally backward with the eyes closed. A young healthy individual can typically maintain his or her posture and move in a nearly linear fashion under all three conditions—errors are easily corrected and the individual is able to quickly get back on track. Concussed individuals will often stumble, sway, and overcompensate for small errors during at least one phase of the test.

Coordination is dependent on neural pathways that are similar to those involved in balance. Coordination can be easily tested by asking an individual to touch his or her nose and then to touch your finger. The test can be made more challenging by asking them to do this rapidly or to hit a moving target. Individuals with deficits in coordination are more likely to miss either their own noses or your finger, or they can only complete the task if they cheat by using the broad portion of their fingers rather than the fingertips.

Individuals with concussion have difficulty with ocular tracking and focus, functions that rely on a surprisingly complex series of interdependent neural structures, all connected to each other by high-speed white matter tracts. A concussion may disrupt any component in this network and produce clinical findings. An example of this is axonal stretching in a white matter tract that delays signal transmission from one hemisphere of the brain to the other resulting in a dysconjugate gaze as an individual attempts to look from one side of the room to the other.

Patients may have difficulty focusing, suffer from eyestrain, or feel worse when they try to read or shift their gaze. Physical examination should include testing of several eye tracking and focusing tasks (Table 16.2): smooth pursuits, saccades, gaze stability, and convergence. Under-recognized in the past, an emerging body of primary research and clinical experience now convincingly suggests that an assessment of visual tracking and focusing skills can significantly enhance the sensitivity and accuracy of the physical exam for concussion.

Several diagnostic tools have been developed to help standardize the evaluation of concussion and make it possible for first responders with various experience and levels of training to conduct the initial evaluation. These tools can be quite useful for first responders who are present on the sidelines of sporting events, where rapid and comprehensive assessment is helpful in making decisions about whether an athlete should be removed from play. These tools can also be very useful for physicians looking for a template to organize their approach to the evaluation and for those who do not regularly encounter concussion. One of the most commonly used diagnostic tools is the Standardized Concussion Assessment Tool 3 (SCAT3), designed for evaluation of athletes aged 13 and older with suspected sport-related concussions. The Child SCAT3 has been developed for use with children

Table 16.2 Visual tracking tasks

Task	Standard challenge	Increased challenge	Abnormal performance
Smooth pursuits	• Patient keeps the head still	• Examinee's finger moves at higher speed, changes direction with less predictability	• Cannot track fast movement
	• Smoothly tracks examiner's finger as it moves side to side		• Tracking lags or misses changes in direction
			• Nystagmus
			• Dysconjugate gaze
Saccades	• Patient keeps the head still	• Patient does 20–30 rapid repetitions in each direction	• Cannot complete 20–30 repetitions
	• With both eyes, look rapidly from one stationary point to another (both of examiner's thumbs held up in air) and back again		• Can only complete at slow speed
	• Test with two objects in horizontal plane and then in vertical plane		• Symptoms worsen with task (classic symptom is eye pain or pressure)
			• Grossly abnormal or wandering eye movement
Gaze stability	• Examiner holds up stationary object (thumb)	• Patient does 20–30 rapid repetitions in each direction	• Cannot complete 20–30 repetitions
	• Patient maintains gaze on object while turning the head as if saying "no"		• Can only complete at slow speed
	• Patient then does same task, moving as if saying "yes"		• Symptoms worsen with task (classic symptom is dizziness)
			• Dysconjugate gaze
Near-point convergence	• Patient focuses on an object as examiner moves object closer to patient's eyes	• Repeat test at the end of physical exam, when fatigued	• Double vision when object is >6 cm from patient's eyes
	• Preferred object is fine print (written on the side of a pen or a box of medical gloves); turn 90° so print runs down the vertical line		
	• Patient reports when object becomes double		

Source: Data from Mucha A, Collins W, Elbin RJ, Furman JM, Troutman-Enseki C, DeWolf RM, Marchetti G, Kontos AP. A brief vestibular/ocular motor screening (VOMS) assessment to evaluate concussions: preliminary findings. *American Journal of Sports Medicine* 42:2479–2486, 2014

under the age of 13, but is not yet validated, and many question the accuracy of the test in younger patients. The SCAT3 is a four-page document that provides instructions for a multifaceted assessment combining several instruments independently validated to support the diagnosis of concussion: a symptom severity checklist, questions about orientation, memory tasks, and a modified BESS test. The SCAT3 does not include any testing of visual tracking skills or convergence. Although the use of the SCAT3 produces a score, there is no evidence-defined score that rules in or rules out the diagnosis of concussion. Rather, the score can be used for following an individual's recovery from concussion over time. A digital copy of the SCAT3 assessment can be downloaded for free from the *British Journal of Sports Medicine* at http://bjsm.bmj.com/content/47/5/259.full.pdf.

There are several common challenges that can result in a missed diagnosis or misdiagnosis. The symptoms of concussion are variable and nonspecific and can overlap with the symptoms of other common conditions. Fatigue and a dazed appearance can be symptoms of physical exhaustion, somewhat common on the sidelines of a sporting event. Headache, nausea, and photophobia are typical of a migraine, which can be triggered by stress, hunger, and exhaustion, not unusual in the context of trauma. The list goes on. We recommend maintaining a high level of suspicion and a low threshold to make a preliminary diagnosis of concussion, which can help guide management during the critical stages of early recovery and can be revised if a patient's symptoms resolve after an observation period of 24 h.

Another challenge is the fact that the first signs and symptoms may not manifest until hours after the injury has occurred. This feature contributes to cases of missed diagnosis or detrimental actions prior to diagnosis. In the emergency room, a history of trauma should prompt clinicians to (1) consider a few hours' period of observation to watch for signs and symptoms of concussion in evolution and (2) provide anticipatory guidance about the features and early treatment strategies of concussion prior to discharge. Clinicians who provide coverage on the sidelines of sporting events also need to take this into consideration. When an athlete sustains a suspected concussive injury, he or she should be temporarily removed from play for assessment. The simplest cases are those in which the athlete immediately shows signs or symptoms of concussion. The more complex case is the athlete who appears well and feels well or the athlete who reports only a nonspecific symptom like fatigue or nausea.

A concussion cannot be confidently ruled out when this occurs. These athletes should receive a brief but comprehensive evaluation for signs of neurologic impairment. If the initial evaluation is negative, we often recommend holding the athlete at the sidelines for 5 min or so to see if symptoms develop. Before clearing the athlete to play, most clinicians will require him or her to perform a brief test of physical exertion, such as wind sprints, push-ups, or jumping jacks, to see if this causes symptoms to develop. If the athlete is symptom-free and has a normal examination after exertion, then he or she may be cleared for return to play. Reassessment should occur periodically throughout the remainder of the play period, and anticipatory guidance should be provided to the athlete and his or her family before leaving for the day.

Physical and cognitive developmental issues affect the assessment of both healthy and concussed subjects. Young children may not be able to cooperate with a comprehensive assessment and require keen observation and modified examination maneuvers. Even in older children and adolescents, the developmental landscape can complicate an examiner's interpretation of exam findings. Healthy individuals experience improvements in reaction time and cognitive performance throughout adolescence. Similarly, individuals improve with regard to the quality and speed with which they complete visual tracking tasks.

Patients or their parents will often ask if a change they have observed at home could be the result of a concussion, or they might ask what to expect after a concussion. We find it helpful to rely on the concept that concussed individuals tend to struggle most with the cognitive tasks that they have just mastered, or are working to master, at their developmental stage. While a healthy 6-year-old might be in the process of developing the capacity for sustained attention in school, fine motor coordination, working memory, and emotional regulation, a 6-year-old with a concussion might have inattention, hyperactivity, sloppy handwriting, and irritability. His parents might say, "He is acting like a 4-year-old again!" At the same time, a healthy teenager is developing the capacity for abstract reasoning and mastering skills that integrate complex motor functions with spatial awareness, while one recovering from a concussion may report that she can read a familiar book without any trouble but develops a pounding headache when she tries to finish her calculus homework or she feels fine walking to school but experiences nausea when she attempts to drive a car. This heuristic helps to make educated predictions about how a concussion could manifest and when reviewing a child's symptoms with his or her family. For cases in which the diagnosis of concussion is suspected but complicated by developmental considerations, we recommend making the diagnosis in a preliminary fashion so that treatment can be initiated and then seeking consultation with a pediatric concussion specialist for further evaluation.

Initial Management

The principles of initial management are built upon the concept that concussion is a problem of injury on the cellular level that is then complicated by a period of metabolic mismatch. Recognizing that the injured brain is at increased risk of energy failure, the treatment of concussion can take one of two theoretical approaches: increase the supply of metabolic substrates (glucose, amino acids) to injured cells, which is not possible yet, or decrease the energy demands of the brain, which can be achieved safely and with available strategies.

Physical and cognitive rest should be prescribed as soon as possible. Rest limits the possibility that vulnerable cells will undergo further stress, progressive injury, or death. Rest also allows the brain to dedicate available substrates to the healing process rather than to other functions.

In cases of sport-related concussion, the first step is to remove the athlete from play. An athlete suspected of having a concussion should not be permitted to return to competition or practice on the day of injury. This is important as a therapeutic step and to limit the possibility of a second trauma to the injured brain. They should be instructed to go to safe location where physical demands can be minimized. Strict bed rest is probably not necessary but patients should be instructed to focus on conserving energy. This includes not just walking or exercise but also tasks that require significant amounts of eye tracking, reading, screen-based forms of entertainment, and driving a car. Many patients will experience an increased need for sleep. This should be permitted, as it promotes physical rest and may represent an adaptive response of the brain to alterations in energy balance. In the individual who has a hard time falling asleep, we routinely use a small dose of melatonin. In the absence of signs of a more severe TBI or intracranial bleeding, it is no longer recommended that caregivers prevent a patient from falling asleep or wake a patient every 1–2 h to monitor for signs of clinical deterioration. Such efforts are of dubious utility and may actually be harmful to the injured brain.

Given that the signs and symptoms of concussion are believed to reflect the structural and metabolic state of the injured regions of the brain, symptom severity is probably a helpful guide to what level of activity is acceptable in the days following an injury. Some patients will feel highly symptomatic even at rest. These patients should not increase their degree of activity. The asymptomatic or minimally symptomatic patient should be encouraged to pursue activities of daily living and low-exertion tasks as long as they do not result in an increase in symptoms.

Immediately following a concussion, patients should also be counseled to minimize cognitive exertion. They should not be permitted to return to school or work for at least 24 h and should be reminded that cognitive exertion includes tasks that

require prolonged concentration, sustained attention, problem solving, or emotional stimulation. This might include watching television, reading, and social interactions, depending on the content. Total avoidance may not be necessary but they should certainly avoid activities that make symptoms worse.

We generally recommend against the use of over-the-counter analgesics. Nonsteroidal anti-inflammatory drugs (NSAIDs) and acetaminophen are not particularly helpful in treating concussion-related headaches. NSAIDs might increase the risk of bleeding in patients with TBI, and the effect of their anti-inflammatory effects on healing after concussion has not been clarified. There is some concern that analgesics could mask symptoms and cause patients to exert themselves. Although in most cases the risks seem to outweigh the benefits, patents with a history of migraine headache might be an exception. This is because headaches are more likely to occur in the period following a concussion and most patients can differentiate a typical migraine headache from a concussion-associated headache.

Recovery

Recovery from concussion is spontaneous and occurs in a graduated and predictable fashion. It is believed that the resolution of clinical signs reflects healing on the cellular level and restoration of physiologic cerebral blood flow. Patients with a recent injury will typically experience symptoms at rest. As they recover, symptoms are less common at rest but may be worse after physical or cognitive exertion. Eventually patients will find that they can tolerate increasing degrees of exertion without exacerbating their symptoms. Patients are considered fully recovered when none of the signs or symptoms of concussion can be provoked with full cognitive and physical exertion.

The timing of recovery varies and is influenced by age, a history of prior concussions, and the presence of comorbid conditions. Adults are thought to heal more quickly from concussion than adolescents and children, perhaps due to anatomical and physiologic differences such as the degree of myelination and synapse density. Adults typically return to baseline neurocognitive performance a median of 3–5 days following injury, while college athletes need 5–7 days and high school athletes take 10–14 days. Formal studies in younger age groups are lacking, but it is believed that the healing process is further prolonged. Clinically, the resolution of symptoms and physical examination findings tends to follow similar trends. Although most patients experience steady improvement, recovery does not always progress in a linear fashion. A few will experience prolonged recovery, during which improvement seems to slow down or plateau. Recognizing these aspects of the healing process, we often employ this summary statement when working with adolescents: “Ninety percent of patients in your age group will experience full recovery by the time 4 weeks have passed. About 10 % will have prolonged symptoms, and will take months to fully recover.” Fortunately, complete recovery is realistic even for those with prolonged symptoms.

A history of previous concussions, particularly those characterized by prolonged recovery, increases the risk of delayed healing or persistent impairment. There is intense interest in defining how many concussions are “too many.” This remains an area of debate, without clear evidence to suggest an absolute number. At this time, emphasis for most clinicians should be placed on understanding and communicating the trend.

Comorbid conditions also influence recovery. Not only can depression, attention-deficit disorder, migraine headaches, or problems with the visual and vestibular systems alter the pattern, severity, and duration of concussive symptoms, but patients often experience an exacerbation or recurrence of these conditions following a concussion, perhaps because the metabolic derangements of the concussed brain make it more difficult to functionally compensate for these underlying conditions. It is important to screen for preexisting or comorbid conditions and to help patients anticipate the possibility of their recurrence or worsening at some point during recovery.

Follow-Up

Concussion is often diagnosed in a chaotic setting—at the scene of an accident, in the emergency room, during a trauma evaluation, and on the sidelines of a sporting event. It is not unusual for the diagnosis to seem preliminary or uncertain to the health-care provider and to the patient. The emphasis in the acute setting is to identify high-risk patients who require further evaluation (cervical spine injury or more severe TBI) and to provide instructions for initial management.

The first follow-up evaluation should be arranged within days of a concussive injury with the goals of establishing the diagnosis, gathering additional details of the past medical history and the injury history, documenting signs and symptoms that have evolved since the injury, and providing further guidance. Periodic subsequent evaluations should be scheduled until full recovery has occurred. Serial interviews and physical exams are required to track symptom resolution. The same exam techniques and diagnostic tools described in the diagnosis section can be used to follow recovery.

Early in the recovery period, recommendations for management should continue to emphasize both physical and cognitive rest. As the recovery process moves forward, patients can be instructed on the gradual reintroduction of activity, using symptoms as a guide. In straightforward cases, we should anticipate spontaneous improvement in symptoms and full recovery, with return to full cognitive and physical function, within 2–4 weeks.

In the past, discussions about sport-related concussions focused on an athlete's return to play. As our understanding of concussion has evolved, equal if not greater emphasis has been placed on an individual's return to full cognitive function. Current recommendations stress a "return-to-learn" plan before considering "return to play."

There is no widely accepted protocol to ensure a return to full cognitive function. In fact, the science behind cognitive rest is still being debated—too much cognitive activity early in the concussion is probably detrimental, but too little could be counterproductive. A stepwise plan should be tailored to the individual's needs and pattern of recovery (Table 16.3). The cognitive rest stage is meant to last a few days after the injury, after which there should be a gradual transition back to school, starting with light reading or easy academic work at home. If symptoms do not worsen, they can gradually increase the time and complexity of the cognitive work, for 20–30 min at a time and frequent breaks. Worsening symptoms should be taken as a sign that the brain is still under metabolic stress. Cognitive exertion can be increased at home day by day, according to symptoms (stage 3).

When an individual is able to complete 30–45 min of cognitive work at home, he or she may be considered ready to return to school or work. We usually suggest starting with half days at first. Arrangements should be made for an exit strategy (a ride home, longer breaks) if symptoms develop while in class or at work.

Academic planning is required to make sure the transition goes smoothly. When a student returns from an absence, the default mode in many academic institutions is to simply double the workload, to make up missed material while learning new material. This is often counter-therapeutic and can result in academic catastrophe. The patient, parents, teachers, and administration should all agree on an academic plan that allows the patient to gradually increase cognitive effort. Helpful guidelines include (1) working on learning missed material or new material but not both, (2) dropping nonessential assignments, (3) reducing workload when possible, and (4) no tests or quizzes during the first week. Finally, following the progressive framework of a return-to-learn plan, patients should focus on being able to complete a full day of school or work without symptoms before adding extracurricular activities or additional responsibilities.

Individuals with prolonged recoveries or persistent symptoms may require additional accommodations. This form of advanced management should be deferred to clinicians with expertise in the management of concussion.

Some states and local governing bodies have mandated that student athletes be cleared, in writing, by a licensed health-care professional to return to sports following a concussion. These mandates have heightened awareness about the importance of return-to-play guidelines in households, on sports fields, and in the medical office. Expert consensus has defined return-to-play guidelines that should be considered the standard of care. The process should occur in a stepwise progression (Table 16.4). At minimum the child should be without symptoms at rest, though it is prudent to delay any exercise until after they have returned to full cognitive function. As a general rule, we often recommend that an athlete delay significant aerobic exercise until the day after he or she is able to get through a full day of school without symptoms.

The minimum amount of time in between each stage of the return-to-play progression is 1 day. Athletes should not be permitted to complete two new stages on the same day. The progression is from light aerobic activity, then sport-specific exercise (or heavier aerobic activity and weight lifting), then noncontact training drills, and finally full-contact practice. If a full practice can be completed without triggering symptoms, the athlete may then be formally cleared for full participation in practice and competition.

Not all athletes will experience a straightforward progression. If symptoms worsen with any stage of progression, the athlete should rest and wait to reattempt that stage until the following day. Athletes with prolonged recovery or failure to progress should not be permitted to advance to the next stage of the return-to-play progression and should be referred for expert evaluation.

Table 16.3 Graduated return-to-learn protocol[a]

Rehabilitation stage		Activity level
1	Cognitive rest	• Sleep, sedentary activities
2	Light cognitive exertion	• Reading, simple homework
3	School or work-specific activity	• Reading or homework for 20–30 min periods
		• Increasing complexity and number of repetitions of work (fine print, dense literature, algebra) as tolerated
4	School or work with reduced workload	• Half or full days of school
		• Make up old material or learn new material, *but not both*
		• No testing
5	Full cognitive exertion	• School or work, fully caught up on missed material
		• Full class and homework load
		• Feels ready to reintroduce extracurricular activities

[a]Patients begin at stage 1. Once able to complete the current stage without worsening symptoms, they may progress to the subsequent stage in no less than 24 h. Recurrence of symptoms indicates the need for rest and return to the previous level of cognitive exertion

Table 16.4 Graduated return-to-play protocol[a]

Rehabilitation stage		Objective of stage
1	No training activity	Recovery, reduce metabolic demands
2	Light aerobic exercise	Increase heart rate
3	Sport-specific exercise	Add movement
4	Noncontact training drills	Exercise, coordination, and cognitive load
5	Full-contact practice	Restore athlete's confidence; coaching staff assesses functional skills
6	Return to play	Full activity

[a]Patients begin at stage 1. Once able to complete the current stage without worsening symptoms, they may progress to the subsequent stage the following day. The recurrence of symptoms indicates the need for rest and return to the previous level of cognitive exertion
Source: Data from Harmon KG, Drezner JA, Gammons M, Guskiewicz KM, Halstead M, Herring SA, Kutcher JS, Pana A, Putukian M, Roberts WO. American Medical Society for Sports Medicine position statement: concussion in sport. *British Journal of Sports Medicine* 47:15–26, 2013

Referral for Expert Guidance

Despite the fact that concussion is a common injury and its presentation often fits into predictable patterns, the diagnosis, evaluation, and management of concussion can quickly become very complex. The astute clinician knows when to seek expert consultation. There are a growing number of experts who can provide advanced care for patients with concussion in fields as diverse as sports medicine, neurology, and primary care.

We suggest referring your patient to an experienced expert clinician in any of the following scenarios: (1) neither you nor the patient's primary care physician can provide periodic, complete outpatient follow-up visits through the recovery process; (2) history of prior concussions; (3) history of a complicated concussion or a prolonged recovery; (4) presence of comorbid conditions; (5) a recovery that lasts longer than 2 weeks; (6) issues presented by the case seem unfamiliar or too complex; and (7) the patient or the patient's family requests an expert evaluation.

A concussion specialist can provide care at any stage, from the initial diagnosis and management to the treatment of prolonged or severe symptoms, management of academic accommodations, supervision of rehabilitation, and counseling on complex issues such as retirement from sport.

Editor's Comment

For far too long, the importance and implications of concussion have been ignored, dismissed, or minimized, mostly out of ignorance—we simply had no idea how bad they were, especially for the developing brains of children—but also as a side effect of several deep-seated aspects of our sports culture: machismo, competitive zeal, foolish pride, and the like. We now appreciate the dangers associated with all forms of TBI, including the "minor" brain injury known as concussion. Over the past 10–15 years, several myths about concussion have been dispelled: (1) *No LOC*, *no concussion*. We now know that one can sustain a concussion without loss of consciousness and even without a direct head injury, as any impact or sudden deceleration can result in a concussion in a susceptible individual. (2) *The brain heals itself and so there are no long-term effects from one or even multiple concussions*. This is demonstrably false and supported by many studies of athletes and trauma victims. (3) *Getting back to school, work, and sports as quickly as possible* ("Get back in the game!") *is the best way to deal with a concussion.* We now know with certainty that cognitive and physical rest is important to promote healing, restore function, and avoid secondary injury.

Recognition of concussion is critical. We owe it to students and athletes to err on the side of caution when pronouncing the presence or absence of a concussion. This includes having a high index of suspicion, the use of careful and specific tests of cognitive ability, oculomotor skills, and balance and coordination. Mostly this involves having the confidence and authority to keep them out of the big game despite the protests of coaches, fans, and bettors, which can be extremely difficult.

For a time, strict and prolonged cognitive and physical rest was prescribed for anyone with concussive symptoms without individualization or consideration of mechanism, history of prior concussions, or severity of the current injury. It seems clear that an individualized approach based on symptom severity and subtle clinical signs and a gradual and closely monitored stepwise approach is safe and avoids the unnecessary restriction of important activities such as school and exercise. We know that an injudicious early return to

competition can prolong recovery but it also places the incompletely recovered brain at risk of another concussion, which likely increases the severity and long-term sequelae of the injury in a multiplicative rather than an additive fashion—the injured brain is almost certainly more prone to injury. On the other hand, the strict restriction of light cognitive tasks like reading or watching television, assuming the patient can do these things without producing *any* symptoms, is probably overkill.

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Acute Head Trauma

17

Gregory G. Heuer, Todd J. Kilbaugh, and Jimmy W. Huh

Pediatric head trauma patients are initially evaluated in the prehospital setting and then the emergency room or trauma bay. As part of the secondary trauma survey, a detailed neurologic exam is performed whenever possible. A specific note should be made of the admission Glasgow Coma Scale (GCS) score, which includes assessment in three areas: eye opening, verbal response, and motor response. The scale ranges from 3, which is a deep coma, to 15, which is awake and alert (Table 17.1). The utility of the score is twofold. First, the GCS helps predict the severity of injury. Trauma patients with a GCS of greater than 12 generally have a minor traumatic brain injury (TBI), those with a score of 9–12 tend to have a moderate TBI, and those with less than 9 have a severe TBI. Second, because the GCS is a simple and reproducible test, it can be used to follow inpatients for deterioration.

Another important concept is the Monro–Kellie doctrine: the intracranial vault is incompressible and holds a fixed volume of the brain, blood, and cerebrospinal fluid. An increase in volume of one of the cranial constituents (such as cerebral edema) must be compensated by a decrease in volume of another. The initial compensatory mechanisms for this increase in intracranial volume are displacement of CSF to the spinal canal and displacement of venous blood to the jugular veins, which prevent elevation of intracranial pressure. Once these compensatory mechanisms are exhausted, even small increases in intracranial volume will lead to a profound increase in ICP, which compromises cerebral perfusion. This then causes cerebral ischemia and further worsening of cerebral edema, which, if not promptly recognized and treated, culminates in brain herniation and death.

Patients with TBI and increased ICP often present with headache, irritability, and vomiting but can rapidly progress to altered mental status, loss of consciousness, pupillary reactivity abnormalities, focal neurologic changes, or obtundation. However, as the ICP continues to rise with subsequent intracranial hypertension, herniation is heralded by the classic clinical findings of the Cushing triad: irregular respirations, bradycardia, and systemic hypertension. Additionally neurogenic posturing, seizures, and changes in cranial nerve exam due to brain and brain stem compression (anisocoric, dilated pupils) can be seen.

A special consideration in infants who present with nonspecific symptoms such as irritability, vomiting, lethargy, seizure, or apnea due to non-accidental head trauma is that there is usually *no history of trauma*. Concerning signs of abusive TBI include retinal hemorrhages on ophthalmologic examination and subdural hematoma (SDH). Papilledema signifies intracranial hypertension, necessitating emergent further evaluation.

Initial Treatment

Based on a review of the pediatric TBI literature, in 2012 the Society of Critical Care Medicine and World Federation of Pediatric Intensive and Critical Care Societies updated their *Guidelines for the Acute Medical Management of Severe Traumatic Brain Injury for Infants, Children, and Adolescents*. Treatment of severe pediatric TBI follows trauma life support guidelines: stabilization begins with

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Table 17.1 Pediatric Glasgow Coma Scale (Simpson and Reilly)

Modality	Response	Score
Eye opening response	Spontaneously	4
	To speech	3
	To pain	2
	No eye opening	1
Verbal response	Oriented	5
	Words, irritable cries	4
	Vocal sounds	3
	Inconsolable cries	2
	No response	1
Motor response	Purposeful	6
	Withdraws to touch	5
	Withdraws to pain	4
	Decorticate	3
	Decerebrate	2
	No response	1

securing the airway, achieving adequate oxygenation and ventilation, and avoiding or rapidly treating hypotension.

Early airway management involves proper airway position while keeping cervical spine precautions in place and orotracheal intubation. Hypoxia and hypercarbia must be avoided because both are potent cerebral vasodilators that result in increased cerebral blood flow and volume and potentially increased ICP and intracranial hypertension. In the initial resuscitation period, efforts should be made to maintain eucapnia at the low end of the normal reference range ($PaCO_2$ of 35–39 mmHg) and prevent hypoxia (PaO_2 <60–65 mmHg or oxygen saturation <90 %) to prevent or limit secondary brain injury. Unless the patient has signs or symptoms of herniation, prophylactic hyperventilation ($PaCO_2$ <35 mmHg) should be avoided. Hyperventilation causes cerebral vasoconstriction, which decreases cerebral blood flow and subsequent cerebral blood volume that will lower ICP, but ischemia can also occur. Nasotracheal intubation should be avoided because of the risk of cervical spine injury and direct intracranial injury, especially in patients with basilar skull fractures.

Special considerations must be given to the choice of medications used to facilitate tracheal intubation to prevent elevated ICP and avoid hypotension. Common medications used in the intubation of patients with TBI include midazolam, fentanyl, etomidate, and lidocaine, as well as neuromuscular blockade. Potential side effects of these medications include (but are not limited to) hypotension, chest wall rigidity, and adrenal suppression with etomidate. Thiopental, once commonly used for intubation in the setting of TBI, is no longer available in the USA.

Ketamine is traditionally avoided because it was thought to have the potential for vasodilatory effects and elevating ICP. However, recent studies in intubated and mechanically ventilated children with elevated ICP, who were already receiving continuous IV infusion sedatives and who may have received hyperosmolar therapy or decompressive craniectomy, suggest that ketamine may in fact decrease ICP without lowering blood pressure and cerebral perfusion pressure. Nevertheless, further studies need to be done before being able to recommend its routine use in the setting of TBI.

It should also be noted that the FDA recommends against the use of a *continuous* infusion of propofol for either sedation or the management of refractory intracranial hypertension in infants and children with severe TBI, due to a concern for "propofol infusion syndrome," which manifests as myocardial failure, rhabdomyolysis, severe metabolic acidosis, and renal failure. Although the syndrome is rare and is typically associated with prolonged use of high doses of propofol, it is often fatal.

Every effort should be made to *avoid hypotension* in these patients, because hypotension has been shown to increase morbidity and mortality. Hypotension is defined as a systolic blood pressure less than the fifth percentile for age or the presence of clinical shock. Euvolemia should be maintained. Isolated TBI rarely leads to severe hypotension. Other occult causes of hypotension in the trauma patient that should be considered include, among other things, intra-abdominal injuries, pericardial tamponade, hemothorax, pneumothorax, spinal cord injury causing spinal shock, and excessive sedative and analgesic medications.

Once the patient is hemodynamically stable, a quick but thorough neurologic exam is performed as the patient is taken for a non-enhanced head CT. Imaging patients after head trauma normally consists solely of a non-contrast head CT. Imaging should be considered in patients who have a history of loss of consciousness, a depressed or declining GCS, a fixed neurologic deficit, or an injury that places the patient at sufficient risk for TBI. An MRI is rarely indicated in the acute management of head trauma. Head CT and serial physical examination are usually sufficient to allow proper medical and neurosurgical management of the patient.

Epidural and subdural hemorrhages are usually neurosurgical emergencies that require immediate evacuation to lower the ICP. In contrast, intraparenchymal hemorrhage and skull fracture, unless they are extensive, are usually managed nonsurgically. Patients with nonsurgical lesions are supported in the PICU and closely monitored for deterioration.

Secondary Brain Injury

Patients with TBI are at risk for secondary brain injury. This includes patients with an expanding epidural hematoma (EDH), which can worsen the extent of the brain injury and usually requires emergency surgical evacuation as well as other treatable conditions such as systemic hypotension, hypoxemia, hypercarbia or hypocarbia, hyperglycemia or hypoglycemia,

electrolyte abnormalities (especially hyponatremia), coagulopathy, hyperthermia, seizure, and intracranial hypertension.

Severely brain-injured children who do not have a reliable neurologic exam often require placement of an ICP device to monitor for intracranial hypertension, defined as ICP ≥20 mmHg. If the patient has a nonsurgical injury, is not localizing on exam, and has a GCS ≤8, an ICP monitor should be placed. Options include a simple ICP monitor, a dual monitor that records ICP and brain tissue oxygen, or a ventriculostomy drain. The ventriculostomy drain has the advantage of being both diagnostic and therapeutic. These monitors have risks such as infection, especially when used for a prolonged duration. It is our practice to place a ventriculostomy drain if based on the head CT, the lateral ventricles are accessible. If not, we favor placement of a dual monitor that measures ICP and brain oxygenation (Licox monitor, Integra, Plainsboro, NJ). The goals of therapy are an ICP <20 mmHg and a minimum cerebral perfusion pressure (CPP = mean arterial pressure − ICP) >40 mmHg in infants and >50 for adolescents. CPP <40 mmHg is associated with worse outcome. We also strive to maintain brain tissue oxygenation above 20 mmHg to prevent brain hypoxia and below 35 mmHg to prevent brain hyperoxia, although published guidelines currently recommend (level III evidence) a minimum of 10 mmHg. It is also important to prevent spikes in intracranial hypertension and brain oxygenation desaturations, both of which have been associated with poor outcome.

Raising the head of the bed to improve venous drainage might help to control ICP. Traditionally, elevation of the head to 30° in the midline position is recommended, but titration of head elevation to achieve the lowest ICP is even better. Again, care of the cervical spine must always be a consideration when moving patients with TBI.

Posttraumatic hyperthermia (core body temperature ≥38.0–38.5 °C) is not uncommon in patients with TBI. Fever increases cerebral metabolic requirements and oxygen consumption and can promote intracranial hypertension. Fever also lowers the seizure threshold. Consequently, efforts should be made to avoid hyperthermia. The patient should also be investigated and treated for other etiologies of fever, such as infection.

Sedation and analgesia are also important adjuncts to minimize increases in ICP. Painful stimuli and stress increase metabolic demands and increase blood pressure and ICP. However, sedatives and analgesics must be judiciously chosen to prevent unwanted side effects, such as hypotension or delirium. Short-acting and reversible analgesics, such as fentanyl, are commonly used. Short-acting benzodiazepines, such as midazolam, are also commonly used and have the added benefit of increasing the seizure threshold. If adequate sedation and analgesia are unsuccessful in controlling intracranial hypertension, neuromuscular blockade may be considered. Neuromuscular blockade also prevents shivering, which increases metabolic demand and oxygen consumption, improves cerebral venous drainage by decreasing intrathoracic pressure, and makes ventilation easier by eliminating ventilator–patient asynchrony. Disadvantages include masking of seizure activity (continuous EEG monitoring should be in place), risk of nosocomial pneumonia from ineffective pulmonary drainage, and inability to perform a clinical neurologic examination to monitor the patient's course.

Intravenous hypertonic (3 %) saline has been shown to be an effective therapy for intracranial hypertension in children with TBI and presumably decreases cellular edema by increasing serum osmolality and shifting water out of the intracellular compartment into the intravascular space. Additional theoretical benefits of hypertonic saline include improved vasoregulation, cardiac output, immune modulation, and plasma volume expansion. Pediatric patients with severe TBI generally tolerate a high osmolar load (up to 360 mOsm/L), though some may develop transient renal insufficiency. Effective doses for acute bolus administration of IV 3 % saline for intracranial hypertension range from 6.5 to 10 mL/kg, while continuous infusion of IV 3 % saline may range between 0.1 and 1 mL/kg/h administered on a sliding scale. The minimum dose needed to maintain ICP <20 mmHg should be used. According to current guidelines, the serum osmolarity should be maintained <360 mOsm/L to help prevent renal insufficiency; however, in our institution, we become concerned when the serum osmolarity approaches 320 mOsm/L. Risks of hypertonic saline administration include rebound intracranial hypertension after withdrawal of therapy, central pontine myelinolysis with rapidly increasing serum sodium levels, subarachnoid hemorrhage due to rapid shrinkage of the brain and tearing of bridging vessels, renal failure, metabolic acidosis, and hypervolemia.

Mannitol has long been successfully used to treat intracranial hypertension following TBI especially in adults. An osmolar agent with rapid onset of action by two distinct mechanisms, the initial effects of mannitol result from reduction of blood viscosity and a reflex decrease in vessel diameter to maintain cerebral blood flow through autoregulation. This decrease in vessel diameter contributes to decreased total cerebral blood volume and ICP. This mechanism of action is transient (about 75 min) and requires repeated dosing for prolonged effect. Mannitol also has osmotic effects, which, though slower in onset, last up to 6 h. Pitfalls of mannitol include the potential to accumulate in regions of injured brain tissue if the blood–brain barrier is damaged and subsequent reverse osmotic shift and worsening of ICP. Because this has been associated with continuous infusion, intermittent dosing is recommended. Mannitol has been associated with renal failure at serum osmolality levels greater than 320 mOsm/L in adults. However, the literature supporting this finding is limited and was published at a time when dehydration therapy was common. With current neurocritical

care for treatment of intracranial hypertension, a euvolemic hyperosmolar state generally is targeted when hyperosmolar therapy is used. Because mannitol is a potent diuretic, hypovolemia can occur, leading to hypotension and a decrease in CPP. Nevertheless, there are very few adequately controlled studies supporting the use of mannitol in children. At our institution, we favor IV 3 % saline over mannitol because of the risks of hypovolemia and subsequent hypotension.

Clinically evident seizures should be aggressively treated because they contribute to hyperthermia and intracranial hypertension. Prophylactic phenytoin reduces the incidence of early (<1 week) posttraumatic seizures. In our institution we will consider antiepileptic drug prophylaxis in the youngest pediatric population with severe TBI who are especially at risk for seizure, especially when they have hemorrhage, depressed skull fracture, or cerebral contusion. We will also use video EEG to monitor for electrical or nonconvulsive seizure, which is not clinically evident.

Refractory Intracranial Hypertension

Hyperventilation has the potential to reduce intracranial hypertension by reflex vasoconstriction in response to hypocapnia. The vasoconstriction leads to decreased cerebral blood flow, decreased cerebral blood volume, and decreased ICP. Hyperventilation remains one of the fastest methods to lower ICP in a child with impending herniation. Refractory intracranial hypertension that is refractory to standard treatments (sedation, analgesia, head elevation, CSF drainage, neuromuscular blockade, IV hyperosmolar therapy) will often respond to mild hyperventilation ($PaCO_2$ 30–34 mmHg). The potential dangers associated with hyperventilation are related to the cerebral vasoconstriction and subsequent risk for cerebral ischemia due to insufficient cerebral blood flow. Ensuing respiratory alkalosis also shifts the hemoglobin–oxygen dissociation curve to the left, making release of oxygen to tissues more difficult. As a result, routine prophylactic severe hyperventilation ($PaCO_2$ <30 mmHg) should be avoided for at least 48 h after injury.

Severe hyperventilation ($PaCO_2$ <30 mmHg) is sometimes necessary in emergency situations such as impending herniation (Cushing triad or anisocoria), but it should not be used for prolonged therapy unless there is truly refractory intracranial hypertension. If aggressive hyperventilation is used for an extended period, advanced neuromonitoring for cerebral ischemia (brain tissue oxygen monitoring, cerebral blood flow monitoring, jugular venous oxygen saturation, transcranial Doppler, or near-infrared spectroscopy) is suggested.

High-dose IV barbiturate therapy (pentobarbital) is used for refractory intracranial hypertension. This class of medications suppresses the cerebral metabolic rate, improves regional blood flow relative to metabolic demands, decreases cerebral blood volume, and inhibits excitotoxicity. With continuous EEG monitoring, barbiturate infusions can be titrated to achieve burst suppression. The minimum dose required to control refractory intracranial hypertension is recommended, as barbiturates can also cause myocardial depression, decreased systemic vascular resistance, and hypotension. Furthermore, the ability to perform neurologic examination is lost when barbiturates are used to control ICP. Prolonged barbiturate therapy can also result in immune suppression leading to sepsis and ileus with subsequent feeding intolerance. When administering high-dose barbiturate therapy, continuous blood pressure monitoring and adequate cardiovascular support with IV continuous inotropic and vasopressor medications are required to maintain adequate CPP.

Decompressive Craniectomy

If medical management of increased ICP is inadequate, we rapidly move to surgical decompression consisting of a hemicraniectomy or bifrontal craniectomy for children with severe TBI who show early signs of neurologic deterioration or herniation. After a bony decompression, the ICP monitor waveform and values are not representative, but brain tissue oxygenation values will still provide accurate data that can be followed. Potential complications from decompressive craniectomy include hygroma, infection, and hydrocephalus.

Therapeutic Hypothermia

Experimentally, hyperthermia (core body temperature ≥38.0–38.5 °C) has been shown to exacerbate neuronal cell damage, whereas hypothermia (core body temperature <35 °C) has been shown to decrease many of the mechanisms associated with secondary brain injury, such as inflammation, excitotoxicity, and cellular metabolism. The impact of therapeutic hypothermia on pediatric severe TBI has been studied in two separate randomized clinical trials. In one study, a multicenter, international study of children with severe TBI randomized to induce moderate hypothermia (32.5 °C) for 24 h initiated within 8 h after injury or to normothermia (37 °C) found a worsening trend in morbidity and mortality in the hypothermia group. In a separate study, a multicenter international study of children with severe TBI to determine if induced moderate hypothermia (32–33 °C) initiated for a longer duration (48–72 h) and a slow rewarming period was recently terminated due to futility. As a result, we currently do not have an induced moderate hypothermia program for children with severe TBI.

Skull Fractures

Skull fractures occur in over 20 % of all children hospitalized with head trauma, higher in children (about 50 %) less than 1 year of age. Skull fractures are classified as linear, depressed, or basilar skull fractures. Linear skull fractures are the most common. In the absence of any significant underlying hemorrhage, patients with linear fracture rarely need to have surgical intervention.

Depressed skull fractures are more likely to result in underlying brain injury and to require intervention. Prior to 4 years of age, the skull is relatively thin and pliable. As a result, young children present with a "ping-pong ball" fracture in which the skull is depressed inward without a fracture line. This unique type of fracture rarely necessitates surgical intervention and can usually be followed clinically. We routinely reevaluate in 4–6 weeks, when most of the posttraumatic swelling has resolved. With time a "ping-pong ball" fracture will spontaneously resolve as the bone remodels under the pressure of the growing brain.

True depressed skull fractures are most often identified by CT scan (Fig. 17.1). Indications for operation include underlying clinically significant hematoma, neurologic deficit specifically related to the depressed fracture, a break in the skin overlying a fracture with gross contamination of the wound, CSF leak through the wound, and location of a fracture in a site that will lead to a poor cosmetic result. There are several goals of surgical intervention. First, the fractured segment must be elevated (Fig. 17.1). For "ping-pong ball" fractures that need treatment, a burr hole can be placed next to the depressed segment, and the area can be flexed outward using an elevator. In some instances, fractures in older children can be similarly elevated directly with a Penfield dissector or another tool. In some instances where the bone is fragmented, a craniotomy is performed around the fracture, and then the fracture can be elevated along with the craniotomy. After the segment is elevated, any clinically significant underlying hematomas should be evacuated and hemostasis obtained. Dural tears should be repaired either primarily with suture or with a duroplasty. In cases where the fracture extends into the frontal or other sinuses, the sinus needs to be cranialized, the mucosa exenterated, and the remaining sinuses separated from the intracranial compartment with a vascularized pericranial graft. The last step in repairing a skull fracture is molding the bone back to a normal shape (Fig. 17.1). In rare instances, a cranioplasty is needed to fill a defect. The bone is reattached to the skull with mini-plates (Fig. 17.1f, g).

A unique delayed complication of skull fractures in children, occurring in less than 1 % of cases, is a growing skull fracture or leptomeningeal cyst, which presents as an enlarging scalp lesion. Diagnostic criteria include age <6 (usually less than 3) and a torn dura resulting in CSF leak. The CSF leak typically occurs within the fracture line and arachnoid tissue is caught within the fracture. As a result, the fracture line cannot heal and instead widens with time. A growing skull fracture presents as a pulsatile mass at a site of previous trauma and can result in seizures or a focal neurologic

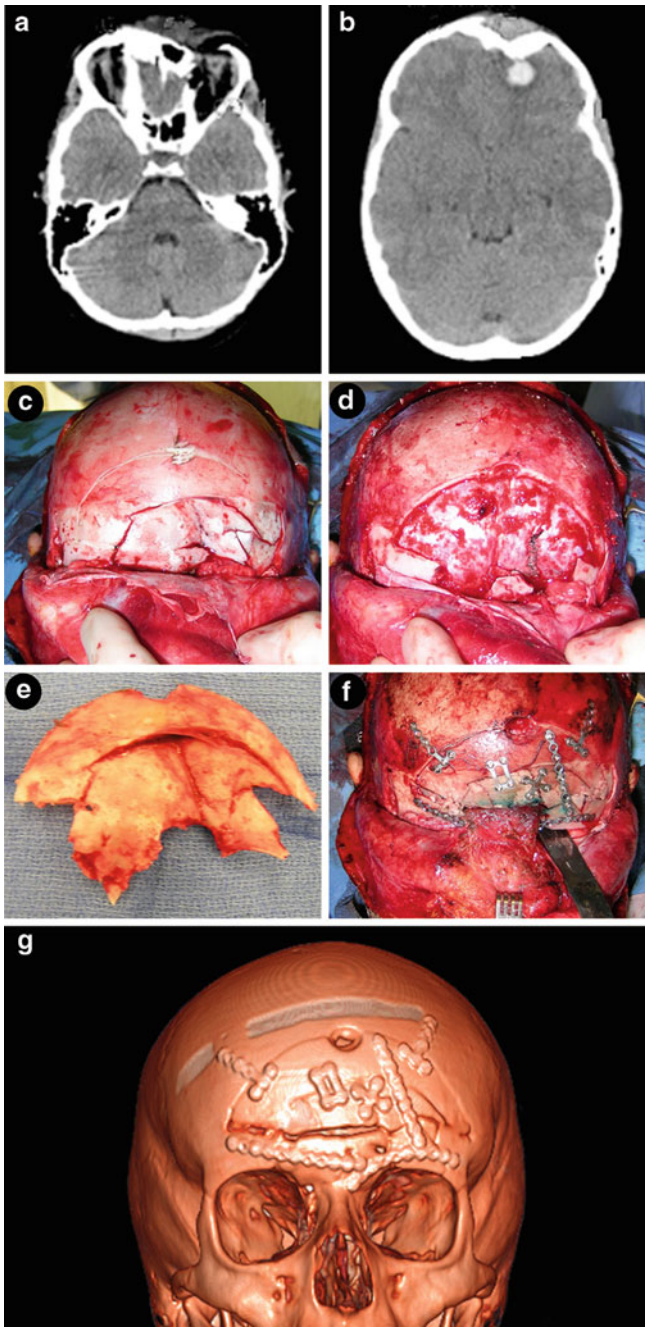

Fig. 17.1 Representative pediatric patient who suffered a skull fracture after a blow to the head with a baseball. (**a**) CT image demonstrating a skull fracture involving the orbit and (**b**) an underlying contusion. (**c**) Intraoperative images demonstrating the skull fracture and (**d**) the dura after elevation of the fracture and repair of the dural tear. (**e**) Elevated fracture. (**f**) Intraoperative image after plating of the fracture. (**g**) Postoperative CT reconstruction

deficit. These lesions are surgically treated by performing a craniotomy around the previous fracture with the dura dissected from the bone edges and repaired in a watertight fashion.

Basilar skull fractures involve the bones of the skull base. These fractures must be recognized due to their relationship to other injuries and a tendency to extend into the auditory canals, leading to sensorineural hearing loss. These fractures can extend into the sinuses or be associated with a CSF leak, which may require surgery to prevent ongoing leaks or infection. In addition, a fracture into the petrous bone can cause a facial nerve injury or lead to a carotid artery dissection. An angiogram should be considered to rule out a dissection, which would then be treated with antiplatelet therapy, anticoagulation, or rarely endovascular stenting or surgery.

Epidural Hematoma

EDHs normally result from birth trauma in neonates or in older children from a localized blow to the head. Trauma associated with an epidural bleed can lead to a classic pattern of neurologic decline. A patient may have an initial loss of consciousness with subsequent recovery, known as the "lucid interval," and then a deterioration as the EDH enlarges. EDH results when an injury results in a tear in a meningeal artery or a venous structure that leads to the accumulation of blood in the space between the skull and the dura. Most EDHs are confirmed by head CT and have a classic convex shape that normally does *not* cross suture lines (Fig. 17.2a). Clinical suspicion needs to be high in patients with a skull fracture—EDH classically involves a skull fracture in the squamous temporal bone that tears the middle meningeal artery. However in children EDHs more commonly result from bone bleeding after a fracture rather than a middle meningeal artery injury. Even if the head CT fails to demonstrate a fracture, one is inevitably found intraoperatively.

Management of EDHs depends on physical examination findings and the size and location of the lesion. A patient with a decreased level of consciousness and a several-centimeter EDH is a neurosurgical emergency. Controversy exists when the patient has a GCS of 15 and is neurologically intact. Some neurosurgeons advocate conservative management for all intact patients regardless of size and location. Our practice is to intervene surgically on intact patients if the lesion is expanding on serial imaging or if the patient is complaining of severe or worsening headaches. We also have a much lower threshold to operate if the EDH is located in the middle fossa pushing on the temporal lobe due to the risk for uncal herniation.

Intraoperatively a craniotomy should be performed over the lesion (Fig. 17.2b). The craniotomy needs to be large enough to evacuate the hematoma and to localize and coagulate the bleeding blood vessels. The bone edges of the craniotomy should be waxed to prevent bone bleeding, and dural tack-up sutures can be placed to re-approximate the dura to the bone, thereby eliminating any dead space and reducing the risk of recurrence.

Subdural Hematoma

SDHs occur after trauma when blood collects between the dura and the brain. These lesions have a classic concave appearance by head CT but unlike EDHs, SDHs *do* cross suture lines (Fig. 17.3a). These are also much more common than EDH and usually do not require surgical intervention. In patients with a reliable neurologic exam, no coagulopathy or bleeding disorder, and a SDH that is not causing a great deal of compression, the patient can be monitored closely in the PICU.

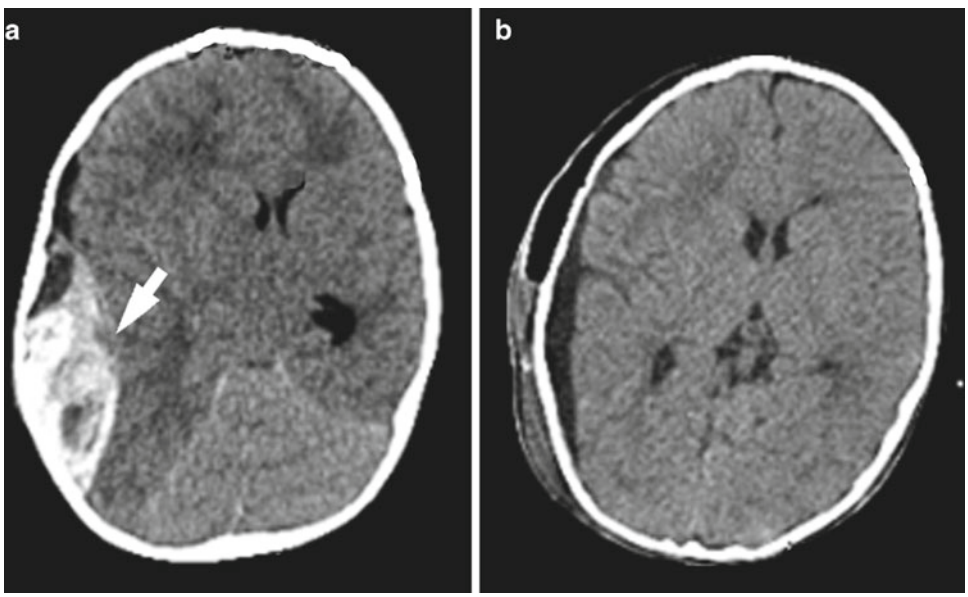

Fig. 17.2 Representative head CT of epidural hematoma (EDH). (**a**) Head CT image demonstrating a right temporal–parietal EDH. (**b**) Postoperative HCT demonstrating evacuation of the EDH

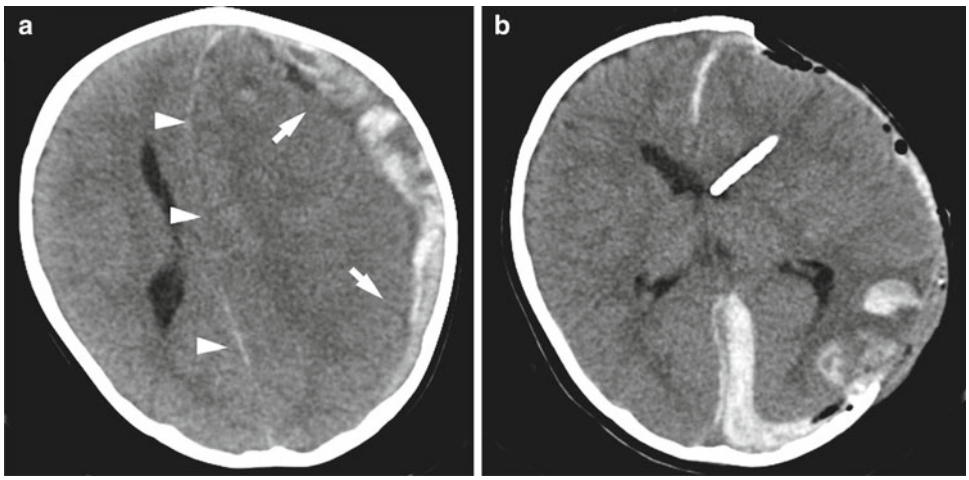

Fig. 17.3 Representative head CT of a subdural hematoma (SDH). (**a**) Patient is an 18-month-old boy who was a victim of abusive trauma with a large holohemispheric hemorrhage (*arrows*) and midline shift (*arrow heads*). Note that the blood crosses cranial sutures and that there are underlying cerebral edema, ischemic changes, and effacement of the ipsilateral ventricle. (**b**) Postoperative head CT after the patient was managed with a decompressive craniotomy, clot evacuation, and placement of a ventriculostomy. The ipsilateral ventricle is now visible, and the midline shift is much improved. There remains interhemispheric and intraparenchymal blood

Indications for surgical intervention (Fig. 17.3b) include significant mass effect and enlargement of the SDH. Decompressive hemicraniectomy should be considered even for small SDHs associated with significant unilateral cerebral edema. If all variables are controlled, the outcomes for patients with SDH are much worse than those with EDH, probably because they require injury to the brain for the blood to accumulate, while EDHs can occur in the absence of any brain injury, at least at the time of the initial insult.

Intraparenchymal Hematoma

Cerebral contusion or intraparenchymal hematomas (IPHs) are a common finding after head trauma (Fig. 17.4). These injuries commonly result from acceleration–deceleration injuries in which the brain strikes the inside of the skull. It is important to note that in head-injured patients, an IPH may enlarge with time, particularly 24–48 h after admission. This enlargement is described as "blossoming" and can lead to significant cerebral edema and increased ICP. A similar management strategy to SDH can be employed for IPH. In the absence of mass effect or cerebral edema, no surgical intervention is required. If medically intractable intracranial hypertension develops, the goal of surgical intervention is decompression, not necessarily complete evacuation.

It is important to establish a complete history of the trauma and assure that the cerebral contusion is consistent with the history. In patients with an unexplained IPH, a nontraumatic cause, such as a vascular malformation, infarct, or tumor, should be considered.

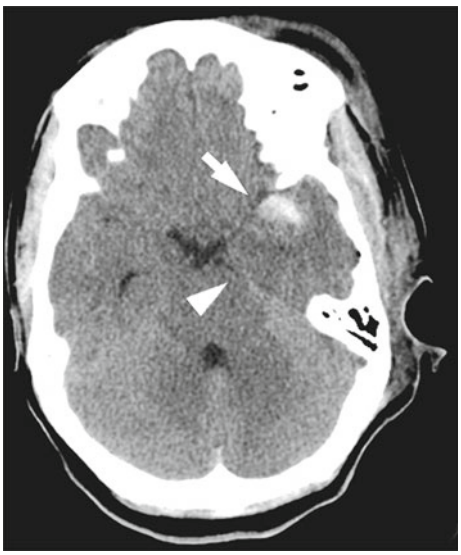

Fig. 17.4 Head CT of an intraparenchymal hemorrhage. Patient is a 14-year-old girl who was riding her bike without a helmet and was struck by an SUV. There is an intraparenchymal clot in the anterior temporal lobe (*arrow*) and uncal herniation (*arrowhead*). She was managed with an ICP monitor and medical therapy

TBI is a serious and potentially fatal condition in the pediatric population. These patients require prompt identification of the primary brain pathology and institution of correct therapeutic intervention to prevent or treat factors that promote secondary brain injury. The coordinated efforts of a multidisciplinary team are crucial for optimizing outcome (Fig. 17.5).

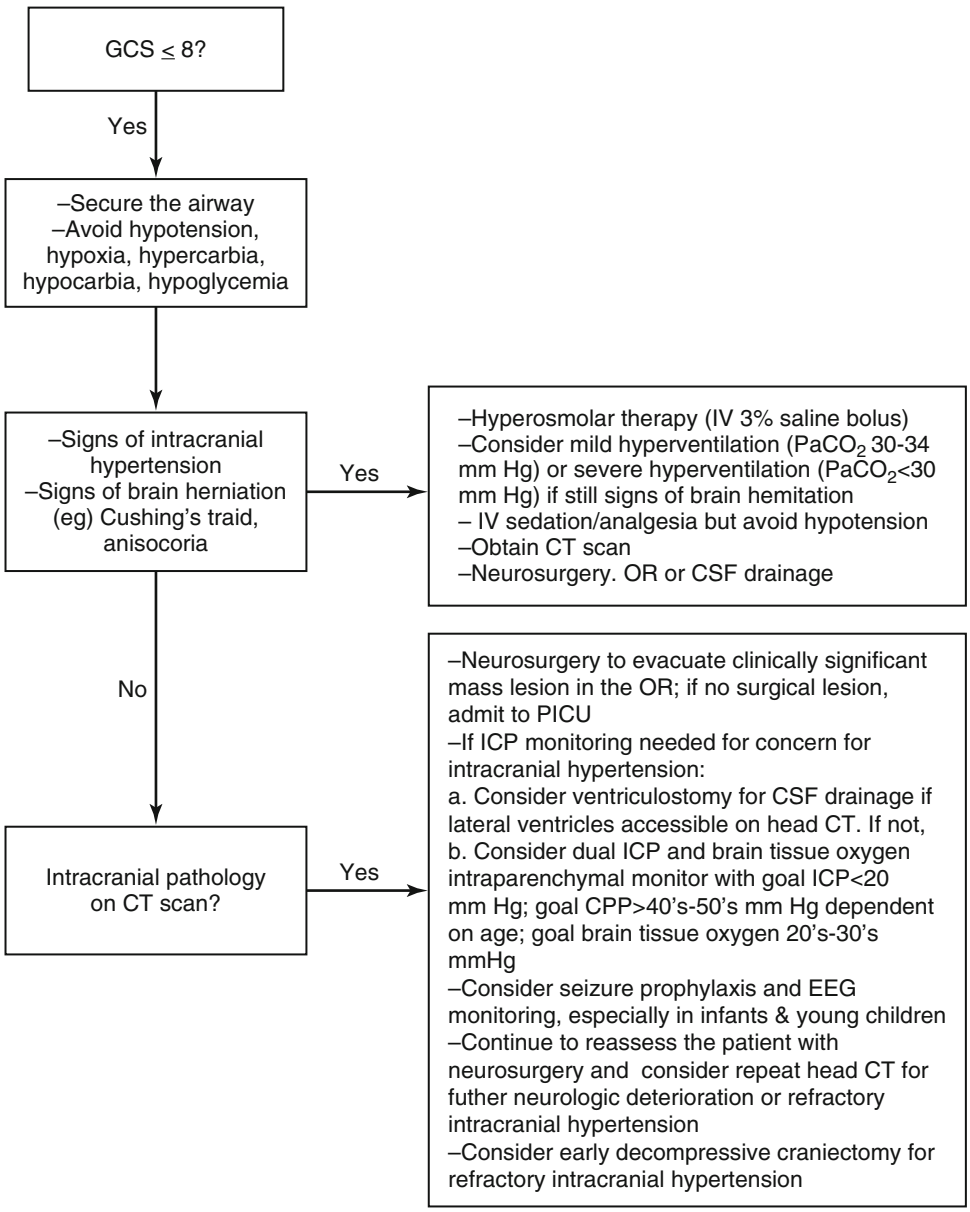

Fig. 17.5 Clinical pathway for acute management of severe pediatric traumatic brain injury (TBI)

Editor's Comment

We should be treating every child with a head injury according to standard ATLS protocols, with initial assessment of airway, breathing and circulation, and rapid but thorough primary and secondary surveys. Time is of the essence and the patient needs to undergo brain imaging as soon as possible. On the other hand, sending an unstable patient to the CT scanner is counterproductive and dangerous. Temperature should be regulated to avoid both hyperthermia and hypothermia. Despite its potential benefit in the case of spinal cord injury, corticosteroids appear to have no role in the management of TBI. The comatose patient (GCS <8) should be intubated prior to leaving the trauma bay, with careful in-line traction of the neck and minimal extension of the neck. An orogastric tube should be used to decompress the stomach; nasogastric tubes are avoided due to the possibility of a cribriform plate fracture and subsequent intracranial penetration. During the primary survey, the scalp should be carefully inspected and palpated. Scalp lacerations can bleed extensively and in a small child this can lead rapidly to exsanguination. A seemingly innocuous puncture wound of the scalp or forehead in an infant can be an indication of penetrating head injury. To avoid dangerous intracranial pressure elevation, seizures should be treated aggressively with rapid IV administration of fosphenytoin. Finally, it should be kept in mind that brain injury can result in significant coagulopathy due to release of brain tissue thromboplastins, which can have significant systemic consequences.

There seems to be a very low threshold to recommend head CT in children with a potential head injury. Although regional and institutional protocols vary, for the most part, any child with evidence of injury above the clavicles, a suggestive mechanism, or a history of loss of consciousness or even the slightest mental status change or neurologic deficit will get a scan. Although a period of observation with serial neurologic assessment is probably just as safe and avoids unnecessary exposure of the developing brain to ionizing radiation, there is a widespread belief that frequent scanning is the best way to avoid a missed injury (and a lawsuit). MRI is also being used with increasing frequency to assess the degree of diffuse axonal injury and previously underappreciated cervical ligamentous injuries. Whether this is of any clinical significance in most cases is unclear. Nevertheless, head CT remains the initial study of choice in the assessment of the child with acute brain injury.

Suggested Reading

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Neck Injuries

18

John K. Petty

Few endeavors in the care of a child require immediate assessment, sound judgment, and technical skill like neck trauma. The successes in this arena are obvious and the failures more so. In any trauma situation, care begins with the airway. Mismanagement of the airway is the most important preventable cause of death in acute pediatric trauma care. Operative pediatric neck trauma is uncommon. Few pediatric surgeons would say they have "seen it all" with regard to operating on emergent neck injuries. Fortunately, clear-headed application of foundational principles of surgical trauma care can bring order to chaotic situations.

The pediatric neck is different. Compared to the adult neck, it is proportionally shorter. The musculature in the child's neck is less well developed, allowing more force to be transmitted to the internal structures. The larynx of a child sits behind the mandible at C3–C5 and is afforded a measure of protection by the mandible, whereas in an adult, the larynx sits lower in the neck (C6–C7) and is more exposed. The cartilage of the larynx and tracheal rings are more pliable and therefore less likely to fracture. However, because of the smaller diameter of the pediatric airway, it is much more vulnerable to partial or complete obstruction from edema, contusion, chemical irritant, or hematoma. The vasculature has greater elasticity and less atherosclerosis; thus, it is more likely to transmit blunt forces rather than be disrupted by them. Finally, the bones are less calcified, favoring ligamentous and soft tissue injury over bony fracture, particularly in regard to the cervical spine.

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Principle 1: It Begins and Ends with the Airway

Having an organized system in place for the management of a child's airway will favor successful care once the injured child arrives in the trauma bay. This system involves personnel, equipment, and assigned roles. Neurotrauma is the most common reason for endotracheal intubation of an injured child in the field or in the trauma bay. Various members of the trauma team may have the skill set to intubate a neurologically altered child. However, in the child with direct neck injury, the value of effective spontaneous or bag-valve-mask ventilation should not be disregarded and, in fact, should be considered success, not failure, in pediatric neck trauma.

In the circumstance of a child with an anatomically unstable airway, priority for airway management should be deferred to the most experienced airway expert in the room. Depending on the practice environment, this might be an anesthesiologist or even an otolaryngologist. A child with an anatomically unstable airway who might need a surgical airway should be taken emergently to the operating room if at all possible. This is especially true in children with isolated neck trauma. In the child with the anatomically unstable airway, medications for rapid sequence intubation and unsuccessful attempts at intubation can convert a tenuous but manageable situation into a fatal situation. For the child with traumatic stridor, a failed attempt at intubation in the ED creates trouble—take that child directly to the operating room.

For pediatric trauma, placement of a surgical airway in the field or in the ED should be resisted for the same reason. In the event that an airway is lost before the operating room, a needle cricothyroidotomy is typically a better invasive option than an incision airway. The indistinct landmarks and the pliability of an infant or toddler airway make an incision airway extremely difficult and potentially dangerous. Needle cricothyroidotomy is performed using a 12- or 14-gauge angiocatheter. The cricothyroid membrane is palpated and the airway is stabilized with the nondominant hand. A small skin nick may allow smoother passage of the catheter into

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the airway. The catheter is initially introduced at a 45° angle until air is aspirated. The catheter is advanced over the needle caudally. Once the needle is removed, the catheter is connected to a high-flow oxygen source. This is accomplished using oxygen tubing with a side hole cut into it. Alternatively, a 3-mL syringe (plunger out) can connect to a 7-mm endotracheal tube adaptor, which can in turn be connected to bag-valve ventilation (Fig. 18.1). A patient with a needle cricothyroidotomy should then be taken urgently to the operating room for a formal tracheostomy, as it is difficult to achieve adequate ventilation through the catheter. In the situation of an incisional cricothyroidotomy, the patient should have a formal tracheostomy within 24–48 h to avoid scarring of the airway.

Initial Evaluation

History taking in pediatric trauma should be focused and injury driven. The child's prehospital physiology frames the child's care. Prehospital personnel or the child's caregivers can inform the trauma team about the time of the injury, neurologic alterations, respiratory compromise, blood at the scene (and prehospital hemorrhage control), suspected additional injuries, and features of the injury mechanism. For dog attacks, it is helpful to know if the dog was a pit bull (or another highly injurious breed) and if the animal has been vaccinated for rabies. For hangings, it is important to know if there have been signs of life since the event and what has been the patient's best neurological exam.

Physical examination can reveal patient's injuries early in the evaluation. Perhaps the most important point of emphasis here is to actually *do* a physical examination. In the physiologically unstable polytrauma patient, it is not uncommon for the neck examination to be little more than an early-level resident palpating the thyroid cartilage through the small opening in the cervical collar and declaring, "Trachea midline!" Neck examination is part of the airway evaluation, and during the primary survey, the surgeon should be attuned to stridor, dysphonia, cough, swallow, gag, and oral bleeding. With the patient's head held in a stable position, the cervical collar should be opened. Patients with penetrating injuries might not have or even need a cervical collar. The wounds of penetrating injuries are often readily apparent but might be

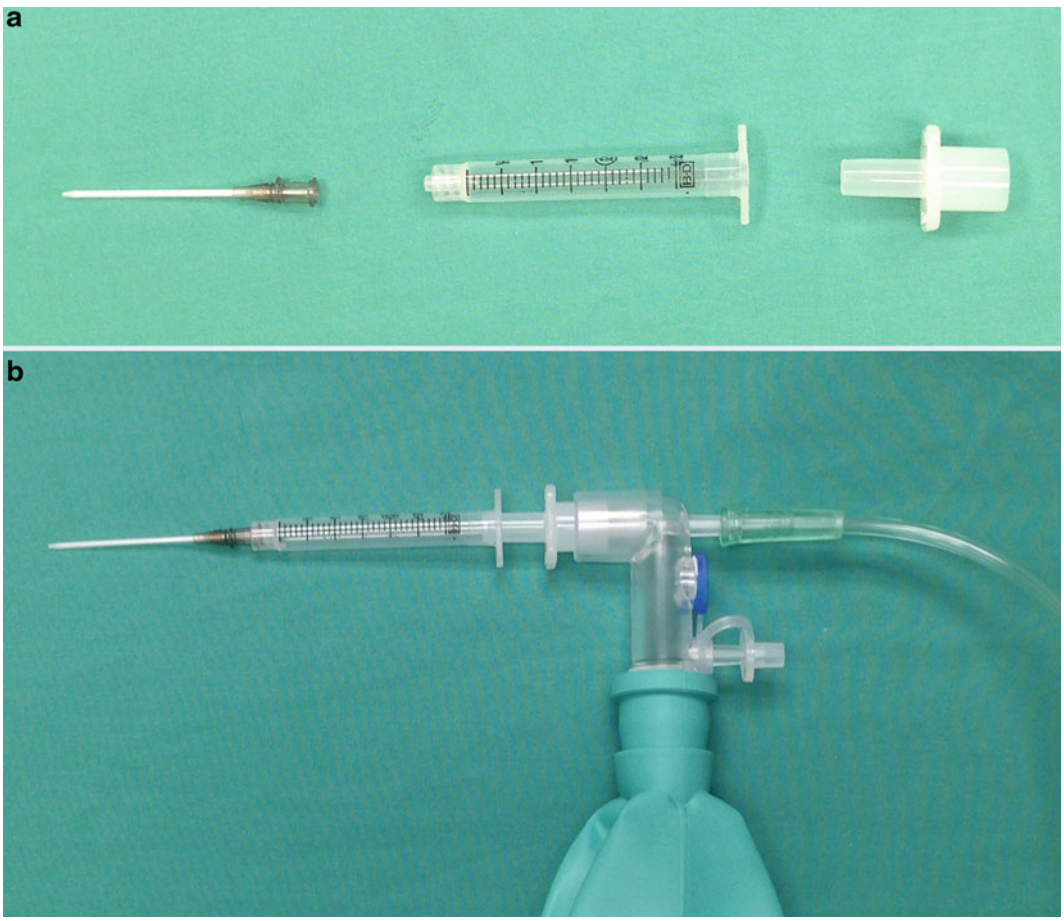

Fig. 18.1 Needle cricothyroidotomy ventilation. (**a**) Angiocatheter connects to a 3-mL syringe with a 7.0-mm endotracheal tube adaptor. (**b**) These assembled components connect to bag-valve ventilation. Forceful compression of the bag is required to overcome the resistance of the angiocatheter

hidden in skinfolds or behind hairlines. The foreign body can be palpable or visible. Vascular injury is suggested by lacerations with bleeding, hematomas, or bruits (hard to hear in the trauma bay). Aerodigestive tract injury might create a sucking wound, subcutaneous emphysema, tracheal displacement, or instability. Neurologic examination should include a quick cranial nerve assessment with particular attention to pupils and extraocular movement, voice, swallow, tongue, and face motion. Though not cranial nerves, phrenic nerve (respiratory effort and motion) and sympathetic chain (Horner syndrome) function should receive comment in the secondary survey. *If you are taking a child to the operating room for neck exploration, the time to sort out if she or he has functional nerve injury in the neck is before induction of anesthesia, not in the recovery room.* Also, findings on physical examination outside of the neck may indicate injury in the neck: focal or lateralizing findings on the general neurological exam (cerebrovascular injury), severe midface fractures (risk for vascular injury), paraplegia or quadriplegia (cervical spine injury), or tissue emphysema outside the neck (aerodigestive tract injury).

Zones of the Neck

From a trauma standpoint, the neck is divided into three zones: Zone I extends from above the sternal notch to the cricoid cartilage, Zone II extends from the cricoid cartilage to the angle of the mandible, and Zone III extends from the angle of the mandible to the skull base (Fig. 18.2). This classification is intended to guide the surgeon as to operative strategy, with Zone II injuries being accessible through neck incisions; Zone I injuries might also require chest incisions; Zone III injuries can require mandible disarticulation or skull base surgery. For vascular injuries in particular, the conventional wisdom would suggest that Zone II injuries should be managed operatively, while Zone I and Zone III injuries should be addressed with interventional radiology. This classification has some value as a rule of thumb for operative management but also as a guide for the use of imaging. CT angiography (CTA) of the neck is a valuable diagnostic tool to assess for vascular injury. A child with a penetrating injury to Zone I of the neck should have a CTA of the chest and neck. Similarly, a child whose injury is in Zone III should have a CTA of the head and neck.

Despite its helpfulness as a general framework, the classification of the zones of the neck is by no means a definitive guide as to operative or nonoperative management of neck injuries. The cricoid cartilage as a landmark migrates caudally throughout childhood relative to the vertebral bodies, so injuries inferior to the cricoid cartilage may indeed be accessible through a neck incision in a pediatric patient. In the absence of a cervical spine injury, the neck of a child can be extended, providing additional access to the mediastinum. Pediatric surgeons are familiar with this principle from the repair of H-type tracheoesophageal fistula. Such fistulas can usually be repaired through a neck incision, even when the fistula is radiographically in the mediastinum. Regarding vascular injuries, interventional radiology techniques are also effective in Zone II of the neck, particularly with regard to vertebral artery injuries but also for carotid artery injuries. Finally, a patient's injuries themselves may take the surgeon out of the intended zone. Missile tracts are not always straight horizontal lines. The anatomic "fault line" of an injury to an artery or the esophagus is longitudinal dissection within the wall. Also, the ends of transected vessels and nerves retract following injury, so additional exploration cephalad or caudad to the site of injury is sometimes required.

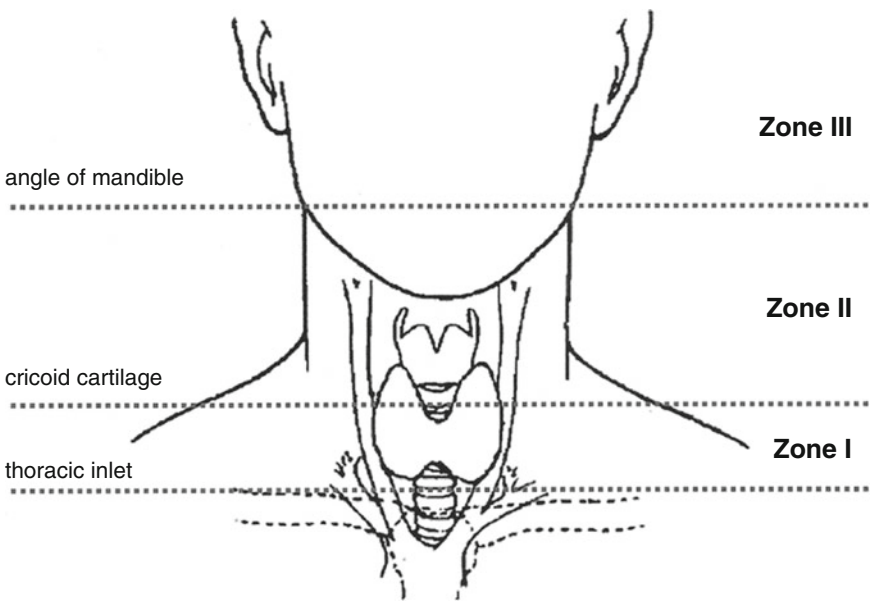

Fig. 18.2 Anatomic zones of the neck (Modified with permission from Bee TK, Fabian TC. Penetrating Neck Trauma. In: Cameron JL, editor. Current Surgical Therapy, 7th ed. St. Louis, Mosby, 2001)

Principle 2: Image for a Reason, and You Will Image Reasonably

Few topics in pediatric trauma are as contentious as the use of ionizing radiation for diagnostic imaging. Although the "pan scan" (CT of the head, cervical spine, chest, abdomen, and pelvis and neck CTA) may be routine in the evaluation of the adult blunt trauma patient, this approach should be avoided in pediatric trauma. Radiation exposure early in life is associated with an increased lifetime risk of cancer, leukemia, and thyroid cancer in particular. This risk is dose dependent and is associated with age at exposure. Thus, limiting radiation exposure in the pediatric trauma bay is an important principle to be diligently maintained. That said the absolute cancer risks in children with diagnostic radiation exposure are small. With regard to neck CT, estimates vary between 12 and 700 additional cancers per 100,000 children 0–6 years old who receive a neck CT. The vast majority of children will not be harmed by diagnostic imaging. This small risk must be weighed against the risk of missing an occult but serious injury. The balance between these risks is challenging in the context of a specific patient.

Ultimately it is fair to say most pediatric trauma patients do not need CT soft tissue imaging of the neck. Soft tissue CT of the neck should not be used as a screening tool. Rather, soft tissue CT of the neck should be used to assess an injury that is suspected on the basis of history or physical examination. A physician should have a reason for ordering a soft tissue CT of the neck. As a general rule of thumb, if you assess that a child has a 10 % risk of a serious injury to the neck or higher, it is appropriate to obtain a CT. (In actuality, the risk-benefit threshold for neck CT is closer to 1 %, but this accounts for additional radiation the patient may sustain during their evaluation.) Clearly, neck CT can be very helpful at times. It could clarify the source of a neck hematoma in a stable patient or illuminate operative planning in the stable patient with penetrating injury. Even using the 10 % "gut check" for imaging, most CT scans will be negative. The fact of a negative study does not mean that it should not have been ordered, as long as the reasons for ordering it were sound. Whenever it is safe and appropriate, the use of imaging without ionizing radiation (US, MRI) is preferred if it is practical and safe.

Management Challenges

Blunt injuries to the carotid and vertebral arteries (blunt cerebrovascular injury, BCVI) are uncommon, affecting perhaps <1 % of blunt pediatric trauma patients. Children with these injuries sometimes present with or subsequently develop strokes. The early use of anticoagulation or antiplatelet therapy might slow the progression of or even prevent strokes in these patients. The infrequency of BCVI in children and the caution surrounding the use of neck CTA (radiation to a child's thyroid gland) can create a feeling of nihilism around stroke prevention in pediatric trauma. There is support in the literature for the use of the Memphis criteria in pediatric trauma patients (Table 18.1). Patients who meet one or more of these criteria should be screened for BCVI, typically with neck CTA. Nearly 1 in 4 children with one or more Memphis criteria is found to have BCVI on CTA. Children with BCVI who are treated had a lower rate of stroke than those who are not treated. Although the Memphis criteria are currently the most evidence-based guide to screening for BCVI in children, they are not comprehensive. Children can have BCVI in the absence of Memphis criteria and CTA may be appropriate in other circumstances. Anticoagulation carries risks. The use of anticoagulation should be tempered by the risk of bleeding associated with other injuries and considered in the context of the patient's overall condition.

A *seat belt sign* forms during a severe motor vehicle crash when the shoulder strap creates a contusion or an abrasion across the anterior neck of a restrained child, often when it is improperly high. Because of the force transmitted, concern for BCVI is appropriate. A simple seat belt sign in the absence of other abnormal findings does not correlate significantly with BCVI. While the seat belt sign itself is not a sufficient indication for CTA in most patients, a seat belt sign associated with other abnormal findings should prompt a CTA to evaluate for BCVI. These additional abnormal findings would include the presence of one or more of the six Memphis criteria as well as abnormal GCS, intracranial hemorrhage, neck hematoma, significant thoracic injury, or fracture of the first rib or clavicle. It is probably reasonable to evaluate the child with the isolated seat belt sign using duplex ultrasound, though data to support this approach are not well developed.

Survival of a *hanging* event is a function of duration of anoxia. Cardiac arrest and unresponsiveness following establishment of an airway portend a poor outcome and consideration should be given to cessation of resuscitative efforts in the trauma bay. Patients who respond to resuscitation should receive a CT of the neck to evaluate for hyoid bone fracture and laryngotracheal trauma, in addition to imaging of the

Table 18.1 Memphis criteria

1.	Anisocoria
2.	Basilar skull fracture
3.	Cervical spine injury
4.	Neck soft tissue injury
5.	Le Fort II or III fracture
6.	Neurologic examination findings unexplained by brain imaging

Children with one or more of these criteria should be considered for CTA to diagnose blunt cerebrovascular injury

cervical spine. Furthermore, these patients may benefit from early ENT evaluation, as they are at risk for glottic and subglottic injuries.

Subcutaneous emphysema in the soft tissues of the neck can often be appreciated on physical examination as soft tissue swelling and crepitus and might be detected in smaller amounts by imaging. This is a vexing finding as it could indicate an injury to the airway or esophagus or it could be an interesting but innocuous finding, representing rupture of distended alveoli at the moment of blunt trauma with subsequent tracking of air along the soft tissues of the mediastinum and neck. Children with acute airway or esophageal injuries need urgent operative management, while children with benign tissue emphysema are better left alone. Management decisions should be based on additional findings. Symptomatic patients (stridor, dyspnea, dysphagia, odynophagia) should proceed urgently to the operating room for a secure airway, panendoscopy (laryngoscopy, bronchoscopy, esophagoscopy), and possible neck exploration to repair identified injuries. An esophagram should be performed postoperatively if the esophagoscopy is negative.

The finding of subcutaneous emphysema should not be automatically dismissed. Asymptomatic children should be observed for 24 h in a setting where urgent airway and operative resources are available. Inasmuch as a delay in diagnosis of an esophageal injury is associated with a more challenging repair and potentially worse outcome, it is probably reasonable to obtain an esophagram on these patients, though this point is controversial. Patients who develop symptoms during the period of observation should undergo panendoscopy, esophagography and repair of identified injuries. Finally, although the subcutaneous emphysema itself does not typically cause symptoms, the rare patient will have progressive soft tissue emphysema to the point of respiratory distress. Not all of these patients will have a source of the tissue emphysema identified even after a comprehensive imaging and endoscopic evaluation.

Children are frequent targets for *dog bites*. Compared to adult patients, children are more likely to sustain injuries to the head, face, and neck. It is important to remember that *dog attacks in children are a combination of blunt and penetrating trauma*. Attacking dogs will often crush and shake their victims, with consequent blunt forces exerted to the head, cervical spine, and chest. Although the penetrating injuries will need to be assessed and managed on their own merits, the most life-threatening injuries are typically related to the blunt component of the trauma. Small children with dog bites to the neck should have cervical spine precautions maintained and should have a low threshold to receive head CT.

Expectant Management of Penetrating Injuries

Classic teaching regarding the asymptomatic patient with a penetrating neck injury has been to proceed urgently to the operating room for neck exploration. Over the past 20 years, this teaching has been challenged, favoring imaging and endoscopy to diagnose injuries and reserving neck operation as a therapeutic undertaking rather than a diagnostic one. Currently, expectant management of penetrating neck trauma is widely practiced. It is no longer the controversy that it once was. Components of expectant management include panendoscopy (laryngoscopy, bronchoscopy, esophagoscopy), esophagography, and CTA of the neck. CTA has supplanted interventional angiography, as modern high-resolution CTA is accurate, quick, and noninvasive and does not carry a stroke risk. Interventional angiography should be used for therapeutic maneuvers or to clarify equivocal findings on CTA. Though controversial, some authors advocate early imaging alone followed by a period of close observation. The decision about whether or not to proceed with panendoscopy is then based on imaging and observation findings.

Principle 3: Operate "ABCDE" for Success in Neck Trauma

The mnemonic ABC has become the standard worldwide for the care of any individual who is injured or acutely ill. The neck contains in its multiple compartments many anatomic structures – the dysfunction or disruption of which may impact the overall well-being of the patient in critical ways. We have found it useful to use a modification of the classic paradigm when evaluating and treating the child with a neck injury.

A: Airway, Angiography, and Ask

A definitive airway is a cuffed tube in the trachea (Table 18.2). Patients who have been temporized with bag-valve-mask ventilation, airway adjuncts, or needle cricothyroidotomy should have a surgical tracheostomy if they cannot be orotracheally intubated. Key points for tracheostomy in children are to maintain dissection in the midline and to avoid damaging the cricoid cartilage. Patients with open laryngotracheal injuries may be temporarily intubated through the wound if an orotracheal airway cannot be achieved but these patients should still proceed to formal tracheostomy.

Children with certain cervical vascular injuries might be optimally managed in the angiography suite rather than the operating room. The best time to make this decision is before the patient is brought to the operating room. The question of

Table 18.2 ABCDE strategy for neck exploration in pediatric trauma

A—airway, angiography, ask
B—bleeding
C—central compartment, contralateral side
D—defend suture lines, drain
E—endoscopy

angiography should be asked and answered early. Arterial injuries in Zone I and Zone III are extremely difficult to repair operatively and therefore prompt interventional radiology management is preferred. Similarly, vertebral artery injuries are extremely challenging to expose and manage operatively. These are far better managed with interventional radiology. Carotid artery injuries in Zone II are also sometimes better managed successfully with interventional radiology.

Early consultation with additional experts is a sign of wisdom, not weakness. The trauma surgeon should make an early assessment of the patient's injuries, the available resources, and the interventions needed to care for the injuries. In certain circumstances the patient might be best served with a second attending trauma surgeon, an otolaryngologist, a vascular surgeon, a neurosurgeon, a brachial plexus microvascular surgeon, or a cardiothoracic surgeon. Under these circumstances it is senseless not to call for expert assistance.

B: Bleeding

Exploration for bleeding is best approached through a sternocleidomastoid incision for unilateral exploration and a collar incision for bilateral exploration. Dissection proceeds along the anterior border of the sternocleidomastoid muscle to retract the muscle posteriorly and gain access to the carotid sheath. Five crossing structures are often encountered when exposing the contents of the carotid sheath: the omohyoid muscle, the ansa cervicalis, the common facial vein and its tributaries, the middle thyroid vein, and the inferior thyroid artery. Each of these structures may be divided or retracted as needed. The common facial vein lies very close to the carotid bifurcation. If the indication for neck exploration is a traumatic arteriovenous fistula, it is advisable to obtain proximal and distal control of the vessels before entering the hematoma associated with the fistula. This might not be an option if the indication for operation is an expanding neck hematoma.

When dissecting within the carotid sheath, it is important to keep in mind that the vagus nerve runs within it and that the nerve fibers that will form the recurrent laryngeal nerve have not yet departed—an injury to the vagus nerve in the neck is tantamount to an injury to the recurrent laryngeal nerve. Injuries to the internal jugular vein or its tributaries are treated with ligation, though it might also be reasonable to repair some internal jugular vein injuries. Arterial injuries are addressed after obtaining proximal and distal control of the common carotid, external carotid, and internal carotid. It is worth bearing in mind that distal control is sometimes fastest with an endoluminal Fogarty catheter rather than with external dissection and a vascular clamp. Primary intima-to-intima repair is preferable for carotid injuries. However, ligation is an option for common carotid injuries, external carotid injuries, and internal carotid injuries with good distal back bleeding. Children do not have atherosclerosis and they generally tolerate vascular ligation well.

For large arterial injuries, destructive injuries, or injuries that will require an interposition graft for repair, it is a good idea to place a *temporary intravascular shunt* if possible. This maneuver will buy some time to allow you to mobilize the ends, to harvest vein for interposition, or to perform other aspects of the exploration while awaiting the arrival of an additional expert. Though rare in pediatric trauma, there are times when placement of an intravascular shunt is prudent as a damage-control technique, allowing for additional resuscitation of the multiply injured patient before proceeding with definitive repair.

The vertebral artery is difficult to approach operatively, particularly in the setting of active bleeding. In the base of the neck, the vertebral artery lies posterior to the common carotid artery. If brisk bleeding is noted near the transverse processes of the cervical vertebrae, the bleeding can be mitigated with bone wax tamponade rather than unroofing the bone over the transverse foramen to access the vertebral artery for ligation. Vertebral artery injuries are better managed with angioembolization than with operative ligation.

C: Central Compartment and Contralateral Side

The central compartment of the neck contains the larynx, trachea, and esophagus. The esophagus can be approached by retracting the carotid sheath contents laterally and proceeding toward the palpable orogastric tube and the anterior longitudinal ligament overlying the vertebral bodies. The recurrent laryngeal nerve runs in the tracheoesophageal groove and should be treated delicately. Perforations of the esophagus should be debrided of devitalized tissue and closed in a single full-thickness layer. Perforations of the pharynx above the thyroid cartilage will generally heal on their own, so extensive dissection to expose and repair these injuries is not necessary. Simple tracheal lacerations should be primarily closed with monofilament absorbable suture. Nonabsorbable suture in the airway should be avoided as it fosters airway granulation tissue formation that can create airway compromise much later. Large tracheal injuries and

laryngeal injuries should be managed with the help of an experienced otolaryngologist. Postoperative care of aerodigestive tract injuries should include a short course of antibiotics and a longer course of proton pump inhibition.

If a penetrating injury traverses the neck, the side opposite the index injury should also be explored. Similarly if the findings at unilateral exploration suggest more extensive injury, particularly regarding injury to the contralateral wall of the esophagus or trachea, the surgeon must have a low threshold to explore the other side. An anterior sternocleidomastoid incision can be converted to a modified collar incision to provide access to the contralateral side.

D: Defend Suture Lines and Drain

Suture lines of the esophagus or the trachea can be tested for airtightness by intraluminal inflation, while the suture line is immersed in saline. Additional sutures can usually be placed if leaks are identified. Suture lines in separate but adjacent structures are at risk over time of erosion and creation of a fistula. This is particularly concerning for adjacent suture lines of the trachea and esophagus or of the carotid artery and internal jugular vein. Healthy tissue should be interposed between the two suture lines. A pedicled segment of the strap muscle or sternocleidomastoid is a good option. If extensive muscle injury in the region makes muscle interposition unreasonable, consider the use of commercially available acellular dermis or comparable biologic tissue substitute.

Placing a closed-suction drain in the operative field is usually a good idea. This can manage small salivary leaks until they heal. A drain also allows egress for small air leaks or accumulated soft tissue emphysema. In addition a drain can help manage a chyle leak and facilitate nonoperative delayed closure. A neck drain will not prevent a neck hematoma, so hemostasis should be ensured prior to closure of the wound.

E: Endoscopy

Endoscopy is not necessary in all neck explorations for trauma, but it is worthwhile to ask the question in the operating room. Tracheobronchoscopy can be helpful early in the operative course. Once an airway has been secured, flexible bronchoscopy helps determine the location and extent of an injury, allows suctioning of secretions or blood, and provides guidance of the tracheal tube cuff below an airway repair. Similarly, flexible esophagoscopy can facilitate assessment of injuries and subsequent repairs. Finally, early consultation with an otolaryngologist allows for prompt upper airway evaluation, laryngoscopy, and repair. The value of early collaboration with an otolaryngologist for airway injuries cannot be overstated. Airway injuries may have downstream sequelae that are best managed by an otolaryngologist.

Summary

Neck injuries are always potentially very serious and require a thoughtful and meticulous approach. Surgical therapy is rarely needed but needs to be in the armamentarium of the pediatric trauma surgeon. Imaging and adjuncts such as endoscopy and interventional radiology should always be considered when surgical exploration or misguided attempts at surgical repair could be avoided. Finally, regardless of experience or self-confidence, the trauma surgeon should never hesitate to ask for help from other specialists who can assist in the assessment or repair of a serious neck injury that involves the airway, large vascular structures, or neurologic structures.

Editor's Comment

Neck injuries are appropriately associated with grave concerns over missed injuries and so prior protocols have emphasized aggressive attempts to exclude injuries with invasive diagnostic procedures and a very low threshold for surgical exploration. Modern medical imaging has helped to minimize both missed injuries as well as iatrogenic trauma. Based on the mechanism and a thorough physical assessment for soft signs of injury to the vascular and aerodigestive structures of the neck, one can now use Doppler US, CT, CTA, or MRI to produce accurate and detailed images of the complex anatomy of the neck.

It is becoming increasingly common to detect intimal injuries of the carotid artery after blunt trauma or deceleration injuries of the neck. Most are minor (slight irregularity, small thrombus) and can be managed safely with anticoagulation and follow-up angiography. More serious injuries (transections, pseudoaneurysms, significant occlusive thrombus) should be treated surgically. If the vessel is inaccessible or completely occluded by thrombus, the patient is probably best treated with anticoagulation. Consultation with an experienced interventional radiologist is critical as endovascular techniques such as stenting or embolization of smaller vessels might be considered.

The surgical approach is usually best done through a transverse incision in one of the skin creases, though occasionally a traditional oblique carotid incision is necessary. The exposure should be generous and all structures should be dissected carefully to avoid iatrogenic nerve injury. The thigh should be sterilely prepared in case saphenous vein graft is needed. If the patient is stable, a brief rigid bronchoscopy and esophagoscopy before intubation can be very useful and

should be part of the standard surgical approach. Vocal cord position and movement should be documented before exploration is undertaken. Vascular injuries are treated using standard principles such as proximal and distal control and direct suture repair.

Patch repairs can be performed with autologous vein. The external jugular vein can be used but is thin and therefore needs to be doubled (by eversion) to prevent aneurysm. Postoperative anticoagulation or aspirin therapy should be considered for complex repairs. Most pharyngeal or cervical esophageal injuries can be treated nonoperatively or with simple drainage, though associated airway injury needs to be excluded. Airway injuries can usually be treated with simple direct repair, but intraoperative control of the airway can be treacherous and requires coordination with the anesthesiologist and a carefully planned approach, including consideration of a fallback position (ventilating bronchoscope, tracheostomy, ECMO) in the event of an airway catastrophe. A multidisciplinary approach that includes an adult vascular surgeon, otolaryngologist, neurosurgeon, or oral surgeon should also be considered.

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Spine Trauma

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Taryn M. Bragg and Robert W. Letton Jr.

The anatomic and biomechanical properties of the pediatric spine are unique. Ligamentous laxity and cartilaginous bone are key reasons the pediatric spine is more flexible and thus more resilient to injury. Anatomic factors that contribute to increased mobility include the shallow nature of the occipital condyles, horizontal orientation of the facet joints, small uncinate processes, undeveloped uncovertebral joints, and laxity of the posterior capsules and cartilaginous junction between the vertebral bodies and their end plates. In addition, the relative size of the head compared to the spine also creates a fulcrum leading to different patterns of pediatric cervical spine injuries.

The overall incidence of spinal column injury in children is low, with rates varying from 1 to 3 %. However, 80 % of pediatric spinal trauma occurs in the cervical spine. In children less than 5 years old, the highest rates of injury involve the occiput to C3. These injuries are commonly seen in association with traumatic brain injury. Thus any child with TBI should be screened closely for associated spine injury and immobilized immediately at the scene. In children older than 10 years, lower cervical spine injuries are more common.

The mechanism of injury in pediatric patients varies with age. In children ages 0–9 years, the predominant cause of injury occurs in conjunction with motor vehicle accidents (~50 %), falls (15 %), and child abuse (up to 20 %). In older children, motor vehicle accidents remain the highest percentage, followed by falls and sport-related injuries. Also, older children are more likely to have subaxial, thoracic, and lumbar spine injuries. Aside from non-accidental injury, the vast majority of cervical spine fractures occur because the child was either unrestrained or incorrectly restrained.

Children with cervical spine injuries are more likely to have neurological injury. The mortality rate of pediatric patients with cervical spine injuries ranges from 15 to 20 %. Common signs of spinal cord injury include absence or asymmetry of the deep tendon reflexes, paralysis, and clonus, but these can be delayed in presentation. There may be a transient (24–72 h) period of "spinal shock" defined by paralysis, areflexia, and hypotonia, which is usually followed by return of reflexes and progressive spasticity. There is no literature to support the use of corticosteroids in children. In fact, current guidelines for the management of acute cervical spine and spinal cord injuries also recommend against use of steroids in adults.

The incidence of spinal injuries has two peaks: one around 5 years of age and the other in those older than 10 years. Spinal cord injury without radiological abnormality (SCIWORA) usually occurs in children less than 8 years of age. SCIWORA describes an acute spinal cord injury that can result in sensory and/or motor deficit without radiographic evidence of vertebral fracture or alignment abnormalities. Though the concept was proposed in 1907, the acronym SCIWORA was coined in 1982. The incidence in children with a spinal cord injury has been reported as high as 20 % but falls dramatically to <1 % in adults. Hyperextension coupled with hypermobility is thought to result in momentary dislocation followed by spontaneous reduction, resulting in a spinal cord injury with a normal appearing vertebral column. Plain radiographs and CT scan are usually normal, but MRI will often reveal signs of trauma, such as T2 signal change within the cord. Children with SCIWORA can develop paraplegia up to 4 days after the injury. The upper cervical spine is more commonly involved in children younger than 3 years due to the orientation of the facets, ligamentous laxity, and relative size of the head compared to the spine. This hypermobility is often associated with more significant injuries. Thoracic SCIWORA is less common because the splinting effect of the rib cage prevents

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the thoracic spine from forced flexion or extension. The lumbar spine is very rarely affected, as the spinal cord normally ends at L2.

If at any time the neurologic examination of a child with a history of trauma is abnormal, the child should be assumed to have a spinal cord injury and should be immobilized appropriately. If plain radiographs and CT scans show no evidence of fracture or malalignment, neurosurgery or orthopedics should be consulted and MRI scans should be obtained. Likewise, if a child is unconscious after injury, rigid immobilization should be maintained until proper imaging is obtained.

Diagnosis

While the presence of a neurologic deficit facilitates the diagnosis of an underlying injury, it can be difficult to detect these deficits in children with multiple injuries. Spinal cord injuries sometimes cause significant neurogenic shock, characterized by hypotension, bradycardia, hypothermia, and peripheral vasodilation. Other signs of spinal cord injury include paradoxical breathing, priapism, and Horner syndrome. Severe cord injury results in symmetric flaccid paralysis and sensory loss. Lesser injuries can result in transient dysfunction of the limbs, bowel, or bladder. Any history of transient neurologic dysfunction regardless of duration must be recognized and evaluated further.

A child who is alert (and not intoxicated) and has no midline spine tenderness, distracting injury, or history of transient neurologic dysfunction can be cleared clinically without radiographs. All other children should have their spine immobilized with an appropriately fitted cervical collar until they can be cleared clinically and radiographically. Due to the size of the occiput relative to the rest of the body, a pediatric spine board should have adjustable padding that allows the torso to be elevated with respect to the head, thus keeping the cervical spine in a neutral position and preventing excessive anterior cervical flexion.

There are a number of normal anatomic variants and radiographic anomalies associated with the pediatric spine that can confuse the diagnosis. The presence of multiple ossification centers and complex synchondroses in the spine can result in the misdiagnosis of fracture. Pediatric vertebral bodies often have a physiological wedge shape, which can mimic compression fractures. Physiological pseudosubluxation is commonly noted in children less than 8 years of age and can mimic ligamentous injury and dislocation. The prevertebral space and atlanto-dental interval may appear widened. Interpretation of soft tissue anatomy can also be more difficult in children as the posterior pharyngeal soft tissues appear thickened in the child who is crying and uncooperative during the examination. The size variability in children requires that the soft tissues be judged in reference to vertebral body size, with normal prevertebral soft tissues being two-thirds or less of the length of the adjacent vertebral body.

Plain cervical spine imaging remains the preferred imaging modality in conscious patients complaining of neck or back pain. Plain films have a sensitivity of 90 % or greater in identifying cervical spine injury. Despite an increase in use of CT, current literature continues to support that CT be used only to evaluate areas of concern based on initial plain imaging. Helical CT scans with digital three-dimensional reconstruction provide excellent delineation of osseous injury patterns (Fig. 19.1). Many centers will utilize CT in patients who present with mechanisms at high risk for injury, such as high-speed accidents, falls from significant height, and hangings. The benefits of CT strategies suggest that they are cost-effective, requiring no sedation (compare MRI), less need for repeat imaging, earlier diagnosis, and higher detection rates of injury. However, the risk of radiation exposure with CT scans remains concerning. Optimizing CT algorithms and parameters is one way to reduce exposure. While identification of cervical spine injuries is improved with CT, the routine use of CT on low-risk cases approaches a point where harm (cancer risk) equals or exceeds its benefit.

MRI plays an important role in the evaluation of pediatric spinal trauma as it allows superior soft tissue and neural element visualization, providing specific advantages in the pediatric population. Protocols involving MRI have been shown to be cost-effective, especially in the head-injured patient in the ICU whose spine cannot be cleared clinically. MRI can be of significant benefit in children who are uncooperative and have multiple injuries or TBI. Magnetic resonance imaging protocols have been clearly demonstrated to be useful in detecting injuries that were not appreciated on

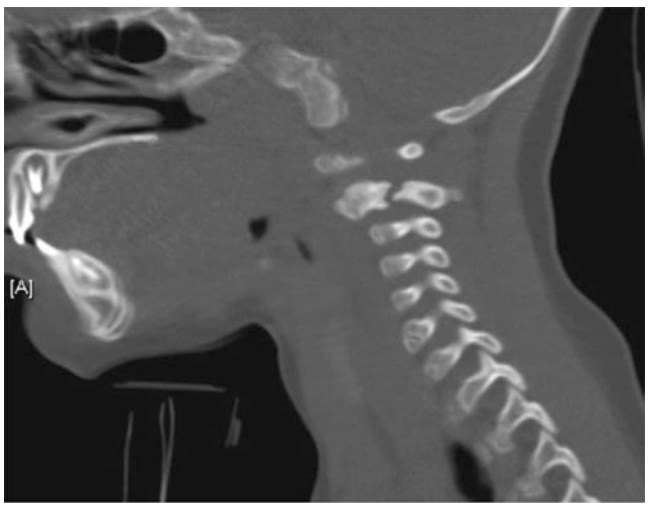

Fig. 19.1 Helical CT scan reconstruction of C2 "hangman's" fracture in a 1-year-old

plain radiography, ruling out the presence of injuries suspected on the basis of plain radiographs, predicting cervical stability and allowing for collar removal, and evaluating the potential for recovery in patients with spinal cord injuries. The ability to quickly rule out problems in the cervical spine greatly facilitates the care of patients in the ICU. Delays in obtaining this information can interfere with bedside care, patient positioning, initiation of therapy, airway management, extubation, and operative procedures.

Specific Injuries

The types of cervical fractures in children are similar to adult fractures; however, the incidence, distribution, and location differ. Ligamentous injuries and fractures can result from translation, flexion/extension, distraction or compression. *Atlanto-occipital injuries* are associated with high-energy transfer resulting in contusion or transection of adjacent structures and are frequently fatal at the scene of the accident. The injury is frequently associated with severe cord and brainstem injury, causing respiratory arrest, and diffuse axonal injury resulting in TBI. The early diagnosis of atlanto-occipital injury can be challenging because the initial displacement is reduced with cervical immobilization. In addition, anatomic variation, adjacent level trauma, and poor visualization make radiographs difficult to interpret. One should have a high clinical suspicion in very young children and should never apply traction to the cervical spine. T2-weighted MRI imaging demonstrates increased T2 signal in the ligaments or spinal cord. In addition, there may be evidence of paravertebral edema, epidural retroclival, or intraspinal hematoma. Children who are diagnosed with atlanto-occipital dislocation can be difficult to treat as the ability to perform surgical fixation of the occiput to the cervical spine is limited in young children because the bone is thin and cartilaginous.

In adolescents, odontoid fractures are similar to those seen in adults. In young children, on the other hand, they can occur after relatively minor trauma. Often these fractures occur through the synchondrosis at the base of the odontoid and can be missed on initial evaluation. Plain radiographic interpretation is challenging; CT with reconstruction or MRI is highly recommended. Although relatively uncommon, the injury can be associated with neurologic injury. Odontoid injuries typically heal well with adequate immobilization. Halo immobilization is not recommended in young children. A custom casted Minerva brace works quite well in children less than 3 years. Closed reduction may be necessary but should be done under sedation with SSEP/EMG monitoring (Fig. 19.2).

Injuries of the subaxial cervical spine are uncommon in children younger than 9 years. In adolescents, the injury patterns are similar to those in adults. Injury types include fracture-dislocations, burst fractures, simple compression

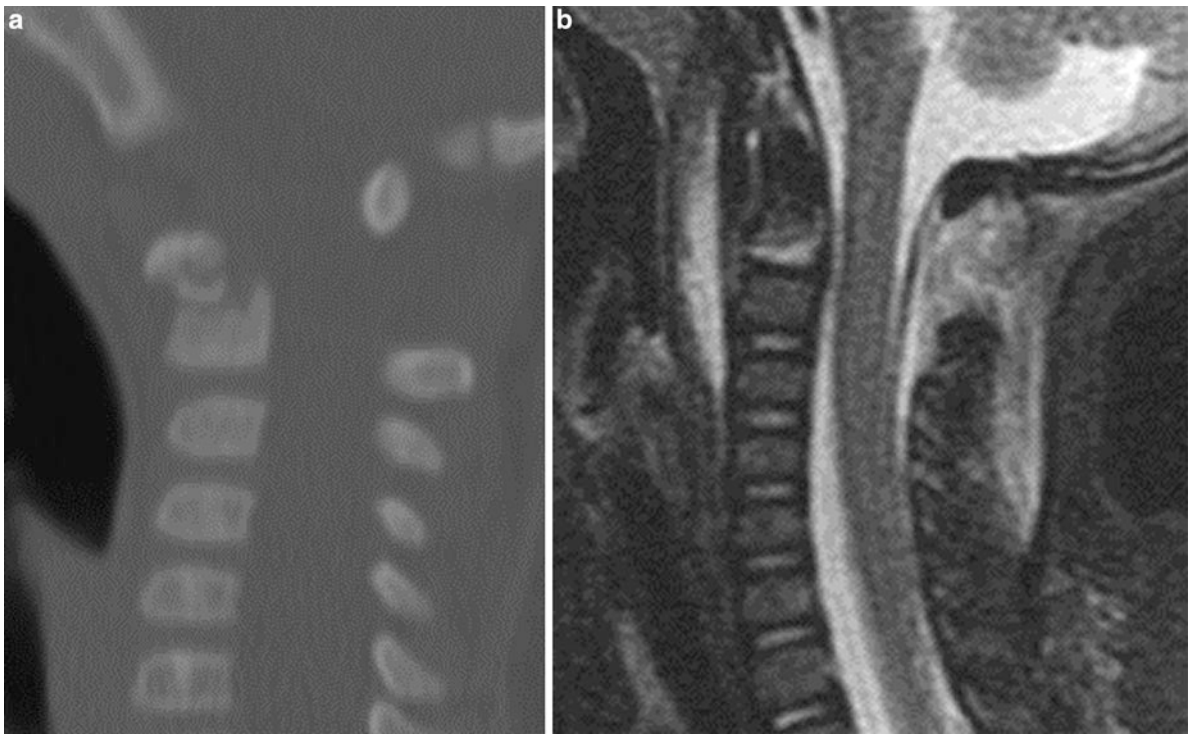

Fig. 19.2 A helical (**a**) CT and (**b**) MRI scan reconstruction of C2 synchondrosis fracture in an 11-month-old

fractures, facet dislocation, and posterior ligamentous injuries. These injuries usually involve major trauma and are most frequently related to motor vehicle collisions.

The bone size and cartilaginous anatomy of the pediatric spine make placement of instrumentation more difficult than in adult patients. In addition, commercially available instrumentation of appropriate size is limited. In cases where fixation is needed, wiring techniques, autologous bone graft, and immobilization are frequently utilized. In very young children, custom casted Minerva brace is ideal as halo immobilization is fraught with complications. In older children, typical hard collar and halo-vests may be used. Stable compression fractures require collar immobilization for 4–6 weeks. Unilateral and bilateral facet dislocations often require reduction under sedation, which allows for a controlled reduction in a cooperative patient. Three months of Minerva or halo immobilization followed by evaluation by dynamic flexion/extension radiography should be sufficient for most of these injuries. Facet fracture-dislocation is an unstable injury for which conservative management is more likely to fail. Primary posterior instrumentation and fusion are usually required to provide long-term stability in these patients.

Injuries to the thoracic and lumbar spine are rare in the pediatric population. Fractures include lateral shear fractures, compression fractures (falls), burst fractures, Chance fractures (flexion/distraction), and discrete impact fractures (localized trauma). Fractures occur less frequently in the thoracic spine because of the stabilizing effects of the rib cage. Young children sustain thoracolumbar spine injuries as a result of non-accidental injury or motor vehicle collision, whereas older children are likely to sustain sport-related injuries from snowboarding, mountain biking, motocross, and extreme sports. Most such injuries at the thoracolumbar junction and are often related to a seat belt injury while being improperly restrained. Back pain and abdominal bruising may suggest a posterior distraction injury and can be a hallmark of multisystem injury. Spinal cord and cauda equina injuries are also common in these patients and can be partial or complete.

The mechanism of injury in the thoracic and lumbar spine determines the fracture pattern that is seen and is reflected in fracture classification and spinal stability. Moderate flexion moments can lead to compression fractures and a greater axial load leads to a burst pattern. The Chance fracture is created with a posterior distractive force and a violent flexion moment and is commonly referred to as a flexion/distraction injury. The anterior column can fail as a result of compression in these injuries or it may remain intact. Fracture-dislocations are rare in children and are characterized by severe instability, translational displacement, and a high prevalence of neurologic injury.

Compression injuries most commonly occur at the thoracolumbar junction. They are typically stable fractures characterized by failure of the anterior column in the absence of either clinical or radiographic evidence of posterior element injury. The superior end plate fails more commonly than the inferior end plate. These injuries can occur over multiple levels and with a relatively low-energy injury in a growing patient. Most compression fractures can be managed conservatively, either with activity restriction or orthotics. Long-term kyphosis is rare since anterior growth is preserved. Injuries with more than 50 % compression of the anterior column should be evaluated for evidence of posterior injury and are more commonly treated with rigid bracing. Surgical fixation for kyphosis is rare in young children.

British radiologist G.C. Chance initially described flexion/distraction injuries due to seat belt injuries in children in 1948. Chance fractures are characterized by a transverse or oblique fracture involving all three vertebral columns. The fracture results from a combined flexion/distraction mechanism around a fulcrum, commonly a seat belt (Fig. 19.3). While in older children and adolescents the injury typically involves L1, in younger children the injury is likely to be more caudal and tends to occur at L3. It is important to consider the possibility of a major vascular injury, including aortic dissection and major abdominal injuries, which occur in almost half of these children (Fig. 19.4). Jejunal transection and small bowel perforation is also a common finding in these patients. These intra-abdominal injuries can present up to 3 days after injury, placing the patient at greater risk of complications.

Optimal management of flexion/distraction injuries in children largely depends on the extent of the fracture and ligamentous injury. Fractures that have a major osseous component but remain well aligned should heal well with immobilization alone and are usually associated with good long-term stability. The presence of multisystem injuries and severe kyphosis indicates instability and the potential need for operative management.

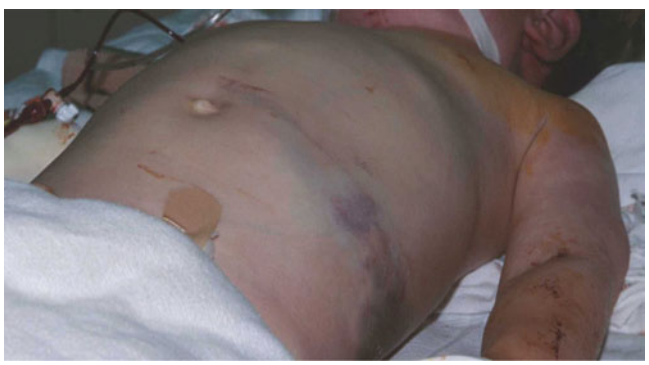

Fig. 19.3 Significant seat belt sign in a young trauma patient who was improperly restrained with a lap belt

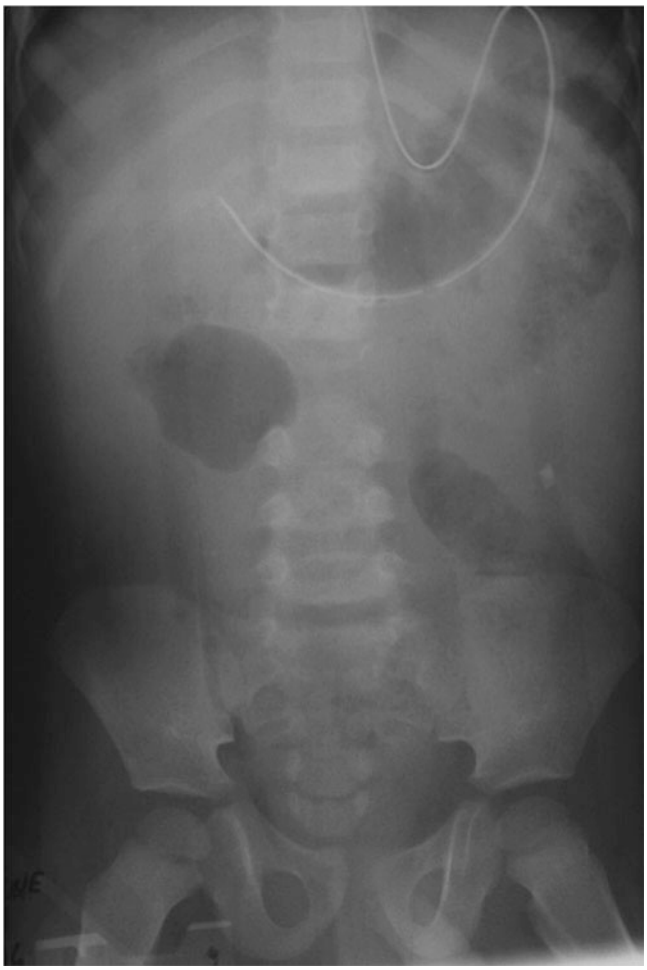

Fig. 19.4 A flexion/distraction, or Chance fracture, of the lumbar spine. Notice the significant distance between the L2 and L3 vertebral bodies. This patient succumbed from an associated abdominal aortic transection

Preoperative Preparation

Spine clearance is difficult to complete in children who require emergent surgery upon presentation. This is of greatest concern in patients that are unresponsive at presentation as there is no indication of pain and possibly no visible signs of injury to assist in the evaluation. The presumption is to assume an injury until otherwise excluded. In the conscious child without a distracting injury, such as a long bone fracture or possible intra-abdominal injury requiring general anesthesia, it is likely that obvious fracture will be able to be excluded. However it is not possible to clear the spine in the setting of a distracting injury and spine precautions should be continued. Once the distracting injury is treated, the child's spine can often be cleared the next day. In the event of severe head injury, MRI may be helpful for spine clearance if performed within 48 h of presentation.

Treatment

The majority of pediatric spine fractures can be treated conservatively with bracing. However, treatment of spinal cord injury requires a multidisciplinary approach. Prevention of secondary spinal cord injury is the principal treatment objective. Resuscitation should focus on providing adequate oxygenation and ventilation and cardiovascular support with blood pressure management, hydration, and potential transfusion. Cooling and fever management should be initiated, particularly in the setting of a TBI. A nasogastric tube should be placed for associated delayed gastric emptying and a Foley catheter inserted to monitor urine output. Hypotension should be assumed to be secondary to hemorrhagic shock and is treated with ATLS resuscitation protocols until hypovolemia is ruled out. Once blood loss is excluded, neurogenic shock should be treated with euvolemic fluid resuscitation and pressors to minimize excessive fluid administration.

Complications

There are numerous potential complications from spine fractures and spinal cord injury. Children with high cervical lesions often have serious associated injuries, such as carotid and vertebral artery injury and brain injury, which can be lethal. Chance fractures are associated with major vascular and intestinal injury. And, of course, paralysis or disability may result from an associated spinal cord injury. In addition, these children are at risk for nosocomial and iatrogenic complications, such as ventilator-acquired pneumonia and central line, blood stream, and urinary tract infections. Pressure sores from prolonged immobilization are known risks in patients with a documented spine fracture, but even patients without spine fracture who are immobilized on a backboard or in a hard cervical collar for a long period of time are at risk for decubitus ulcers. Perhaps the most tragic complication is conversion of a partial or fully functional spinal injury into a complete cord injury by not realizing that a patient is at risk for spinal injury and subsequently subjecting them to improper immobilization, inappropriate workup, and delay in diagnosis.

Editor's Comment

Especially in children, spinal injuries are among the most devastating. All aspects of care in children, including identification and treatment of a suspected injury, are more challenging than in adults. Likewise, establishing the absence of a spinal injury can be very difficult. Though CT and MRI are known to be more sensitive than clinical examination and

plain radiographs, they are also associated with some risk and higher costs. It is more important than ever to develop evidence-based protocols that not only prevent missed injuries but also avoid excessive exposure of the child to unnecessary radiation or general anesthesia.

Though popular for a time and seemingly supported by anecdotal reports, there are no data to support the use of corticosteroids in children (or, for that matter, adults) with spinal injuries. It is currently not a recommended practice. It is much more important to avoid progression of the injury by proper immobilization (properly fitting hard collar, taking into consideration the relatively large size of the child's occiput) and fastidiously addressing airway, breathing, and perfusion of vital organs. Given the relatively high incidence of SCIWORA in children, MRI has become standard in many protocols when a significant spinal injury is suspected. It is unfortunate that in certain parts of the country, some parents will equate the performance or a delayed MRI after discharge even in the asymptomatic child who is in no real danger of paralysis or disability with a "missed" injury if it turns out to be positive, placing ever more pressure on caregivers to obtain the MRI prior to discharge or to prolong admission until it can be done. This leads to unnecessary studies and increased cost but a simple solution is not readily apparent.

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Burns

20

Brooke Burkey and Gail E. Besner

Approximately 450,000 people sustain burn injuries every year in the United States. The vast majority of these patients have minor burns and are treated as outpatients. Of the 45,000 patients who require hospitalization, almost 30 % are children. There are unique characteristics of children that make caring for the burn-injured child more challenging than the typical adult burn patient. The high ratio of body surface area to body mass means that children are at higher risk of dehydration and shock from insensible losses and inadequate oral intake. Thinner skin and subcutaneous tissue place young children at higher risk of deeper burns, hypothermia, and water loss. Overall, their physiologic reserve is limited, which predisposes to a systemic inflammatory response from even moderate burn injuries. Additional challenges include trying to convince a frightened and irritable child in pain to drink or eat enough to meet increased caloric needs. Burns and smoke inhalation rank 3rd or 4th as leading causes of accidental death in children under 10. Fortunately, we have seen a strong decreasing trend in burn mortality in this population over the past several years, mostly due to improved prevention and advances in care. Children remain at high risk for burn injuries, including those that are the result of child abuse and neglect. Published rates vary, but up to 35 % of burns in children are the result of abuse or neglect. Recognition and intervention in these cases is critical to prevent recurrent abuse and death.

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Initial Management

Burn patients are trauma patients. First priority is the primary survey for rapid identification and treatment of immediately life-threatening conditions. An airway is established first, breathing and ventilation are maintained, and circulation is assessed and supported. During the secondary survey an effort is made to obtain a detailed history of the circumstances of the burn injury and a thorough assessment of the burn wound is undertaken. Special attention is paid to preventing hypothermia. The combination of loss of skin integrity and the baseline challenges that young patients face in maintaining body temperature put them at high risk of hypothermia. As much as possible, the patient should be kept covered by clean, dry sheets. Ambient room temperature should be kept high and fluid warmers should be used.

It is useful to categorize burns into major, moderate, and minor injuries, based on the extent and depth of the burn. Major burns in children include larger surface area injuries, 15 % total body surface area (TBSA) or greater. These patients are at risk of a systemic inflammatory response and shock. Flame burns are more likely to produce major burns and smoke inhalation injury, which substantially increases mortality risk. These patients require rapid assessment and treatment of immediately life-threatening conditions, followed by admission or transfer to a pediatric burn center.

Minor burns are by far the most common in children. These are smaller surface area injuries, less than 5 % TBSA. They tend to be scald or contact burns, without smoke inhalation injury. While these burns can be quite morbid, they do not put the patient at immediate risk of SIRS or shock and do not require the emergent mobilization of the burn or trauma team. Many children with minor burns can be managed as outpatients, although exceptions are common, especially in very young children.

Moderate burns include those between 5 and 15 % TBSA. The need for admission in these patients depends on the depth and location of the wounds and patient factors such

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Table 20.1 Burn center referral criteria

1.	Partial-thickness burns of >10 % of the total body surface area
2.	Burns that involve the face, hands, feet, genitalia, perineum, or major joints
3.	Third-degree burns in any age group
4.	Electrical burns, including lightning injury
5.	Chemical burns
6.	Inhalation injury
7.	Burn injury in patients with preexisting medical disorders that could complicate management, prolong recovery, or affect mortality
8.	Burns and concomitant trauma (such as fractures) when the burn injury poses the greatest risk of morbidity or mortality. If the trauma poses the greater immediate risk, the patient's condition may be stabilized initially in a trauma center before transfer to a burn center. Physician judgment will be necessary in such situations and should be in concert with the regional medical control plan and triage protocols
9.	Burns in children—children with burns should be transferred to a burn center verified to treat children. In the absence of a regional pediatric burn center, an adult burn center may serve as a second option for the management of pediatric burns
10.	Burn injury in patients who will require special social, emotional, or rehabilitative intervention

Source: Data from Guidelines for Trauma Centers Caring for Burn Patients, Resources for Optimal Care of the Injured Patient 2014, Committee on Trauma, American College of Surgeons, pp. 100–106

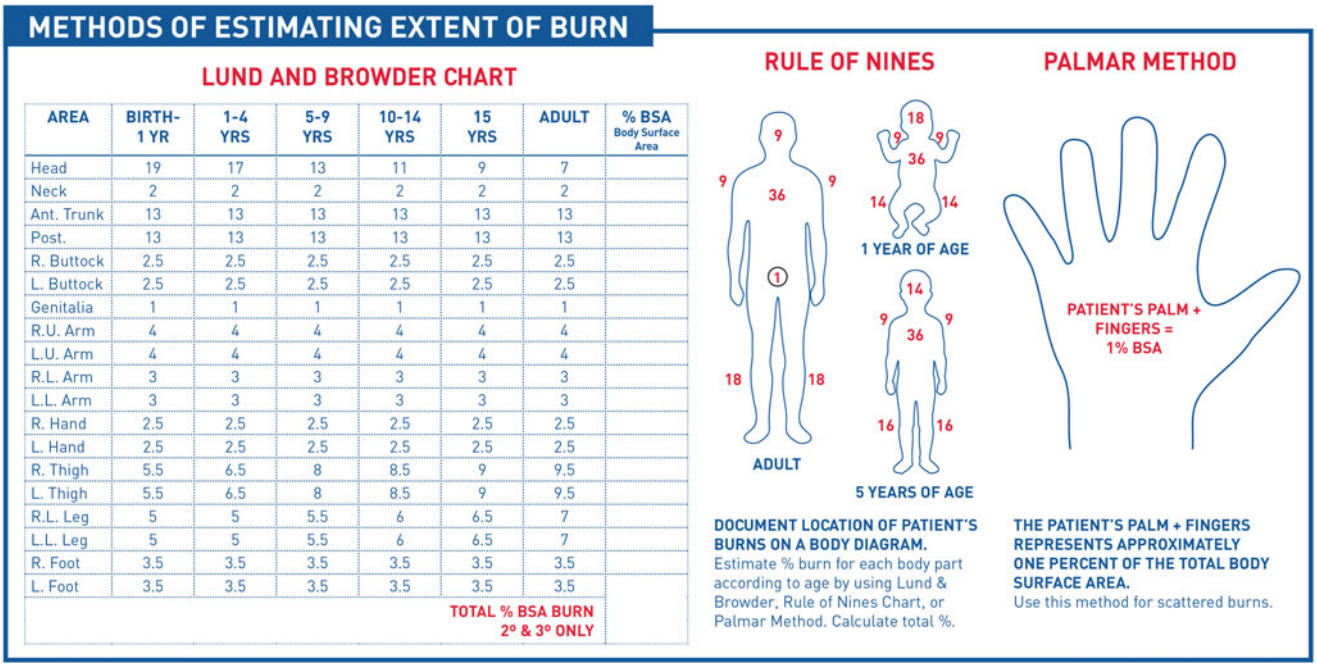
as age and comorbidities. Most children with moderate burns will require admission or transfer to a burn center. Criteria for referral to a burn center are published by the American College of Surgeons Committee on Trauma (Table 20.1). Practically speaking, one must consider the following factors, both from the parent's or caregiver's and the child's standpoint, when determining which child requires admission: risk of dehydration and ability to meet fluid needs with oral intake, need for intravenous pain medication, need for complex wound care, and home safety and concern for abuse or neglect.

The *burn mechanism* is an important initial consideration. In young children, scalds from hot liquids are the most common burns. As patient age increases, flame burns become more common so that in adults, flame is the most common etiology. Contact burns are the third most common type of burn in children. Electrical and chemical burns are less common and are usually not as severe as in adults, who often sustain these burns in industrial settings. Friction burns are a combination of mechanical abrasion of the skin and thermal trauma from the heat generated by the skin shearing against an object. Common causes of friction burns in children are exercise treadmills and vacuum cleaner belts. Sunburn is actually a radiation dermatitis caused by exposure to ultraviolet radiation. Most sunburn is superficial in nature and does not require specialized wound care, but severe cases are best treated by experienced burn practitioners.

There are three ways to calculate the *extent* of a burn injury, which is measured in percentage of TBSA (Fig. 20.1). With regard to fluid resuscitation and risk assessment, only partial- and full-thickness burns are included in the calculation, as only these burns contribute to fluid losses. The rule of nines must be modified for small children, as their distribution of body surface area differs greatly from adults. This method is best used only for initial triage as it provides a very rough estimate of the burn extent. The most accurate way to calculate burn extent is the Lund and Browder burn chart. Each body part affected is evaluated systematically and the individual values are added to obtain a total percentage for the burn. The palmar method is also accurate and works well for small or scattered burns. With this method, the palmar surface of the patient's hand and fingers represents 1 % of the TBSA. There are now computer-based and mobile device programs that calculate burn percentages based on varying inputs, including user drawings, photos, and scanning of actual patient wounds. Examples include Wound Flow, a computer-mapping algorithm developed by the US Army Institute of Surgical Research, and BurnMed, a mobile device application developed at Johns Hopkins University. These have not yet gained widespread favor, but as the technology improves and they become more accurate, user-friendly, and inexpensive, they will likely become a standard part of burn evaluation.

Burns are classified into four categories of *depth*: superficial (first degree), partial-thickness (second degree), full-thickness (third degree), and subdermal (fourth degree) (Table 20.2, Fig. 20.2). Partial-thickness burns are further subdivided into superficial and deep categories. Evaluations of burn depth have typically been based on clinical assessment. An accurate judgment of burn depth can be challenging, even in the hands of experienced burn surgeons. Studies have documented that clinical assessments are accurate in only about 60–75 % of cases.

Since burn depth is the key determinant of wound management and surgical decision making, tools that can improve diagnosis of burn depth are valuable. Historically, tissue biopsies with histological analysis have been considered the gold standard for judging burn wound depth, although the routine use of biopsies has fallen out of favor because they are expensive, are subject to sampling error, require an experienced pathologist, and create scarring. Indocyanine green video-angiography is used to assist in assessment of tissue and organ perfusion in many surgical specialties and can be



AREA	BIRTH-1 YR	1-4 YRS	5-9 YRS	10-14 YRS	15 YRS	ADULT	% BSA Body Surface Area
Head	19	17	13	11	9	7	
Neck	2	2	2	2	2	2	
Ant. Trunk	13	13	13	13	13	13	
Post.	13	13	13	13	13	13	
R. Buttock	2.5	2.5	2.5	2.5	2.5	2.5	
L. Buttock	2.5	2.5	2.5	2.5	2.5	2.5	
Genitalia	1	1	1	1	1	1	
R.U. Arm	4	4	4	4	4	4	
L.U. Arm	4	4	4	4	4	4	
R.L. Arm	3	3	3	3	3	3	
L.L. Arm	3	3	3	3	3	3	
R. Hand	2.5	2.5	2.5	2.5	2.5	2.5	
L. Hand	2.5	2.5	2.5	2.5	2.5	2.5	
R. Thigh	5.5	6.5	8	8.5	9	9.5	
L. Thigh	5.5	6.5	8	8.5	9	9.5	
R.L. Leg	5	5	5.5	6	6.5	7	
L.L. Leg	5	5	5.5	6	6.5	7	
R. Foot	3.5	3.5	3.5	3.5	3.5	3.5	
L. Foot	3.5	3.5	3.5	3.5	3.5	3.5	
						TOTAL % BSA BURN 2° & 3° ONLY	

Fig. 20.1 Methods of calculating extent of burn injury (Printed with permission from St. Christopher's Hospital for Children Pediatric Burn Management Emergency Reference. © Tenet HealthSystem St. Christopher's Hospital for Children, LLC. All rights reserved)

Table 20.2 Burn depth categories

Depth	Clinical characteristics	Prognosis
Superficial (1°)	Dry, erythematous, painful, no blistering	Heals spontaneously within 1 week without scarring
Superficial partial-thickness (2°)	Weeping blisters, exposed dermis bright pink/red with brisk capillary refill, very painful	Heals spontaneously within 1–2 weeks, usually without scarring; pigmentation may be irregular
Deep partial-thickness (2°)	Some blisters, drier, exposed dermis paler/whiter, mottled	Heals spontaneously, but usually after 3 weeks, with high risk of hypertrophic scarring. Autografting usually required
Full-thickness (3°)	White, brown, black, gray or yellow, with dry, leathery, insensate eschar; sometimes may have cherry red color due to carbon monoxide poisoning	Healing by secondary intention and wound contraction with high risk of hypertrophic scarring and functional problems. Autografting required
Subdermal (4°)	Similar to full-thickness burns; thrombosed veins may be visible through eschar	Healing by secondary intention and wound contraction with high risk of hypertrophic scarring and functional problems. Autografting required

used to measure perfusion in burns and other wounds. It is safe and approved for clinical use in children. Limitations include the requirement for intravenous access, large variability, and the expense of the scanning equipment. Laser Doppler imaging (LDI) and Laser Doppler line scanning (LDLS) are the most promising new technologies in burn depth assessment. LDI and LDLS measure the extent of superficial microvascular blood flow, which can correlate with the depth of a burn injury.

There is a growing body of adult and pediatric literature on LDI and LDLS in burns that suggests it has a very high positive- and negative-predictive value and that it might accurately estimate healing potential in burn wounds earlier than clinical judgment alone. It is relatively quick to perform and is noninvasive, which is particularly relevant to pediatric patients. These technologies can be affected by many factors, including patient movement, the moisture and temperature of the wound, the angle at which the laser hand piece is held while scanning the wound, the presence or absence of shock and whether dressings or topical medications are present on the wound. It is also most accurate between 48 h and 5 days from the time of injury. The cost of the Laser Doppler equipment is relatively high, which is likely the primary barrier to its widespread adoption in burn centers.

Smoke Inhalation/Airway

Inhalation injury should be suspected in any patient with a history of being trapped in a confined space or losing consciousness in the presence of smoke or fire. Signs and symptoms of possible inhalation injury include facial burns, singed nasal

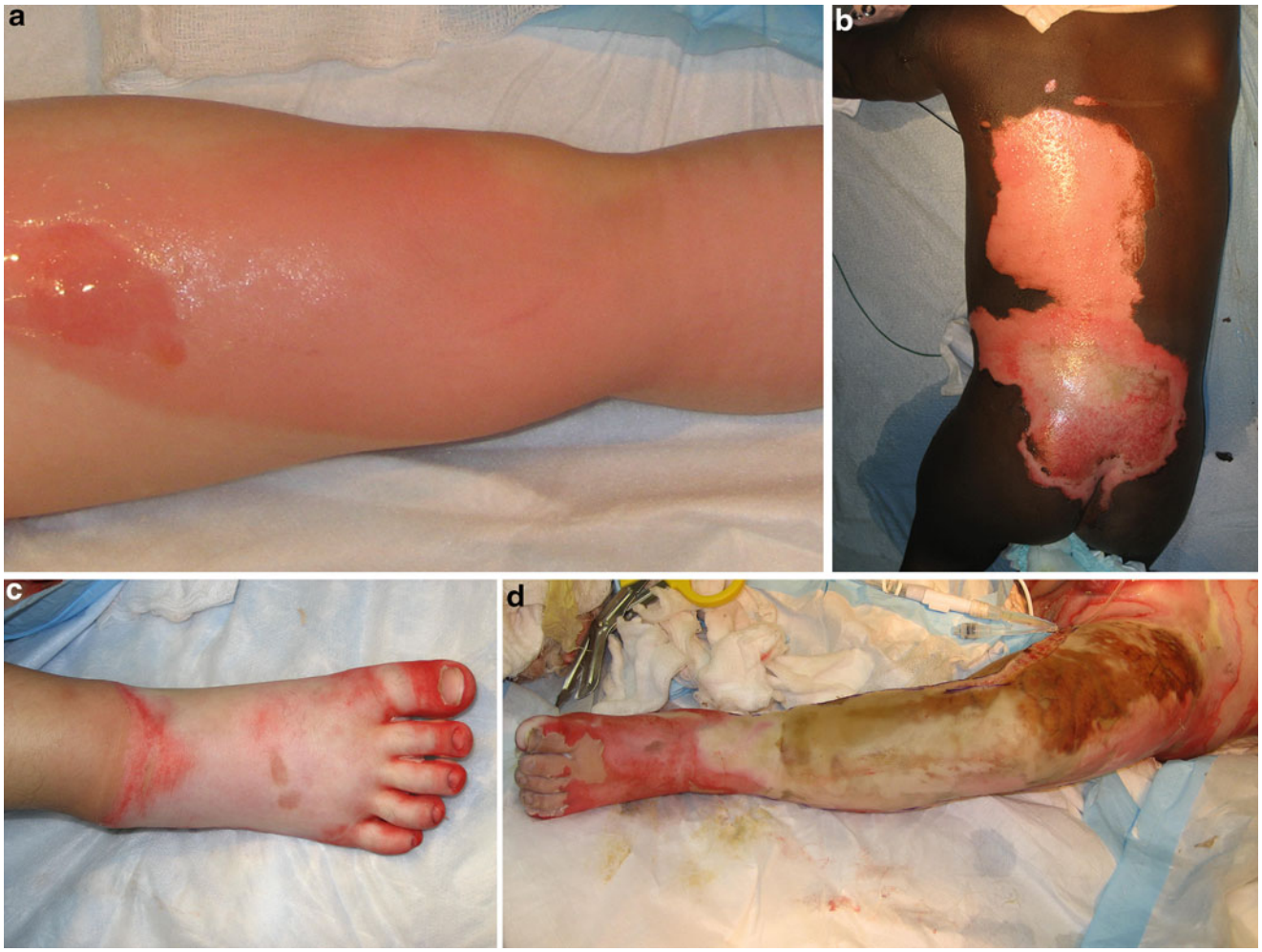


Fig. 20.2 Depth (degree) of burn injury: (**a**) mostly superficial (1°) scald burn of thigh and leg with small area of superficial partial-thickness burn at superior/left margin; (**b**) mixed superficial partial-thickness and deep partial-thickness (2°) scald burns of posterior trunk; (**c**) mixed deep partial-thickness (2°) and full-thickness (3°) intentionally inflicted immersion burn of the foot with classic stocking pattern; (**d**) mixed full-thickness (3°) and subdermal (4°) flame burns—note the thrombosed veins visible in the anterior thigh

hair, soot in the oropharynx, inflamed oropharyngeal mucosa, carbonaceous sputum, and altered mental status. Hoarseness, wheezing, and other markers of respiratory distress such as sternal retractions, grunting, and flared nostril breathing are often not apparent on initial triage, as airway edema does not peak for 24–48 h after injury.

Patients presenting with respiratory distress or airway compromise from other causes such as diminished level of consciousness should prompt urgent intubation. If inhalation injury seems likely, intubation should be strongly considered even in the absence of respiratory distress. If in doubt, it is generally safer to intubate than to defer intubation, as the small diameter of the pediatric airway is predisposed to obstruction and can become occluded quite rapidly from edema. Someone with experience managing pediatric airways should intubate the child.

Children have a more cephalad, funnel-shaped larynx with its narrowest point at the cricoid ring and a floppy and acutely angulated epiglottis. In patients with facial burns, the airway must be well secured with umbilical tape or tracheostomy ties, as standard tape and adhesives will not adhere to the burns (Fig. 20.3). Once patients are admitted and stabilized, the endotracheal tube can be secured using a heavy braided suture placed circumferentially around the lingual base of teeth (if present and stable) or a circummandibular 24- or 26-gauge wire. These methods provide clear access to any facial burns for wound care and surgical treatment. There are also various commercially available devices for stabilizing endotracheal tubes, although care must be taken to select those that are appropriately sized for pediatric patients.

Smoke inhalation injury has three components: toxicity from noxious gases, upper airway injury, and lower airway injury. The onset of symptoms from inhalation injury can be quite unpredictable and close monitoring for rapid decompensation in these patients is necessary. Exposure to carbon monoxide and noxious gases like cyanide present in smoke

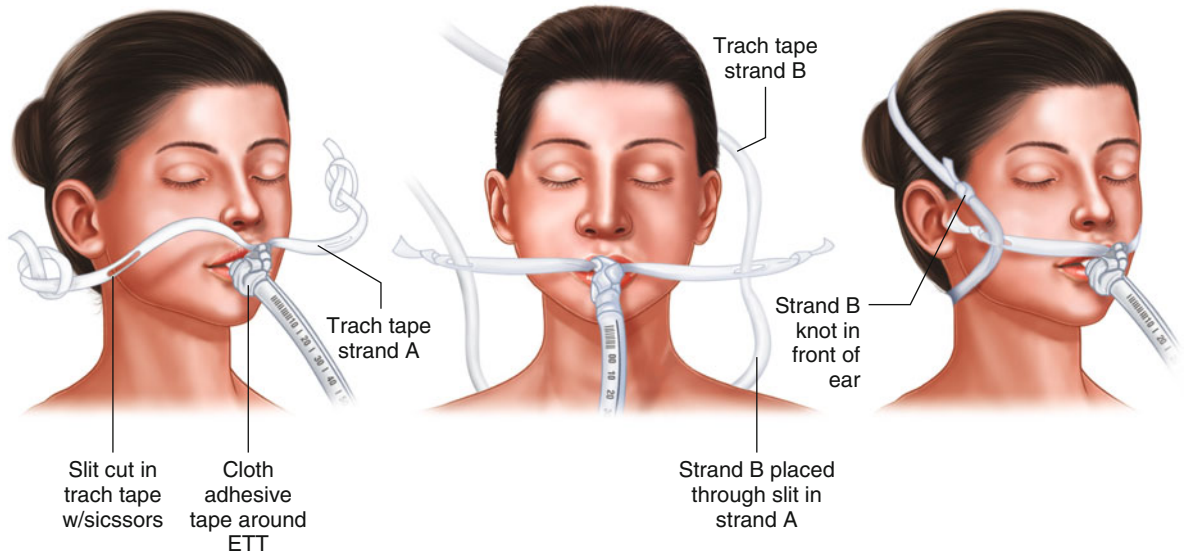


Fig. 20.3 Endotracheal tube immobilization in patients with facial burns

is the cause of most deaths at the scene of a fire. Carbon monoxide displaces oxygen from hemoglobin, reducing the delivery of oxygen to tissues and resulting in a hypoxic state. The neurologic system is primarily affected, although the vascular system also is subject to damage. Standard pulse oximetry and PaO_2 will be normal, so specific testing of carboxyhemoglobin levels must be performed, ideally with an arterial blood gas sample.

All patients with suspected inhalation injury should be treated with humidified 100 % high-flow oxygen, which reduces the half-life of carbon monoxide from 3 to 4 h at room air to 30–90 min. Hyperbaric oxygen therapy (HBO) at 2.5–3 atm decreases the half-life to 15–23 min and should be considered for patients with significant neurologic compromise including seizures, carboxyhemoglobin levels greater than 50 %, and failure to respond to 100 % oxygen. There are no accepted standard indications for HBO or guidelines for duration and intensity of treatment, largely because there is no correlation between carboxyhemoglobin levels and the severity of neurologic sequelae, patient prognosis, or outcomes. Its value is unproven and its use remains controversial, as a majority of randomized controlled trials have shown no benefit in terms of neurologic sequelae. Transfer to a burn center, when appropriate, should not be delayed for HBO therapy.

Cyanide toxicity results from the inhalation of hydrocyanide gas that is formed during the combustion of many natural and synthetic materials commonly found in houses and other buildings. It manifests with hypoxia, metabolic acidosis, and elevated blood lactate levels. Signs and symptoms are the result of hypoxia and are quite similar to those of carbon monoxide toxicity. Diagnosis and treatment of cyanide poisoning is based on clinical judgment, as laboratory testing of cyanide levels is typically not available in a timely fashion. There are two currently available antidotes to cyanide: hydroxocobalamin (Cyanokit) and the cyanide antidote kit of sodium nitrite and sodium thiosulfate (Nithiodote). Hydroxocobalamin is significantly more expensive but has a much better safety profile. It is the preferred option for empiric treatment in burn patients as it does not compromise oxygen delivery like the cyanide antidote kit and can improve hemodynamics in hypotensive patients. As with HBO for carbon monoxide poisoning, standard and accepted indications and guidelines for use of either cyanide antidote are lacking. Most burn centers do not administer a cyanide antidote to all smoke inhalation patients, instead reserving it for those who have persistent hemodynamic instability, significantly elevated blood lactate levels, refractory metabolic acidosis, and neurologic deterioration despite aggressive resuscitation and delivery of 100 % oxygen.

Carbon monoxide and cyanide poisoning are immediate and critical threats to life in the first minutes to hours after smoke inhalation injury. In the ensuing hours to days, the inflammatory component of inhalation injury from airway damage blossoms and predominates. In the upper airway, most damage is the result of direct heat from inhaled hot air at temperatures greater than 150 °C although some chemical irritation from the hundreds of toxins in smoke can occur. Oropharyngeal edema or obvious burns, hoarseness, or stridor heralds impending upper airway obstruction and mandates intubation. The lower airway and lung parenchyma caudad to the epiglottis is usually not exposed to significant heat but can sustain significant damage from inhaled toxins. The result is an intense inflammatory process with edema, epithelial sloughing, mucus plugging, fibrinous cast formation, decreased pulmonary compliance, surfactant inactivation, and ultimately airway obstruction. On initial presentation, patients with significant lower airway injury will have signs

of bronchitis and bronchiolitis: bronchorrhea and expiratory wheezing. Intubation is frequently required to relieve respiratory distress, ensure adequate oxygenation and ventilation, and facilitate pulmonary toilet. Acute lung injury, acute respiratory distress syndrome, and pneumonia commonly develop.

The definitive diagnosis of smoke inhalation injury is made by direct visualization with bronchoscopy, which demonstrates mucosal erythema, blistering, edema, erosions or necrosis, and/or particulate matter in the tracheobronchial tree. Treatment is largely supportive and includes standard measures such as aggressive pulmonary toilet, early ambulation, mechanical ventilation, and judicious use of antibiotics for associated respiratory infections. Inhaled heparin and *N*-acetylcysteine therapy, designed to decrease fibrin cast formation, mobilize secretions and provide some free-radical scavenger function, may improve mortality in the pediatric population receiving mechanical ventilation for inhalation injury. In severe cases, high-frequency oscillatory ventilation or extracorporeal membrane oxygenation may be needed.

Fluid Resuscitation

Severe burn injury results in significant substantial tissue trauma and hypovolemia, which cause the release of multiple inflammatory mediators. This state of *burn shock* is a complex process of cardiovascular dysfunction that is not easily or fully resolved by fluid resuscitation. The released inflammatory mediators affect the microcirculation, large vessels, and major organ systems. Decreased cardiac output from intrinsic myocardial dysfunction and increased systemic vascular resistance unrelated to hypovolemia are hallmarks of this systemic inflammatory process. All patients with burns greater than 30 % TBSA will develop a systemic inflammatory response syndrome. In small children, even patients with burns as limited as 15 % TBSA are at risk of some degree of SIRS.

Fluid resuscitation is challenging in the pediatric burn population for several reasons. Children have relatively greater insensible losses due to their higher body surface area-to-mass ratio. They also have less intravascular volume per unit of surface area burned, which makes them more vulnerable to fluid overload and hemodilution. Young children have immature kidneys that are less capable of concentrating urine, increasing the risk of dehydration. They also have limited glycogen stores in the liver, so resuscitation fluids must contain some dextrose and blood glucose monitoring is necessary. Fluid resuscitation is a constant balancing act between maximizing tissue and organ perfusion and avoiding the complications of inadequate or excessive resuscitation.

As with any trauma patient, peripheral intravenous access is preferred. Unburned sites are ideal, but not always available. Intraosseous lines may be placed in the proximal tibia or distal femur if intravenous access is not immediately obtained. Venous cutdown may be necessary. Central venous and arterial lines in the emergent setting should be avoided to minimize infection risk. Unless absolutely necessary, it is better to place these lines in the more controlled setting of the burn unit.

There are many formulas available for calculation of pediatric burn resuscitation needs. There are no class I or II data to support one particular formula or type of crystalloid. It is known that delays in resuscitation are related to increased mortality, sepsis, and renal failure, so instituting resuscitation immediately and efficiently is paramount. The most important concept when resuscitating a patient is that the formula is just a starting point and fluids must be titrated closely based on the clinical response. Calculations are based on the %TBSA of partial and full-thickness burns only (superficial burns are not included). Isotonic crystalloid solution is used for resuscitation and most centers utilize lactated Ringer's solution, as it is isotonic with plasma and can mitigate the metabolic acidosis. At our center, we have guidelines for resuscitation based on weight and TBSA burned. We use the American Burn Association Consensus Formula (also known as the Parkland Formula) for all patients with burns of 15 % TBSA or greater (Table 20.3).

The best way to monitor response to fluid resuscitation is by urine output, which necessitates placement of an indwelling

Table 20.3 Pediatric fluid resuscitation guidelines

Extent of burn	
<10 % TBSA[a]	1× maintenance rate[b]
10–14 % TBSA	1.5× maintenance rate[b]
≥15 % TBSA	*Consensus formula* (*Parkland formula*):
	4 mL Lactated Ringer's per **kg** (body weight) per **% TBSA** burned (2° and 3° only)
	• Subtract any prehospital fluids from calculated total
	• Give half of total amount over first 8 h *from time of injury*
	• Give half of total amount over following 16 h
	For children <20 kg, add 1× maintenance rate[b]

[a]Need for IV fluids in this group is based on clinical situation and surgeon's judgment
[b]Maintenance rate calculated with standard weight-based formula. For children <20 kg, use D_5LR; for children >20 kg, use LR

urinary catheter for any patient receiving Consensus formula resuscitation. These patients are assessed at least hourly for adequate urine output. In children weighing less than 30 kg, the goal is 1 mL/kg/h. Larger children should be maintained at a urine output of 30–50 mL/h. Standard vital signs, mental status, peripheral perfusion, and lab studies can also aid in assessing resuscitation efforts, although these elements are not as reliable as urine output due to the effects of inflammatory mediators. Patients with smoke inhalation injury and young children commonly require more than their calculated fluid needs for effective resuscitation, often in the neighborhood of 6 mL/kg/%TBSA. Patients who require more than 6 mL/kg/% TBSA may be "failing" resuscitation; in these cases, the use of colloid, inotropic or pressor support, and escalation of invasive monitoring may be needed. Colloid remains controversial in burn resuscitation, as limited class I and II studies have demonstrated that its use can reduce total fluid volumes given in resuscitation but makes no difference in outcomes. We reserve the use of colloid until late in the first 24 h postburn in patients with 30 % TBSA burns or greater. If the clinical decision is made to use colloid, we infuse 5 % albumin at 0.3–0.5 mL/kg/%TBSA.

Temperature Regulation

Children younger than 2 years have thin layers of skin and insulating subcutaneous tissue. As a result, they lose more heat and water and they lose them more rapidly. In very young children, temperature regulation is partially based on non-shivering thermogenesis, which further increases metabolic rate, oxygen consumption, and lactate production. Hypothermia should be avoided by paying careful attention to increasing the room temperature, minimizing exposure time, and using radiant warmers and fluid warmers. In major burn patients, the systemic inflammatory response usually results in a hypothalamus-mediated resetting of the basal body temperature to 38–39 °C. Allowing these patients to become cold only exacerbates hypermetabolism and protein catabolism as the patient attempts to return to this elevated basal range.

Ancillary Studies

Monitoring of electrolytes and blood counts is often helpful, especially with large burns requiring aggressive fluid resuscitation. Carboxyhemoglobin levels are important in patients with suspected inhalation injury. Prealbumin levels should be monitored weekly in patients with burns of 20 % TBSA or greater. Major burn patients are often febrile due to the hypermetabolic state. We generally do not work up fevers in these patients unless they have temperatures exceeding 39 °C or a specific clinical indication. Procalcitonin and C-reactive protein levels are often elevated in burn patients due to the inflammatory state. Following trends in these markers can be helpful in diagnosing sepsis, but are not reliable as stand-alone tests.

Burn wound swab cultures may be obtained to evaluate what is colonizing a wound, but do not definitively diagnose burn wound sepsis. Most burn wounds will become colonized with bacteria within a few days of hospitalization though the burns are not truly infected. If invasive burn wound sepsis is suspected (clinical deterioration, change in the appearance of the burn, odor to the burn) the diagnosis can be confirmed by performing quantitative burn wound cultures, in which a small piece of the burn tissue is excised at the bedside (at least 1 g of tissue is required) and the microbiology laboratory is alerted that quantitative wound cultures are required. Invasive burn wound sepsis is defined as more than 10^5 organisms/g of tissue.

An admission chest radiograph should be obtained in any patient with suspected inhalation injury. This will usually be normal if performed within the first few hours of the injury, but serves as a baseline for future studies. An electrocardiogram is indicated for all patients with electrical burns.

Antibiotics

Prophylactic systemic antibiotics are not used in the treatment of burn patients since this increases the risk of infection with resistant organisms. Instead, systemic antibiotics should be used to treat specific infections and administered at the first sign of clinical infection. Antibiotic regimens are then modified as culture results and antimicrobial sensitivity results become available.

Burn wound cellulitis refers to infection spreading in dermal lymphatics in the non-burned skin surrounding a burn, usually occurring in the first few days after burn injury. Burn cellulitis is commonly caused by *Streptococcus pyogenes*. Invasive burn wound sepsis leads to systemic toxicity with high fever, bacteremia, and a hyperdynamic state with hypotension and cardiovascular collapse. Diagnosis can be made either clinically or by quantitative burn wound cultures. Clinical signs include a change in the appearance of the burn in the patient with signs of toxicity. The burn may demonstrate punctate hemorrhages, new drainage, a change in color, or liquefaction. Treatment should be based on clinical judgment so as not to delay therapy while cultures or histology are pending. Treatment includes parenteral antibiotics, aggressive resuscitation, and aggressive excision and debridement of all necrotic or infected tissue with temporary allografting.

Nutrition

Maximizing caloric intake is extremely important to ensure optimal burn wound healing. Adequate nutrition blunts the typical injury-induced hypermetabolic response and hypercatabolism, and prevents loss of muscle mass and depletion of fat stores. Protein and energy are important for new collagen synthesis and to help maintain visceral protein stores

for optimal immune function. Nutritional support should be started as soon as possible, preferably within the first 24 h of admission.

Enteral feeds are usually best. A high-calorie, high-protein formula is used and includes commercial supplemental beverages as needed. Vitamin and mineral supplementation, including especially vitamin C and zinc, is also important. If oral intake does not meet nutritional demands, a nasogastric or nasojejunal feeding tube should be placed. Calorie counts should be recorded by a dietitian and daily weights obtained. If the enteral route is not feasible or unable to provide an adequate number of calories, then total or supplemental parenteral nutrition should be instituted. For major burn patients who require frequent trips to the operating room, it is safe to continue nasojejunal feeding up to and during surgery (if not in the prone position) with no fasting time.

Multidisciplinary Approach

Burn care, especially in children, is highly specialized and complex and requires a multidisciplinary team approach for optimal outcomes in patients with significant burns. This team includes surgeons and nurses, physical and occupational therapists, child life therapists, dieticians, social workers, and case managers. Child psychiatry and/or psychology services are often needed to help patients and families deal with acute and long-term psychological sequelae. Our Child Protection Team and social work staff are heavily involved in cases of neglect or abuse and work closely with appropriate government agencies to ensure a safe home. Pediatric specialists must be available for management of specific problems such as ophthalmic burns.

Pain Management

Burn injuries are painful. Superficial and superficial partial-thickness burns cause a great deal of cutaneous pain due to exposure of nerve endings in the dermis. Deeper partial-thickness and full-thickness burns, while less sensate or insensate, can still be quite painful due to release of inflammatory mediators. Pain management is a critical element of burn care, especially with the growing knowledge that acute stress disorder and post-traumatic stress syndrome are common in pediatric burn patients. Minimizing pain and anxiety can lessen and prevent the development of these potentially debilitating syndromes.

Burn pain is grouped into three categories: background, breakthrough, and procedural. In our patients, we treat background pain with standing acetaminophen, adding ibuprofen and narcotics if necessary. In severe burns in age-appropriate patients, patient-controlled analgesia devices are useful. Breakthrough pain is typically treated with intravenous morphine. For the procedural pain of burn debridement and dressing changes, patients receive either oral oxycodone, minimal sedation with oral or intravenous morphine and midazolam, or moderate sedation with intravenous midazolam and ketamine. The intramuscular and oral routes can be used if intravenous access is not otherwise necessary. In select patients, propofol may be used instead of ketamine. Our child life therapists play a critical role in the non-pharmacological management of all types of pain and participate throughout the hospital course in preparing patients for procedures and surgery, using multimodality techniques to lessen pain and anxiety, and educating parents in these techniques.

Burn Wound Management

The modern practice of early excision and prompt biologic closure of burn wounds has revolutionized burn care and resulted in striking improvements in survival and outcomes, especially in children. Nonviable tissue, the burn eschar, is at high risk of infection. Bacterial colonization is rapid within this necrotic tissue and the process of proteolysis within the wound creates intense inflammation. The practice of allowing full-thickness burns to heal by waiting for spontaneous eschar separation and then skin grafting on beds of granulation tissue resulted in prolonged hospitalizations with high rates of wound sepsis and extremely painful debridements that we would consider inhumane today. Early surgical intervention as soon as wounds are recognized to be deep dermal or full-thickness is now the standard of care, resulting in shorter hospitalizations with fewer complications, lower mortality, and superior functional and aesthetic outcomes. A reasonable goal is to have deep burns completely excised within 7 days post-burn, although excision within the first few days of injury is ideal if the patient's condition allows. Deep partial-thickness burns that take longer than 2–3 weeks to heal are at very high risk of hypertrophic scarring from prolongation of the inflammatory phase of wound healing, so any burn for which healing time is estimated to fall beyond this range should be excised and grafted as soon as possible (Fig. 20.4).

Removal of nonviable tissue (*burn debridement and excision*) can be accomplished by different techniques depending on the depth of the burn. For superficial burns, the minimal amount of nonviable tissue is epidermal only and does not require active debridement. It can be left in place and will slough and peel once the wound has healed. In superficial partial-thickness burns, the nonviable tissue is mostly epidermal, and removal of this tissue involves either blunt or sharp debridement of the blisters and bullae that form at the epidermal-dermal junction—there is usually no further debridement or excision needed as the remaining dermis is mostly or completely viable. In deep partial-thickness burns, a combined

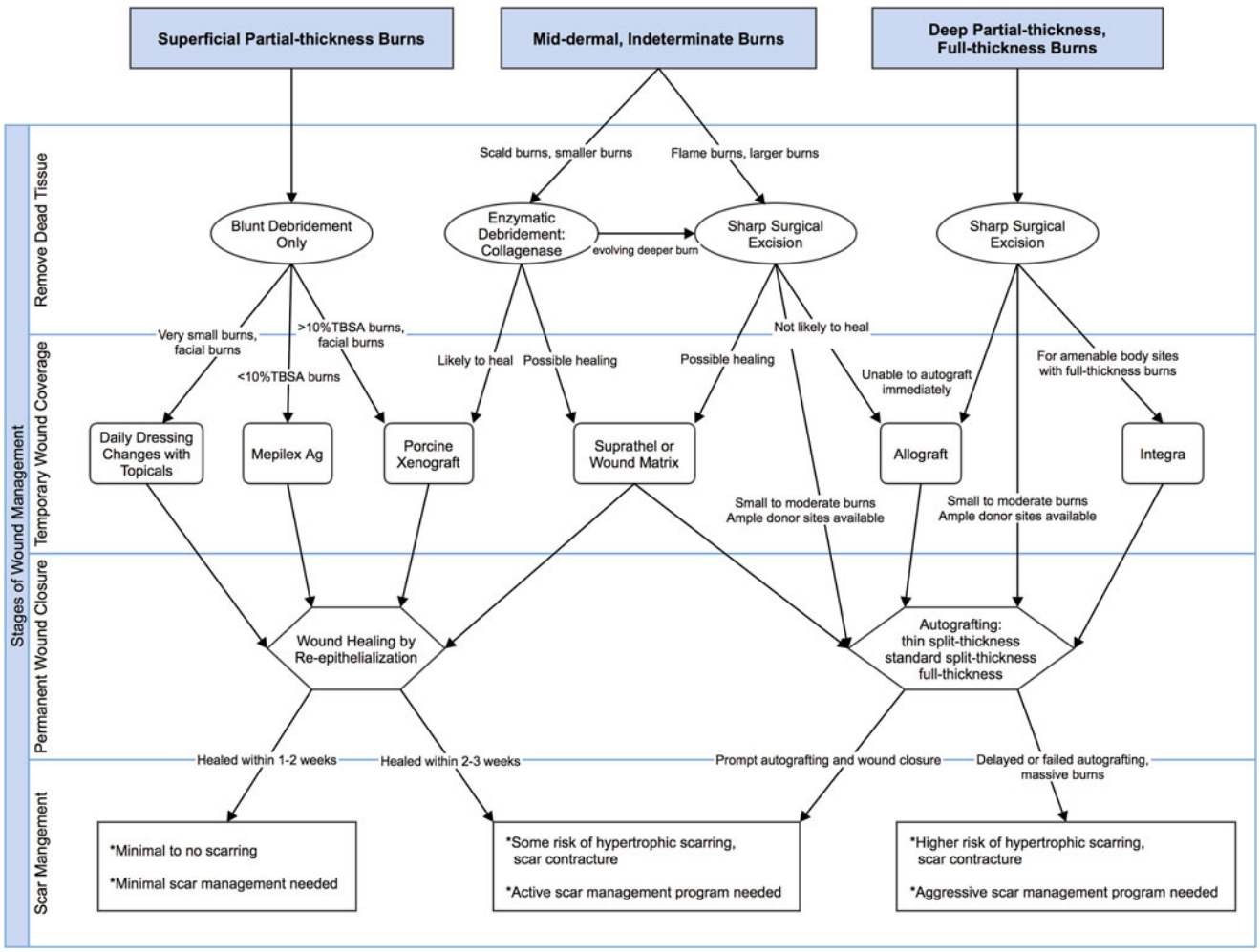


Fig. 20.4 Algorithm for pediatric burn wound management

approach is needed. The first step is debridement of the devitalized epidermis, but then the remaining dermis also has significant nonviable tissue that must be removed prior to wound closure. This can be accomplished by either mechanical (surgical) excision or by enzymatic debridement with a topical medication such as collagenase ointment. Surgical excision is much faster but less specific (which may result in removal of viable tissue) and carries surgical and anesthetic risks. Enzymatic debridement with collagenase (Santyl) will only remove nonviable tissue, but is much slower, requiring several days of daily dressing changes that can be time-consuming and anxiety provoking and may also require intravenous sedation. In full-thickness burns, blisters and bullae are debrided if present, and then surgical excision of all nonviable dermis must be carried out. For massive burns or subdermal burns, excision to fascia may be necessary, which is best accomplished with electrocautery.

Once all nonviable tissue has been removed from the burn wounds, *wound closure* may commence. Definitive wound closure with complete healing of the wound is the ultimate goal, but temporary physiologic wound closure is often needed while awaiting healing or donor site availability. Physiologic wound closure refers to approximating the barrier function of the epidermis, with protection from mechanical trauma, decreased insensible losses of fluid and protein, coverage of nerve endings for pain reduction, and provision of a physical barrier to microbes. Physiologic wound closure reduces the hypermetabolic state created by large open wounds. Again, methods for wound closure are dependent on the depth of the burn. Superficial burns are biologically closed by definition, with intact (although injured) epidermis. Topical agents will provide treatment of pain and pruritus while the injured epidermis regenerates.

Superficial partial-thickness burns will close by reepithelialization. Small- to medium-sized burns can be treated with daily non-adherent gauze and bacitracin ointment dressing changes. If located in an amenable anatomic site, a long-term, silver-impregnated silicone/polyurethane foam dressing is much preferred, which does not provide true physiologic wound closure before healing, but does provide pain control,

a moist wound healing environment, and protection from mechanical trauma and wound soilage. Mid-dermal burns can be treated with collagenase ointment and daily dressing changes while awaiting wound closure. They may also be temporarily closed by xenograft or a wound matrix once nonviable tissue has been removed and if healing is expected or possible. If healing does not seem likely in a mid-dermal burn, then prompt autografting should be done, or allografting can be used for temporary wound coverage. Deep partial and full-thickness burns should either be autografted promptly if adequate donor sites are present and patient condition allows, or temporary wound coverage with allograft (for deep partial-thickness wounds) or a dermal regeneration template such as Integra (for full-thickness wounds) should be placed while optimizing the patient for definitive autografting.

Escharotomy

Escharotomy is sometimes needed to relieve vascular compromise (extremity escharotomy) or ventilatory impairment (chest wall escharotomy). Vascular compromise to an extremity is the result of circumferential burns that create an inelastic eschar. Although vascular compromise usually occurs in extremities affected by full-thickness burns, it can occur in areas of partial-thickness burns, or occasionally in non-burned extremities. If left untreated, underlying tissue edema results in impaired venous outflow, followed by impaired tissue perfusion, and eventually diminished arterial inflow. All extremity burns at risk should be monitored with at minimum hourly vascular checks. Clinical symptoms (severe pain, paresthesias, decreased motor function), direct measurement of compartment pressures with pressures >40 mmHg, or decreased pulses (a late finding) necessitate extremity escharotomy. One should not wait for loss of pulses to immediately treat this condition, for by that time neurovascular damage is already occurring.

The chest wall and lungs are more compliant in children. They therefore become rapidly exhausted by the edema and restriction of a circumferential chest wall burn. Impaired ventilation, with progressive increase in ventilatory requirements, signals the need for chest wall escharotomy.

Escharotomy is typically performed in areas of full- thickness injury and therefore analgesics are not needed. The procedure can be performed at the bedside or in the operating room. Incisions can be made with a scalpel, but, if available, the electrocautery device is preferable. Extremity escharotomy is begun with a longitudinal incision medially or laterally in the extremity, beginning above the burned area and extending below the inferior aspect of the burn (Fig. 20.5). The incision is carried down to the subcutaneous fat, which bulges into the wound once an adequate incision is made. Medial and lateral incisions in the extremity are typically required. Adequate escharotomy should produce return of arterial pulses. Chest wall escharotomy is performed with incisions along the anterior axillary lines bilaterally, extending onto the abdomen, with transverse bridging incisions across the chest (Fig. 20.5). Adequate chest wall escharotomy should result in immediate improvement of lung compliance and ventilation.

Specific Modalities

Topical ointments and medications serve two purposes in burn care: maintaining a moist wound environment and decreasing microbial load. Desiccation and dry scab formation can deepen burn wounds and delay reepithelialization. All burn wounds will become colonized with bacteria, but active infection can lead to further tissue necrosis (and thus a deeper burn) and life-threatening burn wound sepsis. There are several topical agents available (Table 20.4). Silver sulfadiazine remains the worldwide standard for topical burn treatment. It has broad-spectrum antibacterial and some antifungal activity. However, it has significant downsides, especially in the pediatric population: it cannot be used in neonates because it increases the risk of kernicterus, it has been shown to delay reepithelialization, it can form an adherent pseudoeschar that obscures evaluation of burn

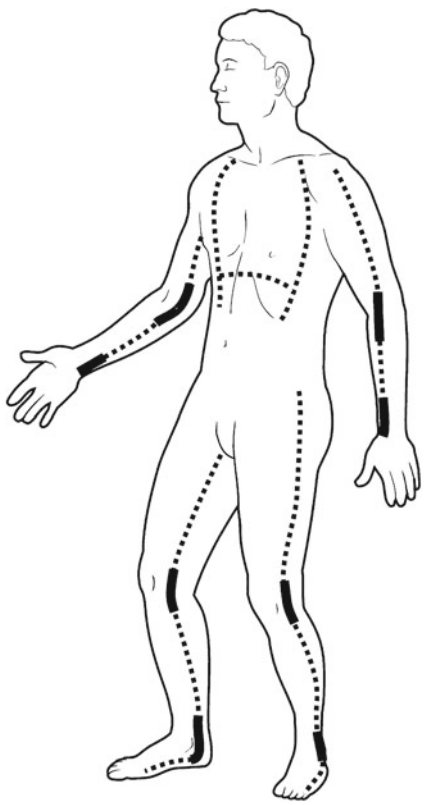


Fig. 20.5 Location of escharotomy sites. The *dotted lines* show the preferred incision sites. The *solid lines* emphasize the importance of extending the incisions across the joints (Reprinted with permission from Carrougher GJ, ed. Burn Care and Therapy. St. Louis: Mosby; 1998)

Table 20.4 Selected topical agents for burn wound care

Agent	Benefits	Precautions and disadvantages
Silver sulfadiazine (Silvadene)	Broad-spectrum antimicrobial, some antifungal coverage	Kernicterus in neonates, neutropenia, pseudoeschar formation, delayed reepithelialization, some *Pseudomonas* resistance
Petroleum-based antibiotic ointments (bacitracin, neomycin, polymyxin B, mupirocin)	Allow easy evaluation of wound, painless, mupirocin effective against methicillin-resistant *S. aureus*	Less broad-spectrum antimicrobial activity, some bacterial resistance
Mafenide acetate (Sulfamylon)	Broad-spectrum antimicrobial, particularly effective against Silvadene-resistant *Pseudomonas*, penetrates eschar and cartilage	Pain with cream application, less antifungal coverage—may combine with nystatin, metabolic acidosis limits use in extensive burns
Collagenase (Santyl)	Enzymatic debridement targeting only nonviable tissue	No antimicrobial action, complete debridement takes several days

wounds and is quite painful to remove, it cannot be used on facial burns because it may cause severe ocular irritation, and it also tends to develop a greenish-yellow coloring that is alarming to patients and parents. Most pediatric burn centers have moved away from using silver sulfadiazine as a default topical. We reserve its use for deep, larger surface area burns. Transient neutropenia is possible in these cases but does not mandate discontinuation.

For typical minor and moderate burns, topical antibiotic ointments such as bacitracin or Neosporin are much more user-friendly. Mupirocin (Bactroban) is useful for wounds heavily colonized or infected with methicillin-resistant *Staphylococcus aureus*. Mafenide acetate (Sulfamylon) is a potent antimicrobial that penetrates burn eschar and cartilage. We use the cream formulation for deep ear burns to prevent suppurative chondritis, which can require disfiguring debridement. The main downside to Sulfamylon cream is pain with application, but the solution is not painful to apply, making it very useful for larger burn areas. We use a 2.5 % mafenide acetate solution to treat pseudomonal burn wound infections and as a postoperative precaution for large area skin grafts that are at higher risk of infection.

Collagenase ointment is an enzymatic debriding agent derived from Clostridium species that only targets necrotic tissue. We have found it to be very useful in mid-dermal and indeterminate burns, especially in young children with thin skin where there is less margin for error with surgical debridement or excision. Cost is a significant factor with collagenase use, as a 30-g tube can cost approximately $200. As it does not have any antimicrobial activity, an antibiotic ointment or powder can be used in addition for infection prevention. On the horizon is NexoBrid, a new enzymatic debriding agent derived from the pineapple plant. It is available in Europe but is not yet FDA approved. In many cases, NexoBrid is capable of completely debriding all nonviable dermis in a burn wound in 4 h, but it is quite painful and requires sedation or general anesthesia for treatment.

The development of synthetic *long-term dressings* has revolutionized pediatric burn care, as children with small to moderate superficial partialthickness burns can now be treated as outpatients since they no longer require intravenous pain medication and sedation for painful daily burn debridements and dressing changes. Our preferred longer-term dressing is a silicone/polyurethane silver-impregnated foam dressing (Mepilex Ag), which can be left in place for up to 7 days, absorbs fluid exudate, does not shrink or slide off of burn wounds (which leads to painful wound exposure and desiccation), and does not mechanically traumatize newly healed epidermis upon removal. It can easily and relatively painlessly be removed prior to 7 days after application to evaluate the burns if necessary. We use Mepilex Ag for most superficial partial-thickness burns less than 10 % TBSA. Other similar longer-term dressings include Aquacel Ag, a silver-impregnated hydrofiber dressing, and Acticoat, a silver-impregnated nylon dressing. Suprathel is one of the newest high-technology wound dressings available in the United States. It is a synthetic, alloplastic lacto-capromer membrane that degrades into lactic acid in the wound bed and creates an acidic environment that is hostile to bacteria. It is designed to adhere to the burn wound until reepithelialization occurs, at which point it separates painlessly. It is significantly more expensive than many of the other longer-term dressings, which has limited its use in our center. It may prove to be useful in deep partial-thickness burns with healing potential. In these cases, the nonviable dermis must be excised operatively prior to placement of the dressing, but then it can be left in place while awaiting wound healing, which is a great advantage in pediatric patients.

Biologic dressings (porcine xenograft) are a valuable part of the pediatric burn care armamentarium that act as a temporary biologic skin substitute. We use EZ Derm, the aldehyde cross-linked form of porcine dermis that is shelf-stable at room temperature. Despite its name, porcine xenograft is not typically used as a true graft that becomes integrated and vascularized. It does, however, provide some degree of biologic wound closure, making it quite valuable in larger surface areas burns that have some risk of SIRS. Porcine xenograft decreases pain of the burn wound and limits insensible losses from burn wounds. It is more expensive than many of the other longer-term dressings, but less expensive than cadaver allograft. The perforated form allows for exudate drainage, but can leave a

persistent mesh pattern once the wound is healed, so the non-perforated form is preferred for facial burns. We primarily use porcine xenograft in superficial partial-thickness burns. It is particularly useful for burns greater than 10 % TBSA in younger children and for facial burns, where traditional dressings can be hard to keep in place and the common practice of applying antibiotic ointment and leaving the burns open to air often results in adherent scabs that are painful for patients and difficult for parents to debride. We will often apply porcine xenograft and secure it with a cyanoacrylate tissue adhesive, a procedure that can be efficiently accomplished under moderate sedation (Fig. 20.6). In larger burns or burns that require more extensive debridement, porcine xenograft can be applied in the operating room after lightly freshening the wound surfaces with the Versajet hydrodissector.

There has been a recent proliferation of *wound matrix products*. Most of these products are derived from porcine or bovine tissue and may promote wound healing with varying combinations of extracellular proteins in collagen and elastin scaffolding. These products are primarily used in the treatment of chronic wounds and ulcers, although they have some limited use in burns. They tend to be quite expensive, and there is a paucity of class I or II data regarding their use as many of them are new and have yet to be widely studied in burn patients. As with Suprathel, we sometimes will use wound matrices in patients with mid- to deep dermal burns or similar wounds with potential for healing without autografting. In some of these cases, avoiding autografts can be beneficial, especially in infants and neonates for whom the creation of donor site wounds in very thin skin can be quite morbid.

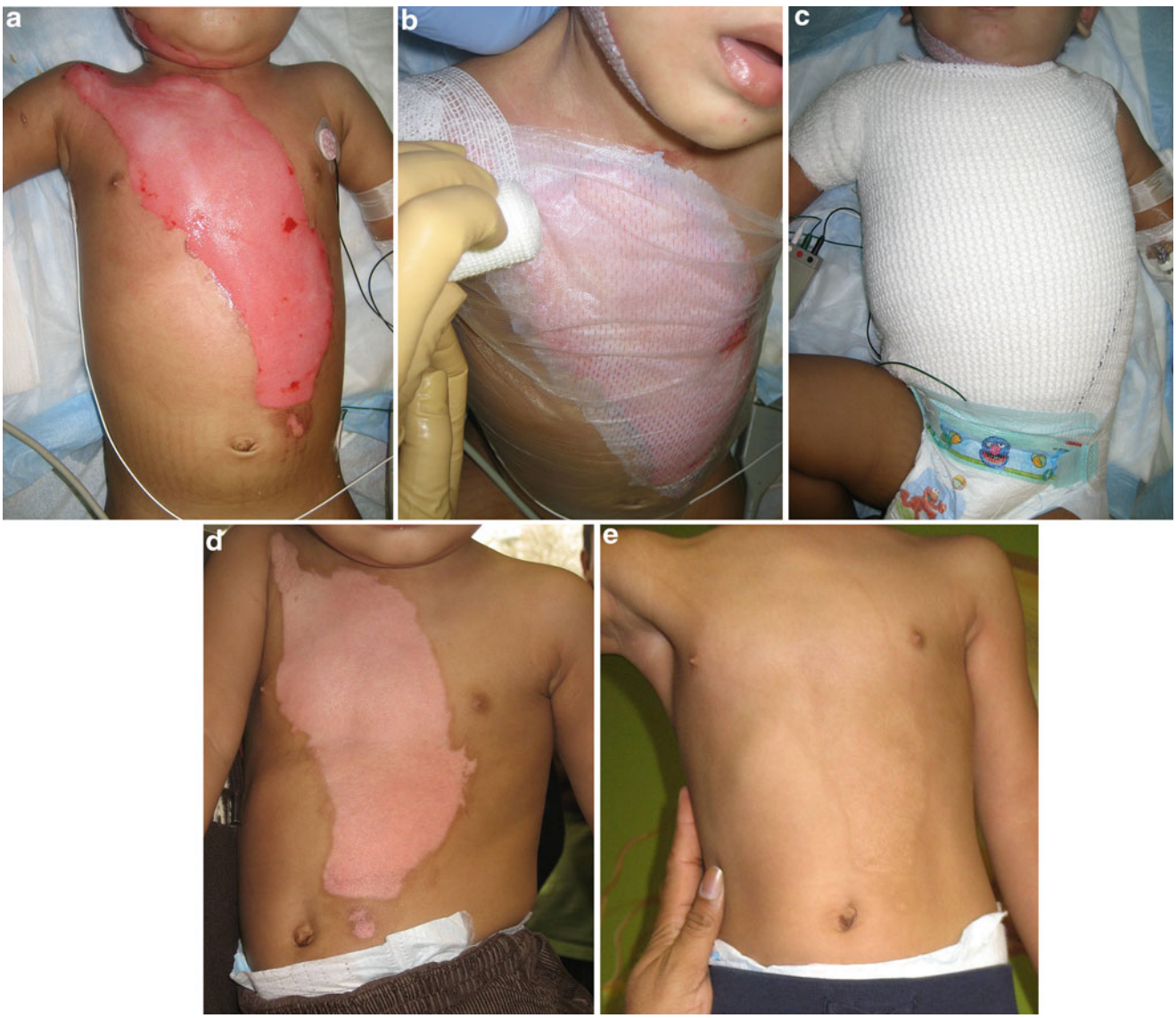


Fig. 20.6 Eight-month-old boy with 5 % TBSA superficial partial-thickness scald burns of anterior trunk and chin: (**a**) postburn day 2, prior to xenograft placement; (**b**) xenograft in place, secured with topical skin adhesive, covered with polyethylene non-adherent contact layer dressing; (**c**) complete gauze dressings in place; (**d**) closed burns at 14 days postburn; (**e**) 20 months postburn

Surgical Treatment

Burn surgery, with the exception of small and limited burns, is a major undertaking that is associated with a significant amount of physiologic stress and potential morbidity. Careful preoperative planning and patient optimization is critical to achieving good outcomes. Patients should be fully resuscitated with normal hemodynamics, end-organ function and fluid and electrolyte balance. Hypothermia must be corrected. The exception to these guidelines is in the patient with burn wound sepsis, in whom urgent removal of infected burn eschar can be lifesaving.

The process of tangential excision can be quite bloody, with blood loss estimates ranging from 0.4 (for very early excision) to 1 (for late excision) mL/cm^2. Blood and plasma should be available and coagulopathy should be treated. Burn patients are at very high risk for hypothermia during surgery because of exposure and the lack of intact skin that can preserve body heat. The temperature of the room should be kept high and fluid warmers and patient warming devices used. Smaller and limited burn patients receive perioperative antibiotic prophylaxis with gram-positive coverage. Larger and high-risk patients receive both gram-positive and gram-negative coverage, including antipseudomonal coverage. If planning to use allograft, sufficient amounts must be available. If custom postoperative splinting by occupational therapy is planned, this must be coordinated. All necessary surgical equipment and postoperative dressing supplies must be available. For major and massive burn patients, the amounts of supplies, including the blades used for excision, can far exceed what inexperienced staff might expect. These patients are best cared for by an experienced burn operative team.

Surgical Burn Wound Excision. Surgical burn wound excision is mandatory for patients with obvious deep dermal and full-thickness burns and should be undertaken immediately once the determination of a deep burn has been made. Mid-dermal and indeterminate burns may also benefit from surgical excision, which will illuminate the true depth of the wound more rapidly than enzymatic debridement over several days.

The most common form of excision is tangential excision, in which thin layers of burn eschar and nonviable dermis are shaved from the wound until healthy tissue with brisk punctate bleeding is reached. Guarded knives, such as the Weck and Goulian knives, and powered dermatomes are most commonly used. Hydrodissection with an instrument such as the Versajet or dermabrasion can also be useful in select cases. Excision typically extends into the deep dermis or subcutaneous fat. If there are small patchy areas that are more superficial within an area that needs to be grafted, tangential excision there should be carried to the level of the reticular dermis to avoid annoying cyst formation that can occur when autografts are placed over papillary dermis with preserved glands. Hemostasis and prevention of blood loss are accomplished by topical thrombin and epinephrine application, subcutaneous clysis with epinephrine solution, tourniquet use, direct pressure, and elevation. Cautery is used very sparingly as most bleeding from excision will stop without it and it creates a pinpoint area of tissue necrosis with each use that can compromise graft take. The entire operating team must work quickly and efficiently during excision to avoid serious hemorrhage and hypothermia.

Autografts. Autografts can be split-thickness or full-thickness, meshed, or sheet grafts. The standard split-thickness autograft is harvested using a powered dermatome at thicknesses ranging from 0.008 to 0.016 in., which captures the epidermis and a varying depth of dermis. In children less than 2 years old, we generally do not harvest grafts thicker than 0.012 in. to avoid significant donor site morbidity. Sheet grafts are preferred for cosmetically or functionally important areas such as the face, neck, hands, and over joints. Meshed grafts are used when donor sites are limited or in areas with difficult contour, such as the axilla. We most commonly use the thigh and scalp as donor sites when available. Donor sites are prepared by subcutaneous injection of dilute epinephrine solution (local anesthetic may also be added if practical) to create tissue turgor and aid in hemostasis. The scalp donor site is especially useful in small children, as the head is relatively quite large. Scalp skin is relatively thick, allowing for repeated harvesting with minimal risk of alopecia, as the hair follicles are located about 0.030 in. deep. Another excellent feature of the scalp donor site is that any scarring is hidden by hair growth. Split autograft donor sites typically heal in 7–10 days and can be ready for reharvesting if necessary in about 14 days.

Full-thickness autografts are the ideal replacement for skin, but their use is limited by the fact that the donor site must be amenable to primary closure. If a large full-thickness graft is needed and ample donor site is available, a very thick split graft can be taken (0.030 in.) and then this donor site can be covered with a standard split-thickness skin graft. Full-thickness grafts are primarily used for deep facial, hand, and genital burns. Donor sites are chosen with regard to optimal color match when possible. The posterior auricular sulcus and upper inner arm are good sites for small facial grafts.

For the special and less common cases where deep burns of the palmar surface of the hand or feet require autografting, glabrous skin grafting provides the optimal replacement with like tissue. The instep of the foot is tumesced to facilitate smooth dermatome passage, then two passes at 0.010 in. are taken. The first, superficial pass is secured back on the donor site wound, and the deeper second pass is used as the graft for the recipient site. Careful attention to graft orientation is necessary. Especially in darker-skinned children, glabrous grafting is preferred to standard skin grafts that can have a very noticeable color difference.

Autografts can be secured with sutures, staples, steri-strips, cyanoacrylate tissue adhesive, fibrin sealants, or perforated silicone dressings such as Mepitel One. In younger children, we try to avoid placing sutures or staples, which need to be removed. We prefer to bolster autografts with a negative pressure wound therapy system, because it is very protective against shear forces, has some splinting function, and removes drainage. The grafts are typically covered with non-adherent gauze such as Xeroflo moistened with bacitracin ointment prior to VAC placement. The VAC can be used on most sites, including the hands and feet, genitals, and large surface area grafts. Alternatively, bulky layered dressings are placed for protection, including an antimicrobial dressing such as Acticoat for prevention of infection. Custom-fabricated splints should be placed in the operating room for immobilization of grafts over joints.

Allografts. Allograft, taken from human organ donors and stored in skin banks, is one of the most versatile tools in the burn surgeon's armamentarium. It can be used to test the viability of a wound bed after excision because it will take just as an autograft would if the bed is viable. It can be used for temporary biologic wound closure and coverage if staging of excision and autografting is necessary, whether due to patient condition or availability of donor sites. Allograft is available fresh or cryopreserved, meshed, or as sheet grafts. It is applied and cared for in an identical fashion to autograft. It will typically reject and slough in 2–3 weeks, at which time new allograft can be placed if autografting is still not an option. Allograft can also be used, although less reliably, as a dermal replacement. It is allowed to revascularize on the wound bed, then any remaining epidermis and the superficial dermis are tangentially excised. This removes the Langerhans cells that are the principal reason for rejection due to class II antigens on their surfaces. Allograft is especially valuable as an overlay graft in massive burns where widely meshed skin grafts must be used. The allograft is placed over the delicate meshed grafts, providing temporary biologic wound closure and protection of the grafts, until the wounds fully reepithelialize, causing the allograft to shed. In a few cases, we have successfully used allograft alone to close wounds definitively in neonates, where autografting would be quite morbid. In these cases, the allograft epidermis sloughs and the wound reepithelializes over the allograft dermis.

Dermal replacements. Integra is the most commonly used dermal regeneration template (Fig. 20.7). It consists of a matrix of bovine collagen and shark glycosaminoglycan formulated to provide a scaffold for cell ingrowth and formation of a neodermis. The matrix layer is protected and covered by a silicone sheet that acts as a temporary epidermis, limiting fluid and heat losses and protecting the inner matrix layer. We use Integra in full-thickness burns of functionally important sites and larger areas. Its primary downside is that it delays definitive autografting by 2–3 weeks while the neodermis forms and revascularizes. We generally dress Integra with Acticoat to prevent infection and use the VAC as a bolster. As with other grafts, sites must be immobilized for 5–7 days to prevent shear. Once the neodermis has formed and vascularized, the silicone top layer is removed and a very thin autograft is placed. The need for only a very thin split-thickness autograft or an epidermal graft is a major benefit to Integra; this results in less donor site morbidity and faster healing of donor sites, which can be critical in massive burns where repeated harvesting is necessary. Integra works best in broad flat areas such as the anterior trunk, but it can be used almost anywhere with sufficient care. Decellularized cadaveric dermis (AlloDerm) and PriMatrix, an acellular fetal bovine dermal matrix, are alternatives to Integra for dermal replacement.

Postoperative Care. In the first 48 h after grafting, close observation and careful precautions are taken to avoid disruption of the graft dressings, which could lead to shear or hematoma formation. Elevation of grafted extremities is important to prevent bleeding, minimize edema, and aid in pain control. In large surface area burns where infection risk is higher, dressings may be changed as soon as 2–3 days postoperatively to allow for wound inspection and to limit accumulation of drainage in the dressings. Sheet grafts may also be evaluated at 2 days post-op so that any hematomas or seromas can be drained by puncture aspiration. Great care must be taken in this early time frame not to disrupt the grafts, which will not have solid adherence to the wound beds yet. Postoperative dressings such as the VAC are typically not disturbed in the early postoperative period, and then taken down on postoperative day 5–7 in uncomplicated cases. At this point any sutures or staples can be removed and mobilization of grafted areas may commence. For meshed grafts, dressings should be continued and changed every 1–3 days until the interstices of the grafts have reepithelialized. Once grafts and donor sites are fully closed, we begin moisturizing the healed grafts and donor sites with emollients and applying light compression with elastic wraps or sleeves.

Complications

Complications in the immediate postoperative period include bleeding, infection, and graft loss. If infection is suspected, dressings should be changed to include broad-spectrum aqueous Sulfamylon solution. Invasive infection and bacteremia should be treated with appropriate systemic antibiotics. Bleeding from freshly excised wounds or under grafts can be prevented by maintaining meticulous hemostasis in the operating room and avoiding coagulopathy with good nutrition and, if necessary, supplementation with exogenous clotting factors.

Long-term complications mainly involve scar hypertrophy and contracture formation. As these can be quite challenging

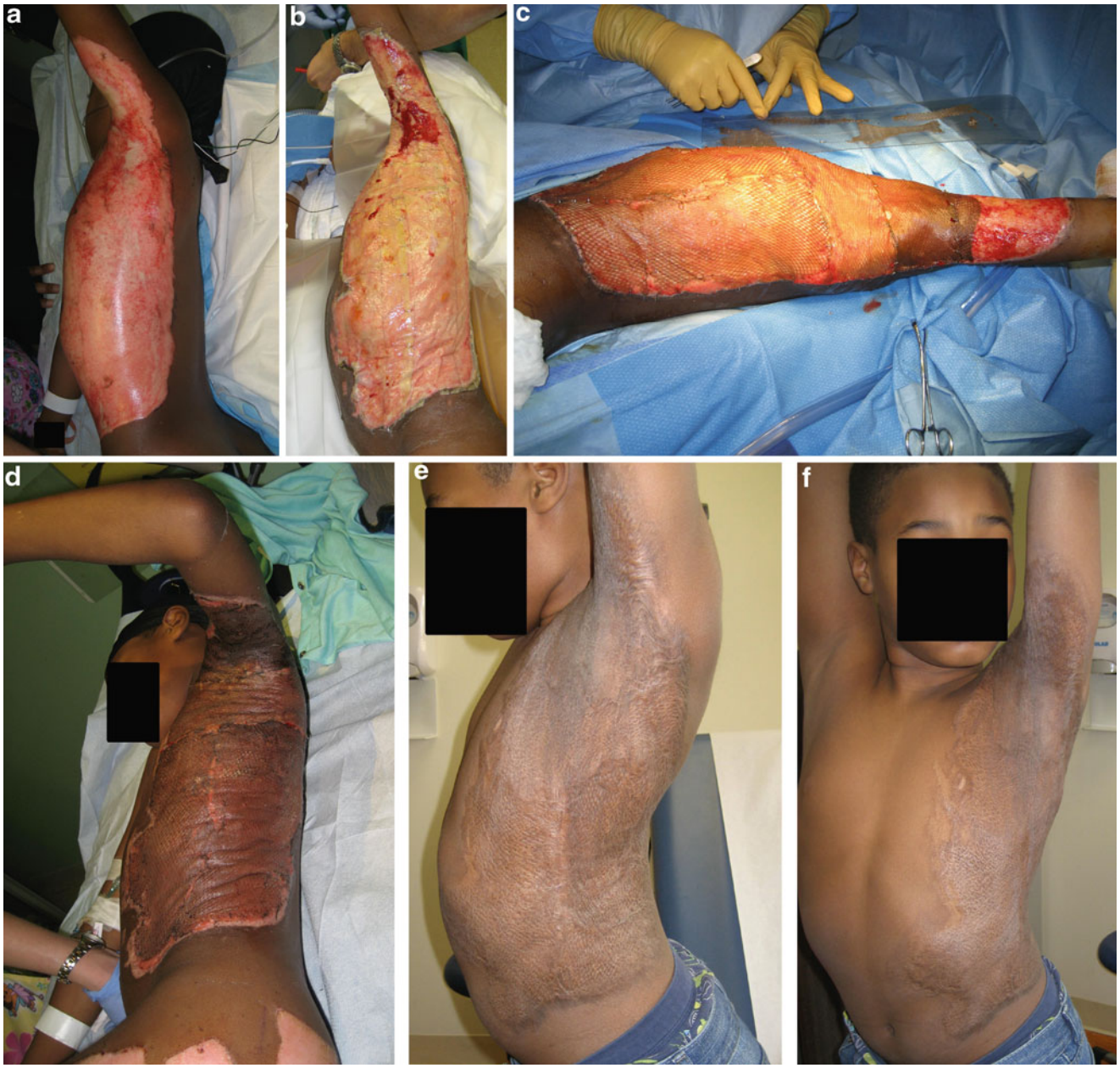


Fig. 20.7 Seven-year-old boy with 12 % TBSA deep partial-thickness and full-thickness flame burns of the left trunk, axilla, and arm: (**a**) postburn day 1, prior to burn excision and Integra placement; (**b**) revascularized Integra 14 days after placement, just prior to autografting; (**c**) placement of thin autografts over Integra; (**d**) 1-week status post definitive autografting; (**e**, **f**) mature grafts 3.5 years after injury

to deal with once they are established, it is advisable to initiate preventive measures early in the course of therapy.

For burns that are grafted or take longer than 3 weeks to heal, hypertrophic scarring can be minimized with the use of compression therapy. Custom-made garments that apply 25–30 mmHg pressure to all wounds usually work best. Silicone gel pads can be used underneath or sewn into the garments, to apply extra compression. Compression therapy is continued throughout the scar remodeling process (12–18 months). Application of emollients with massage therapy helps to keep grafted areas soft and supple.

Contractures are scars that impair joint function or range of motion. Aggressive occupational and physical therapy is necessary to ensure optimal results. Active and passive range of motion exercises are instituted early and splints are worn at night and between exercise periods. Burn patients at risk for contractures are followed for years to monitor for the development of these complications.

Editor's Comment

Besides management of the burn injury and attention to the ABCs of trauma care, care of the burned child demands careful consideration of many simultaneous and sometimes competing issues: social and legal concerns, the psychological and emotional care of the child, alleviating pain and anxiety and, of course, ruling out other injuries. Making matters worse is the fact that for the severely injured child, the care provided in the trauma bay is transitional, as they are accepted from the first responders and safely prepared for transfer to a pediatric burn center. Transfers of care increase the risk of errors and omissions, highlighting the importance of excellent attention to detail and the risk of potential complications. One should never assume that the care provided at another institution or in the field was adequate or sufficient: always check endotracheal tube position by auscultation and chest X-ray, be sure that the cervical spine is properly immobilized, and perform a careful physical assessment—including the calculation of extent of TBSA—yourself. Likewise, if the patient is being transferred, it is important to think ahead as to what will be needed on the receiving end; rather than applying an opaque cream, cover the burns with clear ointment and dry or simple sterile dressings that can be easily removed for a proper assessment of the depth and extent of the injury; secure adequate intravenous access and hydrate the patient well; avoid long-acting muscle relaxants to allow an accurate assessment of neurologic status after transfer; and be sure that copies of all films and medical records accompany the patient.

Silvadene has been the mainstay of burn therapy for many years, though many now prefer to use petrolatum-based antibiotic ointments, which are transparent, keep the wounds moist, and do not necessarily need to be removed or washed off before every application. The antibiotic concentration in most topical antibiotic preparations is too high for use in the eye, so in little children, it is best to use ophthalmic-strength ointment for burns on the face or hands, where it might easily be transferred to their eyes.

Unfortunately many burn wounds in children are due to child abuse, usually due to ignorance, a misguided attempt to punish, or frank negligence. It is therefore important to be skeptical and wary, without being overtly accusatory, in all but the most obvious cases. It is far better to err on the side of caution and to involve child protective services or social work early in the process, before discharging a child into a potentially unsafe or abusive home environment. This is especially true for scald burns (not just classic dip burns), contact burns (from an iron or hot plate) and localized flame burns. When in doubt, the child should be admitted overnight for observation and further assessment.

Suggested Reading

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Abdominal Trauma

21

Christian J. Streck Jr.

Injury is the leading cause of morbidity and mortality in children. Each year, over ten million children require urgent evaluation and treatment of injuries. The different mechanisms of injury and developmental stages seen in injured children result in a unique pattern of injury. In many cases, the mechanism of injury may be lower velocity than seen in adults.

Initial Evaluation

The initial approach to the seriously injured child requires adherence to the principles of Advanced Trauma Life Support. Important information can be gained from the EMS team including the mechanism of injury and the hemodynamic, respiratory, and neurologic status of the child during transport. For motor-vehicle collisions (MVCs), it is helpful to know available details of the incident. The EMS report should include whether there was significant transmission of force with vehicular damage. This report should include whether there was rollover, if there was appropriate use of restraints, and if there was ejection from the vehicle. In the alert and cooperative child, it is important to pay careful attention to the details of the history. The timing of injury relative to presentation, whether there is a complaint of abdominal pain, and whether emesis has occurred should all be considered. The primary survey includes airway and cervical spine evaluation and management, assessment of breathing, and circulation assessment with intravenous access and hemorrhage control. The secondary survey should include a careful physical examination focusing on evidence of thoracic trauma (decreased breath sounds, crepitus, contusions, abrasions), costal margin trauma, and abdominal wall trauma (distension, tenderness to palpation, seat-belt or handlebar contusion, peritoneal signs). The history and physical examination along with consideration of the patient's mental status and hemodynamics should guide subsequent decision making about laboratory and imaging studies. Fortunately, few pediatric patients present with hemodynamic instability from an intra-abdominal source. These rare cases require operative exploration and management. In the vast majority of pediatric patients, selective utilization of imaging and laboratory studies should be planned.

There are several unique characteristics of pediatric anatomy that should be considered when evaluating for intra-abdominal injury (IAI). Because of the smaller, more compact nature of children, greater force may be applied to the torso from falls, seat belts, and car bumpers. There is also usually less body fat separating adjacent organs resulting in a higher frequency of multiple organ system injuries. Because the skeletal system is immature and more pliable, a rib fracture suggests significant energy transfer. In addition, the bladder, liver, and spleen are relatively larger and more intra-abdominal, making them less well protected by the skeleton and immature abdominal wall musculature.

There are several findings on history and physical examination that raise concern for IAI. Significant abdominal pain or emesis in the absence of a head injury should prompt further evaluation. In addition, evidence of abdominal or lower thoracic wall trauma should increase suspicion for possible IAI. The presence of a seat-belt contusion on the lower abdomen after an MVC or an epigastric contusion from a bicycle handlebar following a crash is particularly concerning. Lower rib fractures, lower chest wall contusions, or decreased breath sounds should prompt additional investigation. Furthermore, patients with abdominal distension with pain or signs of peritoneal irritation following blunt abdominal trauma (BAT) should increase suspicion for IAI. Patients less than 2 years of age and those with altered mental status (especially if intubated/sedated) can prove particularly difficult to obtain a reliable history and examination.

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Imaging

The FAST (focused assessment with sonography in trauma) has gained widespread acceptance in most adult trauma centers as an adjunct to the secondary survey in the trauma bay. Four anatomic areas are evaluated for fluid: pericardium, perihepatic, perisplenic, and pelvic. The FAST exam may be helpful to identify large volumes of free fluid in the abdomen in a hemodynamically unstable patient and hasten operative exploration. It is a rapid test and does not require ionizing radiation. FAST has been shown to reduce the number of CT scans and diagnostic peritoneal lavage in adults. The utility of the FAST exam is less clear in children and is rarely helpful in directing clinical care. Several studies have demonstrated a limited sensitivity (50–65 %) and specificity for the diagnosis of injury in children. This may be in part due to variation in technique and experience of the FAST operator. A negative study in a stable patient with a high index of suspicion for injury will likely still prompt an abdominal CT. Based on the high likelihood of success of nonoperative management in pediatrics, a positive study in a stable patient will still prompt an abdominal CT as well. In addition, many pediatric solid organ management protocols rely on information about specific organ injury and grade, which are not provided by FAST. At this time, FAST is commonly performed as a part of the initial trauma evaluation but rarely changes management in children.

After completion of the primary and secondary surveys, laboratory and imaging evaluation should be considered. The use of laboratory testing to predict which patients are more likely to have IAI and might benefit from CT scan has generated significant interest in recent years. The literature on laboratory tests for screening following BAT is conflicting. Some studies have concluded that routine screening labs add little to the trauma evaluation. In addition, studies involving adult trauma victims have concluded that trauma labs contribute to significant and unnecessary cost. Moreover, many clinicians consider CT scan of the chest, abdomen, and pelvis with IV contrast as the "gold standard" for evaluation of the abdomen following blunt torso trauma. CT scans have the advantage of providing rapid diagnostic information with great sensitivity and specificity. In the case of a completely negative CT scan, otherwise stable patients can potentially be sent home with no further observation. In adult emergency departments, this "pan-CT scan" approach has become the standard practice for patients with a significant mechanism of injury. Some studies have even suggested that pan-CT is more cost-effective than selective CT in adults. The growing availability of and reliance on CT is evidenced by the rapid expansion of CT utilization in the evaluation of pediatric patients in the ED. Over the past 15 years, the number of ED visits involving a pediatric CT scan has drastically increased, primarily for the evaluation of abdominal pain and trauma. In addition, the vast majority of CT scans ordered on children are performed outside of children's hospitals. There is growing concern about the long-term cancer risks from medical ionizing radiation exposure in children. Based on data extrapolated from radiation exposure following atomic bombs during World War II, it has been estimated that abdominal CT scans performed in infants create an additional risk of one fatal cancer in 1000. Young children are thought to be more sensitive to radiation exposure due to their small size and rapid growth with a longer life expectancy for the development of cancer. These risks may be magnified by imaging studies performed in community hospitals with scanners utilizing protocols created primarily for adult patients. Importantly, no known cases of medical radiation-induced cancer have been documented to date.

In hemodynamically stable patients with concern for IAI, CT scan with intravenous contrast alone should be utilized. Current practice in most children's hospitals is to use the as low as reasonably achievable (ALARA) principle to limit the dose and frequency of CT scans performed. Although CT has many advantages, there are several limitations in the trauma evaluation beyond radiation exposure. The sensitivity of CT scan for pancreatic and small bowel injury is somewhat limited, particularly in patients who present within a few hours of injury and are imaged without oral contrast. In addition, there is some risk from transport and less intensive monitoring in the scanner itself, and there is additional cost associated with the diagnostic test and interpretation. Furthermore, only 10 % of pediatric trauma activations involve intra-abdominal injuries and only 25 % of these require any active intervention. Unlike the common practice of pan-CT in adult trauma centers following trauma activation, selective utilization of abdominal CT scanning is advocated in most pediatric trauma centers.

Several pediatric studies have suggested that clinical exam and laboratory data alone may be reliably used to predict the absence of clinically significant IAI after BAT. In one study, six findings were associated with IAI: low initial systolic blood pressure, abdominal tenderness, femur fracture, aspartate aminotransferase (AST) greater than 200 U/L, microscopic hematuria, and an initial hematocrit less than 30 %. In the absence of any of these six findings in a hemodynamically stable patient who is alert and available for serial abdominal examination, it is suggested that CT scan may be safely avoided. In a more recent study from the Pediatric Emergency Care Applied Research Network (PECARN), it was suggested that history and physical examination alone could safely predict which patients were likely to have an IAI requiring intervention. In our institution we perform a chest x-ray, FAST examination, and screening laboratory studies including AST, hematocrit, lipase, and urinalysis on all patients for which a trauma alert activation has been initiated. Based on our local clinical practice guidelines (CPG), we have seen a significant decrease in negative abdominal CT scans during the evaluation of hemodynamically stable trauma patients over the past several years (Table 21.1). The decrease is greatest in non-intubated patients with no major

Table 21.1 Clinical practice guideline for selective abdominal CT utilization following blunt abdominal trauma in children

A.	Patient characteristics
	a. GCS 13 or higher
	b. Age 3 years or greater
	c. Systolic blood pressure normal for age
	d. Normal abdominal examination (no evidence of seat-belt contusion, tenderness to palpation, distension)
B.	Trauma bay laboratory/imaging results
	a. Aspartate aminotransferase (AST) < 200
	b. Hematocrit > 30%
	c. Normal chest x-ray

Abdominal CT scan is *not* performed during the initial trauma evaluation if the following criteria are present

distracting injuries and a reliable physical examination. Importantly, we have not seen any missed or delayed diagnoses of IAI after implementation of a CPG. In our center, many of the patients evaluated as a component of trauma team activation are admitted and observed during management of other organ system injuries or for social reasons regardless of whether they underwent abdominal CT imaging. Several other imaging modalities have been considered for screening hemodynamically stable patients with mechanism of injury concerning for possible IAI including a formal ultrasound performed after an established time interval and MRI. Widespread use of these modalities for the initial evaluation of children following BAT has not been adopted at this time.

Penetrating Injuries

In most trauma centers, penetrating injuries account for fewer than 10 % of intra-abdominal injuries in children. Patients with a penetrating abdominal injury with hemodynamic instability require urgent operative exploration. Thorough exploration of the entire abdomen, hemorrhage control, and management of the injuries identified mirror the operative management of adult trauma patients. In patients with penetrating abdominal injuries who remain hemodynamically stable, consideration of the mechanism of injury and course of the projectile or foreign body is important. Some penetrating abdominal injuries may result from entrance wounds at a remote site or present as a result of multiple projectiles. Examination of the wounds including a local wound exploration to evaluate for fascial violation and basic plain film evaluation may help estimate the trajectory and course of the implement or missile. A search for retained foreign bodies, associated orthopedic injuries, and whether a projectile crossed the midline in pelvic injuries may also be helpful. In select patients who remain hemodynamically stable, CT scan may also be useful, particularly for flank injuries which may be isolated to the retroperitoneum or, in rare cases, isolated transabdominal right upper quadrant injuries (Fig. 21.1). Selective nonoperative management with observation has been successfully applied in many stable patients following CT imaging.

Laparoscopy is another valuable tool for pediatric surgeons to evaluate stable patients following penetrating trauma. Laparoscopy can be particularly valuable following knife stab wounds to evaluate the liver, stomach, small bowel, and colon if fascial violation has been demonstrated on physical examination. In addition, laparoscopy is particularly well suited for evaluation of the diaphragm for penetrating injuries. A positive laparoscopy will sometimes prompt conversion to laparotomy for complex injuries; however, many pediatric surgeons are able to manage identified injuries requiring intervention with laparoscopic techniques alone.

Solid Organ Injuries

Nonoperative management of solid organ injuries has evolved significantly over the past 40 years. The concept of a nonoperative strategy for management of major solid organ injuries with improved morbidity and mortality was championed initially by a pediatric surgery fellow at the Hospital for Sick Children in Toronto in 1968. In a nonrandomized population, mortality was similar between patients undergoing splenectomy and those managed nonoperatively following isolated spleen trauma. Support for this practice evolved quickly in the pediatric surgery community, particularly in light of concerns about the potential for overwhelming postsplenectomy sepsis (OPSS). Over the next few decades, transfusion thresholds have decreased, management algorithms have been refined, and pediatric and adult surgeons alike have widely adopted nonoperative management as an initial management option. In current practice, greater than 95% of isolated solid organ injuries in children following BAT can be managed without operation. The patient's hemodynamic status is the primary determinant of whether a nonoperative strategy should be pursued. A child who presents with hemodynamic instability following BAT with peritonitis or a significantly distended abdomen or grossly positive FAST should be transported to the operating for emergent exploration. Resuscitation including warming, intravenous access above the diaphragm, and initiation of a massive transfusion protocol with avoidance of coagulopathy should begin in the trauma bay and continue in the operating room without delay. A trauma laparotomy should focus on rapid hemorrhage control, control of contamination, and, if necessary, temporary abdominal closure with ongoing resuscitation under the direction of the surgeon in the PICU (Fig. 21.2). The "lethal triad" of coagulopathy, hypothermia, and acidosis should be avoided at all costs. In these patients, a second look laparotomy at 24–48 h post-injury is often warranted. In hemodynamically stable patients, the diagnosis of solid organ injury is most commonly made by abdominal CT with IV contrast (Fig. 21.3).

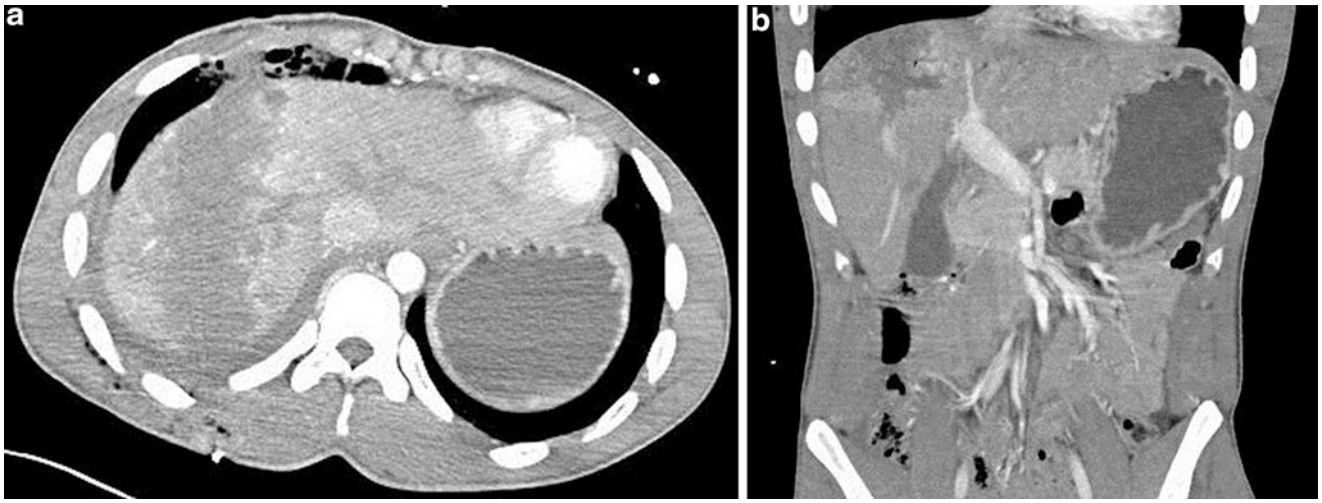

Fig. 21.1 Nonoperative management was used in this hemodynamically stable 15-year-old boy following an isolated transabdominal gunshot with entrance wound above the right costal margin anteriorly and exit wound beneath the right scapular tip. (**a**) Axial abdominal CT image showing bullet trajectory and Grade IV right lobe liver laceration; (**b**) coronal CT image showing laceration to the dome of the liver and associated lung contusion

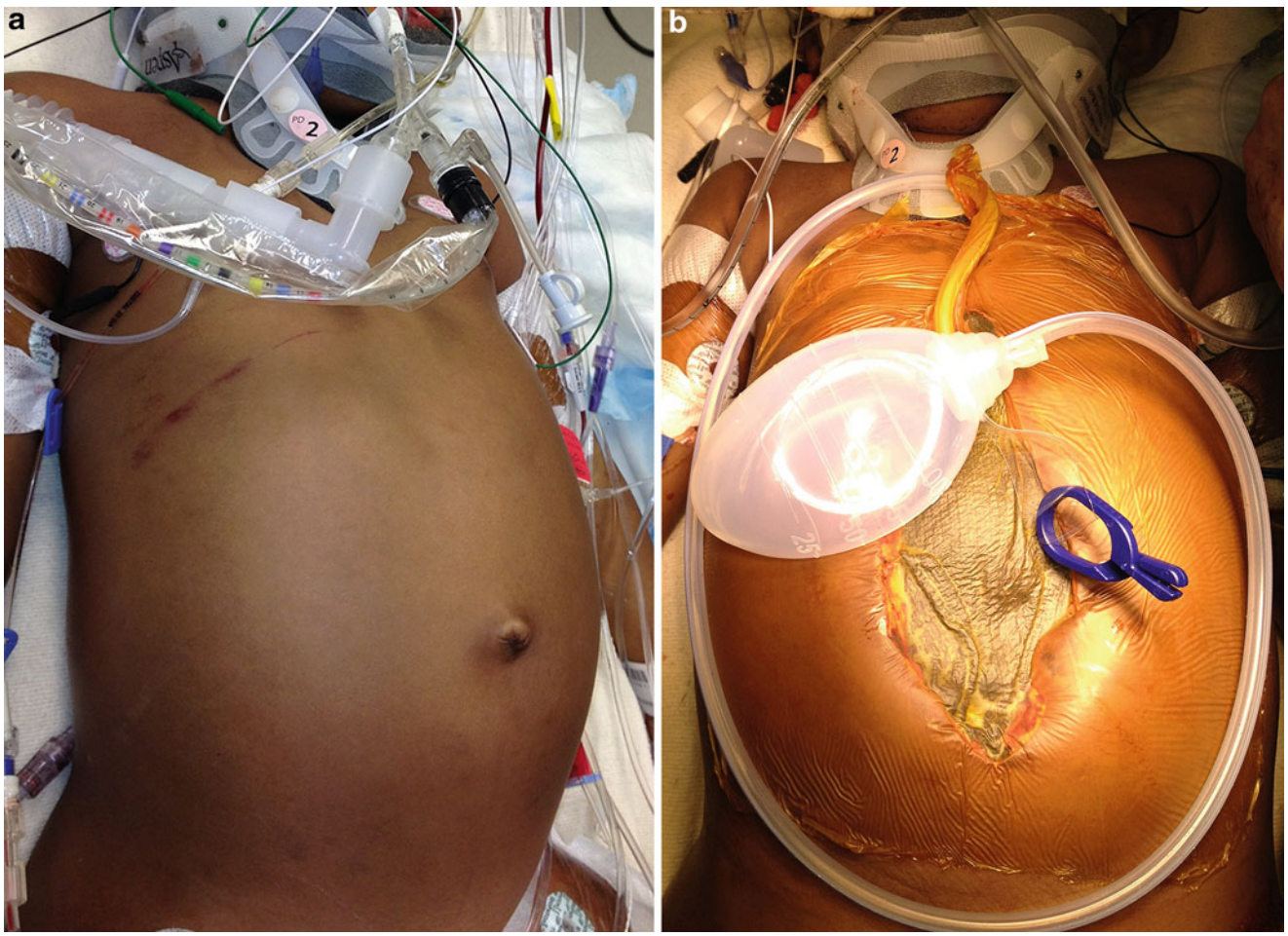

Fig. 21.2 Abdominal compartment syndrome in a 3-year-old girl who was thrown from a three-story balcony and sustained a depressed skull fracture and subarachnoid hemorrhage as well as a Grade III liver laceration through the falciform ligament with active extravasation from a pancreatico-duodenal artery branch. (**a**) Massively distended abdomen; (**b**) temporary abdominal closure following damage-control laparotomy

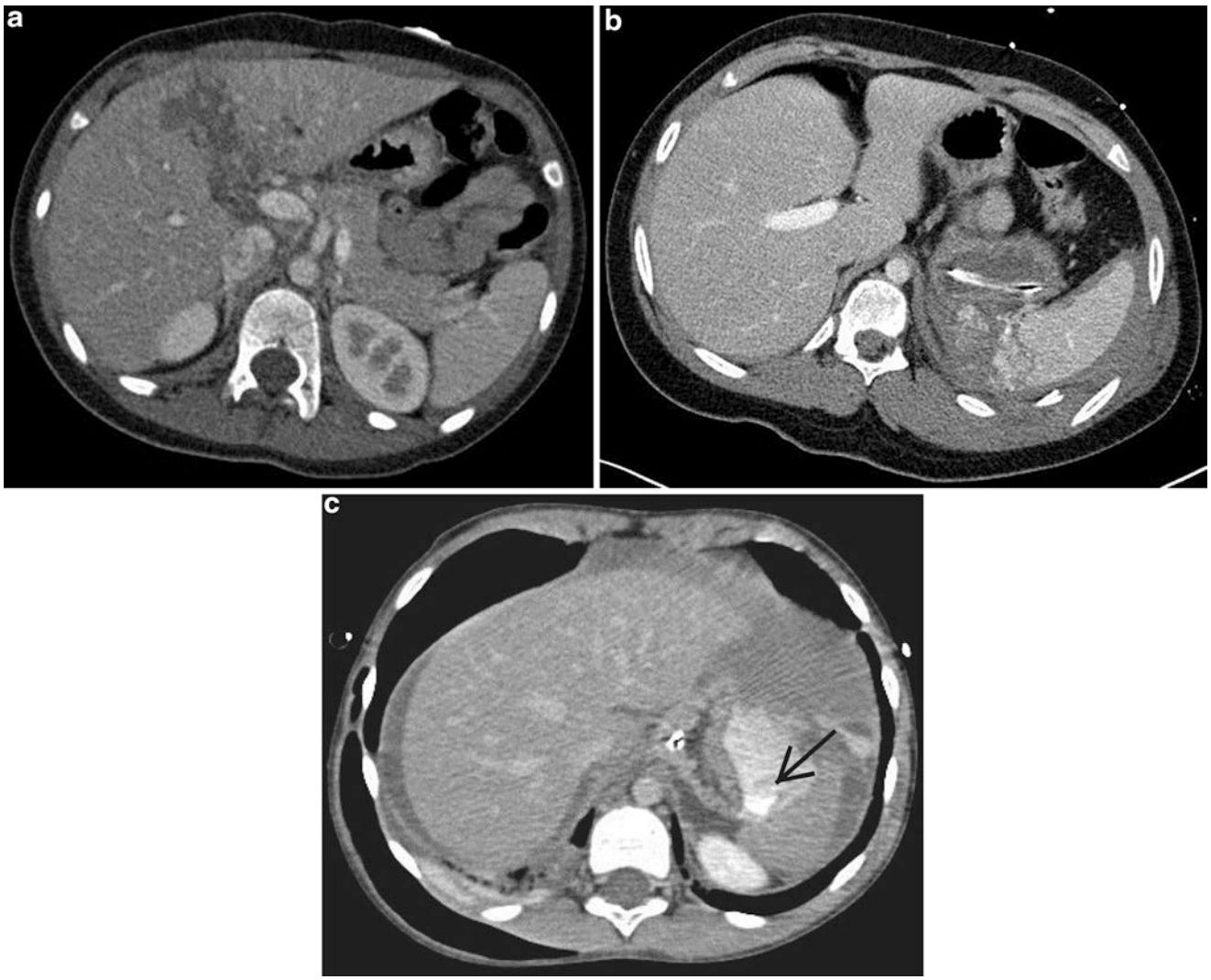

Fig. 21.3 CT scan with intravenous contrast is the standard for evaluation of hemodynamically stable children with suspected solid organ injuries. (**a**) A 9-year-old girl who sustained a Grade IV liver laceration of the right hepatic lobe that extends into the porta hepatis; (**b**) Grade IV spleen laceration in a hemodynamically stable 16-year-old boy following a high-speed motor-vehicle collision; (**c**) Grade III spleen laceration with active contrast extravasation (blush) on delayed images in a hemodynamically unstable 7-year-old pedestrian struck by an automobile

Current management algorithms are based on the grade of injury and whether active contrast extravasation or a pseudoaneurysm is identified. Failure of nonoperative management of solid organ injury is rare and is typically the result of ongoing hemorrhage and occurs in approximately 2 % of children for whom this is the initial management strategy. Most solid organ injuries do not require transfusion, especially given the recent emphasis on hemodynamics and acceptance of a hemoglobin level in the 6–7 mg/dL range. In patients who have more severe solid organ injuries managed non-operatively, an initial phase of transient response to fluid resuscitation is often seen. If there is evidence of ongoing bleeding requiring transfusion, angioembolization is useful in select cases to avoid additional blood loss and operative intervention. Patients who fail nonoperative management for hemorrhage typically do so in the first 24 h. Due to the success of nonoperative management of solid organ injuries, the vast majority of pediatric trauma laparotomies performed today are for management of small bowel or colonic injuries.

Spleen and Liver

The current nonoperative management algorithm for blunt spleen and liver injury is based on the American Association for the Surgery of Trauma (AAST) Organ Injury Scale (Table 21.2). The scale for spleen injury ranges from Grade I (<10 % surface area subcapsular hematoma or <1 cm depth parenchymal laceration) up to Grade V (completely shattered spleen or hilar vascular injury with >25 % of spleen devascularized). The scale for liver injury ranges from Grade

Table 21.2 American Association for the Surgery of Trauma (AAST) organ injury scale for spleen

Spleen injury scale		
Grade[a]	Injury type	Description of injury
I	Hematoma	Subcapsular, <10 % surface area
	Laceration	Capsular tear, <1 cm parenchymal depth
II	Hematoma	Subcapsular, 1–50 % surface area; intraparenchymal, <5 cm in diameter
	Laceration	Capsular tear, 1–3 cm parenchymal depth
III	Hematoma	Subcapsular, >50 % surface area; intraparenchymal >5 cm in diameter
	Laceration	>3 cm parenchymal depth or involving trabecular vessels
IV	Laceration	Involving segmental or hilar vessels producing major devascularization
V	Laceration	Completely shattered spleen; hilar vascular injury with devascularization

[a]Advance one grade for multiple injuries up to Grade III

Source: Data from Tinkoff G, Esposito GJ, Reed J et al. American Association for the Surgery of Trauma Organ Injury Scale I: spleen, liver and kidney, validation based on the National Trauma Databank. J Am Coll Surg. 2008:207:646–55

I (same as spleen) to Grade VI (hepatic avulsion). Candidates for nonoperative management of blunt spleen and liver injuries are those that are hemodynamically stable or respond well to initial resuscitation with improvement in hemodynamics. All stable patients with blunt liver or spleen injuries are admitted and their vital signs are observed closely. We admit stable patients with a Grade I–III liver/spleen injury to the regular inpatient unit and repeat labs at 6, 12, and 24 h (Fig. 21.4). In the past we kept these patients NPO for 24 h with bed rest, but currently our policy has been liberalized to allow for monitored ambulation and an initial clear liquid diet. If the patient remains stable for 24 h, we then advance to a regular diet and allow full ambulation with discharge at 36–48 h if the vitals and hematocrit have remained stable.

For patients with Grade IV injuries or higher or patients who required blood transfusion or more than two 20 mL/kg crystalloid boluses, we admit to the Pediatric ICU on the surgical service. These patients are placed on bed rest and made NPO for 24 h and have their hemoglobin checked every 6 h. If the patients remain stable for 24 h, they are transferred to the floor and follow the care pathway for less severe injuries. For patients who are only transient responders and require additional transfusion in the ICU, we would consider an interval CT to evaluate for active extravasation or pseudoaneurysm that might be amenable to angioembolization. Patients who require more significant blood transfusion or become unstable during ICU observation require abdominal exploration. Nonoperative management is accomplished in the vast majority of spleen and liver injuries.

Following discharge, activity restriction is mandated for 4–6 weeks. We do not routinely perform follow-up imaging in stable patients during admission or after discharge. Clinic follow-up is performed after 6 weeks in the rare patient who is interested in resuming a contact sport after a grade III–V injury. We obtain an ultrasound on the day of the clinic visit to evaluate the status of the solid organ injury and document healing prior to resumption of full activity.

Adolescents admitted to an adult trauma center are more likely to undergo splenectomy even after controlling for age and injury severity score. In addition, studies have shown that angioembolization rates and transfusion rates are lower in children managed at a pediatric trauma center. Intervention for isolated blunt spleen and liver injuries, including surgery, angioembolization, and even transfusion, remains infrequent in pediatric trauma centers.

Surgery is reserved for the rare patient who fails nonoperative management for ongoing hemorrhage or delayed recognition of a mesenteric or hollow viscus injury. In the case of ongoing hemorrhage from an isolated splenic injury, techniques for splenorrhaphy are available including mesh placement and coagulation with the Argon beam. Many of the patients undergoing laparotomy for management of significant ongoing hemorrhage have a non-salvageable spleen and undergo splenectomy. OPSS is extremely rare with a currently reported rate of less than 0.3 % per year. Because of the potentially fatal consequences of sepsis postsplenectomy, vaccination for encapsulated organisms (*pneumococcus*, *meningococcus*, and *Haemophilus influenzae*) is verified or performed in all patients. Prophylactic oral penicillin is typically given for at least 2 years and is thought to be particularly beneficial in patients under age 5.

Major hepatic injury with hemodynamic instability can be very difficult to manage operatively. Activation of the pediatric major bleed protocol, active and passive warming of the patient, aggressive treatment of acidosis and coagulopathy, adequate intravenous access above the diaphragm, and arterial line monitoring are all essential components. Because operative management of these injuries is very rare in current pediatric surgery practice, early involvement of an experienced liver transplant co-surgeon is invaluable.

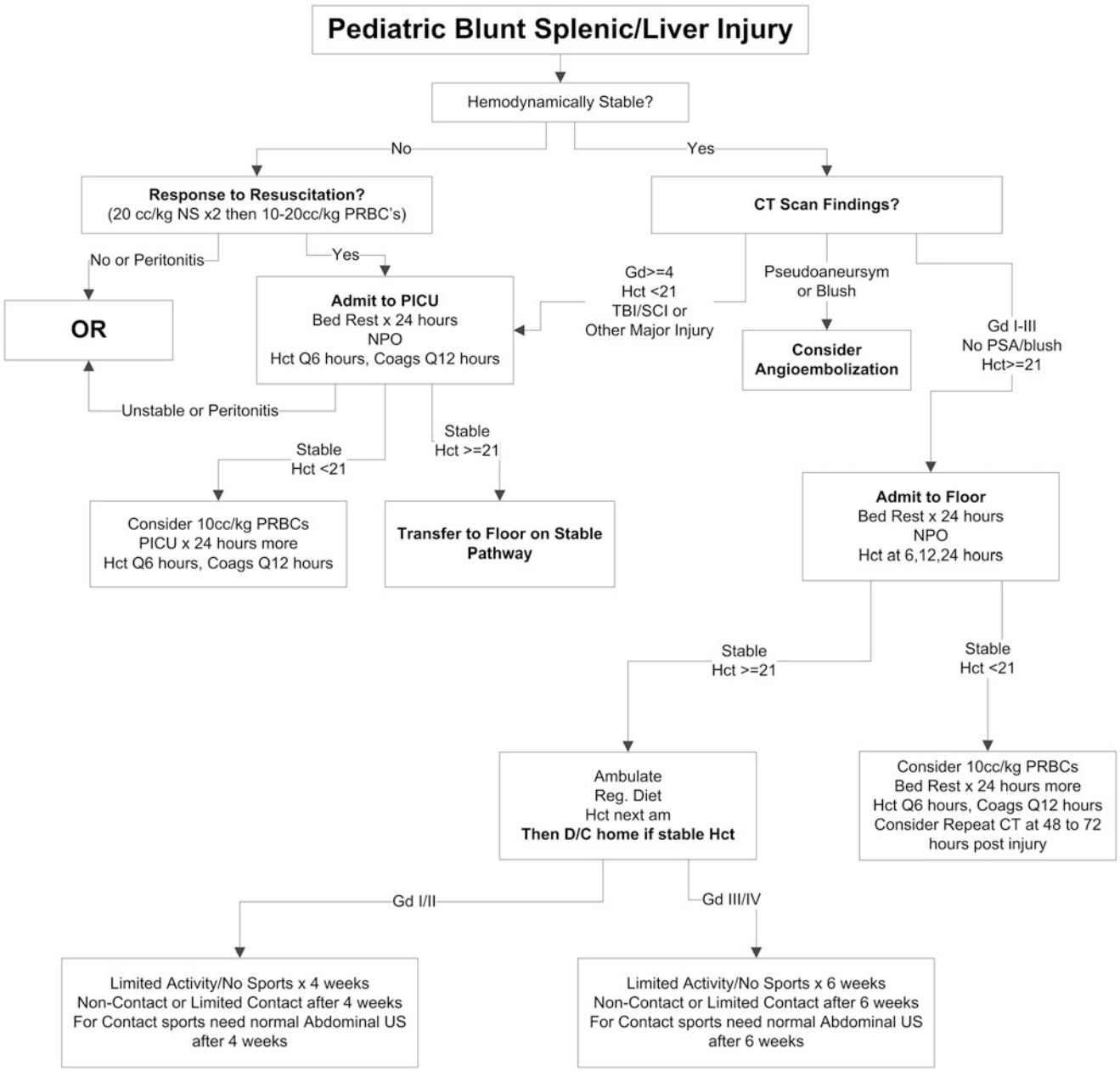

Fig. 21.4 Guidelines for management of pediatric blunt liver and spleen injury are based on the patients' hemodynamic status and injury grade

Operative techniques for major pediatric liver injury are similar to those utilized in adults. Compression, suture ligation, the Pringle maneuver, or resection for large fractures may be required. Frequently, control of hemorrhage and wide drainage are necessary, followed by packing and temporary abdominal closure to allow further ICU resuscitation with a planned second look laparotomy. In the most severe cases that involve juxtahepatic or retrohepatic vena caval injuries, total vascular isolation including the supra- and infrahepatic IVC as well as the porta hepatis may be required to allow for control of bleeding.

Pancreas

Injury to the pancreas is a relatively rare event following pediatric BAT. These injuries typically result from a focal force to the epigastrium that causes compression of the body of the pancreas against the spine. Most commonly these are the result of a seat-belt injury during an MVC or from direct force like falling on a bicycle handlebar or an assault. Abdominal CT is indicated in patients with epigastric pain or evidence of focal abdominal trauma like a seat-belt or

handlebar contusion. When the injury is the result of a low velocity mechanism, there can be a delay in presentation. This is particularly true in patients who sustained an injury as a result of child abuse. In these cases imaging with both oral and intravenous contrast can be very helpful.

Treatment of pancreatic injuries depends on timing of presentation and the severity of injury. Nonoperative management is preferred if there is evidence of a pancreatic contusion with no ductal disruption and with no other intra-abdominal injuries. These patients are admitted for serial abdominal examinations and made NPO. Although the degree of exocrine enzyme elevation does not correlate well with the degree of injury or with outcomes, following serial enzymes can be helpful in management including the timing of introduction of enteral feeding and monitoring for pancreatitis. In select cases, MRCP or ERCP is helpful in determining whether there is ductal disruption and to guide further management. Management of pancreatic transection with major ductal injury is somewhat controversial. If a patient presents within the first 2–3 days following injury with a pancreatic transection, our practice is to perform a distal pancreatectomy with splenic preservation (Fig. 21.5). Patients typically tolerate this procedure well with a low risk of pseudocyst formation and relatively rapid return to enteral feeding. Nonoperative management often requires a trained pediatric endoscopist capable of ERCP to delineate and potentially stent the ductal injury or the common channel. In addition, a pseudocyst might require percutaneous drainage. We reserve nonoperative management for patients with less severe injuries, a significant delay in presentation or pseudocyst. Which patients are likely to benefit from operative or nonoperative management for pancreatic ductal injury is an area of ongoing research.

Intestinal Injury

Hollow viscus injuries are identified in approximately 20 % of patients who sustain an IAI following blunt trauma. Depending on the mechanism of injury, these may be isolated or seen in conjunction with other abdominal injuries. In patients with small bowel trauma, the mechanism of injury is commonly similar to that seen in patients who sustain pancreatic injuries. Focal trauma from a lap belt (often the result of small children riding without a booster seat or avoidance of the shoulder strap), a bicycle handlebar or an assault is commonly associated with small bowel injury (Fig. 21.6). A particularly worrisome constellation for duodenal, small bowel, or pancreatic injury is seen in patients who present with an abdominal wall contusion and a Chance fracture of the lumbar spine.

In patients who present with hemodynamic instability or peritoneal signs following BAT, a trauma laparotomy is performed. More commonly, signs and symptoms of bowel injury are subtle and require a high index of suspicion for diagnosis. Patients typically present with hemodynamic stability and a physical examination concerning for abdominal injury but no definite evidence of perforation on initial CT. Although pneumoperitoneum can be seen, more often there is free intraperitoneal fluid without solid organ injury, mesenteric hematoma or stranding, bowel wall thickening, bowel wall contusion or enhancement, or an inter-loop fluid collection. In these cases inpatient observation with serial examination is warranted. Although significant morbidity and even mortality can occur from blunt small bowel or mesenteric injury, typically a period of observation and serial exam is well tolerated in equivocal cases for up to 24 h without an effect on patient outcome. Prompt operative evaluation is indicated for worsening abdominal pain, distension, or peritonitis. Diagnostic laparoscopy is an excellent tool in these cases. A thorough evaluation of the abdomen is performed. If evidence of intestinal perforation or a large segment of devascularized mesentery is found, many surgeons will convert to an open procedure or utilize a laparoscopic-assisted technique to address the identified injuries. Both small bowel and colon injuries can typically be managed with primary repair and avoidance of an ostomy. The site of small bowel injury is often near a point of retroperitoneal fixation like the duodenum, proximal jejunum, or terminal ileum. In rare cases of colon injury with hemodynamic instability, significant blood loss or massive fecal contamination a colostomy may be performed. In these cases, the focus is on control of contamination often with a temporary abdominal closure. Primary repair or anastomosis is performed as a component of a second look laparotomy after 24–48 h when the patient is stabilized.

Hollow viscus injuries that warrant specific consideration are duodenal injuries. Duodenal hematomas often present in a delayed fashion in patients with epigastric pain and emesis that begins shortly after injury and may continue for 2–3 days prior to hospital presentation. Nonoperative management for a duodenal hematoma is preferred. The patient should make NPO with consideration of TPN and NGT placement if symptoms persist. A limited upper GI series performed in a delayed fashion can be very helpful in determining luminal patency and when to initiate a clear liquid diet. Fortunately, most duodenal hematomas resolve within 1–3 weeks of nonoperative management and rarely progress or require intervention. Unlike a duodenal hematoma, a duodenal perforation requires surgery and can be one of the most challenging injuries to manage operatively (Fig. 21.7). Primary repair of focal injuries with limited tissue damage may be an option. For more severe injuries, several options exist including jejunal serosal patch onlay, afferent and efferent jejunostomy tube placement, pyloric exclusion, and duodenal diverticulization, all of which require wide drainage of the repair.

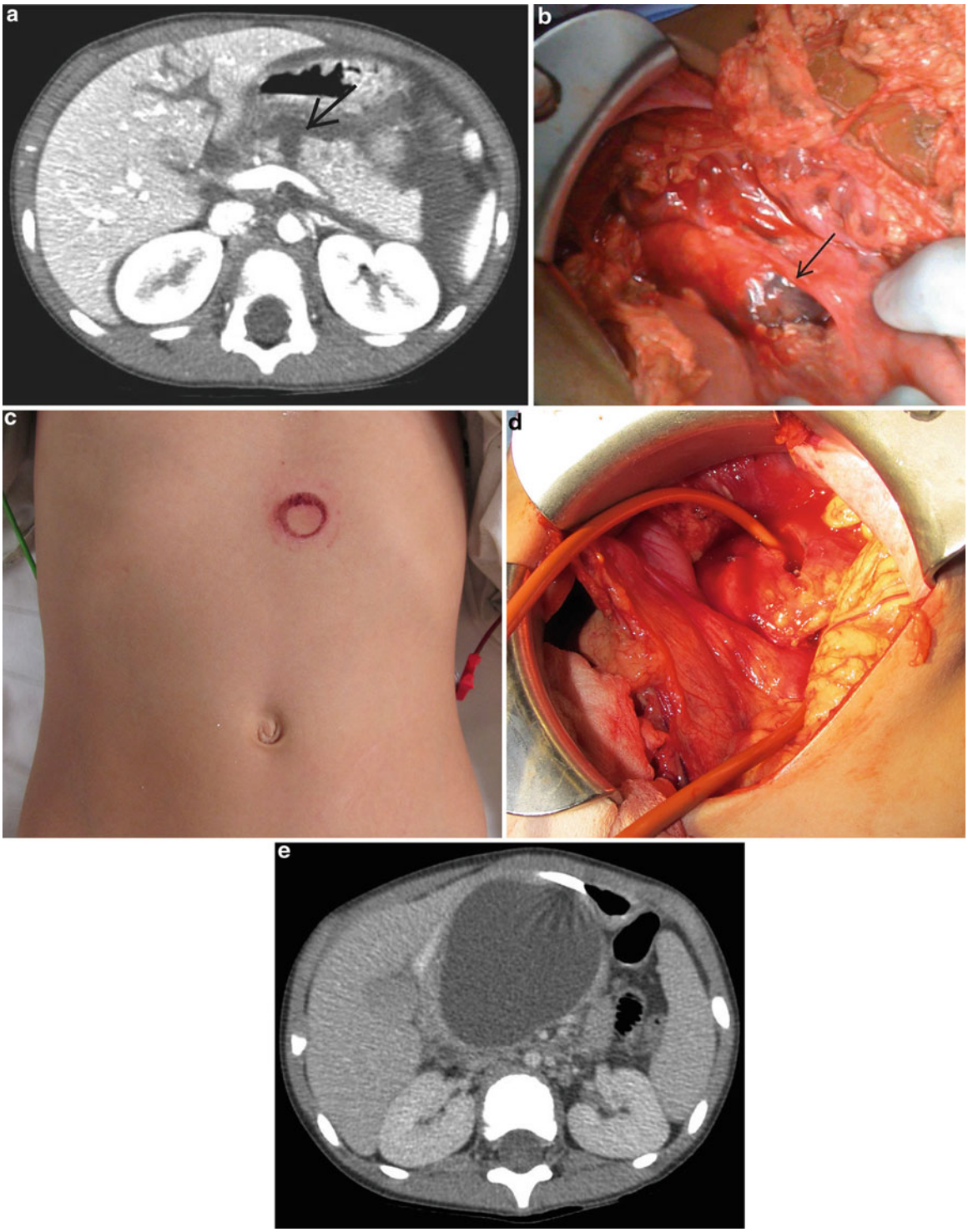

Fig. 21.5 Focal trauma to the epigastrium resulting in pancreatic transection. (**a**) CT scan demonstrating a pancreatic neck transection in a 4-year-old who presented with emesis and an elevated amylase 24 h after a basketball goal toppled over and the rim landed on his abdomen; (**b**) intraoperative view of the complete transection with devitalized distal pancreas; (**c**) bicycle handlebar contusion in a 12-year-old with epigastric pain and an elevated lipase; (**d**) intraoperative view during a spleen-preserving distal pancreatectomy; (**e**) CT demonstrating a pancreatic pseudocyst in a 3-year-old with a several-day history of epigastric pain following an unwitnessed event suspicious for child abuse

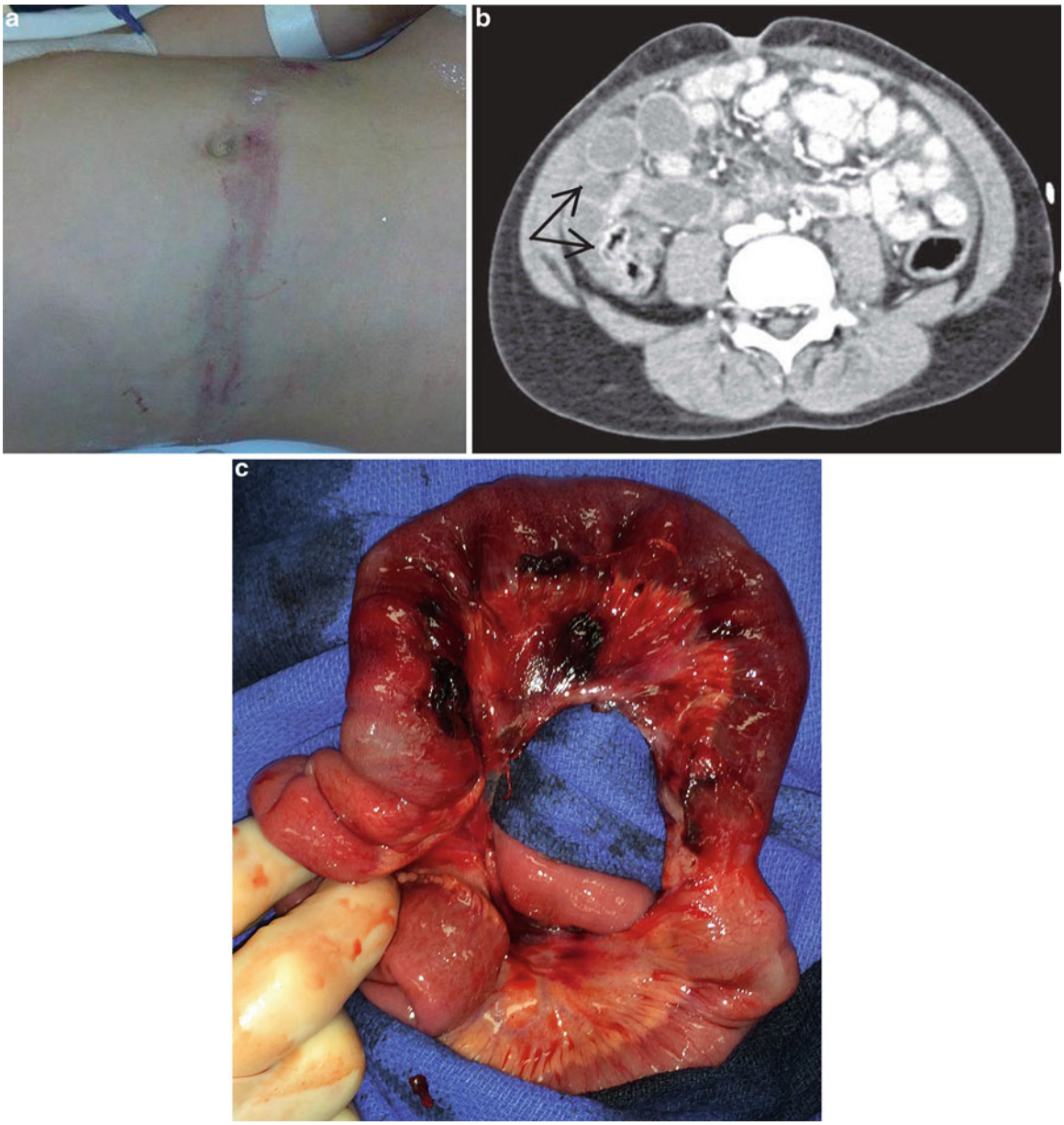

Fig. 21.6 A high index of suspicion for occult intestinal injury in patients who present with a seat-belt contusion and lumbar spine chance fracture. (**a**) Abdominal seat-belt sign in a 5-year-old boy who was riding in the front seat during a high-speed motor-vehicle collision; (**b**) abdominal CT demonstrating a right lower quadrant loop of small bowel with focal asymmetric hypo-enhancement with associated high-density fluid in the pelvis; (**c**) mesenteric injury with devitalized small bowel requiring segmental resection

Much like pancreatic trauma, patients with small bowel injury may present to the hospital in a delayed fashion. This is particularly true for child abuse cases or in patients where the injury occurred in the absence of an adult witness. At least 5 % of all trauma admissions and 10 % of all pediatric ICU trauma admissions involve intentional injury, and there is likely significant under-recognition and reporting of abuse in the trauma registry. Over 90 % of child abuse victims that require hospital admission are under age 4 and outcomes are often worse for victims of intentional injury. Hollow viscus injury is much more common in abused children than following accidental injury. Unlike patients with witnessed BAT and an accidental small bowel injury, the time to presentation is greater than 24 h in at least one third of intentional cases. Although very few of the patients hospitalized for child abuse sustain major IAI, the mortality rate in this population is around 50 %, making IAI the second most common cause of child abuse fatality. A thorough evalua-

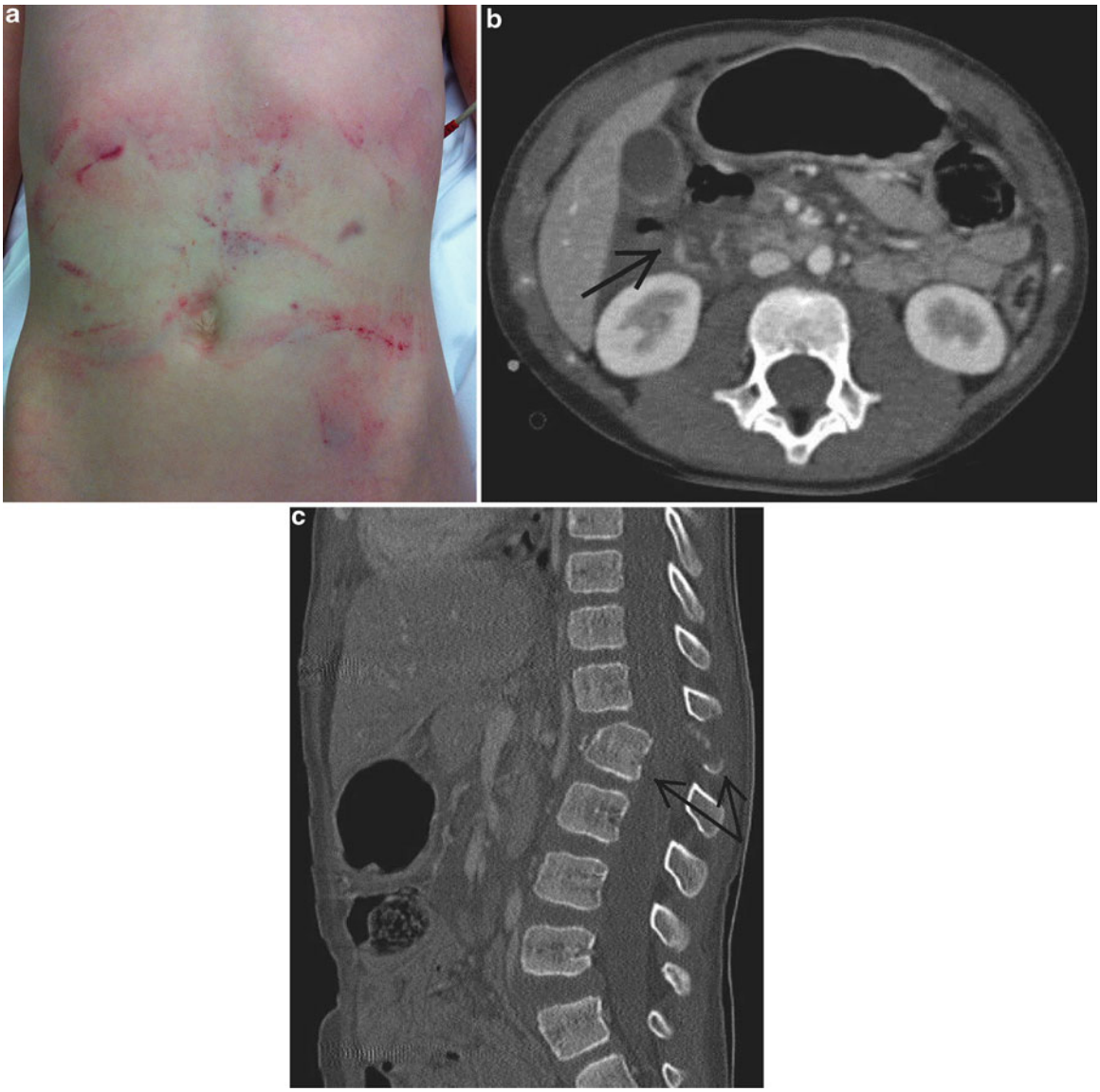

Fig. 21.7 Duodenal trauma in a 7-year-old girl after a motor-vehicle collision. Several small lacerations in the second and third portions of the duodenum repaired primarily with wide drainage and naso-jejunal tube decompression. (**a**) Abdominal wall seat-belt contusion; (**b**) abdominal axial CT image demonstrating a laceration to the second portion of the duodenum with free air and intermediate-density fluid consistent with perforation. (**c**) CT demonstrating anterolisthesis of L1 on L2 with retropulsion of L2 into the spinal canal

tion for child abuse should be performed if the history given is inconsistent or implausible for the patient's age and developmental stage: small bowel injury following a fall down stairs, being dropped by a young sibling, pulling over furniture in a patient too young to stand, or falling while ambulating in a patient too young to walk. Victims of child abuse commonly have soft tissue, head, and orthopedic injuries. Rib fractures in infancy are highly suspicious for inflicted trauma. Patients with intentional trauma resulting in IAI are more commonly younger, likely to have hollow viscus or combined solid and hollow viscus injury, have a delay in presentation, and have a higher mean injury severity score than patients with accidental IAI.

Genitourinary Injury

Renal injuries are seen in 10–15 % of children with an IAI following BAT. Patients with isolated renal injuries may present with flank pain and hematuria. A urinalysis is helpful to evaluate for microscopic hematuria following flank or posterior chest wall trauma. Children are susceptible to retroperitoneal injuries because they have less fat and less well-developed abdominal wall musculature.

Most Grade I–III renal injuries without collecting system disruption or urinary extravasation can be managed non-operatively. Intervention is necessary for patients with

ongoing hemorrhage, infection, or expansion of the urinoma with symptoms. Isolated renal injuries and ongoing hemorrhage may be amenable to angioembolization. Patients with persistent urinary extravasation benefit from ureteral stenting or percutaneous nephrostomy. Indications for surgery include hemodynamic instability and other intra-abdominal injuries that require intervention. In most cases, the kidney can be preserved.

Children are more susceptible to bladder injuries because the bladder lies in a more superior position and is less well protected by the bony pelvis. Pelvic pain or hematuria following BAT should prompt additional investigation. In addition, many injuries to the bladder and urethra have associated pelvic fractures. In cases of suspected lower genitourinary trauma, CT cystography with delayed images can be very helpful in delineating bladder injuries. Extraperitoneal bladder ruptures can be managed with Foley catheter drainage, while intraperitoneal bladder ruptures usually require surgical intervention. A retrograde urethrogram should be performed in cases with blood at the urethral meatus or a high-riding prostate to evaluate for urethral injury.

Future Considerations

Evaluation and management of children following BAT is a common component of any pediatric surgery practice. Occult injuries and child abuse are important considerations in any child presenting following an abdominal trauma. A careful history and physical examination as well as screening laboratory values and plain films are an essential component of most BAT evaluations and can help reduce unnecessary reliance on abdominal CT scanning. The vast majority of blunt solid organ injuries can be managed non-operatively. Patients requiring operative intervention for hemorrhage typically present with hemodynamic instability or have a transient response to resuscitation and fail nonoperative management within 24 h. Although hollow viscus injury is rare, the majority of trauma laparotomies performed in pediatric trauma centers are for management of intestinal or colon perforation. Small bowel injuries from child abuse commonly present in a delayed fashion and are often seen in children under age 4 years. Outcomes following intra-abdominal injuries in children are improved with management by a meticulous pediatric surgeon.

Editor's Comment

In children with blunt solid organ injury, surgical intervention should be considered in the setting of active bleeding, not the apparent severity of the injury. Contrary to the protocols still used in adults, children with free intraperitoneal blood, a blush on CT scan, the need for blood transfusion, or persistent abdominal pain do not require laparotomy unless there is also evidence of clinically significant bleeding or hemodynamic instability. In the stable patient, embolization is also an excellent alternative to laparotomy. Though children can have significant discomfort and fever after embolization, in experienced hands it appears to be safe and effective.

In the stable patient who requires laparotomy, splenectomy should be eschewed in favor of partial splenectomy whenever possible, and pediatric trauma surgeons should be acquainted with the various techniques to accomplish this. Liver injuries that require repair should be considered life threatening, and if the patient becomes unstable, there should be a low threshold to resort to a damage-control approach. Retrohepatic caval injuries are the most serious and, whenever possible, one should consider enlisting the help of an experienced transplant surgeon, who might be able to apply the portal vein bypass techniques used during transplant hepatectomy to allow repair or reconstruction of the vena cava. Renal injuries that require surgical repair commonly lead to kidney loss, justifying seemingly extreme efforts to treat them non-operatively. Injuries to the head of the pancreas should be treated non-operatively whenever possible. Transections of the neck or body of the pancreas that involve the main pancreatic duct can be treated non-operatively (drains, ERCP with stenting, parenteral nutrition), but the subsequent clinical course can be extremely long and complicated. In contrast, distal pancreatectomy or, if the transection is at the neck of the pancreas, a Roux-en-Y pancreaticojejunostomy, is well tolerated and usually results in a much shorter time to full recovery. The operation can be performed up to 72 h after injury, but an operation performed within 24 h is best. The proximal duct needs to be oversewn but, especially in small children, it is often impossible to visualize. In this case, it is preferable to oversew the entire cut surface or use a gastrointestinal stapling device across the parenchyma. It is always prudent to leave a closed-suction drain.

Frank small bowel perforation can develop up to 72 h after an injury to the abdomen, most commonly associated with a handlebar or seat-belt sign. These patients do not necessarily need to be hospitalized during the entire observation period, but parents need to understand that a delayed presentation is not uncommon and what signs to look for. Laparoscopy is an excellent way to diagnose and treat isolated small bowel injuries, which can usually be simply oversewn. Mesenteric defects should be repaired and hematomas left undisturbed. Ileostomy or colostomy should rarely, if ever, be necessary except possibly as part of a damage-control operation in a patient who has multiple bowel injuries, extensive contamination of the peritoneum with stool, or florid systemic sepsis.

Suggested Reading

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Thoracic Trauma

22

Nilda M. Garcia and Erich J. Grethel

The initial management of the child with suspected thoracic trauma begins with Advanced Trauma Life Support (ATLS), specifically with management of the airway, breathing, and circulation. Thoracic trauma has the potential to affect any combination of these physiological processes. The airway can be affected by a tracheal injury, pneumothorax or blockage of the airway from bleeding due to a pulmonary laceration. Breathing is especially susceptible to compromise following a pneumothorax or hemothorax. Circulation can be affected by a tracheal injury, thoracic trauma as severe occult blood loss can occur in the pleural cavity and mediastinum. A tension pneumothorax in a child, due to the mobility of mediastinum in children, can shift the mediastinum and reduce venous return therefore affecting circulation. Most life-threatening thoracic injuries can be identified during the primary survey. These include airway obstruction, tension pneumothorax, open pneumothorax, flail chest, massive hemothorax, and cardiac tamponade.

The workup of the child with a suspected thoracic injury involves external inspection and palpation of the chest looking for tenderness, bruising, and bleeding. Physical examination involves evaluation of breathing, presence of breath sounds, trachea deviation, subcutaneous emphysema, and the quality of the heart sounds.

A standard anterior-posterior chest film should be obtained during the initial assessment in order to help identify injuries. In children aged less than 1 year old, the thymic tissue can be quite prominent and can confuse the interpretation of the trauma CXR—what looks like a widened mediastinum in an older child might represent the thymus in a normal infant.

In most cases a normal CXR is all that is needed to rule out life-threatening thoracic injuries. There is no literature that clarifies the indications for chest CT or CT angiography after blunt injury in the pediatric patient. The indications for CT from the adult literature in blunt trauma include a widened mediastinum, fracture of first or second ribs, blunting of the aortic knob (which can be confusing because of the enlarged normal thymus), apical capping, medial displacement of the left main-stem bronchus, or displacement of the nasogastric tube to the right. Diaphragmatic elevation noted on CXR can also be an indication for a chest CT.

In penetrating thoracic trauma, a chest CT can sometimes clarify the path of the bullet or implement and allow for better identification of injuries. Penetrating injury to the "box"—defined by the vertical nipple lines, the manubrium, and the inferior costal margin—suggests potential injury to both the heart and mediastinum. A chest CT is indicated for further workup in a stable child. A pericardial window or subxiphoid exploration to confirm blood in the pericardial sac should also be strongly considered. If this is confirmed, then a formal sternotomy for exploration is indicated.

A penetrating thoracic injury can also potentially involve the abdominal cavity (Fig. 22.1). The abdomen should be evaluated after any penetrating injury below the nipple line anteriorly on the chest wall and the tip the scapula posteriorly.

An extended FAST (focused assessment with sonography in trauma) can be useful in identifying hemothorax, pneumothorax, and pericardial effusions in the trauma patient. Other ancillary tests include EKG, ABG, and pulse oximetry. If there is a concern for esophageal injury, then an esophagram or esophagoscopy is indicated, and if there is a concern for tracheal injury, a bronchoscopy is indicated.

Emergency department thoracotomy in children is rarely indicated. In those patients presenting with penetrating thoracic injury and signs of life who then lose vital signs during resuscitation, an ED thoracotomy is indicated. But for

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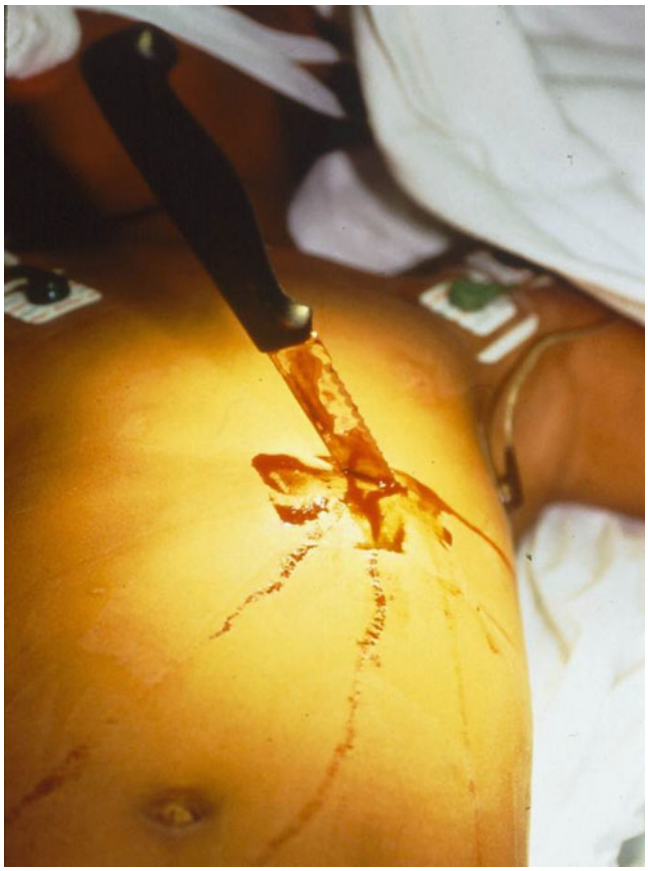

Fig. 22.1 Penetrating injury to thoracic cavity

children who present after a blunt mechanism with cardiac arrest and no signs of life during resuscitation ED, thoracotomy is futile.

Blunt Asphyxia

A large compressive force on a child's chest with a deep inspiration can cause traumatic asphyxia. Capillaries and small veins are ruptured in the face, neck, and chest wall when the atrium is compressed, stopping blood return from the superior vena cava. Children will present with petechial hemorrhages of upper chest and face, conjunctival hemorrhages, and occasionally face swelling. Rarely patients present with neurological changes or vision issues from cerebral edema. Care is mostly supportive.

Rib Fractures

Children (<8 years old) have a very compliant chest wall so the presence of a rib fracture should be considered a sign of a high-energy mechanism. Rib fractures are more common in the older child. Rib fractures in children tend to be well tolerated but can be associated with pleural cavity injury, such as pneumothorax and hemothorax, and these need to be considered and excluded. Fractures of the first rib, implying a very high-energy mechanism, are also usually an indication for a CT angiogram of the chest to rule out injury to the great vessels. Fractures of 10th through 12th ribs can be associated with abdominal injury, especially the spleen, liver, and kidneys.

Rib fractures in children less than 2 years of age are often associated with child abuse but are not always associated with physical findings of pain or bruising, so the diagnosis can be difficult. When evaluating a patient with a suspected child abuse mechanism, the diagnosis of rib fractures is very important and may be associated with other non-apparent injuries. Because of this, a skeletal survey or bone scan might be indicated for further evaluation. Management of rib fractures in children includes supportive care, pain control, and pulmonary hygiene.

Flail chest is a very rare occurrence in children. The paradoxical motion of the flail segment causes depression of respiratory effort. Treatment is geared toward avoiding respiratory depression with good pain control and aggressive pulmonary hygiene. Occasionally positive pressure ventilation is required if the respiratory depression becomes severe.

Sucking Chest Wound

An open penetrating chest wound can act as a one-way valve, with air being pulled into the pleural cavity by negative thoracic pressure that is then trapped when the wound closes during expiration. This can lead to a tension pneumothorax. Management of this injury requires placement of a formal chest tube to drain the pneumothorax and placement of an occlusive dressing to close the open wound and prevent further air from entering the chest cavity.

Pneumothorax

A simple pneumothorax, air in the pleural cavity, occurs when a patient sustains an open chest wound from a penetrating injury or from a pulmonary laceration allowing air to escape the lung into the pleural cavity (Fig. 22.2). Pneumothoraces are common in pediatric chest trauma. They are often asymptomatic and only identified on CXR. The air can loculate in different locations of the chest cavity and will sometimes be missed on the initial radiograph. When identified on a trauma CXR, intervention must be considered. Tube thoracostomy is indicated for a symptomatic patient or a patient with a >20 % pneumothorax; otherwise, the child may be treated with supplemented oxygen alone. Treatment is usually required for 24–48 h.

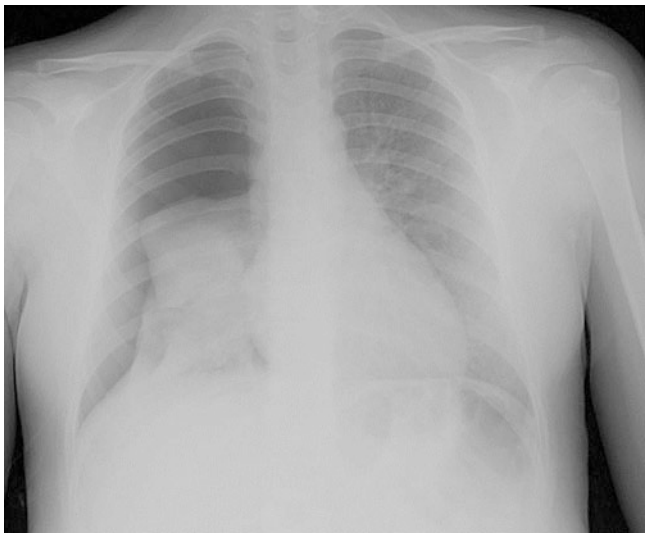

Fig. 22.2 Right pneumothorax

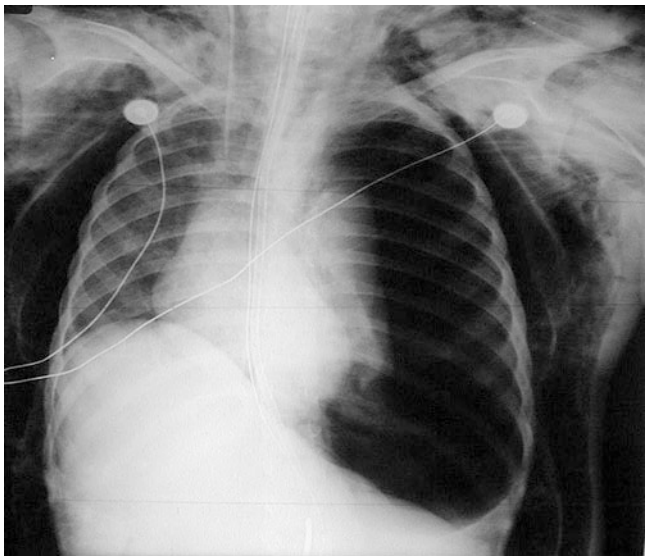

Fig. 22.3 Left tension pneumothorax

A chest CT is more sensitive and will sometimes identify an occult pneumothorax not seen on CXR. If the pneumothorax is seen only on chest CT and the child is stable, observation with no chest tube is often sufficient. These patients must be monitored especially if they require positive pressure ventilation.

FAST exam can also be used to identify a pneumothorax in the acute setting.

A tension pneumothorax with a shifting of the mediastinum can be a life-threatening injury (Fig. 22.3). This can present with shortness of breath, hypoxia, hypotension, absent breath sounds on the affected side, tracheal deviation, and/or distended neck veins. The diagnosis is clinical and immediate decompression is indicated. Needle decompression, midclavicular line second intercostal space, may be necessary to stabilize the child before placement of a chest tube.

Hemothorax

In a hemothorax the source of blood can be the intercostal blood vessels, pulmonary parenchyma, the pleura or, rarely, the great vessels. Hemothorax can be identified by CXR, but a smaller volume hemothorax will be better visualized with a chest CT. It can be difficult to estimate the volume of blood present in the chest on a CXR, so if a hemothorax is suspected, a chest tube is indicated.

The volume of blood obtained from the chest tube is important as a large amount of blood loss (≥15 mL/kg) at the time of chest tube placement or ongoing blood loss (≥2–3 mL/kg/h for 3 or more hours) is indication for a thoracotomy. Drainage of the hemothorax is important because blood left in the chest cavity can become infected leading to an empyema or become a fibrothorax and cause restrictive lung disease.

Pulmonary Contusion

Pulmonary contusions in children are very common. Larger pulmonary contusions can be identified by CXR. Chest CT is more sensitive and will identify smaller contusions. Pulmonary contusions tend to be very well tolerated in children, and often no treatment is required. Many become more prominent after fluid resuscitation. Treatment involves supplemental oxygen and pulmonary hygiene to minimize atelectasis.

A child with a severe pulmonary contusion or multiple injuries might progress to pulmonary compromise or pneumonia and require ventilator support. This can progress in rare instances to ARDS. Another late complication is a pneumatocele, which can usually be observed without surgical intervention as long as the patient continues to improve.

Pulmonary Laceration

A pulmonary laceration might lead to development of a pneumothorax, in which case a chest tube will be required. If the pulmonary laceration is large and the lung is severely compromised, the child might develop a continuous air leak in which case a thoracotomy for lung repair or segmental lung resection is indicated.

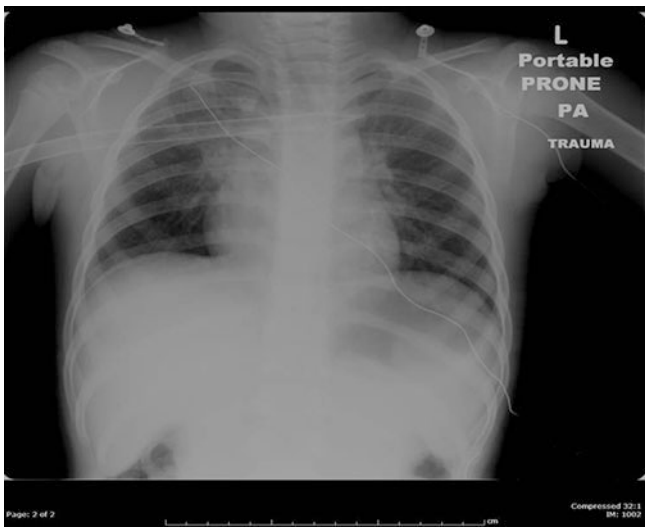

Fig. 22.4 Initial CXR showing the needle traversing the mediastinum (Reprinted with permission from Gettig K, Lawson K, Garcia N, et al. Penetrating Knitting Needle Through the Mediastinum in a Child. J Trauma Nursing. 2015; 22(3): 132–5)

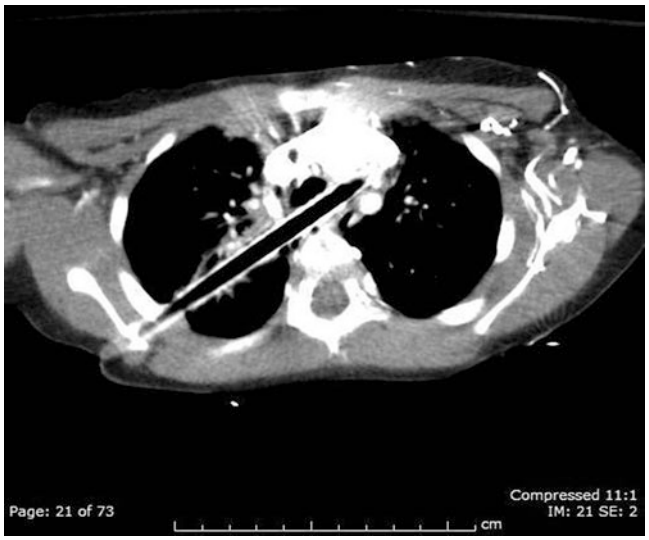

Fig. 22.5 Preoperative CT showing the needle tip crossing midline with hematoma noted along the tract through the right lung (Reprinted with permission from Gettig K, Lawson K, Garcia N, et al. Penetrating Knitting Needle Through the Mediastinum in a Child. J Trauma Nursing. 2015; 22(3): 132–5)

Bronchial Injury

Bronchial injuries are rare. If the injury is in the distal segment of the bronchus, the patient may present with a simple pneumothorax, and a chest tube will be sufficient for treatment. If the injury is located on the more proximal bronchus, the patient might present with a tension pneumothorax, a continuous air leak, or a persistent pneumothorax after placement of a chest tube. Placement of a second chest tube often confirms the diagnosis. A chest CT with three-dimensional reconstruction can be helpful in visualizing the injury. Bronchoscopy is also potentially helpful. This injury requires a thoracotomy for repair of the bronchus injury or pulmonary resection to remove the injured area.

Mediastinum

An injury to the mediastinum can involve the trachea, great vessels, heart, esophagus, or thoracic duct. Evaluation of penetrating thoracic trauma involving the mediastinum begins with a CXR (Fig. 22.4). If the child is stable, chest CT can help identify further injuries (Fig. 22.5). An esophagram, arteriogram, bronchoscopy, or echocardiography might also be indicated depending on the path of the penetrating mechanism. If the child is unstable following a penetrating injury, immediate operative exploration is indicated.

Tracheal Injury

A child with a tracheal injury will often present with respiratory compromise and subcutaneous emphysema of the chest or neck. Most will also have mediastinal air on CXR, but some can present with a tension pneumothorax if the injury is located distally on the trachea. As with a bronchial injury, the pneumothorax may persist even after adequate tube thoracostomy and should alert the physician that a tracheobronchial injury may be present. Mechanical ventilation might be necessary and workup includes a chest CT with three-dimensional reconstruction. Fiber-optic bronchoscopy might be needed for intubation. Tracheal injuries are also diagnosed with rigid bronchoscopy, which can clarify the degree of tracheal involvement. Once an injury is identified, surgical repair is most likely indicated. If the injury is minor, nonoperative management can be considered; however, this can result in airway stenosis or formation of granulation tissue in the airway, eventually necessitating operative intervention.

Pericardial Injury

Blunt cardiac injury, such as myocardial contusion, cardiac rupture, laceration, or tamponade, is uncommon. Of these cardiac contusion is the most common. Most pediatric cardiac contusions are asymptomatic. The patient may present with an arrhythmia, new onset of a murmur, or, in severe

cases, heart failure. Workup includes a CXR, FAST, EKG, and cardiac enzymes including CPK-MB and troponin. Echocardiography is indicated when the patient is found to have EKG abnormalities or elevated cardiac enzymes. Patients with a confirmed cardiac contusion should be monitored with frequent vital signs and continuous electrocardiography. Management is mostly supportive.

Cardiac laceration is extremely rare and if suspected an immediate echocardiogram in the emergency room should be diagnostic. Beck's triad (hypotension, distended neck veins, muffled heart sounds) is indicative of cardiac tamponade. These findings can be difficult to appreciate in a noisy emergency department. If tamponade is confirmed by FAST, then pericardiocentesis or subxiphoid window may be indicated, followed by a formal surgical exploration.

Great Vessel Injury

Aortic and great vessel injuries most often occur after a rapid deceleration blunt injury such as high-speed motor vehicle collision or falls from a great height. CXR findings include a widened mediastinum, abnormal aortic knob contour, depression of the left main-stem bronchus, deviation of the nasogastric tube to the right, or apical pleural hematoma. A chest CT is indicated if the CXR is abnormal and the mechanism fits the potential injury. Operative management of these injuries includes endovascular stenting or open repair.

Esophageal Injury

Blunt and penetrating esophageal injuries are very rare. Presenting symptoms can be vague but include dysphagia, subcutaneous emphysema, and dyspnea. Mediastinal air and pleural effusion may also indicate an esophageal injury. Esophagram with a water-soluble agent and/or esophagoscopy should be performed.

If the esophagus is perforated and the injury is identified early (less than 24 h), antibiotics and operative repair with aggressive drainage of the mediastinum and pleural cavity is indicated. Esophageal diversion with a cervical esophagostomy may be required if the perforation is identified late (>24 h). In some stable patients with a small contained leak, nonoperative management with IV antibiotics and withholding of oral feeds can be successful.

Thoracic Duct Injury

Thoracic duct injury is very rare in children. These patients will present with a non-bloody pleural effusion high in lymphocytes and lipid content. The effusion can develop days after injury. Treatment includes a chest tube placement for drainage and diagnosis. Gut rest with parenteral nutrition or feeding with medium-chain triglycerides is also indicated to facilitate closure of the injury. Octreotide given IV to limit chylous drainage is controversial but has been reported. Most injuries will heal with these measures. Operative intervention by thoracotomy or thoracoscopy is indicated after weeks of failed conservative management and chest tube drainage. The repair involves administering cream into the patient's stomach to help identify the chylous leak in the thoracic cavity. Of note, thoracic duct injury in the absence of a known mechanism has been associated with child abuse.

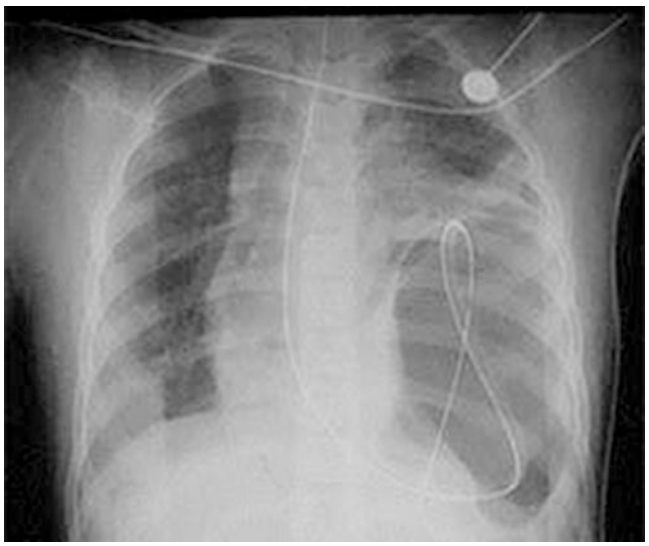

Fig. 22.6 Left diaphragmatic rupture

Diaphragm Injury

A patient with a diaphragmatic injury may be asymptomatic or present with chest pain, abdominal pain, or shortness of breath. Blunt injury is most often on the left as the liver is protective on the right. A CXR may confirm a diaphragmatic injury with herniated bowel loops into the chest cavity, elevated hemidiaphragm, or nasogastric tube tip in the chest (Fig. 22.6). A chest CT is indicated in questionable cases when the CXR is non-diagnostic. Operative repair is indicated with an abdominal approach and a search for associated injuries, though repair might be amenable to a minimally invasive approach.

Editor's Comment

The life-threatening injuries that we see in adults after a blunt thoracic trauma such as aortic dissection, myocardial contusion, pericardial tamponade, pulmonary contusion, sternal fracture, and flail chest are rarely seen in children,

perhaps due to superior tissue resiliency, more favorable dissipation of kinetic energy due to size differences, and in the case of a head-on automobile collision, the absence of steering wheel-induced injuries. Nevertheless, these injuries are occasionally seen in children, and a proper diagnostic algorithm should be followed whenever the mechanism is suggestive. A small amount of mediastinal air or a tiny pneumothorax will sometimes be identified on a chest CT after blunt trauma, but in the absence of other signs of significant organ injury, these can generally be regarded as incidental. Nevertheless, they should prompt a meticulous evaluation and a period of careful observation.

Penetrating injuries are becoming more common and require a meticulous diagnostic approach in order to identify latent injuries. Trajectories based on the location of entry and exit wounds are notoriously inaccurate because the victim is often in a contorted position at the moment of impact, missiles can follow tissue planes and therefore fail to travel in a straight line, and bullets can ricochet within the bony cage of the thorax. Not every patient with a gunshot or knife injury to the chest will require an operation, but a pediatric trauma surgeon needs to be involved in every aspect of the care of these children. The most important diagnostic and therapeutic maneuver in a child with a gunshot wound to the chest is the placement of a chest tube. The stable child with a stab wound should have a chest radiograph and could potentially avoid a chest tube if there is no evidence of a pneumo- or hemothorax. Placing a chest tube in a child should be done using a gentle technique, under sterile conditions, and after sedation and injection of a local anesthetic. In young children, a small incision that passes through the chest wall obliquely is all that is necessary (if it is big enough to insert your finger, then it is probably too big), but it is surprisingly easy to inadvertently place the tube into the subcutaneous tissues and for it to erroneously appear to be in perfect position on a chest film.

The primary indication for operative intervention in the child with a thoracic injury is bleeding. There is no absolute amount of frankly bloody chest tube effluent that can be used to decide if an operation is needed; this must be based on good judgment. Lung injuries can be over sewn or repaired with a linear stapler using a vascular cartridge. Esophageal injuries can usually be repaired primarily provided there is healthy tissue to work with and good drainage can be established. The same is true for most tracheal injuries, but when there are injuries to both the airway and the esophagus, viable tissue (pleural or pericardial flap, ligated azygos vein) should be placed between the two suture lines to prevent the formation of a tracheoesophageal fistula. The vagus and phrenic nerves should be carefully identified and protected throughout the procedure. Major vascular injuries should be repaired using standard vascular techniques, including proximal and distal control of the vessels and the use of side-biting clamps when necessary. Major aortic or cardiac injuries will usually require cardiopulmonary bypass and the assistance of a cardiac surgeon, a decision best made ahead of time rather than in the heat of the moment.

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Vascular Injury

23

Lucas P. Neff and Todd E. Rasmussen

Vascular injury in children is a fairly rare but important clinical condition. Its incidence is less than 1 % of all pediatric trauma patients. The conceptual approach to the diagnosis and management of these injuries for both children and adults is often similar and is based on anatomic location of injury. However, for several reasons children are not simply little adults with respect to vascular injury. A large number of vascular injuries in children are iatrogenic. Concerns about radiation exposure from CT scans during workup of a suspected vascular injury can create anxiety regarding when and how to proceed with diagnostic imaging in an injured child. The inherent differences in the physical structure and physiology of pediatric arteries may preclude therapeutic modalities that are standard of care in adults. Yet, these differences also allow nonoperative management for children in situations that would otherwise necessitate exploration and repair of damaged vessels. Future growth of the injured child and vessel requires special consideration at the time of vascular repair and should prompt concerns about long-term consequences of vessel injury.

Injury Classification

Vascular trauma is often defined by anatomic location (trunk or extremities) and mechanism of injury (blunt versus penetrating). While blunt mechanisms account for the majority of pediatric traumatic injuries in industrialized countries, vascular injury more often results from penetrating trauma. Furthermore, children are often collateral damage of countless wars and conflicts throughout the world. Several series of pediatric trauma from US military trauma registries indicate that penetrating and blast mechanisms far surpass blunt trauma as a cause of vascular injury in regions of armed conflict. However, in the USA, vascular injury in children occurs with an incidence of 0.06 % and occurs more often in males by 3:1. The incidence of vascular injury from blunt trauma is roughly 45 % while for penetrating trauma it is about 55 %. While this ratio holds true for the general pediatric population, blunt injury of the thoracic or abdominal aorta occurs infrequently, with an incidence seven times lower than in adults.

A common injury pattern is intimal disruption and thrombosis in the extremities from blunt force, such as popliteal artery occlusion following posterior knee dislocation and brachial artery disruption due to supracondylar humeral fractures. The increased reporting of blunt cerebrovascular injuries in adults over the last decade has raised awareness of this particular injury pattern in children. Penetrating vascular injuries from lawnmowers, gunshots and stabbings, and lacerations from broken plate glass are increasingly more common mechanisms of injury.

Hospitalized children are susceptible to injury from iatrogenic mechanisms and account for approximately 1/3 of all vascular injuries. Umbilical vein catheters causing aortic occlusion, inadvertent arterial punctures during venous catheter insertion resulting in pseudoaneurysm or acute vessel thrombosis, near-occlusive cannulas for arteriovenous ECMO, femoral sheath access during cardiac catheterization, and arterial access for hemodynamic monitoring are well-described injury patterns in the healthcare setting. Surgeons in busy academic centers and tertiary-care children's hospitals are more likely to encounter these types of iatrogenic injuries. While vascular injuries to older school-aged children and adolescents are often managed using adult vascular injury algorithms, the smaller size of infants and young children that often sustain iatrogenic injuries make their diagnosis and treatment unique.

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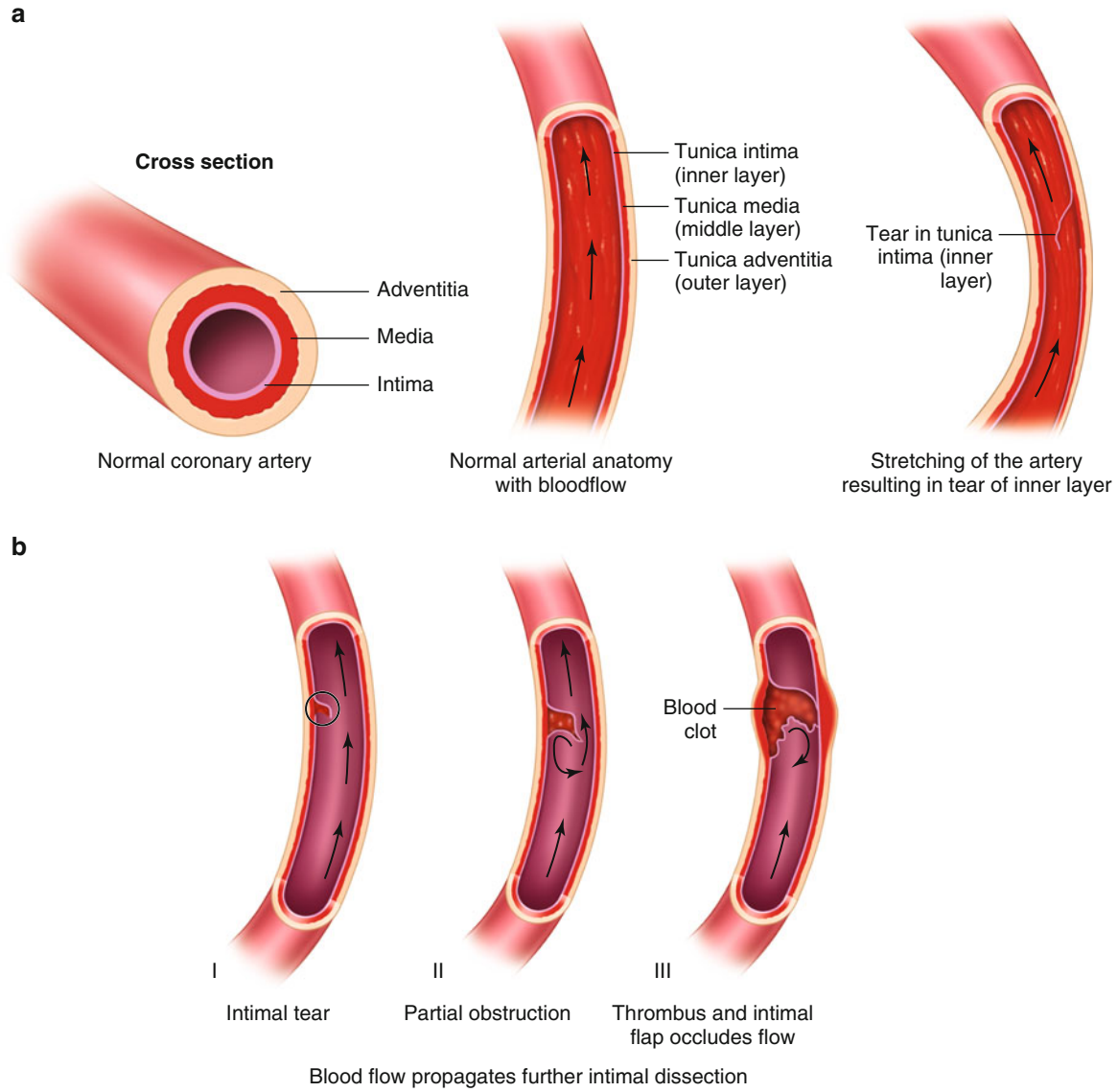

Fig. 23.1 Blunt force deforms arteries and disrupts the internal elastic lamina and portions of the media with resultant pseudoaneurysm or thrombus formation. (**a**) Normal artery anatomy with deformation and intimal tearing (**b**) Enlarged sectional views of injured artery. Blood flow propagates the tear causing inner layer of vessel to partially separate from the medial layers. The resultant obliteration of the true lumen and thrombus formation obstructs distal blood flow

The relatively thin walls with meager support from the surrounding tissues and musculature make pediatric arteries especially susceptible to pseudoaneurysm formation. This arises from complete disruption of the endothelium and internal elastic lamina with dissection into the media of the artery wall (Fig. 23.1). Furthermore, the increased elasticity of young, healthy arteries results in deformation and partial tearing rather than complete transection. The consequence of pediatric arterial composition and response to injury is often intimal tearing leading to thrombosis and occlusion without vessel disruption and hemorrhage. In addition, the vasomotor reactivity of young, healthy arteries make them capable of tremendous vasospasm in response to direct vessel injury or as a physiologic mechanism to augment peripheral vascular resistance and maintain mean arterial pressure in the face of hemorrhagic shock. This ability of pediatric arteries to spasm down to almost complete occlusion presents diagnostic challenges and can mislead the less experienced surgeon into believing there is complete occlusion. Conversely, the resilient nature of peripheral circulation to rapidly form collateral circulation can also mask true vascular injuries and lead to misdiagnoses (Fig. 23.2).

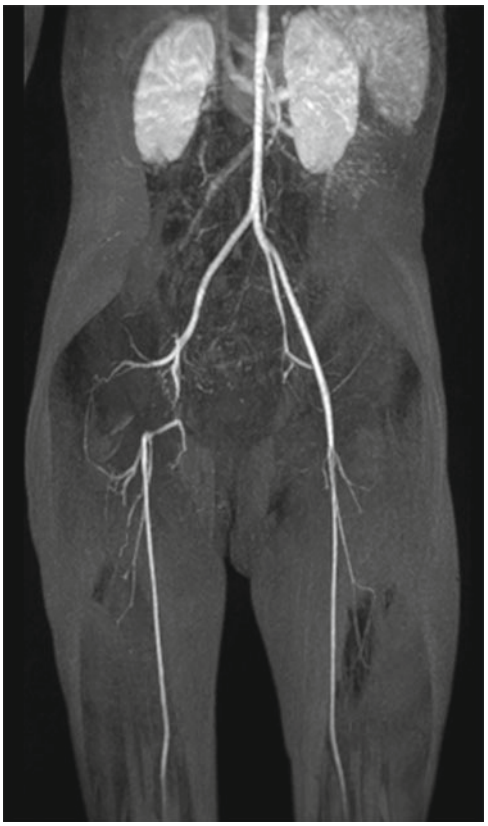

Fig. 23.2 Magnetic resonance imaging demonstrates femoral vessel occlusion (*arrow*) with robust collateralization and reconstituted distal flow (Reprinted with permission from Eliason JL. Pediatric Iatrogenic Vascular Injury, pp. 703–5. In: Stanley JC, Veith F, Wakefield TW, eds. Current Therapy in Vascular and Endovascular Surgery. Copyright Elsevier 2014)

Diagnosis

While vascular injury is rare in the injured child, surgeons caring for children must recognize how injury patterns and the diagnosis can deviate from the adult patient. The history and physical examination is a prerequisite in the workup of the suspected vascular injury in all patients. The traditional dogma of vascular trauma states that "hard signs" of injury (hemorrhage, expanding hematoma, absence of pulse, cold and pale limb, audible bruit or palpable thrill, or mangled extremity) mandate immediate operative exploration. However, anatomic differences and extreme vasoreactivity of pediatric vessels in response to injury make the diagnosis of "hard signs" challenging. There are reports of hard signs such as audible bruits in the carotid artery being managed by observation in children with good results, despite imaging that suggested intimal disruption. Pulse discrepancies seen on ankle-brachial index testing can resolve after bringing fractures to length. Even "soft signs" of vascular injury (missile proximity to vessel, non-expanding hematoma, peripheral nerve deficit, discrepancy in opening pressures, or ABIs between injured and non-injured extremities) can often be managed nonoperatively. Therefore, determining the location of a suspected injury and the degree of distal perfusion is the key diagnostic concept. A disrupted vessel might have little immediate physiologic consequence on perfusion because of compensatory collateral circulation while severe vasospasm in an otherwise intact or freshly repaired vessel can result in distal ischemia. Despite growing concerns about radiation effects to children, the use of CT angiography has largely supplanted formal arteriography due to its superior resolution, speed, and availability. CTA has a sensitivity and specificity of 100 and 93 % for penetrating injuries and 88 and 100 % for blunt injuries. Given this accuracy, CTA is now widely considered the standard of care in the diagnosis of pediatric vascular injury. It also provides important information about the level of injury and whether distal segments of injured vessels reconstitute via collateral branches. Color Doppler and duplex ultrasonography are less invasive methods that quickly provide valuable information about flow and structural abnormalities, with the added benefit of limiting CT-associated radiation exposure. Yet, these modalities require an ultrasonographer with vascular experience and a cooperative patient.

Regardless of etiology, extremity vascular injury and subsequent ischemia should prompt careful vigilance for extremity *compartment syndrome*. This potentially devastating complication of prolonged ischemia is more common in the leg than the forearm. While it is rare (~8 %) in these situations, delayed diagnosis of extremity ischemia, particularly from iatrogenic vascular injuries, results in high morbidity. Children are often not able to verbalize the extremity pain and paresthesias associated with early compartment syndrome. Therefore, the index of suspicion should be high and must lead to testing of fascial compartment pressures.

Treatment

The management options for children fall into three categories: observe, anticoagulate, or operate. Ideally, management decisions should be made by a multidisciplinary team comprised of general pediatric surgeons, adult vascular surgeons, neurosurgeons, cardiothoracic surgeons, orthopedists, and interventional radiologists.

The recommendation of nonoperative observation of pediatric vascular injuries is made based on the size of the child and the anatomic location of the injury. The conceptual shift from adult to pediatric vascular treatment arises from several factors: (1) Most major vessels heal or develop robust collateral circulation to overcome disruptions in flow and so the dictum *primum non nocere* becomes relevant. (2) Fewer therapeutic options are available to children—the expanding role for endovascular therapies for vascular trauma in adults

is limited in children because of device size relative to the child's vessels. (3) Repairing very small vessels is a formidable undertaking—in very small children, arterial repair of their small vessels is so technically challenging and prone to postoperative thrombosis that anticoagulation or simple ligation of the bleeding vessel might be the only reasonable option. Furthermore, systemic anticoagulation or regional lytic therapy is often employed to facilitate distal perfusion via collateral pathways.

For older children and adolescents, the operative treatment and indications are similar to the adult population. Penetrating injuries with pulseless extremities need no special diagnostic evaluation prior to surgical exploration. Decreased perfusion in the setting of extremity fractures requires bringing the fracture to length before making the decision about additional diagnostic imaging or operative intervention. Often intraluminal flaps that arise from stretch and tearing of the arterial intima are simply managed with serial exams and anticoagulation.

When actual vessel repair is indicated, special consideration to technique is warranted, especially in the extremities. As a general rule, anastomoses should be constructed with interrupted permanent monofilament. Interrupting the suture line prevents the subsequent stenosis that occurs when a vessel continues its normal growth and is prevented from doing so by a continuous suture line. When feasible, arteries should be repaired primarily with spatulation and an ovoid anastomosis to ensure patency. The use of vasoactive agents like papaverine and lidocaine is often necessary to relieve vessel spasm. In situations requiring an interposition graft, reversed saphenous vein is the conduit of choice. When not available, alternatives like the internal jugular vein or external jugular vein and cephalic vein doubled over on itself are all suitable options. Synthetic graft material should be avoided whenever possible in the growing child because of the risk of stenosis and neointimal hyperplasia. Advances in the field of tissue-engineered blood vessels are already in limited use and may provide more options for vascular conduit in the future.

In addition to restoring perfusion, every effort should be made to repair injuries to the larger veins of the extremities. Restoration of venous drainage will prevent debilitating venous insufficiency, which can become a lifelong problem. During repair or thrombectomy, care must be taken when using heparinized saline to flush vessels in small children because of the risk of systemic anticoagulation with repeated flushing. Thoracic aortic disruptions require open repair in smaller children. Management of these injuries with thoracic aortic endografts in the adult population is well accepted, but this approach is often not feasible for young children because of endograft sizing and the eventual need for a larger graft as the aorta grows. For adolescents who are closer in size to adults, small iliac or femoral vessel size might still preclude insertion of the standard arterial access sheaths. Laparotomy with more proximal vascular access is a proposed alternative that avoids the risk of paralysis from spinal cord ischemia that is associated with traditional clamp-and-sew technique for primary aortic repair.

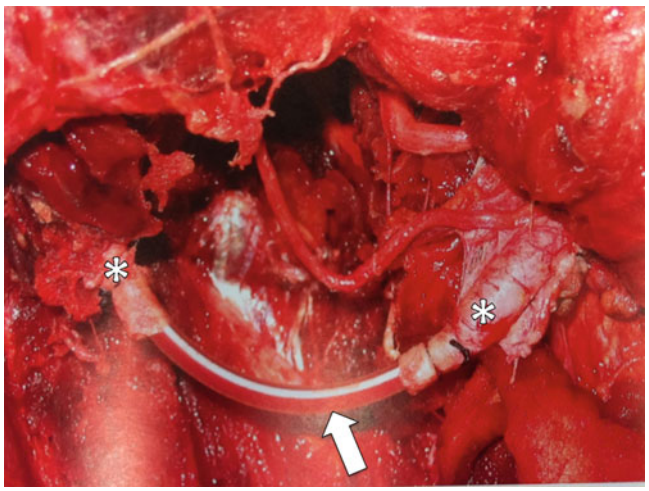

Fig. 23.3 Temporary vascular shunts are an effective means of reestablishing vascular flow to permit time for resuscitation and expert assistance. This figure demonstrates a makeshift shunt fashioned from a small nasogastric tube (*arrow*) restoring flow in a transected superficial femoral artery (*asterisk*) (From Nessen SC, Lounsbury DE, Hetz SP. War Surgery in Afghanistan and Iraq: A Series of Cases, 2003–2007. Office of the Surgeon General, United States Army; 2008)

Currently, the role of endovascular intervention is more often for diagnosis and subsequent embolization of arterial bleeding in the setting of pelvic fractures and abdominal solid organ injury. Pseudoaneurysm as a complication of nonoperative management of blunt injury to solid abdominal organs is often treated with embolization with good effect.

Temporary vascular shunts (TVS) are increasingly employed in the multiply injured trauma patient in whom definitive vascular repair must be delayed for ongoing resuscitation (Fig. 23.3). In our experience with injured children in Iraq and Afghanistan, TVS is a reasonable option. The surgeon must be careful to select a shunt of appropriate size to avoid further vessel damage. Generally, the contused or damaged ends of the vessel should be left in situ and these areas used for securing the vessel to the shunt. The long tails from both points of fixation are then tied together to prevent the ends from slipping apart with patient movement. Prophylactic fasciotomies are generally not performed if warm ischemia time is less than 6 h, but diligent monitoring of the extremity compartments is essential, especially in nonverbal or intubated and sedated children.

The optimal management of blunt cerebrovascular injuries in children is still unknown. Generally, anticoagulation is the therapy of choice when not contraindicated by other associated injuries. There are reports of stroke from vertebral and carotid artery injury.

Pseudoaneurysms in small children will often require resection and primary anastomosis to prevent distal embolic events. The less invasive technique of percutaneous thrombin injection used for adults is not a viable alternative in children because of the relatively small size of the native vessels and inability to adequately compress the pseudoaneurysm.

Outcomes

Short-term complications of vascular injury and repair are well described. Deep vein thrombosis after venous repair mandates surveillance for venous patency with duplex ultrasound. Vasospasm can cause vascular anastomosis to thrombosis and occlude. In children, there is a phenomenon by which the extremity remains perfused in the absence of a palpable pulse. There has been ongoing controversy about whether a pink and warm hand without a pulse or Doppler signal can be observed. This most commonly occurs following supracondylar humerus fractures. Despite attempts to repair venous injuries, size discrepancies with smaller venous interposition grafts and narrowing of large veins repaired primarily can predispose the child to deep venous thrombosis.

Every effort should be made to appropriately match the conduit or carefully reconstruct with a patch venoplasty to avoid stenosis. This recommendation is based on a DVT rate of 15 % following major venous repair in adult combat trauma victims. Surveillance with duplex ultrasound at regular intervals and prompt medical treatment is necessary to avoid life-threatening pulmonary embolism. In certain situations, the seemingly most severe measure may produce the best result. Amputations of extremities are appropriate in certain situations where attempts to salvage injured limbs and restore meaningful function are clearly destined to fail. Mangled extremities, prolonged ischemia, and unsuccessful attempts at operative intervention can be legitimate rationales for limb amputation. While not a decision to be made lightly, developments in prosthetic limbs can enhance function and independence, making amputation an outcome that is no longer as devastating as it was in the past.

There is sparse data on the long-term effects of vascular injury on the child. The overall functional outcome following vascular repair is excellent, with some series reporting 75 % back to normal activity after lower extremity. In the majority of cases, overall function is dictated by the child's other injuries or underlying medical issues. In general, we tell the parents that the child with an interposition graft will still be at slight risk of neointimal formation and anastomotic stenosis and should therefore undergo surveillance with ultrasound over a 5-year period. The same surveillance requirements hold after vein patch angioplasty—there is a nearly 10 % risk of aneurysm formation, which requires resection and interposition with RSVG. In addition, aortic intimal tears and dissections that are managed nonoperatively require follow-up with CT aortography.

Occlusive extremity injuries that are managed nonoperatively with anticoagulation or ligation must rely on collateral flow to perfuse distal tissue beds. The degree to which successful collaterals develop will determine long-term morbidity. Intermittent extremity pain during exertion (claudication) can occur and may require bypass procedures. Leg length discrepancies are a known complication in the setting of femoral artery injuries, with an incidence of approximately 8 % in the setting of catheter-related injury in small children. Arterial bypass is a proposed treatment strategy to promote catch-up growth if a leg length discrepancy is identified early.

Summary

Pediatric vascular injury is an uncommon clinical entity that shares many overlapping treatment principles with the adult population. An understanding of the unique features of the pediatric arterial architecture, injury patterns, diagnosis, and management is essential for surgeons who care for children. Advances in endovascular devices and the emergence of regenerative medicine will provide more therapeutic options.

Editor's Comment

The basic tenets of vascular repair in adults apply to children with some important qualifications: microvascular techniques are often needed, prosthetic material is usually not an option, and subsequent growth of the limb and the vessel itself needs to be considered. Proximal and distal control of the vessel, thrombectomy with a Fogarty balloon catheter, and heparin flushes are all used as in adults, but excessive heparin flushes can cause systemic anticoagulation in a small child. Primary repair is preferred and very often achievable provided the ends are debrided and the vessel fully mobilized to create an anastomosis without undue tension. Circumferential repairs should be done at least partly with interrupted sutures or with a "growth stitch" to allow for radial growth of the vessel as the child grows. Reversed saphenous vein is the best conduit or patch graft material, but other veins, usually harvested from the operative field, can be used as an alternative. In the neck, the external jugular vein can be used, but because it is thin and prone to aneurysm, it needs to be partially everted to double its wall thickness. The same is true for the gonadal vein in the abdomen and other expendable but thin-walled veins in other body

compartments. When reversed saphenous vein graft is used for bypass of major abdominal vessels in children, the graft can be reinforced with a much larger sleeve of artificial graft material to prevent later aneurysm formation.

When repair is impossible, the only reasonable alternative might be ligation, which can sometimes provide enough blood flow to allow the extremity to survive but not quite enough for exercise or growth, resulting in claudication and limb length discrepancy. Traditional bypass grafting techniques can reverse these symptoms and allow significant catch-up growth of the affected extremity if done before the age of skeletal maturity.

Extremities that have been ischemic for more than about 4 h are at risk for compartment syndrome after reperfusion. Fasciotomy is very well tolerated in children and should be performed whenever there is concern for this potentially devastating complication. Children who survive repair of a major vascular injury should be followed every 1–2 years until skeletal maturity for late sequelae. They also seem especially prone to anxiety and post-traumatic stress disorder, more so than with other forms of trauma. Finally, important adjuncts to successful repair of major vascular injury include physical and occupational therapy, social work, and emotional and psychological support systems.

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Hand Injuries

24

Ines C. Lin

Approximately 1.5–2 % of pediatric emergency care involves a hand injury. The hand is a complex, balanced network of the vascular, nervous, and musculoskeletal systems that is important for activities of daily living, occupation, extracurricular interests, and social interaction. There is a bimodal distribution of pediatric hand injuries, with a peak incidence in toddlers from household accidents, and then another nearing adolescence due to sports and more aggressive play. Any injury to the distal upper extremity can involve single or multiple organ systems, and depending on the diagnosis, treatment can vary widely. This includes observation, wound care, immobilization with or without manipulation, and surgical repair or reconstruction. Timing of intervention can also range from emergent to semi-elective.

Initial Evaluation

Initial assessment requires a careful history including the details of the injury and a systematic physical examination. This information, as well as additional tests such as radiographs, leads to a clinical diagnosis that determines the final plan.

In evaluating a pediatric patient with a hand complaint, the provider should query on the quality and location of pain, sensory changes, swelling, skin changes, and difficulty moving the extremity. If an injury was noted, details of mechanism, timing, prior interventions, prior injuries, and changes in symptoms are important. Standard elements of patient history should be included, such as medical and surgical history, medications, allergies, social history (including hand dominance and hobbies/interests), and a review of symptoms to evaluate for other injuries or complaints. Particularly in the setting of a fall onto an outstretched extremity, the provider should also evaluate for symptoms of the more proximal forearm, elbow, and shoulder. It is important to stress the evaluation for non-hand injuries as their management can take precedence. Elements of the history may be unattainable due to patient age and if the injury was unwitnessed.

Physical examination should be systematic and thorough. It involves the skills of observation and inspection, active motion, palpation, passive motion, and manipulation. One should assess skin integrity and quality, perfusion and vascular status, deformity such as shortening or malalignment or malrotation, swelling, tenderness, stability, and a motor and sensory exam. The examination is often limited by anxiety or apprehension and the inability to describe symptoms, follow directions, or discern sensibility. In this situation, observing the child as he or she moves the hand during the visit or with toys or other objects might provide some insight. Studying the hand at rest can also suggest tendon incontinuity or bony injury if a finger does not cascade in line with adjacent fingers or a finger scissors over an adjacent finger (Fig. 24.1). The tenodesis effect describes the presence of passive finger extension when the wrist is flexed and finger flexion when the wrist is extended. Using the tenodesis effect can aid diagnosis of tendon or bony injuries. In finger fractures, assessment of the injured finger in extension and gentle flexion and comparing it to the uninjured contralateral side can also reveal clinical deformity (Fig. 24.2).

Imaging studies are indicated in certain situations. Plain radiographs are most commonly ordered to evaluate for a bone or joint abnormality, a radiopaque foreign body, or bony infection. Standard views include posteroanterior (PA), lateral, and oblique views and should focus specifically on the area of concern (individual finger, hand, wrist, forearm). Lateral views of the hand with all fingers overlapped for a finger injury are essentially useless in assessing finger fractures and may sometimes miss a mildly displaced fracture that is also not seen well on the other views (Fig. 24.3). Ultrasound has utility for assessing tendons, masses, foreign bodies, and fluid collections if the examination is equivocal.

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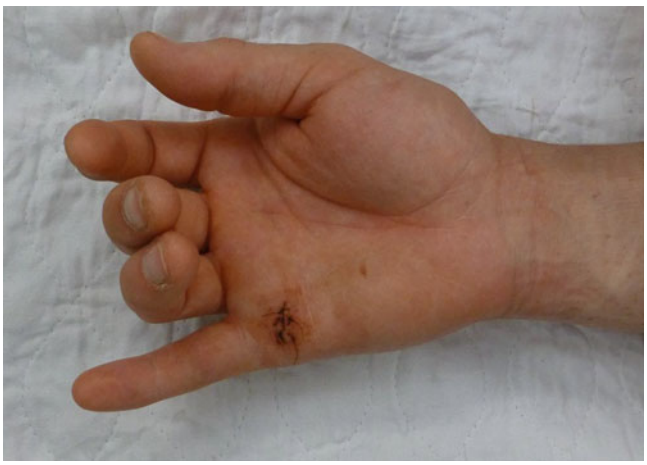

Fig. 24.1 Abnormal resting cascade of right small finger, which rests in extension from flexor tendon lacerations

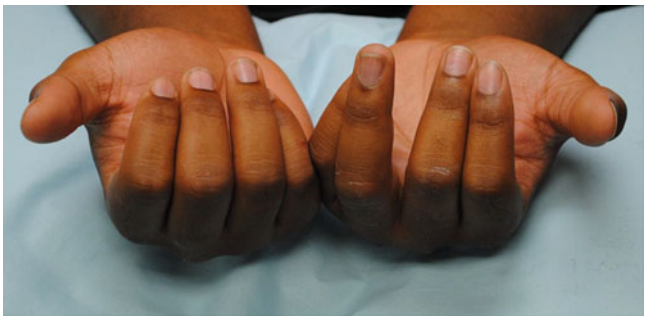

Fig. 24.2 Deviation and malrotation of the left ring finger with a proximal phalanx fracture seen best with fingers gently flexed. Note on uninjured right hand that all fingers point toward the scaphoid when in gentle flexion

CT and MRI can be helpful for diagnosing occult fractures or studying complex injuries. MRI can also be used to evaluate for deep infections such as osteomyelitis if not clearly visible on radiographs. Even though these imaging studies are often readily available, the majority of hand injuries can be diagnosed and treated with a careful history and physical examination, with only plain radiographs as indicated.

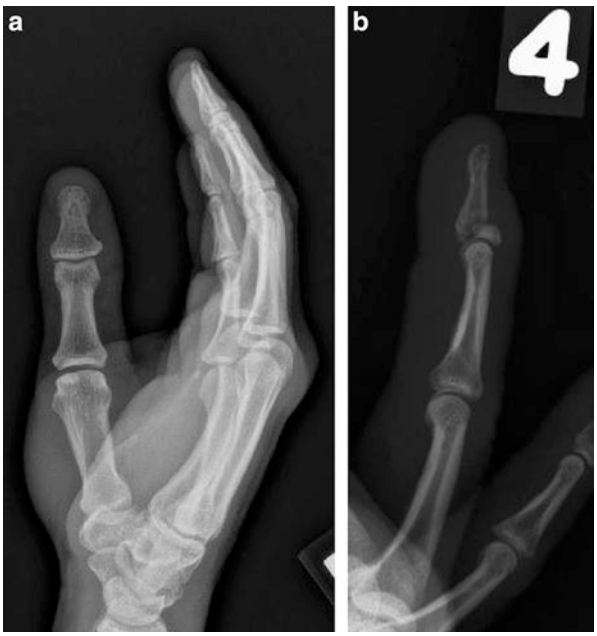

Fig. 24.3 (**a**) Lateral radiograph of the hand with the fingers overlapping is not helpful for diagnosing finger fractures. (**b**) Isolated lateral view of the injured finger of the same patient shows a displaced fracture of the distal phalanx base involving the DIP joint

Acute burn care involves careful cleansing and topical antibiotic ointment or silver sulfadiazine. Clear bullae should be left intact and allowed to rupture on their own in order to limit risk of infection. Splint immobilization and elevation in the first 2 weeks can help with edema reduction, but then motion is encouraged after the burn has reepithelialized 2–3 weeks after injury. Deep second- or third-degree burns can manifest as leathery insensate skin, eschar, or open full-thickness wounds, and the patient will likely need tangential excision or debridement and closure with skin graft and/or flaps (Fig. 24.4). This procedure can decrease the risk of hypertrophic scarring and joint contractures. Patients and their families should be counseled regarding the risk of scar contracture with growth and the possibility of future surgery for scar excision or local flap and skin grafts.

Burns

The hands and wrists are the most commonly burned areas of the body in children. The majority result from direct contact and scalds and are first- and second-degree burns of an isolated area. Less common causes are electrical burns and friction burns (treadmills, vacuum cleaners). Unusual burn patterns or circumstances and delayed presentation to medical care may indicate child abuse or neglect and require social work involvement. Examination of the hand should focus on the area of involvement, depth of burn injury, signs of infection (not typical in acute presentation), signs of pain/tenderness, swelling, and circumferential involvement.

Infection

Pediatric hand infections can frequently be managed with antibiotics and incision and drainage when indicated. The most commonly cultured organisms are *Staphylococcus aureus* and mixed aerobic and anaerobic flora, likely related to digital sucking and fingernail biting as frequent etiologies of infection. Paronychias are infections of the nail fold (Fig. 24.5), and a felon is an abscess involving the volar pad of the finger. Paronychia sometimes can be successfully treated with warm soaks alone in the early stages if the nail fold is erythematous, tender, and indurated but not fluctuant. However, standard treatment includes incision and drainage

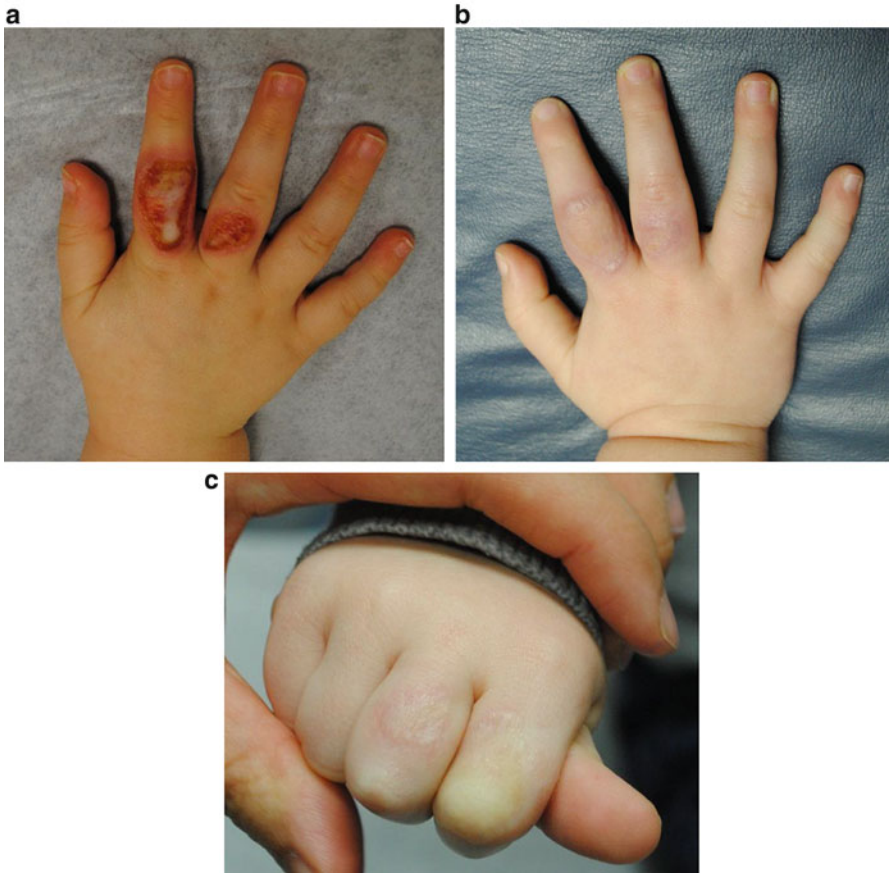

Fig. 24.4 (**a**) Full-thickness burn injury to the dorsal index and middle fingers (**b**) and (**c**) after excision of burned skin and full-thickness skin graft

directly over the area of maximal fluctuance or undermining of the eponychial fold to decompress the abscess (my preferred technique). Felons should be incised to drain the infection. I prefer lateral incisions to avoid a scar over the volar pad, and it is important to bluntly dissect and disrupt the fibrous septa of the volar pad to ensure complete drainage. Warm soaks multiple times a day allow for additional drainage, and antibiotic therapy should be broad enough to cover oral flora (ampicillin-sulbactam or amoxicillin-clavulanic acid). If recurrent or inadequately treated, paronychia and felons can progress to distal phalanx osteomyelitis or flexor tenosynovitis. Osteomyelitic changes can be visualized on plain radiographs (Fig. 24.5). Pyogenic flexor tenosynovitis is a clinical diagnosis characterized by Kanavel's signs of fusiform swelling of the affected finger, which is held in a flexed position, pain with passive extension of finger, and tenderness along the flexor tendon sheath. If suspected, urgent operative treatment involves draining and irrigating the flexor tendon sheath in addition to antibiotics.

Amputation

Patients who suffer an extremity amputation require management as per standard trauma protocols. Particularly in more proximal levels of amputations, blood loss can be underestimated, and aggressive resuscitation is necessary. Standard primary and secondary surveys should evaluate for other injuries. The amputated part should be kept moist and cool by wrapping the part in saline-moistened gauze, and then the part in gauze is placed in a plastic bag or container. The bag is then transported in a slurry of ice and water.

Indications for replantation include thumb involvement, multiple digit involvement, proximal levels of amputation such as hand or forearm, and digit loss in a child. Absolute contraindications are other life-threatening injuries, serious medical comorbidities, multiple levels of injury to the amputated part, and non-accidental self-inflicted injury. Other relative contraindications are crush injury, avulsion mechanism, and significant contamination. Replantation is technically demanding, especially considering the smaller vessels in children, and requires a long operation and often lengthy hospitalization with risk of blood transfusion, particularly if leech therapy is used for venous congestion. Nevertheless, the success rate is quite high (75–95 %).

Distal tip amputations (distal to the distal interphalangeal joint) are common household pediatric hand injuries, often a crush injury with an avulsion as the finger is caught in a door or other object. Management is guided by the size and orientation of the amputation, the presence of exposed distal phalanx, and patient age. Small wounds with minimal bone loss and minimal bone exposure can be managed with local

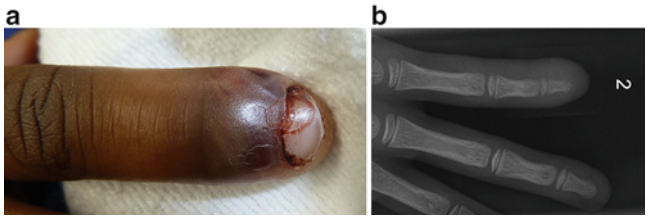

Fig. 24.5 (**a**) Paronychia of index finger and (**b**) associated osteomyelitis of distal tuft on radiograph

wound care, granulation tissue formation, and wound contracture. This strategy allows maintenance of sensibility but requires daily dressing changes, which can be a challenge. If present, the amputated part can be cleaned and sutured on the tip as a composite graft. Successful graft take is dependent on graft size and thickness and is more likely to occur in patients 2 years of age or younger. It is important to prepare parents for the possibility of graft necrosis. If the graft fails, it may serve as a biologic dressing for sufficient granulation underneath and secondary healing.

Alternatively, wound closure can be achieved with local and regional flaps, particularly in larger areas of involvement with more bony exposure. Examples of flaps for digital tip wounds include local V-Y advancement flaps (Atasoy-Kleinert using the volar pad or lateral Kutler flaps), thenar flaps, and cross-finger flaps from the adjacent hand and fingers. Importantly, young children should have only absorbable sutures placed to avoid the difficult situation of attempting suture removal in the office.

Compartment Syndrome

Compartment syndrome requires urgent evaluation and treatment. Common mechanisms include high-energy trauma, severe fractures, crush injuries, hemorrhage, infusion into a closed space and reperfusion after prolonged ischemia. Signs and symptoms include pain, paresthesias, pallor, paralysis, and pulselessness. Importantly, pulselessness and pallor are often late findings of compartment syndrome, and patients with compartment syndrome should ideally be surgically treated before these symptoms manifest. Evaluation should assess for significant pain, a swollen and tense hand or forearm, tenderness with palpation of the compartments, and pain with passive mobilization of the muscles involved. For the forearm, there is pain with passive extension of the fingers, and for the hand there is pain with passive abduction and adduction of the fingers. Increasing analgesic requirement is an important sign in a child who cannot communicate worsening pain, as well as anxiety and agitation (3 A's of compartment syndrome in children).

Once clinically diagnosed, patients should be taken urgently to the operating room for decompressive fasciotomy to avoid muscle and nerve damage. This involves a curvilinear incision on the volar forearm to decompress the superficial and deep flexor compartments and a dorsal incision to decompress the extensors (Fig. 24.6). Decompression of the hand compartments should include the thenar, hypothenar, and interosseus muscles, as well as the carpal tunnel. Any necrotic tissue should be debrided. Patients and their families should be counseled that fasciotomy incisions can rarely be closed at time of release and that additional surgeries are often necessary to close with a delayed primary repair or skin graft. If there is compartment syndrome in a patient with hemophilia or other inherited bleeding disorder, initial management includes hematology consultation for factor replacement and serial examinations with fasciotomy reserved for lack of improvement or worsening after replacement therapy.

Vascular Injury

A deep laceration or penetrating injury with profuse or pulsatile bleeding suggests a vascular injury. Many patients have notable blood loss, particularly given the smaller total blood volume, and trauma protocols with aggressive resuscitation should be initiated. Hemostasis is often achieved with direct pressure on the wound with gauze and two fingers. Prolonged tourniquet use (more than 15–20 min) is quite painful to the patient and can create a vicious cycle of blood pressure elevation and additional bleeding despite the tourniquet. In addition, it will compromise perfusion to the extremity. Thus it is not recommended to use a tourniquet for hemostasis in a laceration with pulsatile bleeding, nor should a provider clamp any structures in the wound. Many vascular structures are adjacent to nerves, which can be crushed inadvertently when hemostasis is attempted to be achieved using a clamp or suture ligation. Posture and tone of the limb and, if the patient is compliant, a careful motor and sensory exam can indicate other musculoskeletal or neurologic injuries.

A dysvascular limb should be taken emergently to the operating room for exploration, revascularization with possible vein grafting, repair of other injured structures, or possible amputation. Depending on the duration of ischemia, prophylactic fasciotomies after revascularization may be needed to accommodate expected edema after reperfusion (Fig. 24.6). If the limb is perfused but there is a concern for arterial injury, pressure should be applied over the wound, and a careful distal examination should be performed. If strict hemostasis can be achieved after 15–30 min of continuous pressure, then surgical repair of injured structures can be performed in a less urgent time frame. This allows for a better neurologic and musculoskeletal examination and appropriate education of the patient and family regarding likely injuries, postoperative care, and prognosis.

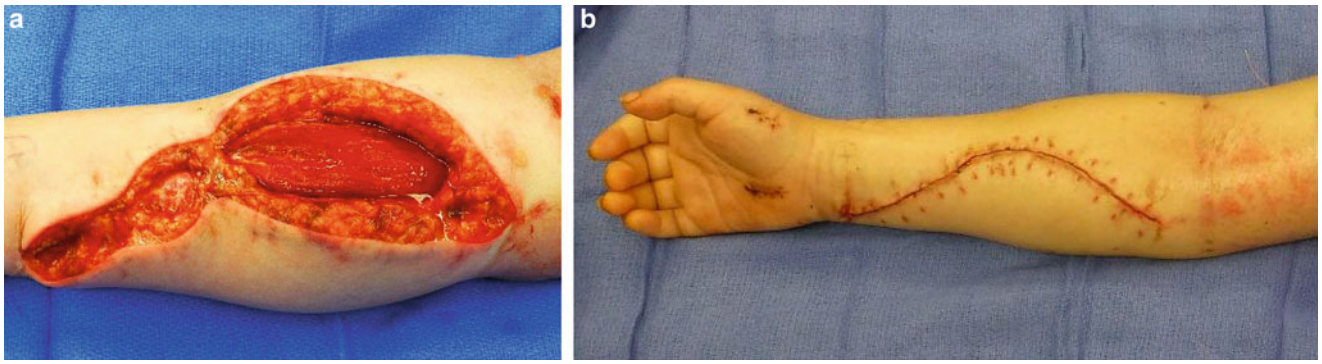

Fig. 24.6 (**a**) Volar forearm after fasciotomy done prophylactically after brachial artery injury that required interposition vein graft for reconstruction in order to reperfuse the extremity which was ischemic for hours. (**b**) Healing volar scars demonstrate the incisions used. These incisions were eventually closed primarily after multiple washouts and resolution of edema. If primary closure is not achievable, then skin grafts are used

Nerve Injury

A penetrating injury with weakness or paralysis requires a careful examination to determine if the loss of function is due to injury to the nerve or muscle/tendon unit. It is important to understand the innervation of muscles by the radial, ulnar, and median nerves (Table 24.1), and this knowledge can help with the diagnosis of a nerve injury. Lacerations of mixed nerves can also have a sensory deficit on top of a paresis. Digital nerve or other sensory nerve lacerations can be difficult to assess in young children and may require putting the finger in water to assess for pruning of the skin, which is dependent on intact nerve function to occur. Nerve lacerations do not necessarily need to be repaired emergently. The skin lacerations can be repaired with early specialty follow-up. Prolonged delay in repair may require some additional mobilization of the nerve ends and sometimes transposition in order to achieve primary nerve repair or nerve grafting (Fig. 24.7).

Closed nerve injuries can occur with displaced fractures and high-energy injuries (brachial plexus). In reducing displaced fractures, such as of the humerus, it is important to monitor the neurovascular status after reduction as nerves and vessels can get trapped within the fracture. Closed nerve injuries should be followed closely over a period of time to distinguish between neuropraxia and more severe axonotmesis or neurotmesis. Neuropraxia and milder axonotmesis will demonstrate recovery of function in days to weeks. More severe nerve injuries will fail to improve and require surgical treatment.

With axonotmesis the nerve distal to the injury undergoes Wallerian degeneration, and repair of healthy nerve fascicles, with or without a nerve graft, is critical for nerve recovery, which progresses at a rate of 1 mm per day. Muscles that are not stimulated will eventually experience motor end-plate atrophy and fibrose. Thus, nerve repair needs to be done soon enough after injury to allow for the nerve to recover while the muscle remains functional. For more proximal levels of injury, early exploration and nerve repair may be warranted if there is no sign of functional recovery. It is sometimes possible to perform a nerve transfer of a working nerve branch with redundant function to stimulate a non-innervated muscle closer to the level of the muscle to bypass a longer distance of nerve recovery. For those who have not recovered much function after repair or have presented long after injury, there are well-described tendon transfers to reconstruct motor deficits.

Flexor Tendon Injury

Flexor tendon injuries are uncommon in children and may be difficult to diagnose due to poor cooperation with the examination. Resting posture and tenodesis effect may aid in diagnosis. If a tendon laceration is suspected in the setting of a well-perfused distal extremity, initial management is irrigation of wound, laceration repair, and splint immobilization. Surgical exploration and repair should be done, ideally within 1–2 weeks from injury to limit scarring and contracture of the flexor tendon sheath, particularly if the injury is at the finger level. This requires careful operative technique to approximate tendon edges with minimal repair gapping and repair bulk to allow for smooth gliding within the flexor tendon sheath. Adjacent nerves and vessels might also have been injured and should be repaired. Well-established flexor tendon rehabilitation protocols for early motion after tendon repair to limit repair adhesions and promote tendon repair healing are used in compliant older patients, but younger patients are often immobilized in a cast after tendon repair with a delayed motion protocol after cast removal. Delayed

Table 24.1 Muscle innervation for the forearm and hand

Muscle name	Function
Radial nerve innervated	
Brachioradialis (BR)	Flexes elbow
Extensor carpi radialis longus (ECRL) Extensor carpi radialis brevis (ECRB)	Extends wrist
Supinator	Supinates forearm
Extensor digitorum communis (EDC)	Extends fingers
Extensor digiti quinti (EDQ)	Extends small finger
Extensor indicis proprius (EIP)	Extends index finger
Extensor pollicis longus (EPL)	Extends thumb
Abductor pollicis longus (APL)	Abducts thumb
Ulnar nerve innervated	
Flexor carpi ulnaris (FCU)	Flexes and ulnar deviates wrist
Flexor digitorum profundus (FDP) to ring and small fingers	Flexes ring and small fingers
Hypothenar muscles (abductor digiti minimi, flexor digiti minimi brevis, opponens digiti minimi)	Abducts, flexes, and opposes small finger (at DIP joints)
Lumbricals to ring and small fingers	Flexes metacarpophalangeal (MCP) joints and extends interphalangeal (IP) joints
Volar and dorsal interossei	Adducts and abducts fingers
Adductor pollicis	Adducts thumb
Median nerve innervated	
Pronator teres Pronator quadratus	Pronates forearm
Flexor carpi radialis (FCR) Palmaris longus (PL)	Flexes wrist
Flexor digitorum superficialis (FDS)	Flexes fingers (at PIP joints)
Flexor digitorum profundus (FDP) to index and middle fingers	Flexes index and middle fingers (at DIP joints)
Flexor pollicis longus (FPL)	Flexes thumb (at IP joint)
Thenar muscles (abductor pollicis brevis, flexor pollicis brevis, opponens pollicis)	Abducts, flexes, and opposes thumb

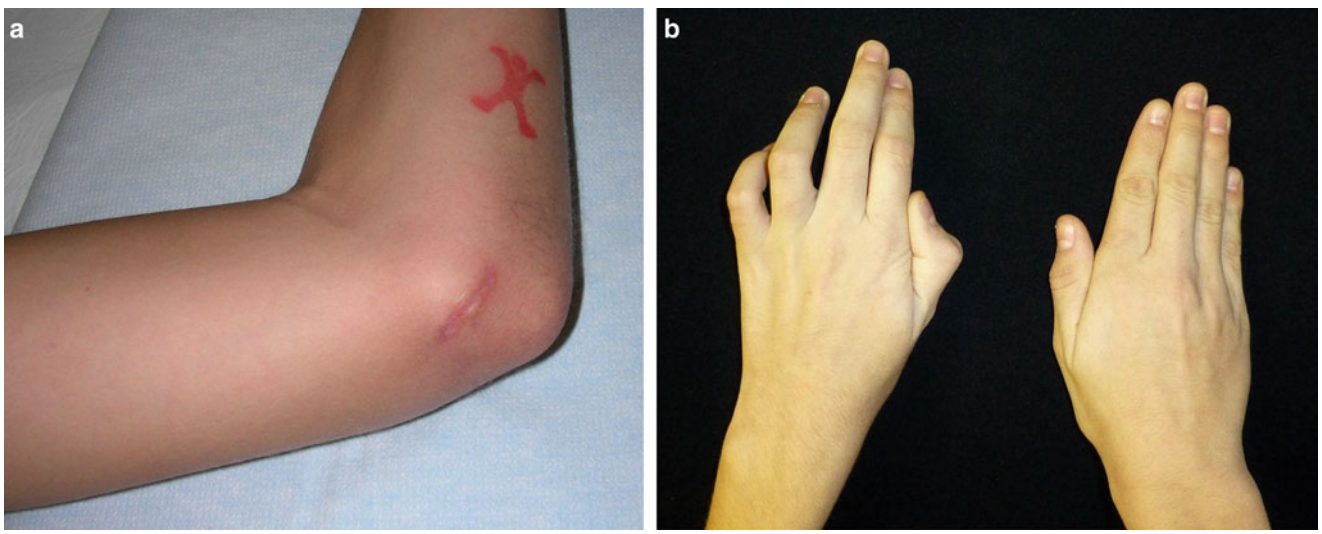

Fig. 24.7 (**a**) A small laceration at the medial elbow from glass associated with ulnar nerve paresis. The upper arm is toward the far left of the picture with the elbow on the right side. (**b**) The patient's distal hand examination is consistent with an ulnar nerve injury: clawing of the ring and small fingers and a positive Froment's sign (compensatory thumb interphalangeal joint flexion in trying to pinch the thumb toward the index finger). On surgical exploration, the ulnar nerve was found lacerated just distal to the cubital tunnel and required transposition in order to repair

presentation of flexor tendon lacerations is typically managed with staged reconstruction using Hunter rods to allow formation of a pseudosheath for subsequent tendon reconstruction with graft.

Fractures

Bony injuries are the most common pediatric hand injury (60–70 % of cases). Important historical details should include location of pain, mechanism of injury, timing of injury related to presentation, and prior injuries. Clinical examination should note deformity, tenderness, skin integrity, neurologic deficits, and vascular compromise. Plain radiographs with multiple views are important. Lateral views of the hand with the fingers overlapping are difficult to interpret for finger fractures. CT and MRI are rarely indicated but can be helpful to identify occult fractures or to better define the anatomy of complex fractures.

Scaphoid Fractures

The scaphoid is the most commonly fractured carpal bone in children. More recent research shows that, similar to adults, scaphoid fractures most frequently occur at its waist and can be easily missed on early radiographs. Patients have snuffbox or volar scaphoid tenderness and pain with wrist motion, particularly radial deviation. Plain radiographs should include a scaphoid view, which is a PA view with the wrist in ulnar deviation that captures the scaphoid in its full extent. If a scaphoid fracture is suspected despite negative radiographs, the patient should be immobilized in a thumb spica splint for 7–14 days and have follow-up radiographs. An MRI should be considered in a patient who has persistent symptoms after a period of immobilization and no fracture seen on follow-up radiographs. CT can help determine degree of displacement for operative planning in the setting of an acute fracture or a nonunion.

Non-displaced scaphoid fractures can be treated with cast immobilization. Waist and proximal pole fractures have lower union rates because of the vascular anatomy of the scaphoid, and thus displaced fractures require open reduction and internal fixation. It is not uncommon for a scaphoid fracture to present as a nonunion in a child who presents with wrist pain and a distant history of a wrist sprain. When diagnosed, these should be treated with open reduction and internal fixation, often with bone grafting, based on the experience in adults that long-standing scaphoid nonunion results in carpal collapse and arthritis.

Seymour Fractures

Seymour fractures are displaced distal phalanx fractures involving the physis. The proximal nail bed is lacerated, and the nail plate is avulsed from the nail fold and often resting superficial to the nail fold (Fig. 24.8). They can be missed on casual inspection as the avulsed proximal nail plate can be mistaken for an intact, non-displaced nail plate or has partially reduced under the nail fold. If managed as a closed injury, these fractures can progress to osteomyelitis (Fig. 24.9), growth arrest, and nail deformity. Thus, Seymour fractures should be treated as open fractures that require timely surgical treatment, including removal of the nail plate, debridement and washout, reduction and possible pinning, and nail bed repair.

Phalangeal Fractures

Phalangeal fractures are the most common hand fractures seen in children. In toddlers, distal phalangeal tuft fractures from fingertip crush injuries are most frequently seen. These are typically managed with careful repair of the laceration, often involving the nail bed, and splint or cast immobilization with minimal sequelae. In older children, more proximal phalangeal fractures are of highest incidence, followed by metacarpal fractures. Patients with these fractures should be carefully examined for deviation, angulation, and malrotation of the involved digit. Precise radiographs should be obtained. Salter-Harris II fractures of the proximal phalanx, which involve the physis with metaphyseal extension, are most commonly seen and can frequently be managed with closed reduction and cast immobilization (Fig. 24.10). Failed closed reduction may require pin stabilization. Phalangeal shaft fractures are often an oblique or spiral pattern, and patients have malrotation and deviation of the finger and usually require some sort of stabilization to hold reduction (Fig. 24.10). Phalangeal neck fractures often present with dorsal displacement and can be missed without carefully done radiographs (Fig. 24.10d, e). Because of the proximity to the joint, stiffness and deformity can result without reduction, and thus phalangeal neck fractures should be managed with reduction and stabilization. Fractures involving the condyle also often require operative treatment with reduction and fixation as these can be unstable and easily lose alignment. Hyperextension injuries of the proximal interphalangeal joint can result in a small avulsion fracture involving the volar plate which can be managed initially with splint immobilization and then transitioned to buddy taping and early mobilization.

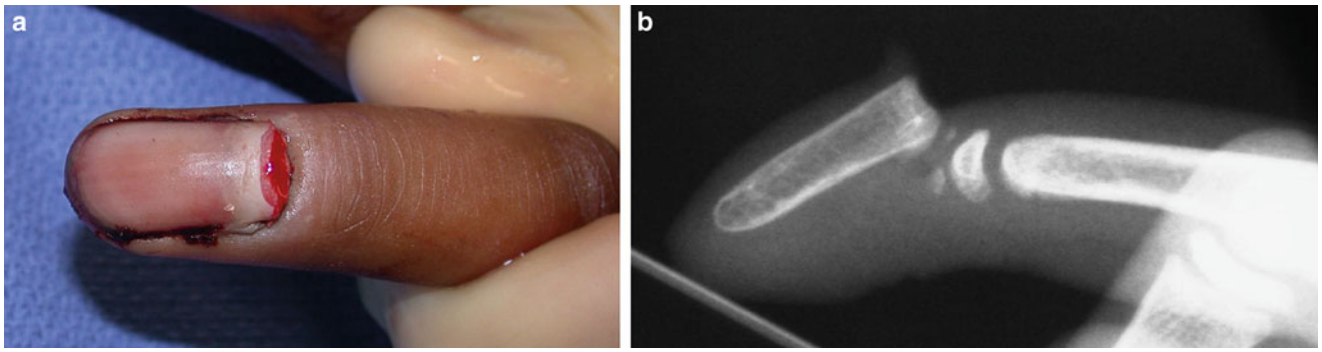

Fig. 24.8 Seymour fracture. (**a**) Avulsed nail plate resting superficial to proximal nail fold. (**b**) Lateral radiograph showing angulated fracture involving the physis of the distal phalanx

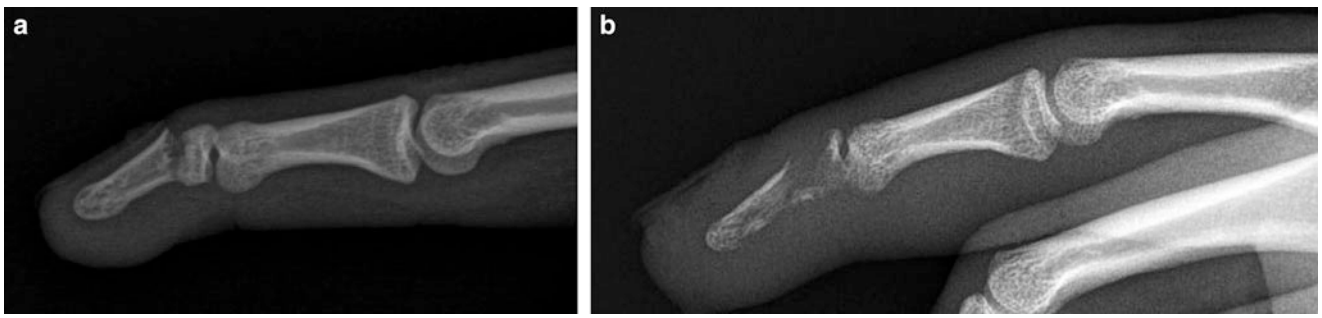

Fig. 24.9 (**a**) Lateral radiograph of an index finger with a Seymour fracture. (**b**) Lateral radiograph of the same index finger 4 weeks after cast immobilization to treat the fracture with development of osteomyelitis of the fracture site. This was treated with bony debridement, nail bed repair, and antibiotics with eventual bony healing

Editor's Comment

Definitive care of hand injuries requires a great deal of expertise and experience, preferably by a dedicated hand surgeon, but the initial assessment and treatment are important aspects of the care of the injured child. General and pediatric surgeons need to be prepared to deal with these situations and should not be intimidated when they occur. In general, a minimalist approach is best: observe and gently examine the hand without excessive manipulation, try to assess distal neurovascular function, obtain appropriate dedicated radiographs, and discuss the case personally with a pediatric hand specialist as soon as possible. If there is bleeding, one should apply direct pressure by hand, never with a "pressure" dressing or weights. Apply only the minimum pressure necessary to stop the bleeding; excessive pressure occludes the artery and causes distal ischemia.

Severe ischemia or pulsatile bleeding should always prompt emergent surgical exploration, not additional diagnostic studies. Always assume that a subungual hematoma could be the result of an underlying distal phalangeal fracture and perform a dedicated radiograph to rule this out. To preserve amputated parts for possible reimplantation, it is best to wrap the tissue in saline-soaked gauze, place it in a specimen cup, and place this into a specimen bag containing a slurry of ice and water and labeled with the patient's name and date of birth. Finally, remember to document every aspect of the physical examination and any therapeutic maneuvers in great detail in the medical record as this will help the hand surgeon during subsequent follow-up and could help reduce medical liability if the functional outcome is less than optimal.

Radial arterial lines are increasingly common in the care of critically ill children and during long operations. They are not without risk and frankly are somewhat overused. Meanwhile the Allen test seems to be a quaint leftover of a bygone era, as no one seems to feel the need to do it anymore. Emboli can cause ischemia to the thumb and first fingers. Hematoma can cause nerve compression and edema. Thrombosis results in the hand having to be perfused with only the ulnar artery. And the skin scarring, especially from excessive stitching to immobilize it, can be very unsightly.

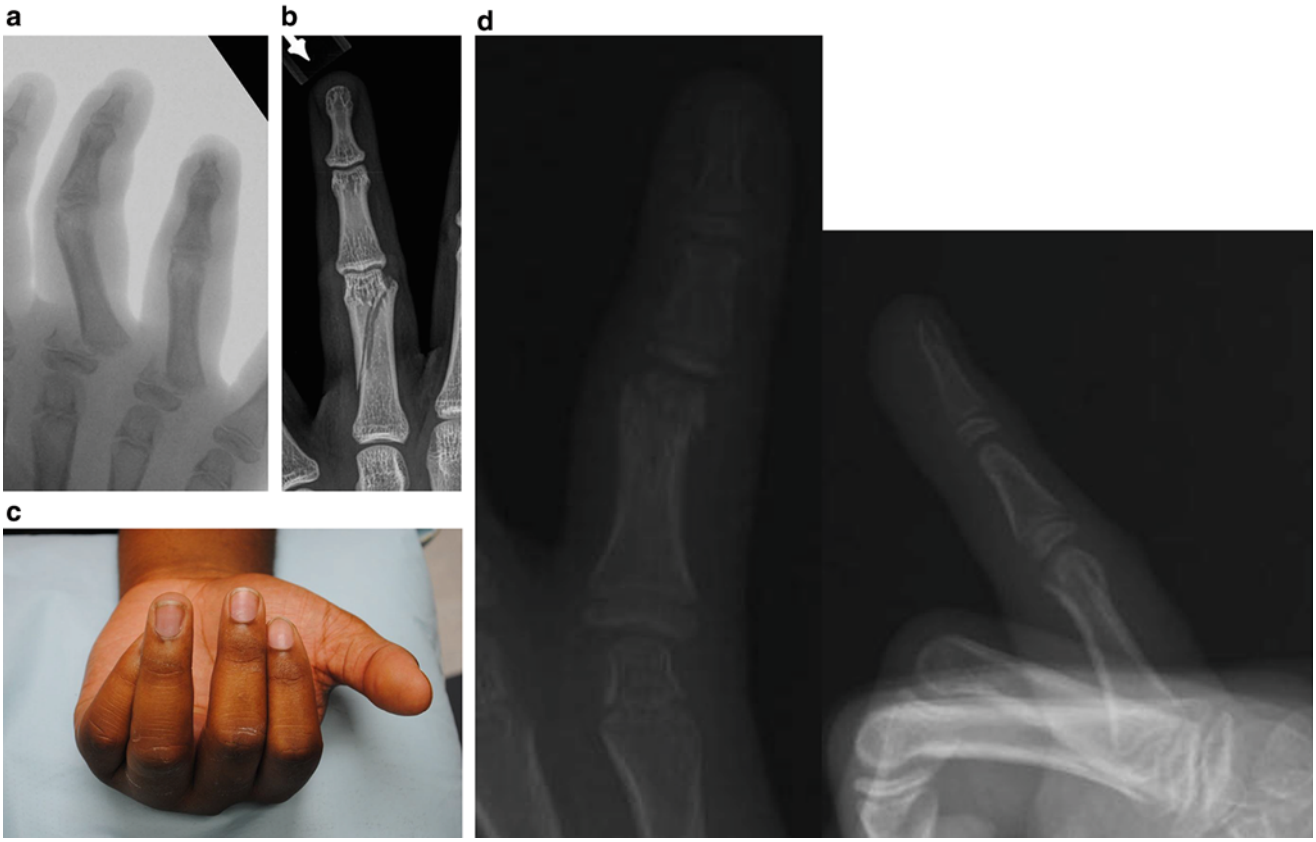

Fig. 24.10 Phalangeal fractures: (**a**) displaced Salter-Harris II fractures of the proximal phalanges of the middle and ring fingers. (**b**) Displaced fracture of the proximal phalangeal shaft. (**c**) Clinical examination shows deviation and malrotation of the injured ring finger. (**d**) PA and (**e**) lateral radiographs of a displaced proximal phalangeal neck fracture

Compartment syndrome of the hand is uncommon but easily missed. This can be due to extravasation of IV fluids causing tense edema of the skin and subcutaneous tissues, resulting in ischemia of the underlying nerves, muscles, and tendons, or true compartment syndrome of the hand from ischemia reperfusion or a crush injury. This can be extremely difficult to confirm or rule out, especially in infants and small children. A high index of suspicion is critical—it needs to be considered in any child with refractory pain or increasing narcotic requirements after an injury or extravasation.

Suggested Reading

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Child Abuse

25

Philip V. Scribano and Carla A. Parkin-Joseph

Although child maltreatment is a significant health problem, inherent biases in reporting and healthcare providers' general lack of comfort and competency in establishing the diagnosis make detection of every child at risk quite difficult. It is therefore important to have a clinical framework to evaluate children with injuries and to include certain evaluations that can assist the surgeon in properly evaluating concerns and suspicion of child maltreatment.

Based on national child protection services data, over 680,000 children are confirmed victims of maltreatment in the USA each year. Although the majority are victims of neglect, nearly 20% (over 125,000) are victims of physical abuse, and about 10% (nearly 64,000) are victims of sexual abuse. The highest rate of victimization occurs in infants less than a year of age, so patients in this age range presenting with signs of trauma warrant an increased level of suspicion. Included in these statistics are approximately 1600 fatalities, the majority of which affect children under 3years. Although younger children are more likely to be maltreated, child maltreatment occurs in all ages, genders, races, and socioeconomic strata.

There are also significant long-term medical and developmental consequences. Therefore, it is crucial that pediatric surgeons, who are frequently on the front line in managing the injured patient, become comfortable with evaluating concerns for abuse.

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General Principles

A high index of suspicion for non-accidental trauma (NAT) as an etiology requires a systematic approach. While the initial presentation is often nonspecific, child abuse should be especially considered in any child less than 5 presenting with an injury and any infant presenting with an apparent life-threatening event (ALTE), altered mental status, respiratory distress, unexplained vomiting, unexplained bruising, or irritability. The evaluation of a seriously ill or injured child should consist of primary and secondary survey assessments. Cervical spine precautions are warranted if traumatic brain injury is a possibility, regardless of the initial injury severity, given the inherent challenge in making a diagnosis of abusive head trauma and associated cervical spine injury in this age group.

Once the primary survey has been completed and emergent interventions provided as necessary, a thorough secondary assessment should be completed and a more detailed history obtained. During this assessment, additional clues may be present to warrant further investigation for possible NAT. The history should include the details of all injuries identified in the primary assessment, the details surrounding symptom onset, the knowledge of the caregiver who was providing care to the child when injured, an assessment of the developmental stage of the patient, a brief family history, and the social history. This comprehensive assessment will assist in determining the plausibility of injury, given the history, and the additional clinical evaluations which may be warranted. The details of an injury must include the time and mechanism, the clinical manifestation, and any associated symptoms. A brief developmental assessment should be established focusing on the gross motor skills of the patient. A brief family history should be ascertained in order to determine the possibility of an underlying medical condition that might have contributed to the patient's injury. Specifically, family history of bleeding, bone disorders, and metabolic or genetic disorders are of interest. Social history,

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including identification of recent caregivers and supervision at the time of the injury or symptom onset, can be useful. Consultation with a medical social worker is also helpful to aid in identification of other risk factors for NAT such as unemployment, prior child protective services involvement, prior law enforcement involvement in a member of the household, mental illness in an adult in the household, and a history of intimate partner violence or substance use.

A meticulous physical examination must include inspection of the entire skin. Evidence of acute or healed trauma, including lacerations, abrasions, bruises, or burns, and identification of injuries to the extremities, including bony deformities or dislocations, provide additional information in determining the likelihood of NAT. Abnormalities in neurologic status, including level of alertness, responsiveness to tactile stimuli, and spontaneous and symmetric movement of the extremities, are important to determine the need for neuroimaging to accurately detect intracranial trauma.

If NAT is suspected, screening for occult injuries as well as for medical conditions that can mimic NAT should be undertaken. This includes both laboratory and radiologic studies. Generally, younger patients and those with more severe injuries require more extensive evaluation. Laboratory investigations, including CBC, coagulation studies, basic metabolic profile, liver transaminases, amylase, lipase, and urinalysis, are suggested for all patients under the age of 6 years. More targeted laboratory investigations should be considered based on the type of injury and other diagnostic possibilities. Radiographic investigations include a skeletal survey for patients less than two years (and consideration for children under five years) and neuroimaging for patients 6 months of age or younger. Head CT should be employed for patients who are acutely symptomatic. To minimize radiation exposure, brain MRI can be considered in asymptomatic infants, but these studies frequently require sedation, which may introduce a potential delay. Abdominal CT should also be performed in patients with symptoms or physical exam findings of abdominal trauma, as well as those with positive laboratory markers of intra-abdominal injury.

The surgeon can then begin to assess plausibility of reported mechanisms of injury and whether the reported mechanism is consistent with the injury identified. Clinical factors that should heighten suspicion for NAT include (1) the lack of a history of trauma, or a vague explanation of injury, in a patient with significant injury, (2) a caregiver's history that changes over time or with different interviewers, (3) a mechanism that is inconsistent with the injury, (4) a mechanism that is inconsistent with the patient's developmental stage, (5) histories that differ among witnesses to the injury event, and (6) evidence of patterned injuries (i.e., loop marks, hand marks, cigarette burns).

Cases of suspected NAT require careful documentation in the medical record. Documentation of the history should state clearly who provided the history and should use quotations when the patient or caregiver relates specific details. Documentation of physical exam findings and injuries should be thorough and descriptive. Digital images or body diagrams are helpful to fully document location, size, and pattern of injuries.

Mandated reporter laws exist in all 50 states, the District of Columbia, and US territories. Physicians, nurses, social workers, and other healthcare providers are required to report suspected maltreatment to a child protective services agency. It is important to know the specific reporting requirements in your state and jurisdiction. Proof of maltreatment is not required to make a report. There is no risk of prosecution if a report is made in good faith; however, failure to report can lead to licensing penalties, malpractice claims, and even criminal charges. Many hospitals have developed multidisciplinary teams to aid in the evaluation of suspected child maltreatment. If available, consultation with a child abuse pediatrician will help not only to guide the medical evaluation but also to navigate the social and legal implications after a report of suspected child maltreatment is made.

Cutaneous Injuries

Cutaneous injuries are the most common manifestation of physical abuse, and bruises are the most common cutaneous injury identified in abused children. To distinguish between accidental and inflicted bruises, one must consider the location of the bruises, as well as if there is a discernible pattern to suggest use of a specific implement. Bruises that are more likely accidental are those located on bony prominences (e.g. the elbows, knees, anterior tibia). Bruises that should raise suspicion for NAT include those located on fleshy surfaces, such as the cheeks (Fig. 25.1) or buttocks, and those located in areas of the body that are usually protected, such as the neck, ears, back, and genitals. Bruises to the ear on both the anterior and posterior aspects of the pinna are highly concerning for abuse and are commonly missed (Fig. 25.2). Patterned bruising, regardless of the location, is indicative of abuse (Fig. 25.3). The surgeon should also take the child's age and developmental abilities into account. Bruises are extremely uncommon in nonambulatory infants, especially in infants less than 6 months of age. Conversely, by the time a child is walking, normal bruising can be observed in over half of children. In an effort to highlight bruises which have high concern for non-accidental trauma in children, a pneumonic "TEN-4" was coined to describe bruises on the torso, ears, neck as being highly specific for non-accidental injury in children < 4 years old, and any bruise in an infant < 4 months old.

As bruises heal, their appearance and color change over time. Despite older literature that suggested some predict-

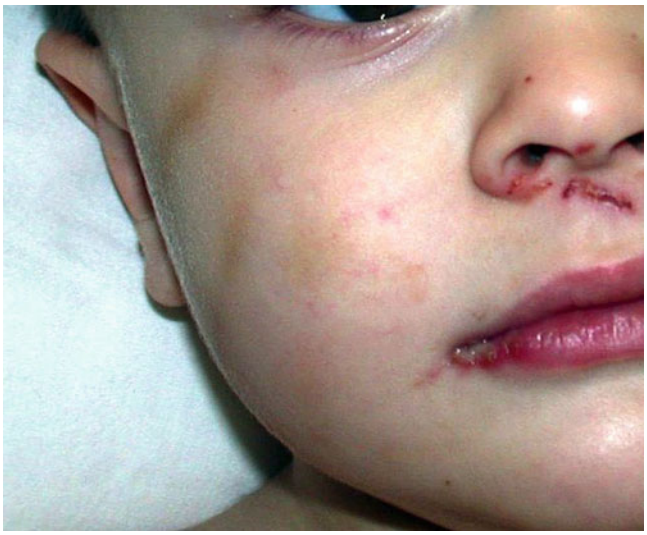

Fig. 25.1 Four-year-old with multiple bruises to the face, arms, and scrotum; this patterned bruise on the right cheek was the result of a hand slap

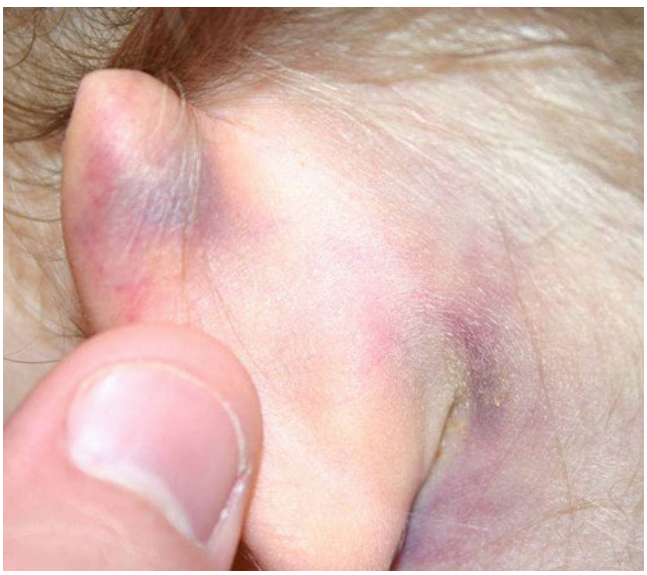

Fig. 25.2 Five-year-old with history of fall and subsequent history of being grabbed by the ear and thrown against a kitchen counter. Also, note ecchymosis to the mastoid region (Battle sign)

ability to estimating the age of bruises, this is very inexact and should be avoided. In addition, there are a number of medical conditions included in the differential diagnosis of bruising, and a surgeon must be mindful of these possible etiologies when evaluating a case of suspected NAT (Table 25.1).

Laboratory evaluation for the most common bleeding disorders should be undertaken. However, the identification of an underlying bleeding disorder does not rule out NAT. Initial laboratory evaluation should begin with a CBC and PT/PTT. Additional testing may include vWF antigen and activity and levels of factors VIII and IX. Should these studies yield abnormal results or if further evaluation is warranted, consultation with a pediatric hematologist is recommended.

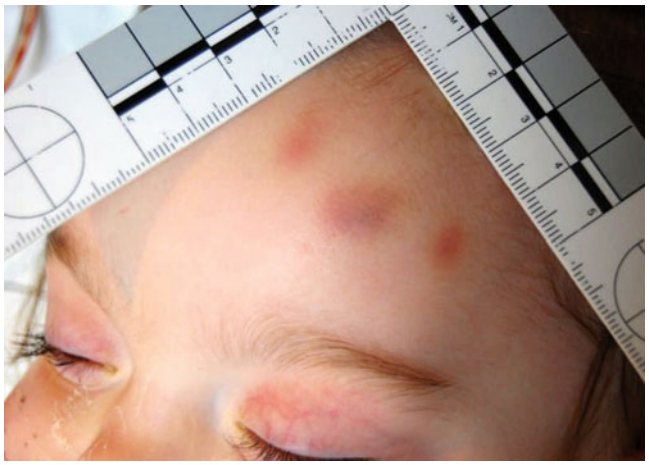

Fig. 25.3 Twenty-eight-month-old with fatal abusive head trauma, multiple fractures of varying stages of healing, and patterned finger pad bruising of the forehead

Burns are another common cutaneous manifestation of NAT, accounting for 5–20 % of all pediatric burns. The majority of abusive burns are scald injuries. As with bruises, one must consider the location of the burns, as well as if there is a discernible pattern to suggest use of a specific implement. Accidental scald burns are frequently sustained in the kitchen and involve the front of the body, including the face, neck, chest, shoulders, and upper extremities. Accidental burns frequently exhibit splash marks and lessen in intensity as the liquid runs down the body. In contrast, abusive burns tend to be more severe and often require longer hospitalizations. Immersion scald burns are the most common inflicted burn. These burns are frequently located on the extremities and exhibit a well-demarcated glove or stocking distribution with no splash marks. Forced immersion in a tub often results in buttock or genital burns, and flexor creases of the involved joints may be spared as the patient is flexing the hip and knee to avoid the hot water. There are some medical conditions that should be considered when evaluating the child with burns (Table 25.2).

Intraoral injuries in young infants are very concerning injuries which prompt suspicion for NAT. Although frenula tears in ambulatory toddlers are common from routine falls when the face strikes an object or the floor, in young infants, they are highly associated with abuse (Fig. 25.4). During the comprehensive physical examination, careful attention should be paid to the oral cavity and integrity of the upper and lower labial and lingual frenula. These injuries can be a harbinger of abuse and warrant additional evaluations for occult trauma.

Table 25.1 Mimics of child abuse bruising

Dermatologic	*Bleeding diatheses*
Dermal melanosis (Mongolian spots)	von Willebrand disease
Henoch-Schönlein purpura	Idiopathic thrombocytopenic purpura
Phytophotodermatitis	Hemophilia
Hemangiomas	Oncologic disorders
Erythema nodosum	*Folk remedies*
Urticaria pigmentosa	Coin rolling (cao gio)
Collagen-vascular	Cupping
Ehlers-Danlos syndrome	Spooning (quat sha)
Infectious	*Miscellaneous*
Maculae ceruleae (pediculosis)	Chilblain (pernio)
	Hemolytic uremic syndrome
	Hemorrhagic edema of infancy

Table 25.2 Mimics of child abuse burns

Dermatologic
Dermatitis herpetiformis
Guttate psoriasis
Epidermolysis bullosa
Infectious
Impetigo
Varicella
Staphylococcal scalded skin syndrome
Miscellaneous
Fixed drug eruption

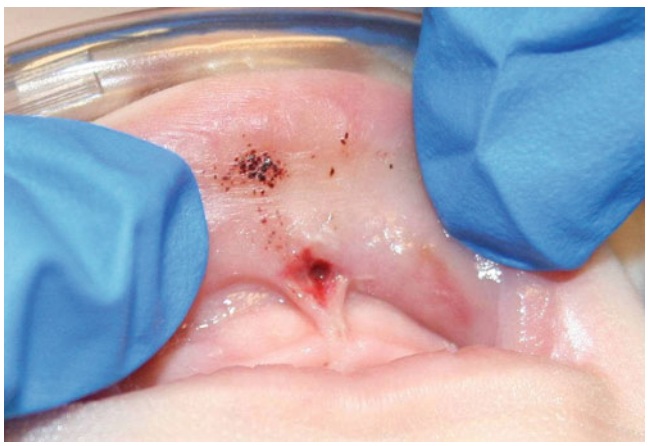

Fig. 25.4 Three-month-old with upper labial frenula injury from force feeding with his bottle; infant sustained abusive head trauma with acute SDH and retinal hemorrhages

Fractures

Fractures are the second most common manifestation of physical abuse. As with cutaneous injuries, distinguishing the accidental from the non-accidental fracture often proves challenging. The surgeon must take into account the history (injury plausibility) provided by caregivers and witnesses, the injury mechanism based upon a basic understanding of the mechanics of the injury and forces involved, the location and type of fracture, and the age and developmental status of the patient. If these factors do not correlate with one another—injury plausibility is not correlated with fracture type, mechanism, or developmental stage—then suspicion for non-accidental trauma is warranted. Further questioning should focus on the mechanism: How did they fall? How did they land? What surface did they land on? Assessing the time to symptom onset may indicate a delay in seeking medical care, or it could indicate a type of fracture that may not manifest with significant signs and symptoms. How the patient behaves following an injury will also offer information as to the physical consequences of a fracture. Younger children have higher rates of inflicted fractures, and extremity fractures in nonambulatory children are more likely to have been caused by abuse.

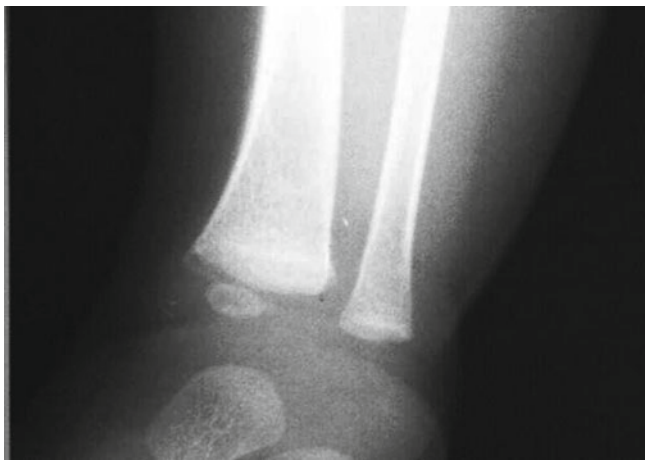

Fig. 25.5 Classic metaphyseal lesion with a bucket-handle fracture of the distal radius in this 23-month-old with evidence of abusive head trauma

Although there is no location or type of fracture that is diagnostic of NAT, some fractures have a high specificity for abuse. Rib fractures, especially posterior rib fractures in infants, are highly specific for abuse and usually caused by anterior-posterior compression of the chest or during shaking. A fulcrum effect of the spinous processes on the ribs is the mechanism of injury. Fractures of the scapula, sternum, and vertebral spinous processes are less common in children but remain highly specific for abuse due to the energy required to cause these injuries. Classic metaphyseal lesions (CMLs), also known as corner or bucket-handle fractures, are also highly specific for abuse in infants (Fig. 25.5). CMLs are caused when shearing forces or traction are applied to the metaphysis of long bones, as can occur with pulling of an infant's extremity or with flailing of the extremities during

Table 25.3 Skeletal trauma mimics of child abuse

Genetic
Osteogenesis imperfecta
Menkes disease (copper deficiency)
Metabolic
Vitamin D rickets
Renal disease
Hypophosphatasia
Infectious
Congenital syphilis
Osteomyelitis
Miscellaneous
Osteopenia of prematurity
Bone demineralization due to disuse/nonuse
Leukemia
Scurvy

vigorous shaking. As CMLs cause little in the way of physical signs and symptoms, radiographic evaluation is frequently required for diagnosis.

Any child less than 2 years of age presenting with one or more fractures, in the absence of a verified traumatic event (motor vehicle crash with EMS documentation), is suspicious for abuse and should include a skeletal survey to evaluate for other fractures. As a standard practice, a repeat skeletal survey in 2–3 weeks allows (1) identification of fractures not identified on the initial study, (2) clarification of indeterminate findings of the initial study, and (3) identification of stigmata of an underlying bone disease.

Although child abuse remains the most common cause of fractures in this setting, the surgeon should be aware of medical conditions that may make a child's bones more vulnerable to fracture (Table 25.3). Clinical history, examination, and laboratory evaluation may facilitate this evaluation, but identification of an underlying bone disorder does not rule out NAT. Initial laboratory evaluation should include calcium, magnesium, phosphorus, and alkaline phosphatase levels in addition to a urinalysis. If the history suggests of vitamin D deficiency (breastfeeding without vitamin D supplementation, lack of exposure to sunlight) or there are radiographic signs concerning for rickets (fraying/cupping of the metaphysis, widening of the physis, "rachitic rosary"), testing should include serum parathyroid hormone (PTH) and 25-hydroxyvitamin D, and a metabolism or endocrine consultation should be obtained. Although extremely rare, osteogenesis imperfecta (OI) should be considered if there is a family history of fractures with mechanisms unlikely to cause injury or typical clinical features (short stature, blue sclera, abnormal dental development, hearing impairment, osteopenia). Mutations of the *COL1A1* and *COL1A2* genes cause 90% of clinically significant OI.

Head Trauma

Abusive head trauma (AHT) refers to any head trauma inflicted on a child, independent of the mechanism (shaking, blunt impact). It is the most common cause of death due to child abuse and causes significant morbidity; however, it can be difficult to recognize for several reasons: These patients are young (usually under 3 years) and developmentally incapable of providing a history, while inaccurate histories provided by caregivers tend to obscure the diagnosis, and these patients can present with a wide range of symptom severity from mild and nonspecific to severely obtunded. Based on these difficulties in diagnosing AHT, it is important for the surgeon to maintain a level of suspicion and adopt a systematic approach.

Infants often present with nonspecific symptoms such as emesis or other gastrointestinal symptoms, decreased activity or irritability, or changes in feeding, which makes the diagnosis of AHT challenging and easily missed. In evaluating the diagnosis of AHT, about one-third of cases are missed in prior medical encounters before the diagnosis is ultimately made. White children from two-parent families are more likely to be misdiagnosed, suggesting a sociocultural bias in the initial suspicion for NAT. Infants who present with more severe symptoms, such as decreased responsiveness or changes in mental status, seizures, altered breathing, or apnea, are more frequently correctly diagnosed as neuroimaging is often ordered to evaluate these children.

When AHT is suspected, physical examination should include a thorough neurologic evaluation as well as identification of other signs of NAT—cutaneous injury, fractures, or intra-abdominal injuries. Since AHT may include acceleration-deceleration (shaking) mechanism of injury, cervical spine precautions are warranted, regardless of the initial injury severity or the history provided by caregivers. Particular attention should be paid to the head examination, to identify signs of blunt impact, including scalp hematoma or skull fracture.

Any child with concern for AHT should undergo diagnostic neuroimaging. In the era of reducing exposure to ionizing radiation down to ALARA (as low as reasonably achievable), any symptomatic patient should undergo a head CT without contrast, which provides a prompt and accurate evaluation for acute hemorrhage and can identify soft tissue swelling and cranial fractures (Fig. 25.6). In asymptomatic patients or when a delay will not place a patient in harm, one can potentially defer the CT in favor of an MRI. Sedation is often required, which might also delay neuroimaging. If acute hemorrhage is identified on head CT, MRI can be helpful to identify other injuries including intraparenchymal contusions, areas of axonal injury, or edema. Recent data support the inclusion of the MRI of the cervical spine in these

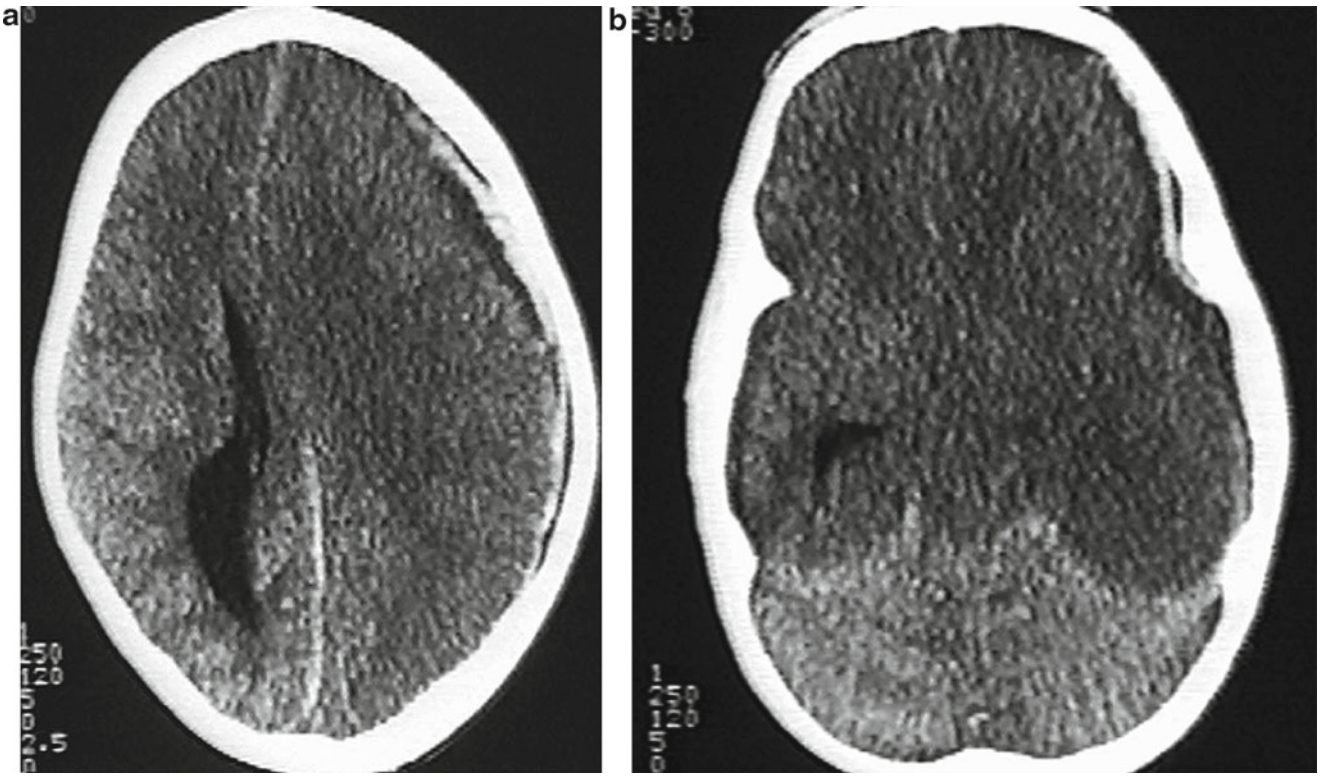

Fig. 25.6 Seven-week-old infant presented with respiratory insufficiency and unresponsiveness; CT with large, acute left subdural hemorrhage, shift to midline, cerebral edema, and layering of acute hemorrhage along (**a**) falx cerebri and (**b**) tentorium

patients. A significant prevalence of injury findings has been reported such as ligamentous or paraspinal muscle injury, which could support a mechanism of injury such as shaking.

As AHT is frequently associated with retinal hemorrhages, an ophthalmologic examination should be undertaken in all patients with AHT. Consultation with a pediatric ophthalmologist and a dilated eye examination with indirect ophthalmoscopy should be performed as soon as it is clinically appropriate. Retinal hemorrhages are not specific to AHT and can also be seen in severe accidental injury, meningitis, vasculitis, and severe coagulopathy. However, characteristics including number of hemorrhages, retinal layers involved, and location within the retina have particular relevance in supporting the diagnosis of AHT.

While many children will exhibit coagulation abnormalities consistent with mild disseminated intravascular coagulation (DIC) due to brain injury, this physiologic response to brain trauma is not due to any underlying bleeding diathesis. However, initial laboratory evaluation, as in evaluation of bruising, should begin with a CBC and PT/PTT, as well as screening for DIC. In some cases, additional testing is warranted and should include vWF antigen and activity and factor VIII and IX levels. A rare genetic condition, glutaric aciduria type 1 (GA1), can also cause intracranial hemorrhage; however, the clinical features, neuroimaging findings, and absence of other NAT findings make this diagnosis relatively straightforward. While most states include evaluation of GA1 in their newborn screens, consultation with a metabolism specialist is warranted if GA1 is suspected, to aid in evaluation for this disorder and other rare genetic conditions associated with intracranial hemorrhage.

Abdominal Trauma

Prompt and accurate identification of abdominal injury in pediatric patients can be difficult. Identifying inflicted abdominal injuries is even more difficult, as the histories provided in cases of suspected NAT are often incomplete, inaccurate, or misleading, and delays in presentation and relatively minor abdominal symptoms with poor sensitivity in detecting occult abdominal trauma often result in delayed diagnosis.

Although abdominal trauma is rare in cases of suspected NAT, abdominal injury is a significant cause of mortality. It is the second most common cause of death in abused children. Although abusive abdominal trauma can be identified

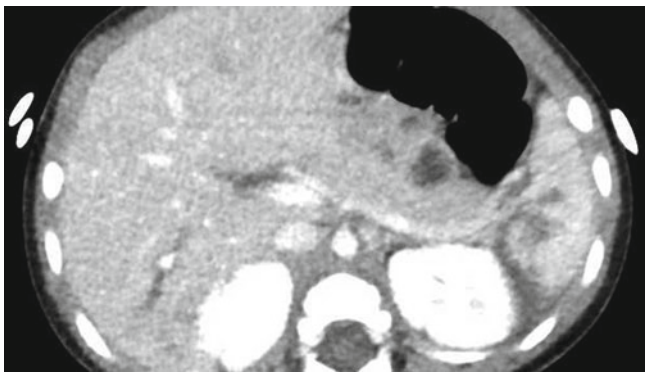

Fig. 25.7 Liver and spleen lacerations in a 3-year-old with nonlocalized, mild abdominal pain and no history of trauma provided; the patient had elevated liver transaminases (ALT 320; AST 196), which prompted this abdominal CT study

in all age groups, younger children are at increased risk. The most commonly injured solid organ is the liver. Injuries to the small bowel and pancreas are also relatively more common in non-accidental trauma. Clinical presentations of inflicted abdominal injuries are similar to that of accidental injuries and as such might be nonspecific: nausea, vomiting, abdominal pain, tenderness, and abdominal distension. Commonly, these patients also have a history that lacks any specific abdominal trauma. Delays in seeking medical attention and in onset of symptoms of some abdominal injuries are common.

The physical examination finding that most frequently initiates investigation for possible abdominal trauma is abdominal wall bruising; however, this finding is absent in a significant number of cases that are later confirmed by imaging to have intra-abdominal injury. Similarly, other physical findings, including tenderness, distension, or hypoactive bowel sounds, lack sensitivity for abdominal trauma.

When the clinical picture is nonspecific or examination findings are seemingly normal but suspicion for abdominal NAT exists, especially in children under 5 years, laboratory screening should include CBC, liver transaminases, amylase, lipase, and urinalysis. Significant elevations in liver transaminases should prompt the performance of diagnostic imaging. As transaminase levels can normalize within days following an injury and patients with inflicted abdominal trauma frequently are delayed in seeking medical attention, levels may have already fallen at the time of presentation, potentially limiting the usefulness of these tests.

CT with IV contrast is the imaging modality of choice in evaluation of suspected abdominal solid organ injury and should be performed in patients presenting with physical findings concerning for abdominal trauma or hemorrhagic shock and in patients with elevated liver transaminases or pancreatic enzymes (Fig. 25.7). Abdominal US has been proposed as a screen for NAT, but there is little evidence to support its routine use, and minor injuries that do not require surgical intervention yet may have significant forensic significance can be missed. US may be used to identify and further characterize bowel wall hematomas and pancreatic injuries. Upper gastrointestinal series is the best study to identify bowel wall hematomas or strictures and should be performed in patients with a normal CT and symptoms or examination findings of abdominal trauma.

Acute Sexual Assault

Although infrequent, pediatric surgeons may be asked to evaluate patients with anogenital injuries due to acute sexual assault. These patients require special care to ensure an accurate physical exam interpretation and forensic evidence collection as well as testing for STI and pregnancy. Although many hospitals have adopted sexual assault response teams or sexual assault nurse examiner programs, a surgeon is involved when injuries warrant surgical intervention.

The medical evaluation of acute sexual assault begins with a history from both the patient and the accompanying caregiver. The purpose of this history is to gather "minimal facts," information that will guide clinical decisions in the remainder of the medical evaluation, and should include the age and gender of the alleged perpetrator, the nature of the sexual contact, time since the alleged assault, the presence of any signs of significant trauma, symptoms of abdominal pain, vaginal pain or bleeding, rectal pain or bleeding, dysuria, and hematuria.

Prior to performing the physical examination or any preparation of a surgical site, the need for forensic evidence collection should be determined. Forensic evidence collection should be obtained in patients who present for medical evaluation within 72 h of the assault. Evidence collection kits vary widely by jurisdiction but will include all necessary supplies for collection, as well as directions for proper technique and storage of the evidence. Careful consideration should also be given to the need for STI testing prior to physical examination, so that appropriate supplies are readily available to obtain these specimens.

The physical examination should be performed in a manner so as not to increase the psychological trauma of the assault. If a patient is unable to cooperate with the anogenital exam, sedation is required. The examination may require labial traction to fully visualize the hymen, but a speculum examination in a pubertal patient is only needed if the patient has signs of vaginal trauma. This would normally require sedation or anesthesia. For prepubertal patients, a speculum examination should only be performed under sedation or anesthesia and when clinically indicated for surgical visual-

ization and repair. Documentation of the physical examination should thoroughly describe each of the injuries identified and should include photodocumentation as part of the medical record.

The decision to pursue STI evaluation should be made on an individual basis. Due to the high rates of asymptomatic infection in adolescents, all pubertal patients presenting with history of sexual assault should undergo full STI evaluation and pregnancy testing. In prepubertal patients, targeted screening should be employed, as the prevalence of STIs is relatively low. Prepubertal patients who should undergo STI evaluation include those with symptoms of infection or identified genital or anal injury and those with evidence of penetration (oral, genital, or anal) or ejaculation, in cases in which the alleged perpetrator is known to have an STI, in communities with a high prevalence of STI, or those patients or parents who request testing. Testing should include evaluation for *Neisseria gonorrhoeae*, *Chlamydia trachomatis*, *Trichomonas vaginalis*, HIV, and syphilis. Hepatitis B serologies are indicated in patients not previously immunized: due to the rising prevalence of Hepatitis C in some communities, consideration should be made to test for this infection.

All pubertal patients should receive prophylactic STI treatment for gonorrhea, chlamydia, and trichomonas. Conversely, in prepubertal patients, STI prophylaxis is generally not recommended unless there are symptoms of infection, acute injury, or evidence of ejaculation on physical examination. If patients have not been fully immunized, they should begin the hepatitis B vaccination series. Consideration should also be given to the need for HIV post-exposure prophylaxis (PEP). Decision to recommend and provide HIV PEP is multifactorial, and consultation with immunology or infectious diseases aids in the decision-making; however, it is important to note that HIV PEP should be initiated within 96 hours of the assault and prescribed for a 28-day course. Depending upon which HIV test is used i.e. 4th generation, HIV surveillance testing should be repeated at 4 and 12 weeks post-assault.

System Response

All healthcare professionals are mandated reporters of suspected child maltreatment. While there are various nuances to the statutory definitions and requirements in each state and jurisdiction, there are some general guidelines that apply to all. First, "definitive proof" of maltreatment is not required prior to creating the report, only reasonable suspicion that maltreatment has occurred. Second, there is no risk of prosecution if a report is made in good faith; however, states have significant penalties including criminal charges for failure to report suspected child maltreatment. Third, the method of reporting (telephone, fax copy, electronic submission) is variable in each jurisdiction. However, once a report is filed, the state or county CPS agency will determine if the report requires further action. All screened-in reports will undergo an investigation to determine whether the suspected maltreatment concern is "founded/substantiated" or "unfounded/unsubstantiated," and specific criteria are established for the CPS agency in making these determinations. This investigation will occur concurrently with ongoing medical care and may include interviewing the victim and any caregivers or witnesses, a home assessment, and a thorough psychosocial assessment. Police may also conduct a parallel investigation and evaluate the crime scene, conduct other interviews including the alleged perpetrator of the injuries being reported, and establish probable cause to file a warrant for an arrest. Communication between medical professionals and the investigating CPS and law enforcement agency personnel is necessary so that the investigation can occur in an efficient manner and so that a safe discharge plan can be created. Prior to discharge from the hospital, a safety plan must be established with CPS. Depending upon the circumstances and location of the alleged perpetrator, a service plan might include services to the child and family in the home i.e. in home protective services, or out-of-home placement i.e. foster or kinship care placement.

Court Testimony

All reports of suspected child maltreatment will receive a response from CPS; if accepted and investigated, the family court (some jurisdictions refer to this as juvenile court) will provide adjudication on whether abuse or neglect exists to warrant court-ordered protection. Not all cases of suspected child maltreatment are brought through the criminal court process. When the investigation has determined that there is sufficient evidence to charge an individual with a crime, the criminal court process is activated as well. It is during these court proceedings of the criminal justice system that a surgeon may be called to act as a witness for the prosecution. In cases of suspected maltreatment, it is important to recognize that effective preparation for court testimony begins with detailed documentation during the patient encounter.

After receiving a subpoena, it is recommended to discuss the surgeon's role in the case with the attorney listed and determine the date and time of the court proceedings. Most prosecutors will try to accommodate the surgeon's schedule to avoid unnecessary delays, but this requires some discussion and negotiation of one's availability in court. Given the unfamiliar territory of the court system, when a subpoena is received, you should contact your institution's legal and risk management teams to assist you in navigating this process. This is especially helpful in light of variability in institutional HIPAA interpretations that may limit your communication

with a prosecutor prior to having a release of information authorization to do so.

Testimony often begins with qualifying the surgeon as an expert witness. This process, known as *voir dire*, begins with an examination of the surgeon's credentials to assess the specific expertise he or she is being qualified in court. Testimony then continues with direct examination from the prosecutor (a series of questions and responses in regard to the details of the case, the surgeon's findings, treatment, and diagnostic opinion) and cross-examination from the defense attorney (a series of questions that are meant to clarify the direct examination responses but also to strategically develop the defense position of innocence of their client). After cross-examination, the prosecutor may ask follow-up questions in a process known as redirect examination, and this process may continue until the witness has adequately addressed all questions or issues, and no additional questions have been raised by the attorneys.

Editor's Comment

For those of us who care for children every day, it is often difficult to maintain equanimity when taking care of a child who has been intentionally harmed. Child abuse is an unfortunate fact of life, but our emotions cannot interfere with our duty to help the child. In most tertiary-care pediatric centers, there are experienced dedicated teams of healthcare professionals and social workers whose job is to help us deal with the myriad social and legal issues involved in these cases. For physicians, it is important to meticulously document every aspect of the child's care and not to compound the injuries with a diagnostic or therapeutic misstep.

The perpetrator is very often an adult guardian (often a single mother's boyfriend is the culprit), but it seems increasingly common to see older siblings, cousins, or peers involved. What might have been ascribed to an accident or horseplay could very well have been a deliberate act perpetrated by a bully. It is important to identify these patterns because it is disturbingly common to see a child returned home to a dangerous environment only to come back later with a more serious injury.

There are specific groups of children at risk for abuse who though often overlooked deserve extra attention: (1) Children who are physically or developmentally disabled are especially prone to abuse not only by the usual perpetrators but also by guardians and caretakers who work with them in their homes or at a custodial facility. Caring for children with special needs requires a special empathy and patience that is sadly lacking even by the people who are hired to be their mentors and protectors. (2) Abusive tactics can be systematically and insidiously allowed or even promoted within certain cultures. But these at-risk children have the same rights as our own children to live in a safe and supportive environment. Ignorance or a misplaced deference to custom or religious practices should not deter us from our duty to protect them from harm. (3) Finally, although one might expect that the days of affording parents the right to treat their children like property or pets are gone, sadly even in this country we witness mistreatment in the form of corporal punishment, body shaming, and flagrant bullying, among other forms of emotional and psychological abuse, on a daily basis. Though at the moment perhaps somewhat nebulous from a cultural, legal, and ethical perspective, the hope is that universal mandatory reporting laws will someday include these forms of child maltreatment as well.

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Part IV

Head and Neck

The Critical Airway

26

Luke A. Jakubowski and Jeremy D. Meier

The symptoms of pediatric airway compromise include dyspnea, voice change, drooling, dysphagia, positioning, coughing, and sore throat. The most obvious symptom is dyspnea, which may present with an increased respiratory rate or a feeling of difficulty catching one's breath. Dyspnea can be positional; a child having difficulty when lying supine suggests possible base of tongue obstruction or anterior mediastinal mass compression of the trachea. Other children will optimize air entry using the tripod position, in which the child supports the upper body with hands on knees or another surface while either standing or sitting. The timing of onset (acute or chronic) of the dyspnea is important, as well as any progression of symptoms. Drooling or dysphagia can be a sign of supraglottic (epiglottitis) or oropharyngeal (tonsillar hypertrophy or peritonsillar abscess) obstruction.

General appearance should be used to gauge the urgency of the situation. Decreased level of consciousness should prompt immediate intervention. Additional signs include restlessness, retractions, anxiety, voice change, and airway sounds (stridor or stertor). Pediatric patients will often maintain their oxygen saturation until they acutely decompensate. Reduced oxygen saturation in an otherwise healthy child without cardiac disease is an ominous sign. The use of accessory respiratory muscles manifests as suprasternal and substernal retractions, nasal flaring, and the use of intercostal muscles. Accessory muscle use is a sign of increased work of breathing but is nonspecific and does not denote a level of obstruction. Tachycardia is often present with an increased work of breathing. Bradycardia is a late sign and denotes impending cardiopulmonary collapse.

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Differential Diagnosis

The differential diagnosis of acute airway obstruction is extensive. When evaluating a patient for airway obstruction, it is helpful to divide the airway into separate anatomic levels (nose and nasopharynx, oropharynx and hypopharynx, supraglottic larynx, glottis larynx, subglottic larynx, and trachea/bronchus (Table 26.1). Neonates are obligate nasal breathers; therefore, nasal obstruction can result in significant airway distress in the newborn (Fig. 26.1). Pathology at the level of the oropharynx or hypopharynx is often congenital or neoplastic. However, infectious etiologies such as deep space neck infections also present with acute oropharyngeal or hypopharyngeal obstruction. The most common etiology of supraglottic airway obstruction is laryngomalacia (Fig. 26.2). Acute airway obstruction from a laryngeal etiology has an extensive diagnosis. Subglottic obstruction is most often secondary to viral laryngotracheobronchitis (croup). Other etiologies can present similar to recurrent croup, such as subglottic hemangioma and subglottic stenosis (Fig. 26.3). There are many intrinsic and extrinsic tracheobronchial etiologies of airway obstruction. Airway foreign bodies are a common cause of tracheobronchial acute obstruction, and their presentation can be acute or chronic (chronic cough or recurrent pneumonia). Vascular compression, such as vascular rings or innominate artery compression, can cause extrinsic pressure on the tracheal wall (Fig. 26.4). As the differential of acute airway obstruction is extensive, the history, physical exam, and radiologic evaluation are paramount to ascertaining the underlying diagnosis.

Airway Sounds

The type, location, and timing of airway sounds can assist in the localization of the level of airway obstruction. Stridor is a high-pitched sound produced by turbulent flow in the trachea, subglottis, glottis, or supraglottis. Stridor should be

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Table 26.1 Differential diagnosis for airway obstruction in children

	Nose and nasopharynx	Oropharynx and hypopharynx	Supraglottic larynx	Glottic larynx	Subglottic larynx	Trachea and bronchus
Congenital	Choanal atresia Pyriform aperture stenosis Craniofacial abnormalities Nasolacrimal duct Cyst	Glossoptosis Macroglossia Lingual thyroid Vallecular cyst Craniofacial abnormality	Laryngomalacia Saccular cyst	Laryngeal web Laryngeal cleft Vocal cord paralysis	Stenosis Cysts	Stenosis/web Tracheomalacia Vascular ring/sling Complete tracheal rings Foregut cysts TE fistula
Infectious Inflammatory	Nasal polyps Retropharyngeal abscess Adenoid hypertrophy	Tonsil hypertrophy Retropharyngeal abscess	Epiglottitis Angioneurotic edema	Laryngitis	Croup	Bacterial tracheitis Bronchitis Asthma (RAD)
Traumatic Iatrogenic	Foreign body	Foreign body	Foreign body	Foreign body Hematoma Fracture Stenosis Vocal cord paralysis	Chondritis Stenosis Fracture Foreign body	Foreign body Tracheomalacia
Neoplastic	Encephalocele Dermoid Glioma	Dermoid cyst Hemangioma Lymphatic malformation	Hemangioma Lymphatic malformation Papilloma	Hemangioma Lymphatic malformation Papilloma Granuloma	Hemangioma Papilloma	Mediastinal tumors Thyroid Thymus Papilloma

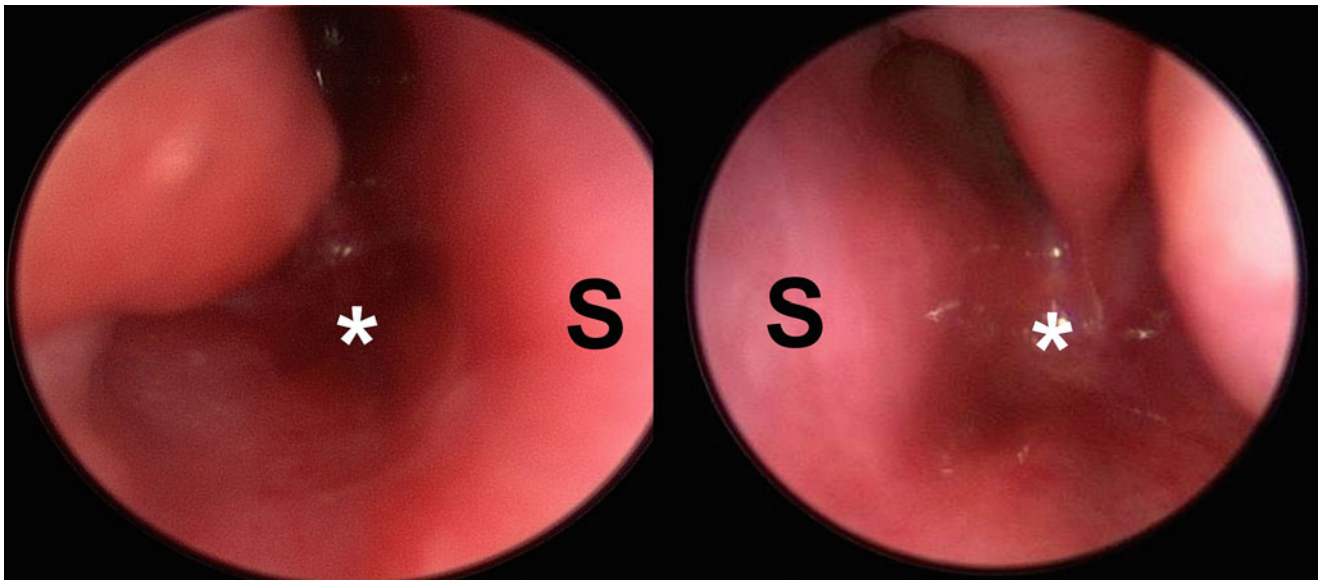

Fig. 26.1 Endoscopic view of bilateral choanal atresia (*asterisk*) in a neonate. Septum (*S*)

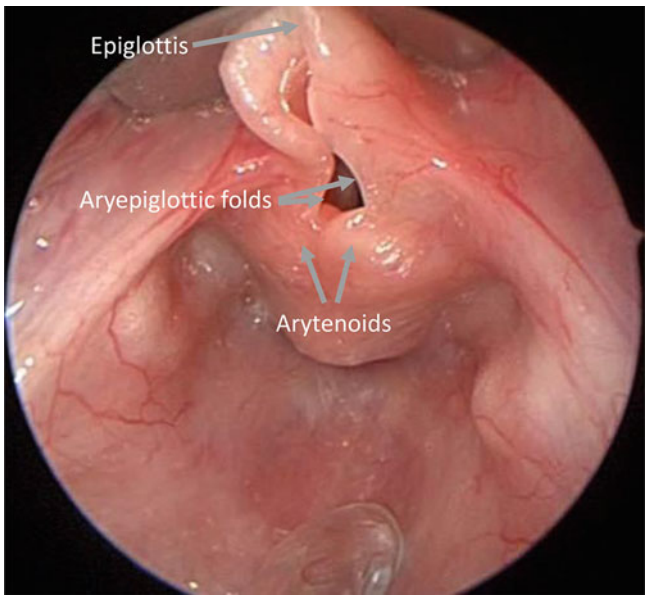

Fig. 26.2 Endoscopic view of laryngomalacia with omega-shaped epiglottis (*E*), shortened aryepiglottic folds (*AE*), and hooding of the arytenoids (*A*)

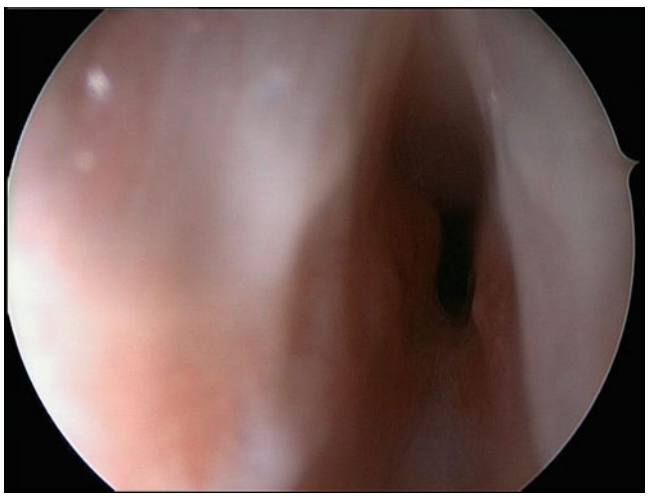

Fig. 26.3 Subglottic stenosis

further characterized as inspiratory, expiratory, or biphasic. Stertor is a low-pitched snoring or snorting sound which is produced in the oropharynx and nasopharynx due to turbulent airflow and intermittent obstruction of soft tissues.

Inspiratory stridor is produced at the level of the glottis or supraglottis. Inspiratory stridor is typically a result of supraglottic tissue prolapsing into the airway with inspiration. The most common cause of inspiratory stridor in children is laryngomalacia. *Expiratory stridor* is a product of an intrathoracic airway obstruction. As intrathoracic pressure increases with expiration, the intrathoracic trachea and bronchi are compressed. Therefore, lesions in the intrathoracic airway become more obstructive during expiration. *Biphasic stridor* is seen with lesions at the level of the glottis, subglottis, or extrathoracic trachea. Lesions resulting in biphasic stridor are "fixed lesions," such as subglottic stenosis, bilateral vocal fold paralysis, subglottic hemangioma, or laryngeal web.

Evaluation of the Airway

In the acute setting, the clinician is taught to always begin with the ABCs (airway, breathing, circulation). The initial process of evaluating a child in respiratory distress is an

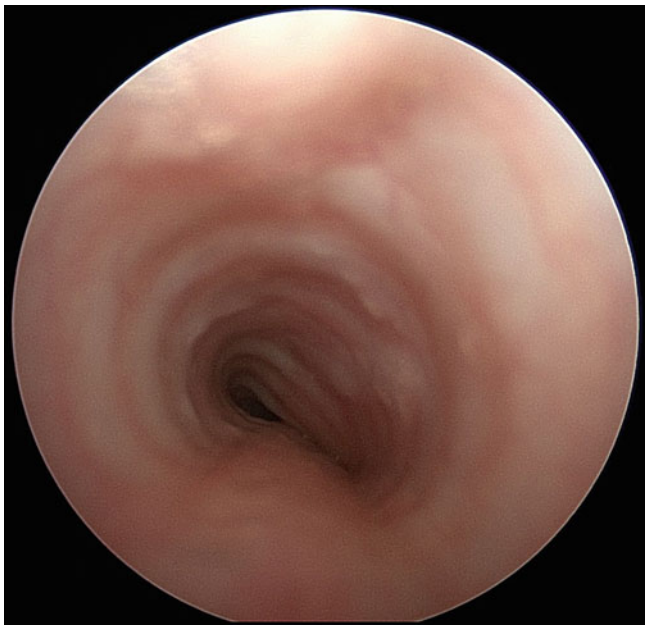

Fig. 26.4 Innominate artery causing distal external tracheal compression

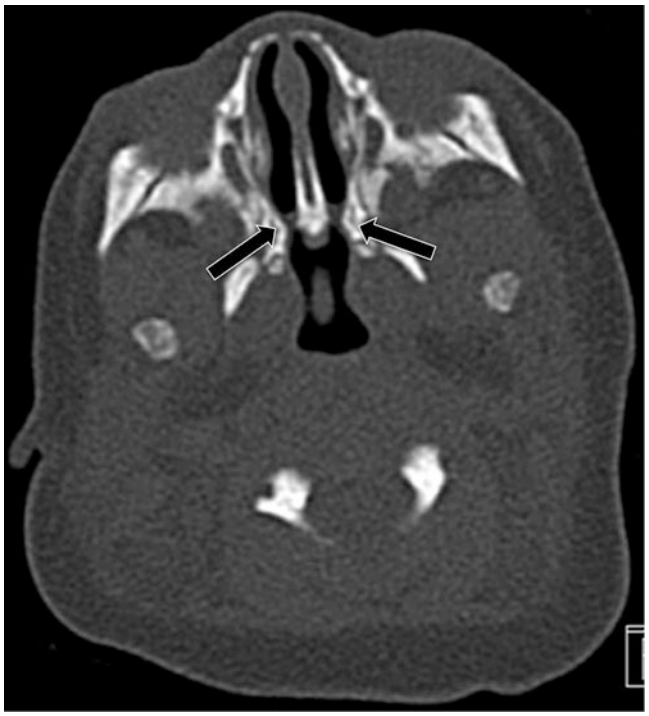

Fig. 26.5 Axial CT scan depicting bilateral choanal atresia

expeditious clinical evaluation to gauge the urgency of the situation. A thorough physical examination, when possible, in conjunction with respiratory rate, heart rate, and pulse oximetry should be used to assess the situation. Although a child might have normal vital signs, one must always remember that a child can compensate well until they rapidly decompensate.

Evaluating and managing the airway is much different than an adult. Infants are obligate nasal breathers, allowing them to eat and breathe at the same time. Therefore, a newborn with complete nasal obstruction from bilateral choanal atresia will have severe respiratory distress and may require immediate intervention (Fig. 26.5). The child's tongue is much larger in proportion to the oral cavity than in the adult. The larynx is much higher and more anterior in the child and the epiglottis, and other cartilaginous structures of the airway are much more flexible. The cricoid ring is much smaller in the pediatric population and more susceptible to minor swelling. Pediatric patients have less reserve and their metabolic needs are much higher than adults. An unstable patient needs prompt intervention prior to a complete diagnostic evaluation. A focused history and physical examination should be performed and Pediatric Advance Life Support (PALS) algorithms followed. In the stable patient, a detailed history and physical examination should prompt further investigation as to the etiology of the acute airway distress.

In stable patients with an acute upper airway obstruction, radiologic examination is quick and can be high yield. Lateral neck radiographs can evaluate the patency of the nasopharyngeal, oropharyngeal, hypopharyngeal, and tracheal airway. Retropharyngeal abscesses can be seen as a widening of the retropharyngeal space on a lateral neck radiograph. A narrow subglottis and ballooning of the hypopharynx can be seen in a child with laryngotracheobronchitis (croup). A "steeple sign" signifies a narrowed subglottis in a child with laryngotracheobronchitis (Fig. 26.6). A "thumb sign" is seen in epiglottitis (Fig. 26.7). Anteroposterior neck radiographs can be helpful in determining the caliber of the trachea and subglottis. A chest radiograph is invaluable at identifying lower airway pathology. Upper airway obstruction may be associated with a pulmonary infection. Radiopaque foreign bodies can be identified in the trachea and lower airway.

Flexible fiberoptic nasal laryngoscopy (FFNL) can be performed in select patients. A flexible nasopharyngoscope is passed into the nose to evaluate the nasopharyngeal, oropharyngeal, hypopharyngeal, and supraglottic airways. In stable patients, this can be a valuable procedure to quickly evaluate the patency of the upper airway. Angioedema associated with acute anaphylaxis can be associated with facial flushing and edema. Involvement of the upper airway can be easily assessed with a FFNL and provide helpful information regarding the need for intubation. Foreign bodies of the nasopharyngeal, hypopharyngeal, and glottic airway can also be identified (Fig. 26.8).

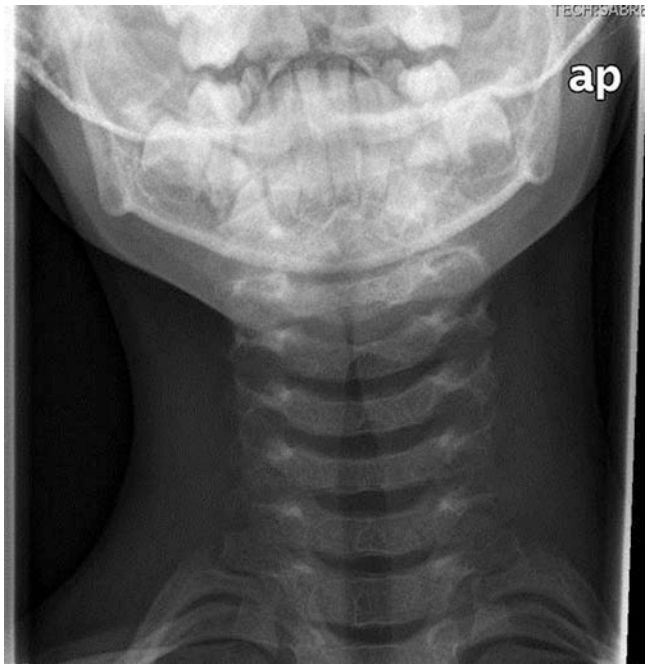

Fig. 26.6 Anteroposterior neck radiograph in a child with croup and the classic "steeple sign"

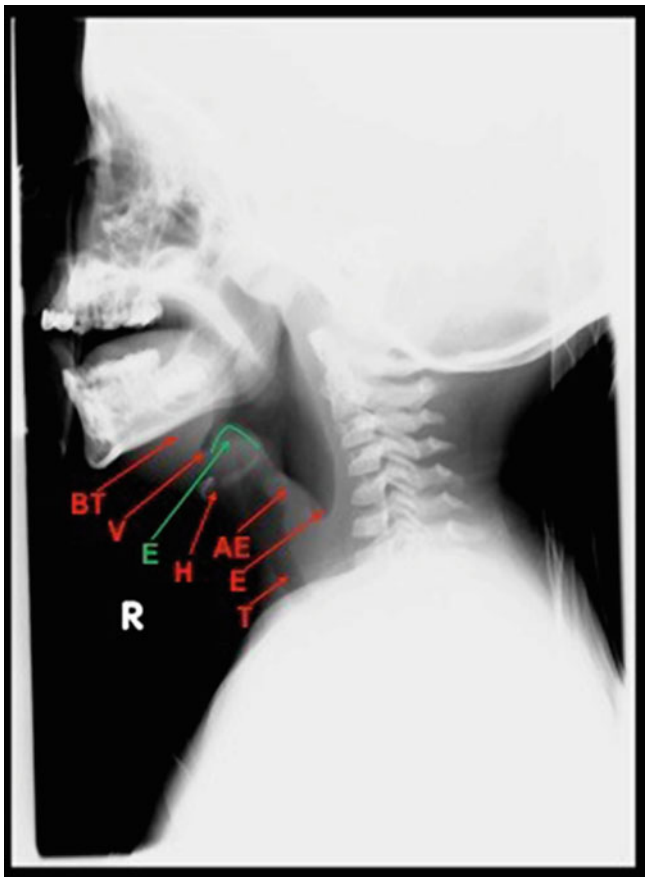

Fig. 26.7 Lateral neck radiograph. Base of the tongue (*BT*), vallecula (*V*), epiglottis with thumb sign (*E*), hyoid (*H*), edematous aryepiglottic folds (*AE*), esophagus (*E*), and trachea (*T*)

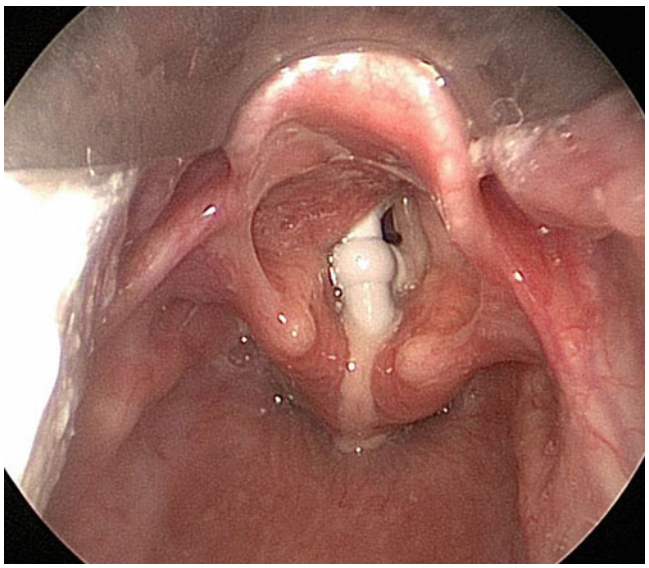

Fig. 26.8 Endoscopic view of the larynx depicting a plastic toy obstructing the glottis

Management of the Acute Airway

An efficient assessment is critical. The unstable patient needs immediate intervention. Stable patients benefit from further evaluation and medical intervention. The most critical situation arises in the patient that cannot be mask ventilated nor intubated. Cardiopulmonary failure is imminent unless a surgical airway or extracorporeal membrane oxygenation is obtained. Therefore, when a surgeon is called to evaluate the acute airway determining if the child can be mask ventilated is paramount. If effective mask ventilation is possible, then the team has some time to determine the next intervention.

A stable patient with an airway obstruction will benefit from observation in a setting where trained personnel can intervene if the child deteriorates, such as the intensive care unit. In the setting of acute anaphylaxis with airway angioedema, observation in conjunction with medical management (epinephrine) may be sufficient. Late-phase reactions can occur with type 1 hypersensitivity several hours after the immediate phase. Medical management with appropriate intervention readily available as needed is usually appropriate.

Oxygen is a mainstay in the medical management of the acute airway. While supplemental oxygen can aid in oxygenating the patient, this does not equate to appropriate ventilation. Oxygenation without adequate ventilation can maintain peripheral arterial oxygen saturation without adequate clearance of carbon dioxide. Although oxygenation can stabilize the patient in the short term, inadequate ventilation will lead to retention of carbon dioxide and respiratory acidosis.

Epinephrine can be administered by nebulization and stimulates the alpha-adrenergic receptors resulting in reduction of mucosal edema (mucosal vasoconstriction). Racemic epinephrine also stimulates beta-adrenergic receptors causing relaxation of the bronchial smooth muscle. *Racemic epinephrine* reduces the symptoms of croup within 30 min of administration and has effects lasting up to 2 h. After this time, symptoms may return to baseline or worsen (rebound phenomenon). Adverse effects of racemic epinephrine are rare, but side effects include tachycardia, nausea, anxiety, heart palpitations, and headaches.

Corticosteroids have anti-inflammatory properties that reduce edema, and glucocorticoids provide long-lasting effective treatment for mucosal edema. Dexamethasone is often used for airway edema because of its long half-life, anti-inflammatory potency, and low mineralocorticoid effect. The typical dose of dexamethasone for airway edema is 1–1.5 mg/kg/day. We typically use 0.5 mg/kg every 8 h. Corticosteroids are often used for post-intubation edema, adenotonsillar hypertrophy secondary to Epstein-Barr viral infection, and angioedema secondary to type I hypersensitivity. Although commonly used in angioedema, it is important to note that a recent systematic review of the literature failed to confirm the effectiveness of glucocorticoids in anaphylaxis.

A mixture of helium and oxygen, *heliox*, has become a useful tool in the management of the acute airway. The mechanics of the respiratory system are a function of the static respiratory system compliance (elastic recoil of the lungs and chest) as well as dynamic factors (airway caliber and density/viscosity of the inspired air). Heliox improves airflow by reducing density and improving viscosity of inspired air. Heliox has been shown to reduce croup symptoms, and there is some evidence that it provides short-term benefit for children with croup.

The utility of a nasopharyngeal (NP) airway is often overlooked. NP airways are soft plastic and can be placed into either or both nares after lubrication. The length of the NP airway can be estimated by selecting one that, when placed adjacent to the patient's face, extends from the nares to the angle of the mandible. NP airways bypass the nasal and oral airways and are positioned above the supraglottis. Nasal oxygen, heliox, nebulized medications, and positive airway pressure can be given via a NP airway. Although not a long-term solution, NP airways can stabilize a critical airway secondary to nasopharyngeal and/or oropharyngeal obstruction.

Noninvasive positive pressure ventilation (NPPV) delivers positive pressure ventilation without placement of an artificial airway. Devices available to provide NPPV include a face mask, oronasal mask, nasal mask, and nasal prongs. Positive pressure ventilation may be provided as continuous positive pressure (CPAP) or with mechanically assisted breaths (BiPAP). NPPV has been used in patients with status asthmaticus, cystic fibrosis, and bronchiolitis.

If noninvasive measures fail to temporize or improve the patient's respiratory status, *endotracheal intubation* becomes the intervention of choice. The ease of mask ventilation should be evaluated prior to administering any neuromuscular paralyzing agent. A partially obstructed airway can become fully obstructed with paralysis. Endotracheal tube size can be estimated by several methods. In an emergency setting, PALS has a length-based ETT estimate. A commonly used formula ([age in years + 16]/4) can also give a quick estimate of ETT size. In neonates aged 0–3 months, a 3.0 ETT is often used and those 3–9 months typically require a 3.5 ETT. An ETT half-size larger and smaller should be available at the time of intubation. Several intubating laryngoscopes should be available (Miller, Macintosh) as well as a Jackson or equivalent laryngoscope. Adequate suction as well as a stylet should be on hand. If a foreign body is suspected, Magill forceps can aid in removal.

In the case of the acutely obstructed airway, the ideal setting for intubation is in the operating room with bronchoscopy and tracheostomy equipment readily available. Emergent situations are not typically amenable to this level of preparation, and several backup techniques should be available including a rigid ventilating bronchoscope and telescope, lighted stylet, laryngeal mask airway, and video laryngoscope as well as other providers able to assist.

Nasal intubation can be performed with a standard laryngoscope. Flexible fiberoptic nasal intubation can be useful for patients with a difficult larynx to visualize or patients with limited neck extension due to maxillofacial trauma or cervical spine fusion.

The use of *transtracheal ventilation* has been described in adults as an emergency form of ventilation. It is used as a stabilizing measure prior to securing an airway. After identifying the cricothyroid membrane, a jet ventilation catheter or angiocatheter (16 gauge) is placed into the airway. Oxygen can be administered via jet ventilation. This method should only be used in children as a last resort. Recent animal studies have shown transtracheal ventilation to be more difficult and less successful than a surgical tracheostomy. The difficulty of this procedure in small children is related to the size of the airway and the soft, immature cartilaginous framework.

When a patient cannot be stabilized with conservative measures and cannot be intubated, surgical intervention is warranted. When proceeding with a surgical airway, the avoidance of any paralytics allows the patient to maintain any residual airway tone. *Rigid bronchoscopy* with a ventilating bronchoscope can ventilate and temporarily stabilize the patient until the patient can be intubated or a tracheostomy

performed. Using a laryngoscope and an appropriate-sized rigid bronchoscope, the airway can be secured and the patient ventilated. The underlying etiology should be addressed and the patient should be intubated, if possible. A tracheostomy can be performed while the ventilating bronchoscope is in place. Additionally, an ETT placed over a telescope is a useful technique to achieve endotracheal intubation in a difficulty airway. When intubating over a telescope, it's important to remember that they are fragile and, unlike rigid bronchoscopes, will bend and break. To intubate over a telescope, the laryngoscope is placed and maintained during the intubation to avoid breaking the telescope.

The use of *cricothyrotomy* in children is limited. The advantages of a cricothyrotomy are that it can be rapidly performed with minimal bleeding. Cricothyrotomy is rarely performed in neonates and children. In adults, the cricothyroid membrane averages 13.7 mm (range 8–19 mm) long and 12.4 mm (9–19 mm) wide. In neonates, the cricothyroid membrane is significantly smaller averaging 2.6 mm long and 3 mm wide. Multiple urgent airway kits are commercially available. However, there is minimal published data on their ease of insertion in infants and children.

In a larger child with palpable landmarks, a cricothyrotomy can be performed quickly and safely. The neck is extended, and the larynx should be stabilized with the nondominant hand and the cricothyroid membrane identified. A scalpel is used to enter the airway through the cricothyroid membrane. A hemostat is used to widen the cricothyroid space and an ETT or tracheostomy tube placed into the airway. Once the airway is established, the patient should be either intubated or tracheostomy performed to decrease the risk of subglottic stenosis.

A *tracheostomy* can be performed in patients who will require prolonged intubation or when translaryngeal intubation is either unsuccessful or contraindicated. An emergent tracheostomy can be a life-saving procedure. As with cricothyrotomy, it is a difficult procedure in neonates and infants due to their soft cartilages, small anatomy, and substantial subcutaneous fat. The neck is extended and the airway stabilized with the nondominant hand. The cervical trachea is identified and a scalpel is used to enter the airway through a vertical incision. A hemostat should be used to widen the tracheotomy space. An ETT or tracheostomy tube is then placed into the airway. Risks of an emergent tracheostomy include bleeding, pneumothorax, and inadvertent injury to surrounding structures. Recognition and treatment of these complications are important to reduce further morbidity. Although emergent tracheostomy is fraught with complication, it is typically the last resort in a patient with no other airway options.

When the site of acute airway obstruction is located in the trachea or lower airway and cannot be removed, *ECMO* can provide support until the obstructing lesion or foreign body can be addressed. The use of ECMO is limited to centers that have available equipment and staff.

Procedural Considerations

Effective preparation and clear communication are essential. Having all equipment readily available (adequate lighting, suction, laryngoscopes, bronchoscopes, tracheostomy instruments, etc.) is crucial as there may not be time later if and when you need something. At our institution, during preparation for a critical airway, the staff is given a checklist filled out by the attending surgeon noting all potential equipment that should be available so that nothing is forgotten. Communication between the surgeon and other disciplines (anesthesia, emergency medicine, critical care) and the support staff is necessary to ensure that all understand the preferred plan as well as all backup options so that there will be no confusion. Once these basic tenets are established, the team can work effectively to secure an airway.

No simple algorithm encompasses all scenarios. However, initially determine whether the child can be mask ventilated. If mask ventilation is not possible, then paralytics and other sedatives that remove the child's drive to breathe should be avoided. In some children, a laryngeal mask airway can be used to effectively ventilate a patient that cannot be intubated. If ventilation is still unsuccessful, intubation or instrumentation of the airway with a rigid bronchoscope should be considered (except in severe neck trauma where a surgical airway may be safer than intubation). If these are not possible, then a surgical airway should be established or the child placed on ECMO.

Editor's Comment

Few situations are more terrifying than a child with acute airway compromise. As always, a calm and systematic approach is best. Mask ventilation should be attempted first while preparations are made for endotracheal intubation, temporary airway, and tracheostomy, usually in that order. It is critical to have all equipment available not only for the intubation but also for all other options. Even in the setting of oral injury or bleeding, one brief attempt at orotracheal intubation—by the person with the most experience—is usually reasonable. If endotracheal intubation is unsuccessful, needle cricothyroidotomy with jet ventilation using an IV catheter is an excellent option and will allow a tracheostomy to be performed in a more controlled fashion, though excessive pressure, especially in an infant, can cause pneumothorax and decompensation.

Patients with dysphonia following blunt or penetrating cervical trauma who are maintaining their airway should be kept in a semirecumbent or sitting position and taken to the OR for additional evaluation with laryngoscopy, bronchoscopy, or controlled intubation. The surgeon should be prepared to perform an emergent surgical airway if needed.

Surgical cricothyroidotomy is relatively contraindicated in young children. Injury to the cricoid cartilage can result in further airway compromise, as it is the only circumferential support structure of the airway. The narrowest part of a child's airway is at the cricoid ring, and any stenosis following cricothyroidotomy will cause significant impairment of airflow.

Emergency tracheostomy is rarely indicated in a child. It is a delicate operation. The lack of adipose tissue and the presence of clean planes of dissection in some ways make it easier; but the small caliber of the trachea greatly increases the risk of iatrogenic injury. As always, meticulous technique, good lighting, and proper instrumentation are critical. All maneuvers should be deliberate and never forced. A trapdoor tracheal incision, popular in adults, should not be used in children and, of course, it is important to avoid injury to the cricoid cartilage. If a tracheostomy tube is not available, an appropriate size cuffed or uncuffed endotracheal tube works just as well. In elective cases, some prefer to create a true fistula by suturing the edge of the tracheotomy to the skin.

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Bronchoscopy

27

Luke A. Jakubowski and J. Fredrik Grimmer

Bronchoscopy, either rigid or flexible, is the detailed endoscopic evaluation of the trachea and bronchi. Unlike pulmonologists, surgeons often perform bronchoscopy for indications that necessitate general anesthesia. The decision to perform rigid bronchoscopy or flexible bronchoscopy depends on the clinical scenario and surgeon preference. Both rigid and flexible bronchoscopy offer a detailed evaluation of the trachea and lower airway. Bronchoscopy is often done in conjunction with a direct laryngoscopy, to evaluate the glottis and supraglottis.

The indications for bronchoscopy are many and varied. In neonates and infants, bronchoscopy is performed for noisy breathing (stridor, stertor), difficult ventilation, or failure to extubate. In older infants and children, bronchoscopy is typically performed for chronic cough, aspiration, noisy breathing, and suspected foreign body.

The surgeon must consider the overall cardiopulmonary health of the patient to understand how the patient will tolerate periods of inadequate ventilation. An anesthesiologist well trained in pediatric anesthesia is key to a successful bronchoscopy. Prior to the start of the procedure, a detailed discussion regarding airway management, sequence of events, and equipment should be made with the anesthesiologist and operating room staff. For airway foreign bodies, preoperative planning and communication is paramount to a safe and successful procedure. All needed equipment should be in the operating room, tested and readily available.

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Anatomy

The surgeon should be familiar with the anatomy of the upper and lower airway. For rigid bronchoscopy, placing a laryngoscope in the vallecula allows for visualization of the supraglottis (epiglottis, arytenoids, aryepiglottic folds, false vocal fold), hypopharynx (post-cricoid region, pyriform sinuses, posterior pharyngeal wall), and the glottis (true vocal cords) (Fig. 27.1). Often the immediate subglottis can be viewed. Immediately below the true vocal folds is the subglottis, which extends from the true focal folds to the caudal boarder of the cricoid cartilage (Fig. 27.2). Next, the cricoid ring is examined. The cricoid cartilage is the only complete cartilaginous ring and is located below the subglottis. Immediately below the cricoid cartilage, the tracheal cartilages will be viewed as C-shaped anterior rings with a flat posterior wall comprised of the trachealis muscle (Fig. 27.3).

Flexible bronchoscopy is often performed through an endotracheal tube, thus bypassing the supraglottic, glottis, and subglottic anatomy. The number of tracheal rings varies from 16 to 20. The soft posterior wall is subject to dynamic movement with respirations, while the firm anterior wall provides rigidity. The tracheal carina is the first branching point of the lower airway, separating into the right and left main stem bronchi (Fig. 27.4). The right main stem bronchus then branches into the right upper lobe bronchus and the bronchus intermedius. The right bronchus intermedius then branches into the right middle lobe bronchus and right common basal stem. The left main bronchus branches into the left upper lobe bronchus and then the left common basal stem.

Prior to the start of any bronchoscopy, we use a bronchoscopy checklist (Fig. 27.5). The bronchoscopy checklist allows for detailed written communication between the surgeon and operating room nurse and surgical technician in regard to all equipment required for the procedure. The equipment is reviewed by the surgeon to make sure all equipment is present, assembled, and in proper working order.

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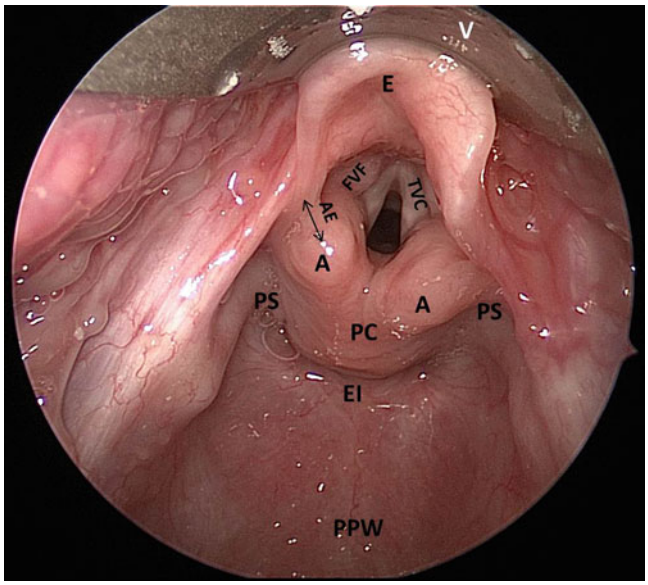

Fig. 27.1 Direct laryngoscopy anatomy. The laryngoscope is placed in the vallecula (*V*) providing exposure to the supraglottis (*E* epiglottis, *A* arytenoids, *AE*↔ aryepiglottic fold, *FVF* false vocal fold), hypopharynx (*PC* post-cricoid region, *PS* pyriform sinuses, *PPW* posterior pharyngeal wall), and the glottis (*TVC* true vocal cord)

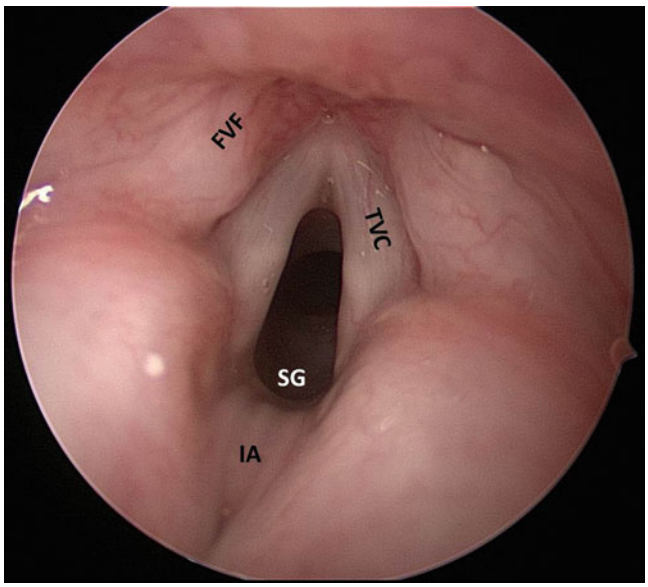

Fig. 27.2 View of the glottis and subglottis. *FVF* false vocal fold, *TVC* true vocal cord, *IA* interarytenoid space, *SG* subglottis

Prior to induction of anesthesia, an intraoperative airway plan is discussed with the anesthesiologist as well as postoperative management. Important discussion topics include type of anesthesia, need for spontaneous ventilation, avoidance of paralytic agents, use of topical anesthesia on the larynx to reduce the risk of laryngospasm, and use of intraoperative steroids.

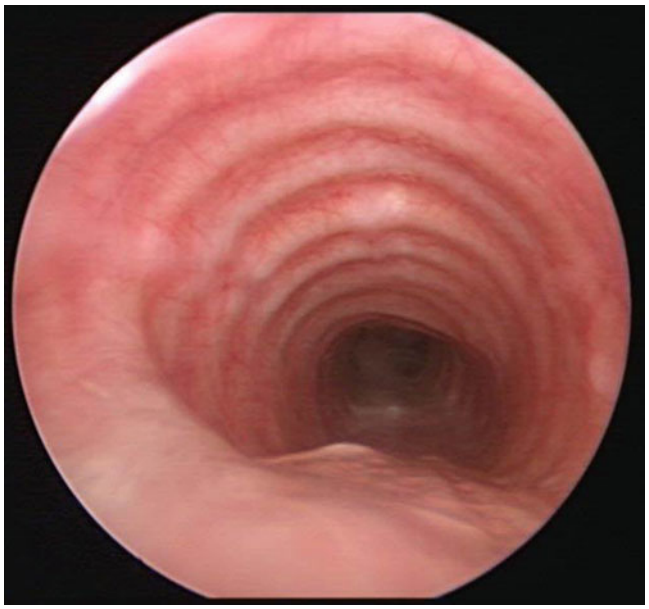

Fig. 27.3 Trachea

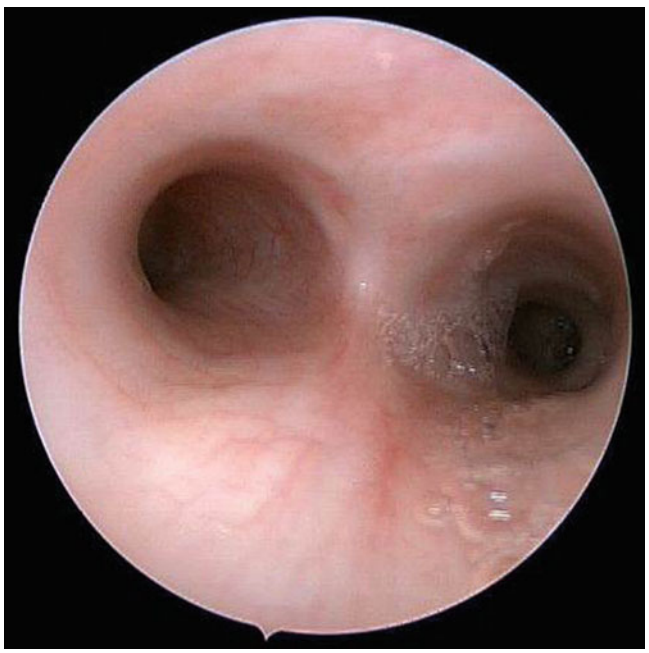

Fig. 27.4 Carina

Flexible Bronchoscopy

Flexible bronchoscopy is routinely performed under topical anesthesia with sedation. Flexible bronchoscopy can also be performed in the intensive care setting through an endotracheal tube or laryngeal mask airway. Flexible bronchoscopes come in a variety of sizes, ranging from ultra thin (1.9 mm) to adult (>6 mm).

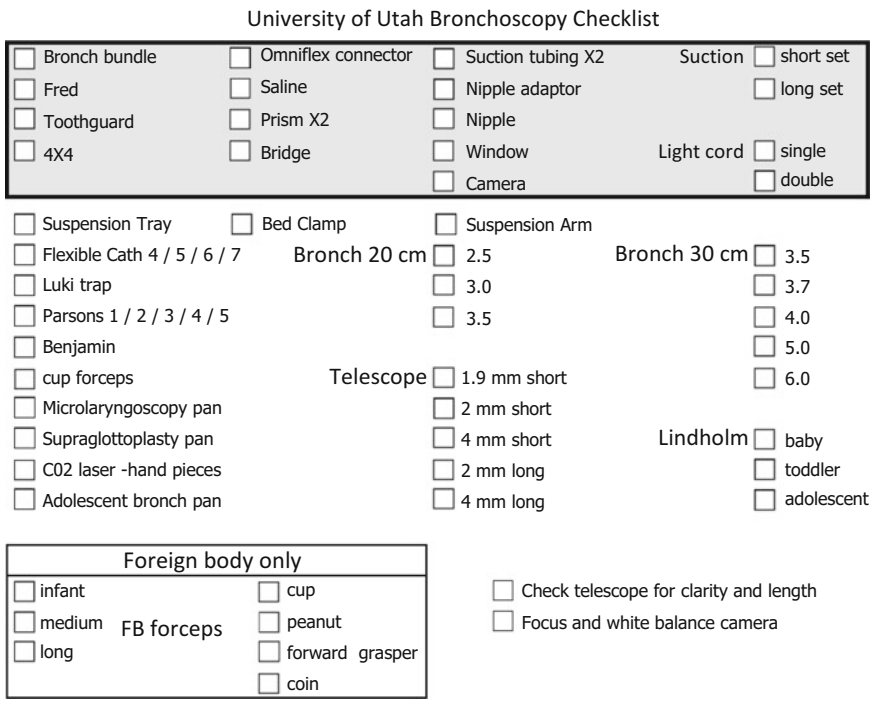

Fig. 27.5 Rigid bronchoscopy check list

In the sedated patient without an artificial airway, use of a decongestant and topical anesthetic is key. The flexible bronchoscope can be passed through the nasal cavity or orally with a bite block in place. If the trans-nasal route is preferred, oxymetazoline sprayed into the nasal passages improves the view and makes the scope easier to pass. Once the glottis is viewed, topical lidocaine is administered through a side port to reduce laryngospasm (maximum dose of 5 mg/kg; 4 % lidocaine = 40 mg/mL). In the appropriate plane of anesthesia, vocal cord function can be assessed although paradoxical movement and reduced mobility are commonly seen during anesthesia with an inhaled agent or propofol. The scope is then passed into the subglottis and trachea. Patients who have an ETT or LMA typically can be scoped through the established airway. If passing the scope through the LMA, topical anesthesia applied to the vocal fold is used to reduce laryngospasm.

A systematic evaluation of the lower airway should be performed. The scope is steered by wrist and finger rotation and flexion of the tip. The scope should be extended so that rotation of the scope results in movement of the tip and not coiling of the scope. Visual orientation can be maintained by identifying the tracheal rings and posterior tracheal wall. A comprehensive airway examination should include the trachea, carina, and bronchi (including right upper lobe, right bronchus intermedius, right middle lobe, right lower lobe, left upper lobe, left lingual, and left lower lobe). Suction should be used liberally to ensure complete examination of the entire airway. Interventions, such as biopsy, bronchoalveolar lavage, and removal of some foreign bodies, can be performed.

A competent endoscopist is skilled with both flexible and rigid endoscopies. Flexible bronchoscopy is useful for diagnostic bronchoscopy with some interventions, including BAL. Most find flexible bronchoscopy most useful in evaluation of children in the intensive care setting when an artificial airway is already established. Interventions such as suctioning and bronchoalveolar lavage can easily be performed at the bedside. In intubated neonates and infants, even the smallest flexible bronchoscope through an ETT does not allow adequate ventilation during the examination or interventions. When performing a diagnostic flexible bronchoscopy in the sedated patient, use of topical lidocaine should help prevent laryngospasm. Calculating the dose of lidocaine is important in pediatric bronchoscopy, as it can be easy to approach the toxic dose with 4 % lidocaine. It is usually safer to use 1 % or 2 % plain lidocaine in neonates.

Rigid Bronchoscopy

Laryngoscopy and rigid bronchoscopy are best performed with a systematic approach. It is important to have all the necessary equipment ready when the patient enters the room and have a detailed discussion regarding the operative and airway plan. Alternative plans should be discussed, especially with an unstable airway that might necessitate a tracheostomy or, in extreme cases, ECMO. Continuous communication with the anesthesiologist is critically important.

There is typically more equipment needed for rigid bronchoscopy than flexible bronchoscopy (Fig. 27.6).

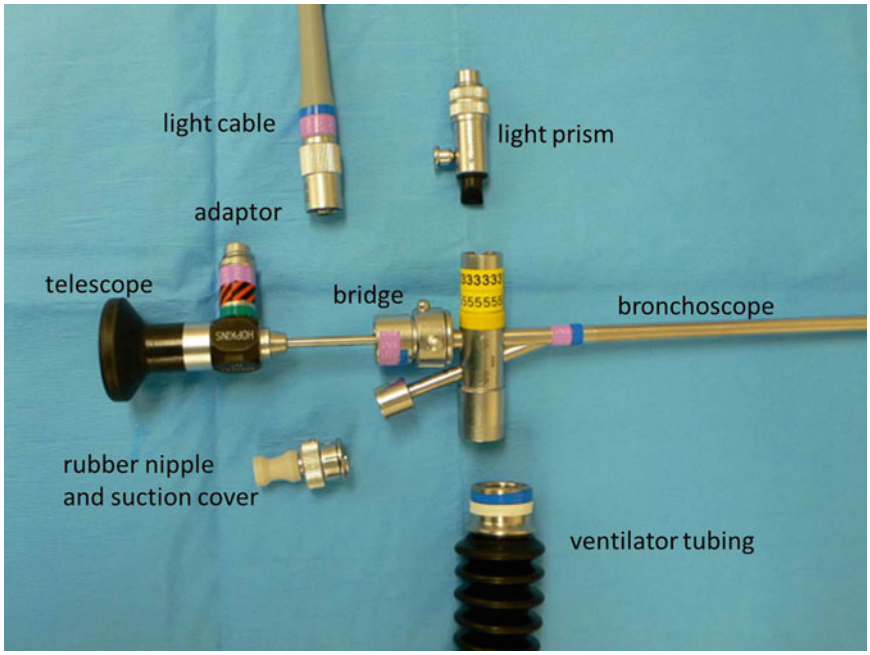

Fig. 27.6 Rigid bronchoscopy equipment

Proper setup should be confirmed by the surgeon prior to the start of the procedure. Appropriate sized rigid bronchoscopes should be selected as well as telescopes. Rigid and flexible suctions should be available.

The patient is masked ventilated by the anesthesiologist. When the appropriate plane of anesthesia is reached, the patient is turned toward the endoscopist. The patient is placed in the sniffing position with the head extended and the neck flexed. A tooth guard, or wet gauze (for edentulous patients), is placed over the maxillary alveolus. Direct laryngoscopy with an age-appropriate laryngoscope exposes the supraglottis and glottis. Direct laryngoscopy is typically performed with the non-dominate hand. A rigid suction should be available to clear secretions. Cricoid pressure can improve the laryngoscopic view. Topical lidocaine can be administered to the glottis to reduce laryngospasm. With the laryngoscope in the non-dominate hand, the rigid bronchoscope should be advanced with the dominate hand. The laryngoscope should remain in place until the rigid bronchoscope is in the trachea. Once the bronchoscope is in the trachea, the anesthesiologist can ventilate through the side port. The laryngoscope is removed, and the non-dominate hand should be used to stabilize the bronchoscope at the maxillary teeth or alveolar ridge, similar to holding a pool cue stick. The bronchoscope rests between the thumb and first digits, and the third digit rests on the palate. This reduces the trauma to the teeth and alveolar ridge and allows for control of the bronchoscope and the patient's head.

If a brief diagnostic bronchoscopy is planned, a bronchoscopy can be performed with a telescope only. Unlike a bronchoscope, the laryngoscope needs to stay in position when only a telescope is used. The scope is advanced to the carina and then advanced into each bronchus. A comprehensive airway examination should include the trachea, carina, and bronchi. Suction should be used liberally to ensure complete examination of the entire airway. To evaluate the lower bronchi, the endoscopist needs to rotate their body and the patient's head to the contralateral side. To evaluate the right main stem bronchus, the patient's head and the endoscopist's body are rotated to the left. This straightens the pathway to the lower airway and reduces trauma to the tracheal and bronchial mucosa.

We use a bronchoscopy checklist (Fig. 27.5) to ensure that all the required equipment is present. Typically, we request one size smaller bronchoscope. Unless the patient is unstable, we request that the patient not be brought to the operating room until the equipment has been properly vetted. We have a chart taped to our bronchoscopy cart that lists ages (with 50 percentile weights) with appropriate-sized endotracheal tubes and bronchoscopes (Table 27.1). In an emergency situation when the age may not be known, weight can be used to choose an appropriate-sized bronchoscope. Prior to turning the patient, we request that the anesthesiologist perform a direct laryngoscopy and spray the vocal cords with topical lidocaine. A preoperative discussion with the anesthesiologist is paramount to safety. The sniffing position is our preferred starting position although some patients allow better viewing with a neutral position or with a shoulder roll placed.

Table 27.1 Estimated bronchoscope size based on endotracheal tube (ETT) size, age, and weight

Estimated bronchoscope				
Bronchoscope size	Equivalent outer diameter ETT	Age	Boy weight (kg)	Girl weight (kg)
2.5	3.0/3.5	<6 months	<7.8	<7.3
3.0	3.5	6–12 months	7.8–10.3	7.3–8.9
3.5	4.0	12–24 months	10.3–12.7	8.9–11.5
3.7	4.5	2–4 years	12.7–16.3	11.5–15.9
4.0	5.0	4–6 years	16.3–21.0	15.9–20.2

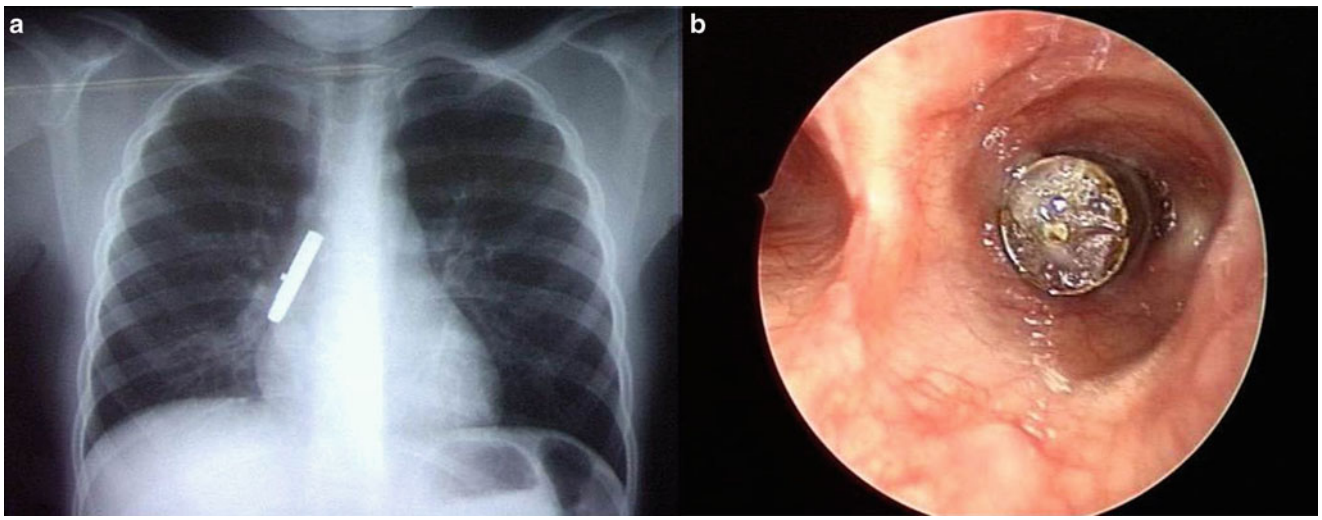

Fig. 27.7 9-year-old boy with an aspirated drain screw. (**a**) Chest X-ray. (**b**) Drain screw in right main stem bronchus

Foreign Body Removal

One of the most common indications for bronchoscopy is the removal of a foreign body from the pediatric airway. The estimated annual incidence is 15 per 100,000. Presentation can vary from a dramatic airway compromise to a subtle cough. The incidence of food foreign bodies peaks at 1 year and declines to low levels at 3 years old. The rate of nonfood foreign bodies is relatively constant until age 3. Chest radiograph might demonstrate a radiopaque foreign body (Fig. 27.7), although most are non-radiopaque. Air trapping on decubitus films or mediastinal shift might be a sign of a partial or completely blocked bronchus. Normal radiographs do not rule out an airway foreign body. Any child with a history concerning for airway foreign body is a candidate for bronchoscopy. Failure to identify an airway foreign body is associated with potentially serious morbidity and possible mortality. The low risk of a bronchoscopy in conjunction with the high risk of a retained airway foreign body justifies a 10–15 % negative exploration rate.

Patients with a laryngeal foreign body should be induced with mask anesthesia. A standard bronchoscopy setup should be ready. Direct laryngoscopy should be performed. Magill forceps can be used for quick extraction of a hypopharyngeal or supraglottic foreign body. Multiple forceps should be available and are useful if the Magill cannot grasp the foreign body or the foreign body has passed distally into the subglottis or trachea. The unintentional conversion of a laryngeal foreign body into an obstructive tracheal or bronchial foreign body can create an unstable situation. Rigid bronchoscopes and optical and nonoptical forceps should be ready.

Tracheal and bronchial foreign bodies often present with a stable airway. Often bronchoscopy can be performed on a semiurgent basis allowing for optimal equipment and staff. The technique for removal of a tracheal or bronchial foreign body starts with obtaining all the possible instruments and a detailed discussion with the anesthesiologist. Once the appropriate depth of anesthesia is reached, a standard direct laryngoscopy and bronchoscopy is performed with a ventilating bronchoscope and standard telescope. It is important to keep in mind that the ventilating bronchoscope provides an airway for gas exchange but is not equivalent to the airway achieved with an endotracheal tube. Removal of the telescope and intermittent or continuous use of a glass window can allow for improved ventilation.

Once the foreign body is identified, the decision about which forceps to use needs to be made. Optical forceps are very useful but are limited to 3.5 bronchoscopes or larger. The peanut-grasping forceps encounters more resistance than the other forceps when passed inside of a 3.5 bronchoscope. If possible the slightly larger 3.7 bronchoscope should be used when employing the peanut grasper. Smaller optical and nonoptical forceps are available for 2.5 and 3.0 rigid bronchoscopes. Once the object is grasped, it should be pulled close to the bronchoscope. The bronchoscope and foreign body are removed as a unit, preferably under constant vision. In the case of a sharp object such as a safety pin or needle, one should attempt to grasp the sharp end of the object and sheath it into the bronchoscope to avoid trauma to the airway during removal. Alternatively, the blunt end can be grasped leaving the sharp end distally and directed away from the airway during removal. Organic material (popcorn, nuts, other vegetable matter) can be removed piecemeal or with suction. For very small foreign bodies lodged distally beyond the reach of a rigid bronchoscope, a balloon catheter can be helpful. The catheter is advanced beyond the foreign body, and the balloon is inflated. The catheter is then retracted bringing the foreign body in closer proximity.

Several options exist in the case of an obstructing tracheal or bronchial foreign body that is not easily removed. If the foreign body is mobile, temporarily advancing it into one or the other main stem bronchi can allow for ventilation of one lung. Open retrieval through an emergency tracheostomy can also be performed. Percutaneous transtracheal jet ventilation below the foreign body can aid in short-term oxygenation. In very rare cases, ECMO has been used.

Congenital Tracheal Anomalies

Subglottic Stenosis

Subglottic stenosis has a variable presentation based on age of the patient, degree of stenosis, and overall medical condition. Subglottic stenosis is rare, and the exact incidence is unknown due to advances in obstetric and pediatric care. The incidence of neonatal subglottic stenosis secondary to intubation has declined over the past four decades from 8 % to less than 0.65 %. Children with only mild subglottic stenosis sometimes present only with symptoms of recurrent croup, though significant subglottic stenosis typically presents within the first few weeks of life. The treatment of subglottic stenosis ranges from observation in mild cases to open laryngotracheal reconstruction. In severe cases, tracheostomy is often required until definitive treatment can be performed. The most important factor to determine the timing of laryngotracheal reconstruction is the child's overall health and pulmonary reserve.

The mainstay of diagnosis is rigid endoscopy under general anesthesia. The size of the airway is estimated by the surgeon, and the patient is then intubated with an appropriate-sized endotracheal tube. A leak test is performed to check for the appropriateness of the tube. A positive pressure breath is administered by the anesthesiologist, and the surgeon listens for a leak. A leak should be present at <25 cm H_2O pressure. If no leak is present, the patient is intubated with a smaller tube and the leak test repeated. The percentage of stenosis can be determined by a chart of appropriate endotracheal tube sizes for patients based on age (Fig. 27.8) and graded on the Cotton-Myer scale (Table 27.2).

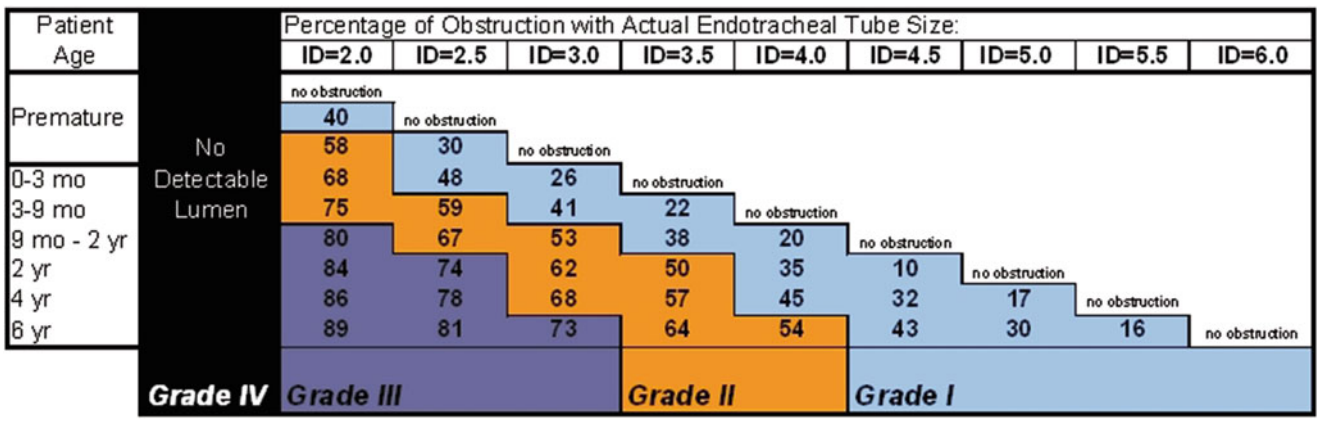

Fig. 27.8 Percentage of airway obstruction based on endotracheal tube size (From Myer CM 3rd, O'Connor DM, Cotton RT, Ann Otol Rhinol Laryngol. Apr;103(4 Pt 1): pp. 319–23. Copyright © 1994. Reprinted by permission of SAGE Publications)

Table 27.2 Grading of subglottic stenosis

Grade	From	To
Grade I	No obstruction	50 %
Grade II	51 %	70 %
Grade III	71 %	99 %
Grade IV	No detectable lumen	

Source: From Myer CM 3rd, O'Connor DM, Cotton RT, Ann Otol Rhinol Laryngol. Apr;103(4 Pt 1): pp. 319–23. Copyright © 1994. Reprinted by permission of SAGE Publications

Complete Tracheal Rings

Complete tracheal rings (CTR) are circular and continuous cartilaginous tracheal rings. Tracheal cartilages are normally horseshoe in shape with a posterior membrane consisting of trachealis muscle. Complete tracheal rings are the most common cause of tracheal stenosis. However, the condition is rare, with an incidence estimated to be one in 64,500, representing less than 1 % of all laryngotracheal stenosis.

Complete tracheal rings are smaller in diameter than a normal trachea. Over 90 % of patients with complete tracheal rings have involvement of the lower trachea. Symptoms typically are not apparent until 50 % stenosis occurs and dyspnea at rest is likely to present at 75 % stenosis. Children with CTR are usually noisy breathers at birth. Symptoms include stridor, retractions, and a characteristic wet-sounding "washing machine" breathing pattern. As the child grows, the tracheal diameter does not grow accordingly. Therefore, symptoms progress, and decompensation typically occurs around the age of 4 months. Over 80 % of children with CTR will have other congenital anomalies, and 50 % will have other cardiovascular anomalies.

Rigid bronchoscopy allows for a definitive diagnosis of CTR, even if a complete examination of the trachea is not possible due to stenosis. Instrumenting though a segment of tracheal stenosis may cause mucosal swelling converting a compromised airway into a critical airway. When bronchoscopy of the lower airway is not possible, CT can delineate the length and severity of the stenosis. Additionally, high-resolution contrast-enhanced CT can evaluate for associated cardiovascular anomalies.

Tracheal Bronchus

Tracheal bronchus is a congenital anomaly of the bronchus in which the right upper lobe bronchus has its origin above the carina. This anomaly is often referred to as *bronchus suis*, or "pig bronchus," because it is the normal arrangement in swine and other ruminants. Tracheal bronchus is a normal anatomic variant occurring in up to 2 % of the population. The majority of patients are asymptomatic, and the diagnosis is incidentally made when the tracheobronchial tree is examined for other indications. In symptomatic patients, recurrent infections, stridor, recurrent pneumonia, and suspected foreign body aspiration are common complaints.

Diagnosis can be made by rigid bronchoscopy, flexible bronchoscopy, or CT. Rigid bronchoscopy allows for direct visualization of the anomaly to further characterize it as an aerated tracheal bronchus or a vestigial diverticulum. Flexible bronchoscopy allows for further characterization of the segmental bronchi within the tracheal bronchus.

Treatment of tracheal bronchus is dependent on the severity of symptoms. Asymptomatic patients are treated expectantly. In the event the patient needs to go under general anesthesia, the tip of the endotracheal tube should be placed in the mid to proximal trachea. Mild amount of airway compromise can be treated medically with bronchodilators. In the case of severe symptoms, including recurrent respiratory infections, tracheal bronchus resection is the treatment of choice.

Tracheomalacia

Tracheomalacia is an abnormal floppiness of the trachea, which is then prone to collapse. The term is typically applied in the setting of increased collapse of the posterior tracheal wall. Tracheomalacia is further subdivided into primary (also referred to as congenital or intrinsic malacia) or secondary. Primary tracheomalacia occurs independently of laryngomalacia. Tracheomalacia is the most common congenital anomaly of the trachea. Although it can be an isolated finding in healthy neonates, it is more often seen in premature infants with a male predominance. Tracheomalacia is often seen in conjunction with other congenital anomalies including trachea-esophageal fistula, esophageal atresia, and posterior laryngeal cleft. Cardiovascular abnormalities are found in up to one half of patients with tracheomalacia.

Isolated congenital tracheomalacia can present with inspiratory and expiratory stridor, wheezing (which can be confused with asthma), chronic cough, respiratory infections, and apparent life-threatening events (ALTE). Symptoms are typically episodic in nature. Onset is typically within the first few weeks of life. Symptoms are typically more noticeable in subsequent weeks to months as the infant becomes more active and can get worse over the first few months of life. Tracheomalacia and associated respiratory symptoms typically improve as the tracheobronchial tree enlarges.

The standard test for diagnosis of tracheomalacia is bronchoscopy. To make the diagnosis, collapse of the trachea needs to be greater than 10–20 %. A collapse of 50 % is typically needed to be clinically significant, less in neonates and more in older children. Chest radiographs have a much lower sensitivity compared to bronchoscopy. CT imaging can be used for further evaluation, particularly in assessing external compression. Radiographic criteria for the diagnosis are greater than 50 % collapse of the trachea.

The mainstay of treatment for tracheomalacia is reassurance and expectant management. CPR should be taught to all caregivers, especially in the case of the child with a history of ALTE. In most children, symptoms will improve over the course of months and resolve by 18–24 months of age. For severe cases in which ALTEs are frequent or if the child experiences failure to thrive, surgical intervention is warranted. If the innominate artery is the cause of external compression, aortopexy or innominate artery reimplantation may be indicated. In rare cases, tracheostomy may be necessary. The tip of the tracheostomy tube is advance to a point immediately above the carina, bypassing the most significant malacia. In addition to tracheostomy, positive pressure ventilation can be beneficial. Recently, bioabsorbable external stents created with a 3-D printer have been used with good results.

Editor's Comment

General pediatric surgeons should be facile in both rigid and flexible bronchoscopy. Flexible bronchoscopy is often useful in the pediatric ICU setting when there is lobar collapse and concern for mucous plugging of the distal airways. The largest diameter scope should be used to allow for effective suctioning.

Rigid bronchoscopy is helpful prior to repairing an esophageal atresia with or without TEF. A ventilating bronchoscope can be used if the patient has an adequate size airway. Alternatively, the telescope alone may be used. Visualization of the trachea is more difficult when using the telescope by itself due to less effective suctioning. Bronchoscopy in this setting should be deliberate and efficient to minimize the amount of air introduced through the fistula. The location of the fistula can be visualized, which allows the surgeon to anticipate the intrathoracic location of the fistula and facilitate the repair, and the trachea can be inspected for a second proximal fistula. The interarytenoid space should be inspected for evidence of a laryngotracheal cleft. The entire procedure should take no more than 5 min.

Extraction of an airway foreign body is often straightforward but can be stressful. Ongoing communication with the anesthesiologist and OR staff is critical in these difficult cases, and having all of the necessary equipment present and in working order prior to beginning the case is paramount. Using a Fogarty catheter to dislodge distal foreign bodies is an effective technique. One should be careful not to lose fragments of organic material down the other bronchus.

Regardless of the reason for bronchoscopy, the surgeon should be familiar with the equipment and be able to perform such a procedure in the OR or at the bedside with confidence, competence, and skill. If opportunities for practice are rarely encountered, one should take the opportunity to participate in an airway course or simulation lab at least once a year or spend an afternoon with an ENT colleague observing and assisting in multiple airway cases. Regardless of one's experience, when preparing to do a detailed evaluation of the distal airways for hemoptysis, foreign body, or suspected tumor, it is a good idea to review the normal bronchial anatomy in a good surgical atlas ahead of time and, if possible, to have a large diagrammatic illustration posted visibly in the OR during the procedure.

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Benign Neck Masses

28

Tony L. Kille

The differential diagnosis for pediatric neck masses is broad. Etiologies are categorized as either congenital or acquired, with the acquired etiologies subdivided into inflammatory and neoplastic entities. Congenital masses comprise upward of 50–60 % of all neck masses with branchial cleft anomalies and thyroglossal duct cysts predominating. Most acquired neck masses are inflammatory or infectious in origin, with only a very small percentage representing benign or malignant neoplasms.

An accurate differential diagnosis relies on a thorough history and physical exam. This should include a timeline for the neck mass, any associated symptoms, and potential risk factors. The age of onset is important: masses present at birth are congenital. However, congenital masses can present later in childhood (or even into adulthood) becoming evident after an acute infection causes enlargement. The growth pattern of the mass is important as well. Benign neoplasms and congenital lesions have a slow growth pattern. Masses that develop quickly over days, or have significant fluctuations, are typically infectious or inflammatory in nature. Steady, rapid growth over the course of weeks raises suspicion for a malignant process. Constitutional symptoms (fever, chills, night sweats, fatigue, weight loss), pain, diminished neck range of motion, dysphagia, hoarseness, and airway obstructive symptoms (stridor, snoring) are important in diagnosis as well. However, the majority of malignant neck masses in children present as an asymptomatic neck mass. Risk factors should be identified particularly for infectious masses, including exposure to cats and unusual travel and exposure to persons with tuberculosis. A history of exposure to ionizing radiation is a risk factor for a malignant neoplasm of the thyroid and salivary glands. In cases of congenital neck cysts, identifying a family history of similar anomalies can lead to a diagnosis of branchio-oto-renal syndrome.

In addition to the mass, physical examination should include all other parts of the head and neck. The size, character, mobility, and consistency of the mass, as well as its relationship to surrounding structures, including the skin must be assessed. A full body examination is also warranted, as certain malignant processes can present with inguinal or axillary adenopathy and hepatosplenomegaly.

The anatomic location of the mass is helpful in formulating the differential diagnosis. The sternocleidomastoid muscle divides the neck into anterior and posterior triangles. Masses located in the posterior triangles (spinal accessory region superiorly, supraclavicular region inferiorly) are most often derived from the lymphatic system and can be inflammatory (lymphadenitis), congenital (lymphatic malformation), or neoplastic (lymphoma). Masses in the supraclavicular region should be approached with a high index of suspicion for malignancy, as lymphoma and metastatic lesions often present here. Pathologies of neck masses in the anterior regions of the neck are more varied. In the midline, thyroglossal duct cysts and dermoids predominate. Branchial cleft anomalies, lymphatic malformations, and inflammatory lymph nodes are located along the anterior border of the SCM, particularly in the jugulodigastric region superiorly. When evaluating a mass in the preauricular, infra-auricular/angle of mandible, and submandibular regions, the clinician should be mindful of a potential salivary lesion, including primary parotid and submandibular neoplasms, intra-parotid adenopathy, and plunging ranulas. Once the history and examination have narrowed the differential, additional diagnostic studies may be appropriate.

Thyroglossal Duct Cyst

Thyroglossal duct cyst is the most common congenital neck mass in children. They arise from the median thyroid anlage, the embryologic precursor to the thyroid gland, which devel-

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ops initially as a ventral diverticulum of endodermal elements at the junction of the anterior and posterior tongue muscles during the 3rd week of gestation. Failure of this tract to completely obliterate after the 8th week in gestation leaves persistent duct epithelium that remains active and creates a cyst, often after stimulation by an inflammatory process. Thyroglossal duct cysts can occur anywhere along the path of descent from the foramen cecum to the thyroid gland but most commonly are located at or just below the level of the hyoid bone. They are almost always found in the midline neck but on rare occasions are located more laterally and can be mistaken for a branchial cleft cyst.

Thyroglossal duct cysts typically present as a gradually growing but otherwise asymptomatic, midline neck mass. In nearly a third of cases, however, these can present as an acute infection with rapid swelling. Depending on the size and location of the cyst, symptoms might include dysphagia or airway obstructive symptoms such as stridor or snoring. Examination reveals a smooth, rounded midline mass that moves vertically with swallowing and tongue protrusion and moves freely from the overlying skin. Infrequently, a thyroglossal duct presents as a draining sinus tract, usually related either to prior infection with spontaneous rupture or to prior surgery (incision and drainage or incomplete excision). The differential diagnosis for such a midline mass includes dermoid cyst, ectopic thyroid tissue, and lymph node enlargement. A more superficially palpable midline mass with elements of skin involvement would be more suspicious for a dermoid cyst. Alternatively, failure of complete thyroid descent could result in ectopic thyroid tissue anywhere along the midline from the tongue base to the pretracheal region. This ectopic thyroid tissue could represent the patient's only functional thyroid parenchyma, and thus inadvertent removal would result in a hypothyroid state requiring thyroid hormone supplementation for the rest of their life.

A preoperative neck ultrasound determines whether the midline neck mass is a cyst and can confirm the presence of normal-appearing thyroid tissue in the standard anatomic position. If ultrasound reveals that the mass is solid or normal thyroid tissue cannot otherwise be identified, radionucleotide scanning should be performed to elucidate whether or not the midline mass is ectopic thyroid.

Without treatment, most thyroglossal duct cysts continue to grow and pose a risk of infection, which complicates eventual management. Therefore, surgical excision is always indicated. However, excision in the setting of acute infection should be avoided as the likelihood of lesion recurrence is unacceptably high. The infection should be treated with oral or intravenous antibiotics where appropriate and inflammation must resolve prior to a definitive resection. If the infection does not resolve, needle aspiration or incision and drainage is performed and should be done so the scar and drainage site can be incorporated into the incision when the cyst is resected.

Surgical Management

The Sistrunk procedure is the standard and recommended method of thyroglossal duct cyst excision. The operation takes into account the embryologic origin of thyroglossal duct cysts, to provide a complete excision of the entire duct remnant, thereby reducing the recurrence rate. Specifically, the cyst is excised in continuity with the tract as it extends cephalad, including the midportion of the hyoid bone, as well as a cuff of intrinsic tongue musculature between the hyoid bone and the foramen cecum.

The operation begins with positioning the patient in a neck extended position. An incision is made within a skin crease or prominent relaxed skin tension line over the palpable cyst. Sub-platysmal flaps are developed superiorly and inferiorly. As the platysma is traversed, care should be taken to avoid inadvertent entry into the cyst. The strap muscles are identified, separated at the midline raphe, and retracted laterally. The cyst, once identified, should be handled carefully because intraoperative cyst rupture might increase the risk of recurrence. Initial dissection is directed inferiorly toward the pyramidal lobe. If a persistent tract is identified, it is dissected in continuity with the cyst and separated from the thyroid parenchyma. Dissection is then directed superiorly toward the hyoid bone and tongue base.

The thyroglossal duct remnant can often have multiple arborizing tracts. Thus, the duct should be dissected out with a cuff of otherwise normal-appearing soft tissues, and skeletonizing the lesion should be avoided. The lesser horns of the hyoid bone are identified, and the intervening portion of bone between them is resected. The bone can be divided with bone snips or heavy scissors. Dissection lateral to the lesser horns should be avoided, as the hypoglossal nerve and ranine vessels course just deep to this area. Excision of the tract and tongue base musculature between the hyoid and the foramen cecum is aided by applying downward pressure inside the mouth at the junction of the anterior 2/3 and posterior 1/3 of the tongue with a double-gloved finger or a Deaver retractor. Care is taken to avoid creating a pharyngotomy (except in challenging revision cases in which it may be necessary). If this occurs inadvertently, it can typically be managed without incident providing it is identified and closed securely and the neck wound irrigated with antibiotic solution. Postoperative antibiotics and allowing only a soft diet for 1 week should also be considered in such a situation.

Outcomes

Recurrence of a thyroglossal duct cyst after excision by Sistrunk operation occurs in approximately 2–5 %. Risk factors for recurrence include intraoperative rupture of the cyst, prior infection, presence of cutaneous components (draining sinus tract), inadequate removal of tongue base musculature,

and patient age <2 years. Revision surgery for recurrent disease can be challenging and necessitates a more aggressive approach, including excision of the prior scar and dissecting widely around residual lesion to encompass presumably arborized tract remnants. This can include excising the fibrofatty tissues between the strap muscles down to the laryngotracheal complex, removing additional hyoid bone and directed excision of tongue base muscle. Suture-guided trans-hyoid pharyngotomy is a particularly useful technique for cases of recurrence involving the tongue base.

Branchial Cleft Anomalies

Branchial cleft anomalies are the second most common type of congenital neck mass. An understanding of the embryology of the branchial apparatus is essential in treating these anomalies. Early in development, there are four well-developed branchial arches and two rudimentary arches. Each branchial arch contains four essential tissue components—cartilage, cranial nerve, blood vessel, and muscle. As the branchial arch protuberances enlarge, spaces or invaginations develop between them both internally and externally. Internally, these invaginations are endodermally lined and are referred to as *pharyngeal pouches*. Externally, they are ectodermally lined and are referred to as *branchial clefts* or grooves. The pouches and clefts are numbered to correspond to the branchial arch immediately cephalad to them. Transiently, the external clefts will come in close contact with the internal pouches, though there is not normally a direct communication between them. Later in embryogenesis, the pouches and clefts are obliterated as the mature head and neck structures develop. Incomplete obliteration of the clefts and pouches later in development results in branchial cleft anomalies. Branchial cleft anomalies exist as a spectrum of developmental abnormalities, including cysts, sinuses, and fistulae.

Branchial cleft cysts result from the persistence of the cervical sinus of His and are usually lined by stratified squamous epithelium. There is no connection to skin externally or to the pharynx internally. When there is a persistent connection to the skin externally or to the pharynx internally, the result is a branchial cleft sinus. Branchial cleft fistulae result from persistence of both the branchial cleft externally that then connects to the pharyngeal pouch internally.

Branchial anomalies are classified based on the cleft or pouch of origin, which can be determined by its relationship to the various branchial arch derivatives. Specifically, the fistula tract will always course caudal to the branchial arch derivatives to which it corresponds. In addition, fistulae can be characterized based on the location of its pharyngeal opening. Second branchial cleft anomalies open into the tonsillar fossa, while third (and possibly fourth) branchial cleft anomalies connect to the pyriform sinus in the hypopharynx. Second branchial cleft anomalies are by far the most common, followed by the much less frequently encountered first branchial anomalies and the rare third branchial cleft anomalies. There is controversy as to whether anomalies derived from the fourth branchial cleft exist.

Branchial cleft sinuses and fistulae most frequently present as a pit in the neck skin that is noted at birth. In some patients intermittent clear liquid drainage is noted and in others they present as a result of acute infection. In adulthood, branchial cysts present as a soft tissue fullness in the upper neck deep to the anterior border of the sternocleidomastoid muscle. There can be fluctuations in size that often correlate to episodes of acute upper respiratory infections.

CT, MRI, or US can be useful in characterizing and diagnosing branchial cleft cysts. CT imaging can delineate the course of a sinus or fistula tract but with only moderate sensitivity. In cases of suspected third branchial cleft fistula, a barium swallow evaluation may reveal the internal connection at the level of the pyriform.

Definitive resection should not be attempted in the setting of acute infection. Instead, infections should be treated with antibiotics and, if necessary, needle aspiration. Incision and drainage should be avoided if at all possible but if necessary should be performed in a fashion that allows for later complete excision of the scar and drainage site in conjunction with the underlying lesion.

Complete surgical excision is the recommended treatment of branchial anomalies of all types, with the goal of avoiding future infection that could complicate ultimate management. There is debate regarding timing of surgery for anomalies diagnosed during infancy. This decision must weigh the risks of anesthesia and surgery in a young child versus the risk of developing an infection. Delaying surgery until approximately 18–24 months of age is a reasonable timeline.

Second Branchial Cleft Anomalies

These account for 95 % of all branchial malformations. Cysts are more common than sinuses or fistulae and most commonly present in young adults. The external opening of a second branchial sinus or fistula is along the anterior border of the SCM, typically in the middle or lower third of the neck. They course deep to the platysma, lateral and above the glossopharyngeal and hypoglossal nerves, between the internal and external carotid arteries, and connect to the pharynx at the tonsillar fossa.

Excision of cysts involves making an incision within a skin crease overlying the mass, elevating platysma flaps, identifying the cyst, and then carefully dissecting around it with care taken to monitor for a pharyngeal connection.

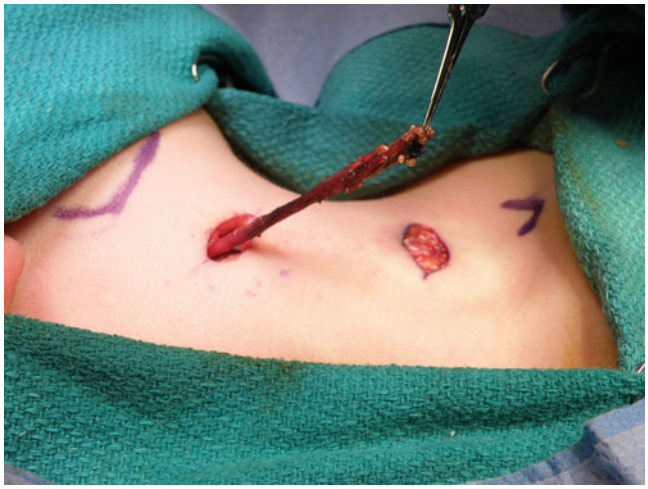

Fig. 28.1 Excision of a second branchial cleft fistula from the right neck via a step ladder incision. Complete excision of a tract extending from the lower neck to the tonsillar fossa is able to be safely accomplished through two small incisions

When an external pit is present, the tract can be cannulated with a lacrimal probe or heavy suture to aid in dissection. Methylene blue injection into the tract can aid visualization, but care must be taken to avoid spillage and tissue staining that will make dissection more challenging. The skin pit is incorporated into the skin incision with a small ellipse around the pit itself. The tract is then traced out, with dissection directly on the tract to avoid injury to the neurovascular structures expected along its course. In cases where there is a long fistula tract, particularly in older children, a step ladder incision will allow for safe dissection through two small incisions as opposed to operating through a single larger incision (Fig. 28.1). Some clinicians recommend concurrent tonsillectomy to ensure complete tract excision in cases of second branchial cleft fistula, although this is debatable.

First Branchial Cleft Anomalies

These are infrequently encountered and are categorized into two types based on the Work classification. Type I anomalies are considered duplications of the external auditory canal. They are derived from ectoderm only, present as swellings near the ear and course lateral to the facial nerve. Type II anomalies are more complex and derive from both ectodermal and mesodermal elements. These course medial to or split around the facial nerve within the parotid gland and often contain cartilage. Type II anomalies present as a swelling or pit in the preauricular or infra-auricular areas and sometimes more inferiorly near the angle of the mandible and anterior border of the SCM. First branchial anomalies always occur above the level of the hyoid. Either type can involve the external auditory canal or middle ear, though type II lesions are more likely to do so. Patients will typically present with swelling in the area around the cheek and ear, often in association with acute inflammation. If there is a connection to the ear canal, otorrhea can occur.

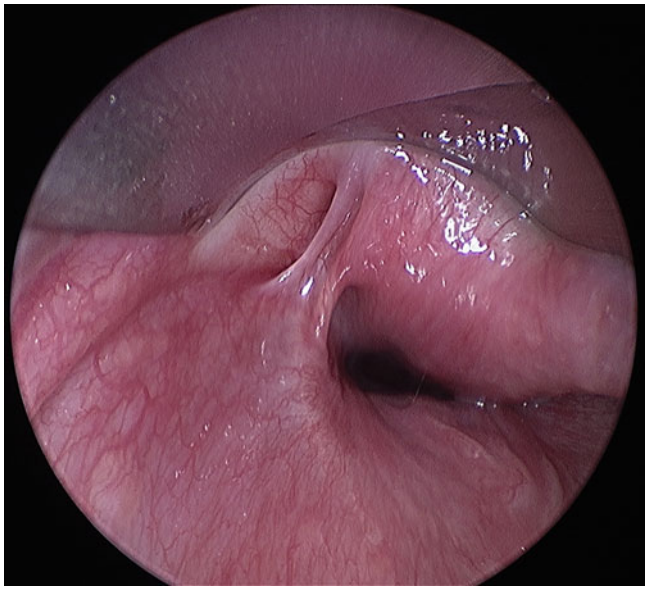

Fig. 28.2 Endoscopic view of a congenital pit in the apex of the left pyriform sinus, immediately adjacent to the upper esophageal sphincter. This finding is pathognomonic of a third or fourth branchial cleft sinus

Surgical excision is the recommended treatment. The most feared complication of first branchial cleft anomaly resection is injury to the facial nerve, which is often closely associated with the lesion. Facial nerve injury is a devastating complication with lifelong effects on important functions and cosmetic appearance. Therefore, this operation should be performed by a surgeon who has significant experience with facial nerve dissection.

The surgical approach is via a parotidectomy incision, and complete lesion excision typically involves superficial or total parotidectomy with facial nerve dissection. Recurrence is common and multiple procedures are sometimes needed for definitive treatment.

Third and Fourth Branchial Cleft Anomalies

These are rare and present as a cyst, sinus, or fistula. When there is a pharyngeal connection, it is located in the pyriform sinus (Fig. 28.2). These anomalies occur much more frequently on the left side and often contain thymic tissue. They can present as a swelling along the anterior border of the SCM low in the neck near the level of the superior pole of the thyroid.

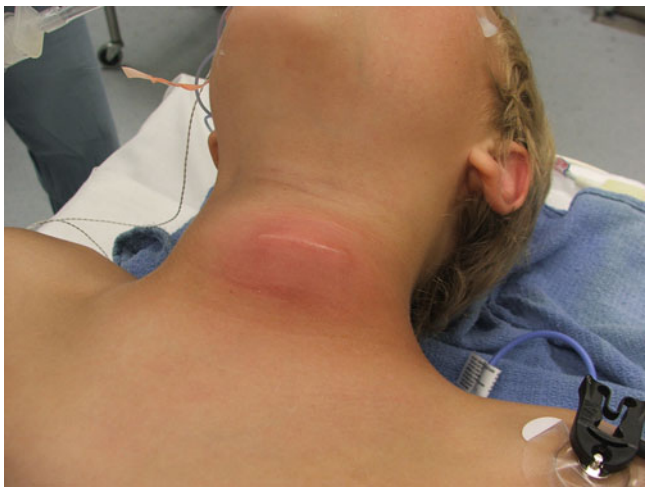

Fig. 28.3 Recurrent abscess of the left lower neck in a 9-year-old male related to an underlying third or fourth branchial cleft sinus. Note the surgical scar from prior abscess drainage at 18 months of age

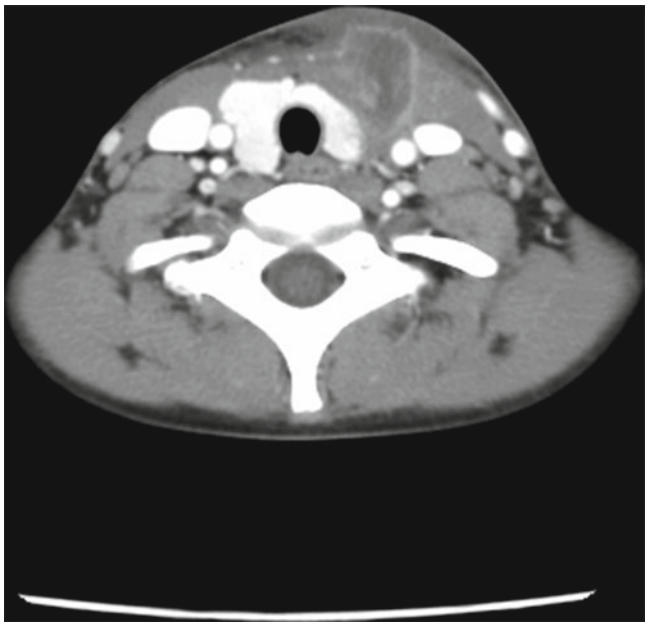

Fig. 28.4 Axial contrast-enhanced CT of a 9-year-old patient with recurrent abscess of the left lower neck related to an underlying third or fourth branchial cleft anomaly. This is located just anterior to the left thyroid lobe (with some involvement) and extends to the left pyriform sinus

Based on its embryologic origin, the course of a third branchial cleft anomaly should be posterior to the internal carotid artery, between the glossopharyngeal and hypoglossal nerves and then through the thyrohyoid membrane to enter the pyriform sinus. The course of a fourth branchial anomaly depends on which side of the neck it occurs. Only a few complete fourth branchial fistulas have been described and the vast majority of these occurred on the left side. On the left, the anomaly courses inferiorly to loop around the aorta medial to the ligamentum arteriosus and then ascends to pass behind the carotid artery and over the hypoglossal nerve on its way to the pyriform sinus. On the right, the course of the tract is similar as on the left with the exception of passing inferiorly under the subclavian artery. The anomaly can often be closely associated with the thyroid lobe on the affected side.

Patients can present with a gradually growing mass but more typically with acute infection. Indeed, a history of recurrent lower neck abscess or recurrent thyroiditis should raise suspicion for an underlying third or fourth branchial cleft anomaly (Fig. 28.3).

CT will typically reveal abnormal soft tissues, fluid collection, or an abscess anterior to the thyroid gland and adjacent to the larynx (Fig. 28.4). A laryngocele could have a similar appearance and should be on the differential. Contrast esophagram (looking for a tract leading from the pyriform sinus) would help differentiate these entities, as would direct laryngoscopy to identify an opening in the pyriform.

Surgical management involves excision of the entire tract and cautery of the pyriform sinus opening. The lesion will often course in close proximity to the ipsilateral thyroid lobe, and thyroid lobectomy should be performed if there is evidence of involvement.

Lymphatic Malformations

The nomenclature for these lesions has historically included the incorrect terms cystic hygroma and lymphangioma (capillary and cavernous), but the most appropriate designation is *lymphatic malformation*. Lymphatic malformations can occur in any part of the body; however, they are more frequently found in areas that are rich in lymphatics. Roughly half of lymphatic malformations occur in the head and neck.

Lymphatic malformations manifest early in life and 50–60 % are present at birth. An estimated 90 % of lesions are diagnosed by 2 years of age. Increasingly, lesions are identified prenatally by routine ultrasound examinations. Most often, patients with lymphatic malformations will present with a fluctuant, slow-growing, non-tender, soft tissue mass. In some cases, however, they can present as a more acutely enlarging mass, usually as a result of associated soft tissue or upper respiratory infection, trauma, or intralesional hemorrhage. The ability to transilluminate the lesion on physical examination strongly suggests lymphatic malformation. Lymphatic malformations commonly exhibit fluctuations in size, but they do not spontaneously involute. There are occasional descriptions of significant cyst reduction or resolution after infection, perhaps due to "auto-sclerotherapy".

Trans-axial imaging with MRI or CT aids in characterizing the lesion. This helps to confirm the diagnosis of lymphatic malformation and categorize the malformation based

on cyst size (macrocystic, microcystic, or mixed) and establishes the extent of the lesion as it relates to surrounding structures. This information is critical in formulating a management plan. Imaging characteristics that suggest lymphatic malformation include a trans-spatial (does not respect fascial planes), non-enhancing, cystic mass. In cases of macrocystic lesions, the presence of fluid-fluid levels within the cyst is also suggestive.

Treatment

Options for management include continued observation, surgical resection, and sclerotherapy. Treatment should be individualized, with the primary goal being to restore form and function while preserving vital structures. Large and more extensive lesions can be disfiguring, cause airway obstruction, and impair feeding and swallowing. Aggressiveness of therapy must be balanced, however, with the potential for injury to important neurovascular structures. Therefore, staged or subtotal procedures should be favored over intentional sacrifice of essential anatomy.

In general, malformations located in the posterior triangle or infrahyoid neck are more amenable to successful treatment without excess risk. Similarly, macrocystic lesions (in any neck location) are typically more responsive to excision or sclerotherapy than microcystic lesions. Simple observation might be reasonable and appropriate for small malformations or for lesions in risky locations, granted they are minimally symptomatic. The most challenging lymphatic malformation cases involve mixed or microcystic lesions located in the suprahyoid neck. These often exhibit complex infiltration into various tissue planes, with frequent involvement of the floor of the mouth, tongue, parotid, masticator space, and pharynx. Not surprisingly, these lesions often cause significant dysfunction of the upper aerodigestive tract.

Historically, lymphatic malformations have been treated surgically, and this remains a common management modality. Ideal surgical candidates are those in which there is an excellent chance of complete resection without excessive risk. Even in these cases, however, there is a significant risk of complications, including infection, bleeding, nerve damage, unsightly scars, fistula formation, and disease recurrence.

Sclerotherapy

Sclerotherapy is an alternative to surgery for patients with macrocystic malformations (>2 cm diameter) and entails needle aspiration of cyst fluid under US or fluoroscopic guidance followed by injection of the sclerosing agent into the cyst space. Over the course of the next several days, the patient may develop fevers and inflammation at the site. The lesion and overlying skin may become swollen, painful, and erythematous. Treatment is supportive but the patient should be monitored to be sure tissue swelling does not affect the airway. Though a single injection is occasionally curative, it is not uncommon to need multiple sclerotherapy procedures to achieve full resolution. In such cases, allowing at least 6–8 weeks between injections is recommended. Commonly used sclerosing agents include doxycycline, ethanol, OK-432, and bleomycin. Doxycycline and ethanol are the most frequently used agents in the USA. Bleomycin use is limited by concerns about potential adverse systemic effects (pulmonary fibrosis). OK-432 (Picibanil) is derived from lyophilized *Streptococcus pyogenes* incubated in benzylpenicillin. It is frequently used in Asia and has shown promise as a safe and effective agent. It is not available in the USA except as part of a research protocol.

Lymphadenitis

Lymph node enlargement related to inflammation or infection is the most common type of acquired pediatric neck mass. This is typically defined as abnormal enlargement when nodes are greater than 1 cm in diameter. The vast majority of cases are caused by viral or bacterial infection. Less frequent etiologies include mycobacterial adenitis, cat-scratch disease, toxoplasmosis, and fungal infection. The pathogenesis of lymphadenitis starts with microorganisms reaching lymph nodes by one of three routes: (1) lymphatic flow from an inoculation site, (2) lymphatic flow from adjacent lymph nodes, or (3) by hematogenous spread. This incites an inflammatory reaction and nodal edema. Cellulitis ensues if inflammation and infection spread to involve adjacent soft tissues. It can also progress to suppuration and abscess.

Cervical lymph nodes are connected by distinct lymphatic channels, which drain anatomic regions of the head and neck in a predictable pattern. This helps to discern the site of inoculation or initial infection. Management of cervical lymphadenitis depends on the underlying etiology and presentation. A comprehensive history will provide clues about etiology. Historical details to consider include duration and progression of symptoms. Acute lymphadenitis (≤2 weeks) most often is secondary to viral or bacterial infection. The differential diagnosis for subacute (developing and progressing over 2–6 weeks) and chronic (>6 weeks) lymphadenitis is more extensive. The most likely etiology in such cases will be nontuberculous mycobacterial infection, but additional causes include tuberculosis, HIV, cat-scratch disease, fungal and parasitic infections, as well as a variety of noninfectious inflammatory disorders (Kawasaki disease, Rosai-Dorfman disease, sarcoidosis, Castleman disease). Neoplastic disorders such as lymphoma, leukemia, Langerhans histiocytosis,

and sarcoma should also be considered in cases of subacute and chronic lymphadenopathy.

Additional information to elicit includes a history of fever, focal neck pain, recent upper respiratory infection, skin infection or trauma, exposure to animals, recent notable travel, exposure to ill individuals or persons known to have TB, as well as associated head and neck issues such as sore throat, dental infection, and diminished neck range of motion.

Further categorizing lymphadenitis based on laterality can also be useful. Acute unilateral lymphadenitis is generally bacterial in origin and most frequently affects children aged 1–4 years of age. *Staphylococcus aureus* and *Streptococcus pyogenes* account for over 80 % of cases; anaerobes should be considered in cases where there is associated dental disease. Acute bilateral lymphadenitis is more commonly viral in origin, often occurring in association with cough, rhinorrhea, conjunctivitis, and sore throat. Typical etiologic agents in such cases include adenovirus, RSV, enterovirus, and influenza. Acute bilateral lymphadenitis can also be caused by group-A streptococcal infections, particularly in school-aged children. This is usually associated with pharyngotonsillitis and rapid strep testing will help clarify such cases. Epstein-Barr virus (EBV) and cytomegalovirus (CMV) can occur as acute bilateral lymphadenitis but more often present as subacute bilateral disease. Causes of subacute unilateral lymphadenitis include nontuberculous mycobacterial infection, cat-scratch disease (*Bartonella henselae* infection), and TB.

In cases of acute lymphadenitis, there is often fever, erythema of the overlying skin, and tenderness to palpation. As infection progresses, induration of the surrounding soft tissues may develop. Palpable fluctuance is indicative of abscess.

Treatment

A significant proportion of acute lymphadenitis cases are viral in origin and are self-limited. Antiviral therapy is not usually indicated and node suppuration is uncommon. Indeed, most patients are managed conservatively by their primary care provider, with surgical opinion sought only in instances where there is concern for abscess or neoplasm.

Subacute bilateral lymphadenitis is most commonly caused by EBV and CMV infection and typically occurs in school-aged children and adolescents. Patients often present with mononucleosis, with lymph node enlargement, fever, exudative pharyngitis, malaise, and hepatosplenomegaly. Lab testing may show lymphocytosis with the presence of atypical or reactive lymphocytes. Monospot testing for the presence of heterophile antibodies is specific but not sensitive. EBV serologies are more sensitive but may take several weeks to show seroconversion. Management is supportive, sometimes with systemic corticosteroids, elective intubation, or even surgical intervention (acute tonsillectomy or tracheotomy) reserved for cases of impending airway obstruction.

Acute bacterial lymphadenitis should be treated initially with antibiotics. Oral antibiotics may be adequate in cases of early infection; however, IV antibiotics should be considered when patients present with more advanced signs and symptoms (cellulitis, extensive node involvement, high fevers). If there is lack of improvement after 48 h of appropriate antibiotics (or when there is palpable fluctuance on exam), imaging (US or CT) should be considered. The role of imaging is to determine the presence of a fluid collection unlikely to improve with further antibiotic therapy alone. In such cases, needle aspiration or incision and drainage may be warranted. Needle aspiration may be appropriate in certain situations as it avoids a scar and can be performed under local anesthesia. However, incision and drainage would be more appropriate when loculations are present or the child is not cooperative (and will require general anesthesia anyway). Culture materials can be obtained with either procedure; however, incision and drainage allows for breakdown of loculations, irrigation of the abscess space, and placement of a drain or packing—all measures that significantly decrease risk of abscess recurrence. The incision and drainage wound is sometimes packed with antibiotic-impregnated strip gauze that is removed gradually over 2–3 days. Late abscess recurrence is not common and should raise concern for a potential underlying congenital anomaly or possible immune deficiency.

Subacute/chronic unilateral lymphadenitis is most commonly caused by mycobacterial infection (either *Mycobacterium tuberculosis* or nontuberculous strains) and cat-scratch disease. *Nontuberculous (atypical) mycobacterial infection* is much more common in the USA and frequently involves *Mycobacterium avium-intracellulare* and *Mycobacterium scrofulaceum*. Patients present with slow-growing, non-tender rounded lymph nodes that become matted into larger nodal conglomerations. Mild systemic symptoms sometimes occur but patients are often asymptomatic. In some cases, infected nodes can become adherent to the overlying skin. Initially, the involved skin will appear violaceous and thinned (Fig. 28.5). Later, the skin becomes more attenuated, and spontaneous drainage and fistula formation can occur.

It is crucial to distinguish nontuberculous mycobacterial infection from TB. Presenting features and treatment are different. Specifically, nontuberculous mycobacterial infection occurs more frequently in white, preschool children in rural communities with no TB contact history. Cervical lymphadenitis usually involves the submandibular and parotid region; PPD skin test is negative or intermediately

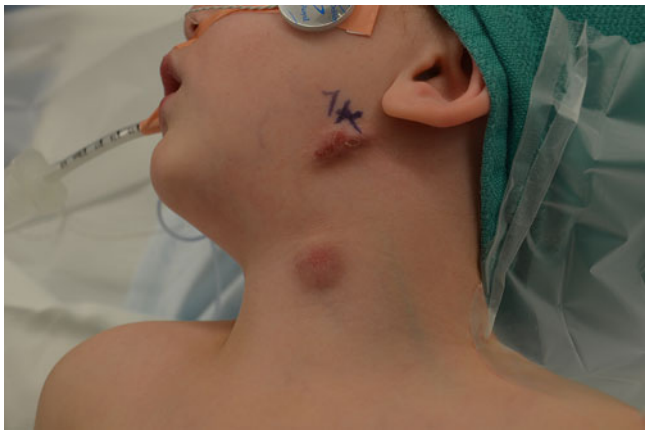

Fig. 28.5 Three-year-old patient with nontuberculous mycobacterial cervicofacial adenitis. Attenuation and violaceous discoloration of the overlying skin is characteristic of this type of infection

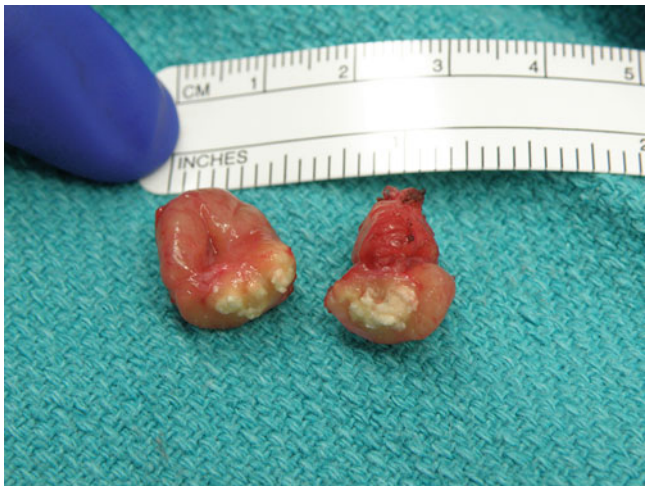

Fig. 28.6 Excised lymph node infected with nontuberculous mycobacteria is transected to reveal early coalescence of intra-nodal microabscesses

positive (0–15 mm induration) and chest X-ray is normal. Conversely, *Mycobacterium tuberculosis* infections more often affect older, African-American children in the urban setting, and there is often a history of contact with TB-infected individuals. Involved nodes are located in the posterior neck or preauricular area; PPD skin testing shows an avid response (>15 mm induration) and chest X-ray is often abnormal.

Imaging reflects gross appearance of the nodes; initially there is a heterogeneous appearance of involved nodes suggestive of microabscesses (Fig. 28.6). Later, these hypodense areas can coalesce into larger abscess collections.

Nontuberculous mycobacterial cervicofacial adenitis is treated with surgery. Complete excision—including all involved lymph nodes, grossly involved overlying skin, and any drainage tracts—provides the best chance for resolution of infection and healing. Management is more challenging when there is extensive skin involvement (especially in cosmetically sensitive areas such as the cheek and jaw margin) or disease that is closely associated with branches of the facial nerve (most commonly the marginal mandibular branch). Full excision could result in unsightly scarring or long-term deficits related to facial nerve injury. In these instances, treatment with curettage or repeated needle aspiration may be more appropriate. Curettage is performed through an incision created over the palpable mass and involves bluntly scraping chronically inflamed and necrotic tissues with curettes and rounded elevators. Skin is preserved, and the wound is packed initially for hemostasis. Packing is removed after 24–48 h, and the wound is left to heal by secondary intent. Additional procedures are sometimes needed for complete disease resolution and scar revision.

Treatment of *Mycobacterium tuberculosis lymphadenitis* is medical, with multi-agent antituberculosis antibiotics administered over an extended period of time (12–18 months). Regression of infected lymph nodes occurs over 3–6 months.

Summary

A thorough history and physical examination are key steps in formulating a differential diagnosis for pediatric neck masses. An understanding of the embryology of the neck is important in the diagnosis and management of congenital neck masses. The most commonly encountered congenital neck masses include thyroglossal duct cysts and branchial cleft anomalies. In cases of midline neck masses, preoperative identification of normal thyroid tissue in its standard anatomic position is important to avoid inadvertent removal of ectopic thyroid tissue. Dissection of branchial cleft sinuses/fistulae should be directly on the tract; close dissection or skeletonizing of thyroglossal duct tracts should be avoided.

Attempts at definitive resection of congenital neck masses (branchial cleft anomalies, thyroglossal duct cysts, lymphatic malformations) should be avoided in cases of acute infection. The most commonly encountered acquired pediatric neck mass is infectious lymphadenitis. Management of lymphadenitis is usually with a combination of medicine and surgery.

Editor's Comment

Walter Sistrunk's operation for the excision of thyroglossal duct cysts is an elegant and straightforward procedure with a high success rate and relatively low complication rate.

Done well, it can be very satisfying. Carelessly performed, it can result in serious complications, including injury to the airway, hypoglossal nerve injury, or recurrence. The head must be positioned anteriorly (sniffing position) to lift the hyoid bone off of the tracheolaryngeal complex. Letting the head fall back compresses the hyoid bone against the airway, inviting injury. To avoid injury to the hypoglossal nerves, only the central 1-cm segment of the hyoid bone should be excised. And the tract must be followed nearly all the way to the foramen cecum. Postoperative wound infection often portends a recurrence, but it is more likely that recurrence causes infection, not vice versa. Recurrent thyroglossal duct cyst excisions can be frustratingly difficult, often resulting in a second recurrence and a great deal of misery for the patient and surgeon. A wide excision of all previously disrupted tissue, being sure to stay in the midline, is the best strategy.

Excision of branchial cleft cysts and sinuses is also usually straightforward, although it takes patience to dissect the entire tract all the way to its origin in the pharynx. Injection of blue dye is rarely helpful and more often leads to extensive tissue staining and a messy operative field. Not all branchial cleft sinuses will track all the way to the pharynx; some instead end somewhat abruptly or in a thin-walled cystic structure with multiple tentacle-like projections that simply peter out in the soft tissues of the neck. This always raises concerns about recurrence, which occurs in a minority of cases.

Lymphatic malformations are increasingly being managed by injection sclerotherapy. Surgical excision is very difficult, is associated with high complication and recurrence rates, and frequently results in an unacceptable cosmetic appearance. The cysts tend to interdigitate between and around vital structures, including the individual fibers of nerves such as the spinal accessory and recurrent laryngeal nerves, which can easily be severed despite meticulous technique. Unfortunately, the cysts that most easily excised are also the most likely to respond to sclerotherapy. Before undertaking excision of any cervical mass, it is important to review the vascular and neural anatomy very carefully and to understand that distortion of normal anatomic relationships is to be expected. One should also be prepared for the occasional unexpected vascular malformation, metastatic focus of papillary thyroid carcinoma, or carotid body tumor, all of which are extremely vascular.

Most pediatric surgery practices are inundated weekly with enlarged cervical lymph nodes and their anxious parents. These can be vexing and unsatisfying, as the parents expect guarantees and the surgeon's options are limited to observation and open biopsy—fine-needle biopsy is rarely available, feasible, or accurate in children and physical findings can be misleading. In general, lymph nodes that are <2 cm, flat or ovoid, soft, mobile, and not enlarging in an asymptomatic child can be observed, but serial follow-up in 2-week intervals is recommended. Nodes that are >2 cm, round, firm, or enlarging should probably be removed, but a brief period of observation, no more that 2–3 weeks, or a trial of empiric antibiotics is usually safe. US techniques have improved greatly and, though never definitive, can often help us decide whether malignancy is a concern.

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Thyroid and Parathyroid Disease

29

Victoria K. Pepper, Christopher Breuer,
and Jennifer H. Aldrink

The thyroid gland begins as a median endodermal thickening in the floor of the primordial pharynx. An outpouching of this embryologic tongue forms and gradually descends into the neck, passing posterior to the hyoid bone and laryngeal cartilages. The hollow structure develops into a mass of cells, eventually dividing into the left and right lobes of the thyroid. By 7 weeks' gestation, the isthmus of the thyroid, which connects these two lobes, attaches to the second and third tracheal rings by the ligament of Berry. The thyroglossal duct involutes in most individuals, but a pyramidal lobe extends superior from the isthmus in approximately half of us.

The thyroid receives arterial blood supply via the bilateral superior thyroid arteries (from the external carotid arteries) and inferior thyroid arteries (from the thyrocervical trunks). In 3–10 % of the population, the thyroidea ima artery arises from the brachiocephalic trunk and enters the gland inferomedially to the thyroid lobe. Venous drainage occurs through the bilateral superior, middle, and inferior thyroid veins (Fig. 29.1).

Two branches of the vagus nerve lie in close proximity to the thyroid: the recurrent laryngeal nerve (RLN) and the superior laryngeal nerve (SLN). Both RLNs travel down intrathoracically first, passing around different vascular structures before traveling back into the neck. The left RLN passes around the ductus arteriosus (ligamentum arteriosum), coursing almost vertically back into the neck. The right RLN travels around the right subclavian artery, approaching the neck in a more oblique fashion. Once in the neck, the nerves pass posterior to the middle thyroid artery and along the tracheoesophageal groove on the posteromedial surface of the thyroid, entering into the larynx posterior to the horn of the thyroid cartilage. Nonrecurrent nerves occur in almost 1 % of patients, but are more frequent on the right side. The intrinsic muscles of the larynx, except the cricothyroid muscle, receive innervation from the RLNs. Unilateral transection results in adducted cord paralysis presenting as hoarseness, while bilateral transection leads to airway compromise secondary to functional airway obstruction.

The SLN branches from the vagus nerve high in the neck, coursing adjacent to the pharynx and medial to the carotid. It divides into an external branch that innervates the cricothyroid muscle and an internal branch that provides sensation to the larynx proximal to the vocal cords. Division of the SLN results in voice weakness and changes in voice quality.

At a histologic level, the follicles of the thyroid are composed of a single layer of epithelial cells surrounding a lumen containing colloid thyroglobulin. Colloid formation is evident by 11 weeks' gestation. Parafollicular C cells are scattered between the follicles and originate from neuroendocrine cells from the ultimobranchial bodies of the embryonic pharynx.

Thyroid hormone production begins with iodization of the tyrosine residues on thyroglobulin at the interface of follicular cells and colloid, forming either 3,5,5-triiodothyronine (T3) or tetraiodothyronine (T4). The active hormone, T3, interacts with receptors in the nuclei of cells, functioning primarily in metabolism regulation. In addition, T3 plays an important role in neurologic development and sensitizes tissues to catecholamines. Thyroid-stimulating hormone (TSH) causes the release and increased production of thyroid hormone by binding specific receptors on follicular cells.

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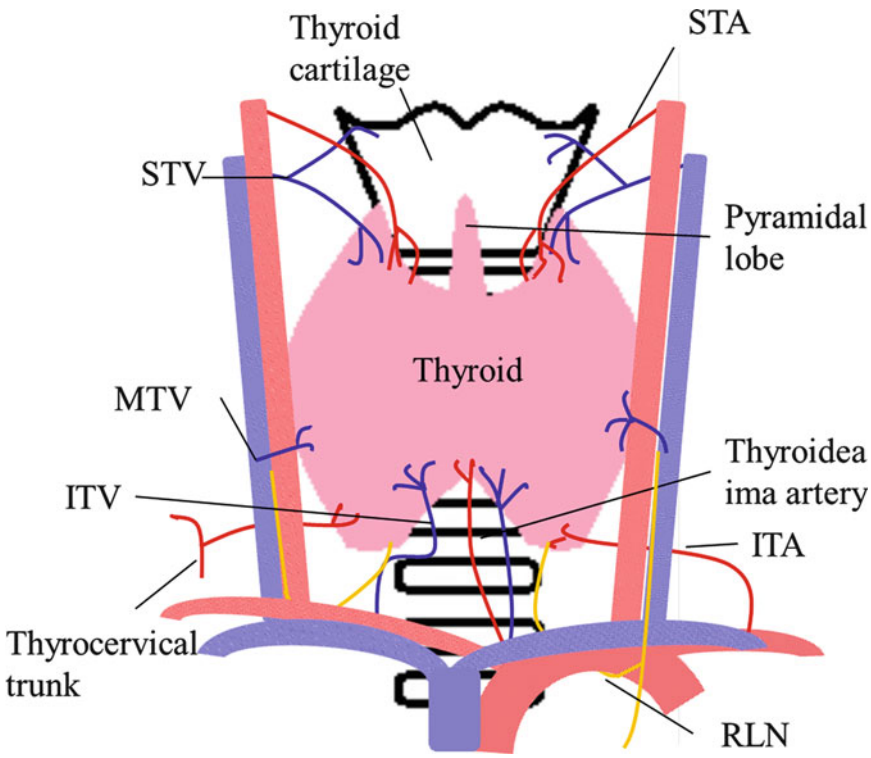

Fig. 29.1 Thyroid anatomy. *ITA* inferior thyroid artery, *ITV* inferior thyroid vein, *MTV* middle thyroid vein, *RLN* recurrent laryngeal nerve, *STA* superior thyroid artery, *STV* superior thyroid vein

The release of TSH from the hypothalamus is controlled by thyrotropin-releasing hormone released from the anterior pituitary. Elevated calcium levels stimulate calcitonin production in the parafollicular C cells, aiding in calcium homeostasis.

Ectopic Thyroid Tissue

Ectopic thyroid tissue can occur anywhere along the midline, but is predominantly located in the tongue (~90 %). There is a female predominance (4:1) and it is typically diagnosed in the second decade of life. This tissue will represent the only functional thyroid tissue in 75 % of patients. Diagnosis is suggested by mass on physical examination, ultrasound (US), computed tomography (CT), or magnetic resonance imaging (MRI), but a thyroid scan (technetium-99 m sodium) is needed for confirmation.

Most cases require no treatment as long as the patient remains asymptomatic, but some authors recommend excision due to possible malignant degeneration. Patients with minor symptoms and increased TSH levels can undergo thyroid hormone therapy to slowly reduce mass size. Surgical excision (transorally or via median/lateral pharyngotomy) can be performed in cases of respiratory distress, dysphagia, obstruction, recurrent hemorrhage, or increasing mass size. In cases where surgical excision is pursued and the ectopic tissue is the only active thyroid tissue, autotransplantation of the excised tissue can be used to prevent hypothyroidism. While ablation of this tissue with radioactive iodine has been discussed for adults, this therapy is avoided in children and adolescents due to potential risks.

Congenital Central Hypothyroidism

Congenital central hypothyroidism (CCH) describes a condition of low TSH, T3, and T4. These patients will not be identified by the neonatal screening of TSH, but can be diagnosed using TSH and free T4 levels. CCH is caused by mutations in various transcription factors involved in pituitary development and differentiation. Approximately 60 % of patients also display a prolactin deficiency. With delayed diagnosis, these patients may present with macroorchidism and delayed puberty. Treatment consists of thyroid hormone supplementation.

Hyperthyroidism

Hyperthyroidism occurs for a variety of reasons in children, including autoimmune diseases, toxic multinodular goiter, and hyperfunctioning thyroid nodule. It can also be genetic (familial non-autoimmune hyperthyroidism). Symptoms include heat intolerance, sweating, palpitations, tremor, weight loss, and malaise. Diagnostic evaluation includes thyroid hormone panel and US, but also requires disease specific testing.

Goiter

A goiter is a diffuse enlargement of the thyroid. In developing nations, the most common etiology is inadequate iodine intake, but autoimmune causes are more prevalent in the USA. While typically euthyroid, these patients can present with hypothyroidism or, more rarely, hyperthyroidism. Testing includes thyroid hormone panel and US. Most goiters can be observed, as 60–80 % of thyroids will return to normal size within 20 years without any intervention. Exogenous thyroid hormone administration has not been shown to enhance resolution. Surgical therapy is rarely required, but is indicated in cases of compression, pain ("globus sensation"), dysphagia, dysphonia, or respiratory compromise. Uninodular goiters are managed with lobectomy, while multinodular goiters require near-total or total thyroidectomy.

Autoimmune Thyroid Disorders

There are two common autoimmune disorders of the thyroid that affect children, one that usually causes hyperthyroidism (Graves disease) and one that can sometimes cause hypothyroidism (Hashimoto's thyroiditis).

Graves Disease

Graves disease occurs due to an IgG-mediated autoimmune reaction against TSH receptors on follicular cells. There is a female predominance (5:1) and the disease typically presents in adolescence. In infants born to mothers with active Graves disease, 1 % will be born with a congenital form due to transplacental passage of maternal antibodies. Initial symptoms include exophthalmos, myxedema, and difficulty in school. Heat intolerance, sweating, palpitations, tremor, weight loss, and malaise may occur with advanced disease. On examination, the gland is enlarged, smooth, firm, and non-tender. Diagnostic testing usually shows elevated T3, elevated T4, and suppressed TSH levels. However, up to 20 % of patients will have isolated elevation in T3 (T3 toxicosis). TSH-receptor antibody detection confirms the diagnosis.

Initial treatment is methimazole, which prevents iodinization of the tyrosine residues of thyroglobulin and inhibits thyroid hormone production. Complications of methimazole use include skin rash, joint/muscle pain, fever, and agranulocytosis. Unlike adults, propylthiouracil is not used in children due to risk of liver failure. Beta-blockers can be added to counter cardiovascular sequelae. Treatment is continued for 1–2 years, at which point the medication is discontinued to assess for remission. Although increased rates of remission have been achieved with prolonged medical therapy, only 30 % of adolescents and 17 % of prepubertal children will achieve remission with a 1–2 year course. Risks for relapse include younger age, larger goiter, lower body mass index, and higher initial thyroid hormone levels. Patients who have adverse reactions or fail to undergo remission are considered for radioactive iodine ablation (RAI) or surgery.

The use of RAI is controversial due to an associated increase in thyroid cancer incidence and associated mortality. In addition, RAI has also been associated with an elevated risk of parathyroid hyperplasia and hyperparathyroidism. These risks are age and dose dependent, leading to avoidance of RAI in children less than 5 years old. RAI is acceptable if kept below 10 mCi in children between 5 and 10 years of age and less than 150 μCi/g of thyroid tissue in children greater than 10 years of age.

Surgical options include total or near-total thyroidectomy, but subtotal thyroidectomy is avoided due to high recurrence rates. For 1–2 months prior to thyroidectomy, methimazole is used to achieve a euthyroid state with or without beta-blockade for cardiovascular sequelae. Lugol's solution (potassium iodide) is given 10 days prior to surgery, reducing vascularity and blood loss. Postoperatively, these patients are more prone to hypocalcemia than patients who undergo thyroidectomy for other reasons and should be supplemented with calcitriol. Most patients suffer hypocalcemia after either thyroidectomy (96–100 %) or RAI ablation (94 %).

Hashimoto's Disease (Chronic Lymphocytic Thyroiditis)

Hashimoto's disease is caused by CD4 T-cell activation against thyroid antigens. These CD4 cells recruit cytotoxic CD8 cells, which attack follicular cells. Most patients are euthyroid at presentation, but 10 % have hyperthyroidism (Hashitoxicosis). Over half will progress to hypothyroidism. On examination, the thyroid will be pebbly or granular in texture with possible tenderness on palpation. T3 and T4 levels are commonly normal or low and TSH is elevated. The majority (95 %) demonstrate elevated antithyroid microsomal antibodies or antithyroid peroxidase antibodies. While imaging is not required, radionuclide scan will show patchy uptake of the tracer and US will show diffuse thyroid hypoechogenicity. Treatment is observation and thyroid hormone monitoring due to risk of progression to hypothyroidism.

Infectious Thyroid Disorders

Infectious disorders of the thyroid gland can be acute or subacute in onset.

Subacute (de Quervain's) Thyroiditis

Subacute thyroiditis is due to viral infection and is unusual within children. Symptoms include a swollen, painful, and tender thyroid. T3 and T4 may be mildly elevated and TSH decreased. Histology shows granulomas and epithelioid cells. Treatment consists of nonsteroidal anti-inflammatory agents or steroids and recovery is anticipated within 2–9 months.

Acute Suppurative Thyroiditis

Acute suppurative thyroiditis occurs secondary to a bacterial infection with staphylococci or mixed aerobic and anaerobic flora. Patients with congenital pyriform sinus anomalies have a higher incidence of infection and usually present with left lobe thyroiditis. Exam will reveal a tender, inflamed thyroid and patients are usually septic. Initial treatment is antibiotics, but drainage with or without ultrasound guidance is sometimes required. Very rarely, patients require thyroid lobectomy (usually left sided) for recurrent infections.

Thyroid Nodule

With an incidence just under 2 %, palpable thyroid nodules in children occur less frequently than in adults (5 %). This incidence increases in both adults and children when ultrasound is used for detection. In children, thyroid cysts occur in 50–60 % and nodules in 1–2 %, with respectively 4–5 % and around 1 % having a size greater than 5 mm. More importantly, over 25 % of pediatric nodules are malignant, compared to only 5 % of adult nodules. With a differential diagnosis that includes benign cystic degeneration, thyroglossal duct cyst, parathyroid cyst, branchial cleft cyst, follicular adenoma, chronic lymphocytic thyroiditis, multinodular goiter, and thyroid carcinoma, an algorithm for management of this finding is important (Fig. 29.2).

Evaluation of a thyroid nodule begins with a detailed history, including any symptoms of hypo- or hyperthyroidism (Table 29.1), personal cancer history, personal history of autoimmune thyroid condition, prior ionizing radiation exposure, family history of thyroid cancer, and family history of thyroid cancer-associated conditions (Cowden syndrome, familial adenomatous polyposis, Gardner syndrome, Peutz-Jeghers syndrome, Carney complex, McCune-Albright syndrome, multiple endocrine neoplasia (MEN) syndromes). Initial information regarding the potential risks of radiation exposure came from Chernobyl, after which higher rates of thyroid cancer, predominantly papillary cancer, were found. More recent evidence suggests that the risk of thyroid cancer increases with radiation doses up to 20–29 Gy, but decreases at higher levels. Physical examination should include the thyroid and surrounding lymph node basins, the nodule dimensions and characteristics (hard or soft, fixed or mobile), any signs of inflammation (tenderness), any signs of compression (dysphonia, dyspnea), and any palpable lymphadenopathy. The clinician should also evaluate for any signs of hypo- or hyperthyroidism.

If a thyroid nodule is evident, testing includes thyroid hormone panel (TSH, free T3, free T4) and neck US. Measurement of calcitonin levels is necessary in patients with suspicion of familial medullary thyroid cancer or MEN syndromes, but the use in all patients is debated due to concerns over cost-effectiveness as a screening test and issues regarding determination of reliable cutoff values in a pediatric population. The ultrasound will assess the general thyroid anatomy, including echogenic patterns and vascular flow, as well as the surrounding lymph node basins. If nodules are apparent, US can be used to measure the diameter, as well as evaluate for echogenicity, microcalcifications, and signs of capsule involvement.

In patients who have hyperthyroidism, a nuclear medicine scan is used to evaluate for "warm" or "hot" spots. "Hot" spots, or toxic adenomas, are hyperfunctioning, while "warm" spots are normally functioning. Hyperfunctioning nodules rarely harbor malignancy, but up to 5 % of these nodules have papillary carcinoma on pathology. Due to the relatively low chance of malignancy, fine needle aspiration (FNA) is usually bypassed in favor of surgical intervention.

Biopsy of nodules with a diameter over 1 cm in size is recommended. In addition, certain factors warrant biopsy in smaller nodules, including history of radiation exposure, syndromes with high risk of thyroid cancer, a first-degree relative with history of thyroid cancer, or thyroid abnormality with FDG positivity on PET scan. Suspicious US signs include microcalcifications, hypoechogenicity, increased vascularity in the nodule, irregular margins, and invasion of the thyroid capsule. Nodules which are growing in size, particularly during levothyroxine therapy, require biopsy. FNA can be performed on a cooperative patient with the use of local anesthetic; however, many children require sedation or general anesthesia. US guidance is recommended to increase the chance of adequate biopsy and can be used to biopsy suspicious lymphadenopathy.

Results from FNA will be reported as non-diagnostic, benign, suspicious (follicular neoplasm, Hürthle cell neoplasm, follicular lesion of undetermined significance), or malignant (papillary). Benign nodules can be followed clinically and re-biopsied or excised with growth. Repeat FNA should be performed with non-diagnostic results, but repeated episodes usually warrant thyroid lobectomy. Both malignant and suspicious lesions undergo resection.

Up to 20 % of thyroid nodules have "suspicious cytology," which includes follicular carcinoma, follicular variant of papillary carcinoma, and Hürthle cell lesions. While all of these patients will undergo surgical intervention, only 20 %

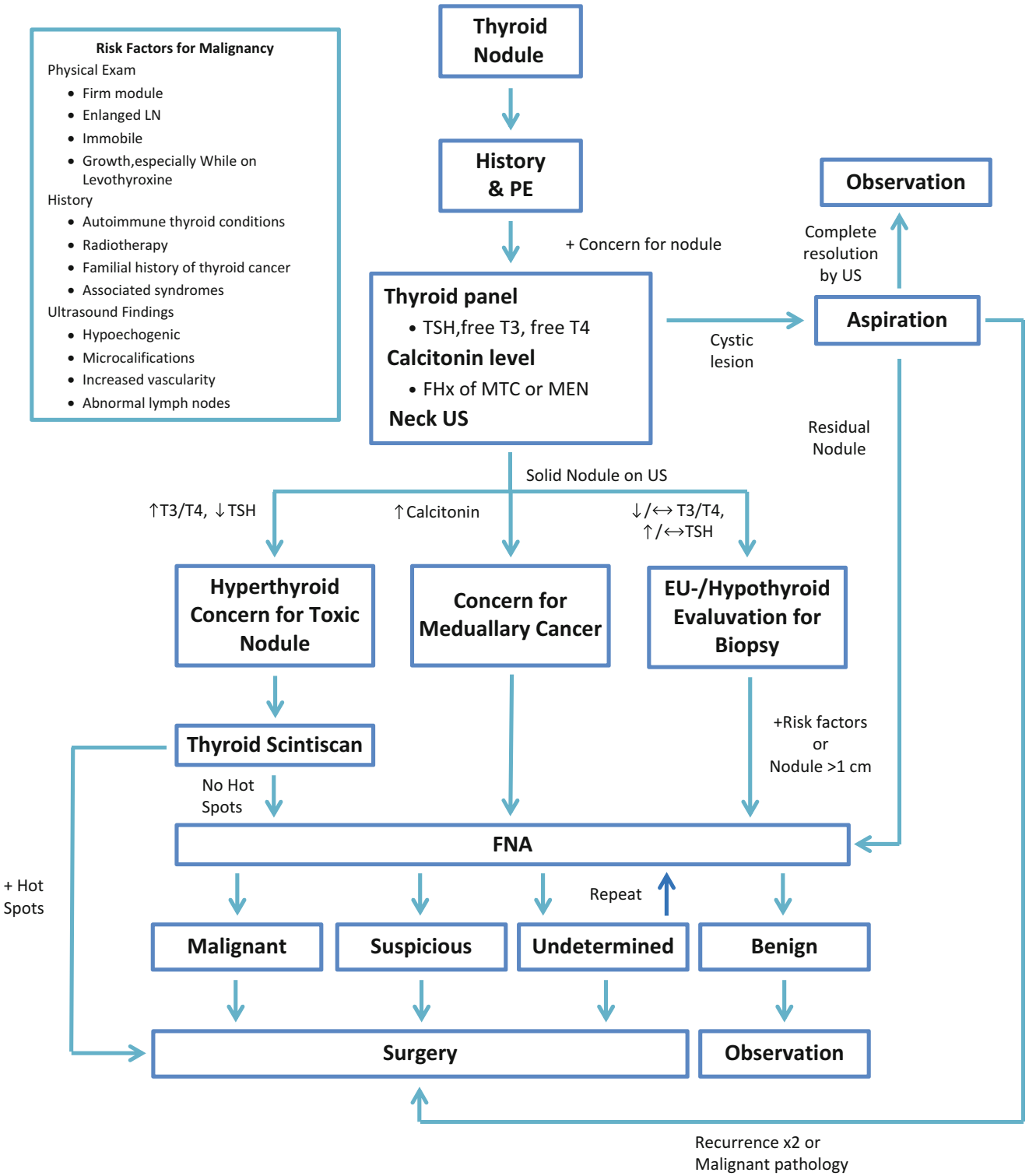

Fig. 29.2 Algorithm for thyroid nodules

of lesions will ultimately be malignant. In order to prevent unneeded intervention, many researchers are evaluating methods to determine malignant potential. One proposed test, ultrasound (US) elastography, analyzes the speed that sound waves pass through the tissue. Malignant nodules usually have increased stiffness compared to the surrounding tissue, potentially allowing US elastography to aid in diagnosis. More recently, ^{18}fluorodeoxyglucose positron emission tomography/computed tomography (^{18}FDG PET/CT) has also been examined as a tool to differentiate benign or

Table 29.1 Symptoms and signs of thyroid function abnormalities

	Hypothyroidism	Hyperthyroidism
Symptoms	Fatigue Weight gain Cold intolerance Constipation Dry skin	Sweating Anxiety Heat intolerance Rapid heart rate/palpitations Frequent stool Insomnia Tremors
Signs	Bradycardia Narrow pulse pressure Weight percentile > height percentile Slowed growth velocity	Tachycardia Widened pulse pressure Height percentile > weight percentile Accelerated growth velocity

malignant nodules. Data for both of these modalities are contradictory and require further testing prior to routine implementation.

Immunocytochemistry has also been evaluated using markers for galectin-3, HBME-1, cytokeratin-19, CD44v6, and telomerase as indicators of differentiated thyroid carcinoma or calcitonin for medullary thyroid cancer. This approach is limited by the fact that a panel of markers is needed for reliability. In addition, these markers have not been rigorously evaluated within a pediatric population. Molecular markers, such as the BRAF mutations seen in many cases of papillary thyroid cancer, could potentially be used to further stratify risk in patients with suspicious cytology and remain one of the more promising areas for future research.

Thyroid Cyst

While thyroid cysts occur in over half of children, little data specifically addresses their management. Currently, evaluation is similar to that of thyroid nodules. If a cyst is discovered on US, aspiration can be performed. Some authors recommend sending this fluid to pathology due to the risk of papillary cancer which is found in anywhere between 5 and 15 % of cystic lesions. If there is a residual nodule after aspiration of fluid, a FNA should be performed and treatment is based on histology. If the cyst completely resolves, the patient should be examined by US in 3–6 months. If the cyst recurs, it may be aspirated a second time, but a third episode prompts hemithyroidectomy. Alcohol ablation has been used for thyroid cysts within adults; however, this technique has yet to be examined within children.

Thyroid Carcinoma

Thyroid disease in children is often grouped into differentiated thyroid cancer (DTC), including papillary thyroid cancer (PTC) and follicular thyroid cancer (FTC), and medullary thyroid cancer (MTC). The most recent data from the Surveillance, Epidemiology, and End Results (SEER) database documents a rapidly increasing incidence in DTC. In the USA, the age-adjusted annual incidence is 0.54 per 100,000 per year. Children present with more advanced disease than adults, with 40–80 % having nodal involvement and 20–30 % with metastatic disease at diagnosis. Despite these factors, 5-year survival is 95–99 % and 20-year survival is 90 %. Efforts to optimize management are hindered by the relative rarity of the condition, and guidelines are based on the adult literature. Staging in children is based on extent of disease with Stage I including any tumor without distant metastasis, while Stage II is any tumor with distant metastasis. This staging system has little relation to outcome.

Papillary Thyroid Cancer

The most common form of thyroid malignancy within the pediatric population (90–95 %) is PTC. PTC will typically present as a thyroid nodule and diagnosis will be made through the previously discussed algorithm. This disease is frequently multifocal and bilateral within the thyroid gland. Grossly, the lesions are firm and white, with invasive appearance into the surrounding tissue. Calcifications may be present and some appear completely cystic. Microscopically, the lesion is composed of neoplastic papillae with a central core of fibrovascular tissue. Psammoma bodies are present due to progressive infarction of the papillae and ensuing calcium deposition. Variants of this pathology (tall cell, diffuse sclerotic, solid, and follicular) tend to act in a more aggressive fashion. Lymphatic invasion is more common than hematologic spread, but metastasis to the lung and bone can be seen late in the disease course.

Due to the high rate of multicentricity, most authors advocate for total or near-total thyroidectomy. Smaller tumors (less than 1 cm) are often treated with lobectomy in adults, but studies within children demonstrate a higher local recurrence rate with this approach, as well as with subtotal

thyroidectomy. With total thyroidectomy, the maximal therapeutic effect of radioactive iodine is achieved and serum thyroglobulin levels can be used to screen for recurrence.

The management of lymph nodes is controversial with management ranging from no lymph node dissection, selective removal of clinically positive lymph nodes, or compartmental dissection. More recent evidence in adults has demonstrated a significantly decreased recurrence after central node dissection. This concern must be balanced against the higher rate of complications with nodal dissection. With the higher rate of lymph node metastasis in children, the growing consensus is that central node dissection should be performed with thyroidectomy for PTC. Additional lateral compartment should be considered with concern for involvement in these regions. In cases of residual disease or metastatic disease, radioactive iodine is used.

Follicular Thyroid Cancer

Follicular thyroid cancer is rare in the pediatric population, representing only 1–1.5 % of cases. Minimal data exists regarding the specific management and outcomes of this disease within children. FTC is less frequently multicentric than PTC, with disease occurring in the contralateral lobe in only 10 % of total thyroidectomies. FTC is generally more aggressive than PTC and metastasizes by a hematogenous route to the bone, liver, or lung. On gross pathology, these lesions are frequently encapsulated with a gray tan or brown color. FTC is distinguished from follicular adenoma by the presence of invasion through the capsule or angioinvasion. The capsule of FTC tends to be thicker than in a follicular adenoma. Angioinvasion is a risk factor for recurrence in both adults and children.

Many of these cases will present as an asymptomatic thyroid nodule and undergo FNA. Due to the difficulty discerning follicular adenoma versus follicular cancer on FNA, diagnosis prior to surgery is difficult unless metastasis is present. Immunocytochemistry and molecular markers may be able to differentiate these groups in the future. For this reason, many surgeons will initially perform thyroid lobectomy with plans for completion thyroidectomy if pathology is consistent with FTC. Due to the lower incidence of lymphatic spread, nodal dissection is not required unless there are clinically positive nodes.

Medullary Thyroid Cancer

Medullary thyroid cancer accounts for approximately 5 % of pediatric thyroid cancer and arises from the parafollicular C cells. MTC can occur sporadically or in association with familial syndromes (MEN IIA, MEN IIB, FMTC syndrome). In sporadic cases, up to 50 % will have lymphatic or hematologic spread at diagnosis. Macroscopically, the tumors are well defined without capsule. The tumors are highly cellular with sheets/nests of cells microscopically.

Surgical management for MTC is total thyroidectomy with central node dissection. In cases of MEN IIA, current recommendations include prophylactic thyroidectomy before age 5. MEN IIB requires thyroidectomy by 1 year of age due to increased aggressiveness of these tumors. Currently, there is no effective therapy for metastatic or recurrent disease.

Surgical Management

Surgical options include lobectomy, subtotal thyroidectomy, near-total thyroidectomy, and total thyroidectomy. Thyroid lobectomy involves resection of one half of the thyroid, the isthmus. With a subtotal thyroidectomy, an entire lobe and half of the remaining lobe are resected in an attempt to preserve both the recurrent nerve and the parathyroid tissue.

The incision for thyroidectomy is a cervical curvilinear incision 1–2 fingerbreadths above the sternal notch, usually along a skin line. The platysma is divided along this line, and skin flaps are dissected superiorly to the thyroid cartilage and inferiorly to the sternal notch. The strap muscles are divided along the midline and retracted laterally. The middle thyroid vein is identified and ligated. The thyroid gland is then rotated medially using blunt dissection. The superior laryngeal artery is identified and ligated, with care taken to identify and preserve the external laryngeal nerve. The superior parathyroid gland, usually located within 1 cm of the crossing of the recurrent laryngeal nerve and inferior thyroid artery, and the inferior parathyroid gland, usually on the anterior or posterolateral surface of the lower pole of the thyroid, are also preserved. The recurrent laryngeal nerve is identified with the aid of a nerve monitor between the common carotid artery, the esophagus, and the inferior thyroid artery. If the procedure is a lobectomy, the isthmus of the gland is divided along the midline and the remaining gland is removed from the tracheal cartilage. In a total thyroidectomy, the same dissection is performed on the contralateral side and the gland is freed from the trachea.

More recently, minimally invasive video-assisted thyroidectomy (MIVAT) has been used within pediatric patients. Initial results show equivalent complication rates with regard to RLN palsy and hypocalcemia, but it is potentially advantageous in terms of operative times and postoperative length of stay. MIVAT is performed through a 1.5 cm cervical skin incision two fingerbreadths above the sternal notch and used a 30° 5-mm endoscope for visualization. In addition, an axillary approach has been used within adults with similar outcomes.

Postoperatively, calcium levels are monitored approximately 4–8 h after completion of the procedure. Surgical complications include hematoma, nerve injury, wound infection, hypothyroidism, and hypoparathyroidism. Notably, complication rates for both nerve injury and hypocalcemia are higher within the pediatric population, ranging from 0–27 % to 6–27 %, respectively. Higher-volume surgeons have significantly lower rates of complication, suggesting that these procedures should be performed in a center with a high-volume surgeon.

Long-term follow-up includes assessment of thyroid hormone levels, US, thyroglobulin level (DTC), radioiodine scans (DTC), and calcitonin levels (MTC). Thyroid hormone levels and cancer markers are routinely assessed every 6 months for at least 5 years, but levothyroxine dosage adjustment prompts assessment of TSH and T4 at 2 months following change. US can be used to screen for disease every 6 months, but may be performed more frequently to follow lymphadenopathy. ^{131}I whole-body scintigraphy is performed in DTC every 6–12 months.

Parathyroid Disease

Parathyroid glands develop during the fifth week of gestation from the third and fourth pharyngeal pouches. During the sixth week of gestation, the glands descend into the neck. The superior parathyroid glands (SPTG) develop from the fourth pharyngeal pouch and typically come to rest on the posterior surface of the upper pole of the thyroid. However, aberrant SPTG can be located in the tracheoesophageal groove, retroesophageal, in the posterosuperior mediastinum, paraesophageal, in the thyroid, or in the carotid sheath (descending order of frequency). The inferior parathyroid glands (IPTG) develop from the third pharyngeal pouch and are typically found on the dorsal surface of the lower pole. These glands are more frequently aberrant, with locations including the thymus gland, the thyroid gland, the thyrothymic ligament, or the submandibular position. Rarer locations for aberrant glands include the carotid bifurcation, posterior triangle of the neck, within the vagus or hypoglossal nerves, within the pericardium, the right diaphragmatic dome, and the supraclavicular region. Grossly, the glands appear yellow brown and are typically 30–35 g in size. The glands are composed of chief cells, which are responsible for synthesis and release of parathyroid hormone (PTH) and oxyphil cells.

The glands secrete PTH in an inverse relationship to calcium levels. This interaction is regulated by the interaction of ionized calcium with calcium-sensing receptors on the surface of parathyroid cells. PTH acts directly on the bones, activating osteoclasts and increasing bone reabsorption, and the kidney, increasing calcium absorption and phosphate secretion. PTH also acts indirectly through vitamin D metabolism to enhance calcium absorption in the gut.

Hypercalcemia

Serum calcium levels are greater in children and neonates than in adults, so age-appropriate references must be used. If unrecognized, hypercalcemia can lead to irreversible end-organ damage. In neonates and infants, signs of hypercalcemia are nonspecific, but include weakness, hypotonia, lethargy, stupor, polyuria, dehydration, nephrocalcinosis, and seizures. The differential diagnosis within this age group includes enriched formulas with excess calcium, inappropriate supplemental parenteral nutrition (low phosphate), neonatal hyperparathyroidism, and extracorporeal membrane oxygenation. Hypercalcemia secondary to enriched formulas is rarely seen due to breast milk fortifiers which have increased phosphate.

In older children, hypercalcemia presents with signs including weakness, fatigue, anorexia, weight loss, renal colic secondary to kidney stones, pancreatitis, and osteitis fibrosa cystica. The differential diagnosis of this condition includes hyperparathyroidism (primary, secondary, tertiary, or ectopic production), hypervitaminosis D, sarcoidosis, subcutaneous fat necrosis, familial hypocalciuric hypercalcemia, idiopathic hypercalcemia of infancy (William's syndrome), thyrotoxicosis, hypervitaminosis A, hypophosphatemia, prolonged immobilization, and thiazide diuretics. In children, unlike adults, neoplasm is rarely the cause of hypercalcemia.

Primary Hyperparathyroidism

Primary hyperparathyroidism is rare within children, accounting for only 1 % of hypercalcemia cases. There is a slight female predominance (3:2) and the incidence is 2–5 per 100,000. Etiologies include parathyroid adenoma (80–85 %) and hyperplasia (10–15 %). While parathyroid adenomas tend to occur sporadically, hyperplasia occurs in the setting of familial syndromes. Children are more likely than adults to present with symptoms of hypercalcemia (80–100 %). In addition, end-organ damage frequently occurs in pediatric patients due to frequent delays in diagnosis as demonstrated by the average time to diagnosis of 24 months.

Labs will reveal elevated PTH and serum calcium levels (Table 29.2). US can be used to evaluate for enlarged glands, but the accuracy is between 48 and 74 % and, in many cases, the gland may not be located. Dual-phase technetium-99 m sestamibi scans with single-positron emission computed tomography/computed tomography (SPECT/CT) have accuracy rates over 90 % for adenoma location. However, these scans are dependent on continued radionuclide uptake in both scan phases, leading to a false-negative rate of up to 40 %.

Management of adenomas is excision of the abnormal gland or glands with or without four-gland exploration, emphasizing the benefit of preoperative localization and

Table 29.2 Types of hyperparathyroidism with associated features

	Causes	Lab
Primary hyperparathyroidism	Parathyroid hyperplasia Parathyroid adenoma	↑Ca, ↑PTH, ↓Phos
Secondary hyperparathyroidism	Chronic renal failure with decreased vitamin D absorption	↓Ca, ↑PTH, ↑Phos
Tertiary hyperparathyroidism	Autonomous activation of glands post-renal transplant	↑or↔ Ca, ↑PTH

intraoperative PTH monitoring. Parathyroid hyperplasia is treated by subtotal parathyroidectomy or total parathyroidectomy with autotransplantation. Surgical management is reserved for patients with patients with elevated serum calcium and elevated PTH, regardless of symptoms due to the high risk of complications secondary to hypercalcemia throughout a pediatric patient's life.

Secondary and Tertiary Hyperparathyroidism

Secondary hyperparathyroidism occurs in patients with chronic renal failure due to decreased vitamin D activation by the kidney and subsequent decreased absorption of calcium in the gastrointestinal tract. In addition, there is decreased excretion of phosphate through the renal tract, which binds calcium within the serum. The resulting hypocalcemia leads to chronic stimulation of the parathyroid glands and four-gland hyperplasia. Labs show hypocalcemia, hyperphosphatemia, and elevated PTH. Medical management includes dietary restrictions (phosphate), vitamin D supplementation, calcitriol, and calcimimetics. Surgical therapy is required in approximately 5 % of patients for severe or persistent hypercalcemia or significant associated complications such as osteopenia, renal calculi, or other complications of hyperparathyroidism. Surgical options include subtotal parathyroidectomy or total parathyroidectomy with autotransplantation.

Tertiary hyperparathyroidism occurs after renal transplantation when glands continue to function autonomously. Labs reveal normal or high-calcium and elevated PTH levels. Surgical options include subtotal parathyroidectomy or total parathyroidectomy with autotransplantation.

Neonatal Hyperparathyroidism

Neonatal hyperparathyroidism is rare and most frequently associated with multi-gland hyperplasia. These children may present with severe bone deformities, fractures, respiratory difficulties due to rib cage deformities, hepatosplenomegaly, and anemia. Causes of this condition include maternal hypocalcemia, pseudohypoparathyroidism, and renal tubular acidosis. In general, serum calcium levels will be normal, but 25 % present with elevated calcium levels. These cases are typically treated with supportive measure and will resolve within a few weeks.

Neonatal Severe Hyperparathyroidism

Neonatal severe hyperparathyroidism (NSHPT) is a life-threatening form of primary hyperparathyroidism that is associated with familial hypocalciuric hypercalcemia (FHH). FHH is an autosomal dominant disorder which is typically asymptomatic and is diagnosed by hypercalcemia and low levels of urinary calcium. Both diseases are associated with a mutation in the calcium-sensing receptor gene on chromosome 3q. FHH occurs with a single defective allele, while two defective alleles are seen with NSHPT. These infants will present with hypercalcemia, hypophosphatemia, elevated PTH, and osteopenia at birth. Medical management of NSHPT includes intravenous bisphosphonates, which can quickly lower the serum calcium levels. Should this therapy fail, urgent subtotal parathyroidectomy is indicated.

Surgical Management

With adenomas, either minimally invasive parathyroidectomy (MIP) or traditional four-gland exploration can be performed. With localized glands, MIP can be performed through a 1.5–2 cm incision in the anterior neck skin fold on the side of identified lesion. A nerve stimulator is used to help identify and preserve the RLN. If the enlarged gland is encountered, it is excised and PTH levels are drawn 5–10 min after excision. The PTH level is expected to drop greater than 50 % from baseline values if the appropriate gland has been removed. If an enlarged gland is not discovered or there is not an appropriate drop in PTH, the procedure is converted to a traditional four-gland exploration.

Total parathyroidectomy with autotransplantation is performed through a cervical incision in the anterior neck skin fold. The dissection into the neck is similar to that of a thyroidectomy until the strap muscles have been retracted laterally. The four glands are identified and excised, preserving the recurrent laryngeal nerves. Intraoperative frozen samples should be used to confirm removal of four glands.

Table 29.3 Multiple endocrine neoplasia (MEN) syndromes

	Tumors	Gene mutation	Initial presentation	Screening with Fm Hx
MEN I	Parathyroid adenoma Pancreatic islet cell tumor (gastrinoma) Pituitary gland adenoma (prolactinoma) *Benign adrenocortical tumors* *Carcinoids (GI, thymic, bronchial)*	*Menin (Chr 11q13)*	Parathyroid adenoma (65 %) Pancreatic islet cell tumor (35 %)	***Start at age 10*** *Annual* • Ca • Pancreatic PP • Gastrin • GH • Prolactin • Pancreatic US • ±Abdominal CT/MRI • ±Brain MRI *Every 3–5 years* • Pancreatic/pituitary MRI
MEN IIa	Medullary thyroid cancer Pheochromocytoma Parathyroid adenoma	RET proto-oncogene (Chr 10q11, extracellular domain)	Medullary thyroid cancer (prior to age 5)	RET mutation screening first year of life • *See Table 29.4*
MEN IIb	Medullary thyroid cancer Pheochromocytoma Mucosal neuromas GI ganglioneuromatosis Marfanoid habitus	RET proto-oncogene (Chr 10q11, intracellular domain)	Medullary thyroid cancer (prior to age 1)	RET mutation screening first year of life • *See Table 29.4*

Autotransplantation can be performed by implanting 50–100 g of a gland into the sternocleidomastoid or the forearm. With a subtotal parathyroidectomy, 50–100 g of one gland is left in situ, taking care to preserve the blood supply. In these cases, banking the remaining tissue can provide the opportunity to perform autotransplantation should the residual tissue fail. In the pediatric population, success of surgical management is 96–100 %. However, complications, including recurrent laryngeal nerve injury, bleeding, infection, and postoperative hypocalcemia, are more common than in adults.

Pediatric Multiple Endocrine Neoplasia Syndromes

MEN I

MEN I syndrome consists of the triad of parathyroid adenomas, pancreatic islet cell tumors (typically gastrinoma), and anterior pituitary gland adenomas (typically prolactinoma). In addition, benign adrenocortical tumors, gastrointestinal, thymic, and bronchial carcinoids can occur. MEN I is caused by mutations in the *menin* gene, located on chromosome 11q13. The majority of patients will initially present with parathyroid adenomas (65 %), while 30 % will have pancreatic islet cell tumors. In patients with known family history or mutation, current recommendations are to start screening at 10 years of age using annual serum calcium, pancreatic polypeptide, gastrin, growth hormone, and prolactin levels. Pancreatic US is recommended annually, while pancreatic and pituitary MRIs are recommended every 3–5 years. Some authors advocate annual abdominal CT or MRI, as well as annual brain MRI.

MEN IIA/IIB

MEN IIA is characterized by medullary thyroid cancer (100 %), pheochromocytoma (50 %), and parathyroid adenomas (Table 29.3). MEN IIB is characterized by medullary thyroid cancer (100 %), pheochromocytoma (50 %), mucosal neuromas, ganglioneuromatosis of the GI tract, and marfanoid habitus. MEN 2 is associated with mutations in the RET proto-oncogene located on chromosome 10q11, which encodes a receptor for tyrosine kinase. While MEN IIA mutations occur in the extracellular domain cysteine residues leading to ligand-independent dimerization, MEN IIB mutations are usually located in the intracellular domain leading to alterations in signal transduction. In general, MTC is the presenting tumor of MEN II and is, therefore, used for screening. These tumors tend to present before age 5 in MEN IIA and around age 1 in MEN IIB. Due to the aggressive nature of these tumors, patients with family history of MEN II are recommended to have testing for the RET mutation within the first year of life. Patients diagnosed with MEN IIA are recommended to undergo prophylactic thyroidectomy before age 5, while those with MEN IIB should undergo thyroidectomy before age 1. General screening recommendations for pheochromocytoma include annual urine catecholamine testing and abdominal MRI every 3 years with specific guidelines published by the American Thyroid Association (Table 29.4).

Table 29.4 ATA-based recommendations for screening and prophylactic thyroidectomy

ATA Level[a]	A	B	C	D
MEN 2 subtype	FMTC	FMTC/MEN 2A	MEN 2A	MEN2B
Common RET mutations	768, 790, 804, 891	609, 611, 618, 620, 630	634	918, 883
MTC aggressiveness	Moderate	High	Higher	Highest
MTC age of onset	Adult	5 years	<5 years	First months of life
Age of prophylactic thyroidectomy	When calcitonin rises or age 5–10[b]	5 years	<5 years	<1 year
Screening for pheochromocytoma[c]	Start at 20 years, then periodically	Start at 20 years, then annually	Start at 8 years, then annually	Start at 8 years, then annually
Screening for HPT[d]	Start at 20 years, then periodically	Start at 20 years, then periodically	Start at 8 years, then annually	N/A

[a]Level D represents highest risk
[b]May delay past 5 years if normal annual basal/stimulated serum calcitonin level, normal annual neck US, less aggressive MTC family history
[c]Annual urine catecholamines, abdominal MRI every 3 years
[d]Serum Ca and PTH

Summary

Thyroid lesions run the spectrum from benign to malignant. Congenital lesions, such as ectopic thyroid tissue, may occur anywhere along the thyroid's path of descent and can require surgical excision. Goiters are usually secondary to autoimmune conditions within the USA and rarely require resection. In children with Graves disease, the majority will not achieve remission using medical management with methimazole, requiring either radioactive iodine therapy or thyroidectomy (total or near total). The risks associated with radioactive iodine therapy for Graves disease are age and dose dependent, including an increased risk of thyroid cancer, increased risk of cancer-related mortality, and increased risk of parathyroid hyperplasia.

Thyroid nodules while rare within the pediatric population, there is an increased risk of malignancy compared to adults. Patients with papillary thyroid carcinoma should undergo total thyroidectomy with central node dissection, while those with follicular thyroid cancer need only a total thyroidectomy. The risk of complications with thyroidectomy, including nerve injury and hypocalcemia, is more frequent within the pediatric population, but rates are ameliorated with high-volume surgeons.

Primary hyperparathyroidism in children may be sporadic or familial and are usually due to adenomas or hyperplasia, respectively. Hyperparathyroidism in neonates may be relatively benign and self-limiting (neonatal hyperparathyroidism), but neonatal severe hyperparathyroidism can be life-threatening and requires emergent surgical intervention. MEN I (parathyroid adenomas, pancreatic islet cell tumors, anterior pituitary gland adenomas) usually presents with parathyroid adenomas, and screening for tumors in patients with known family history or mutation should start at age 10. MEN II usually presents with medullary thyroid cancer. Prophylactic thyroidectomy should occur by age 5 with MEN IIA (medullary thyroid cancer, pheochromocytoma, parathyroid adenoma) and by age 1 with MEN IIB (medullary thyroid cancer, pheochromocytoma, mucosal neuromas, ganglioneuromatosis).

Editor's Comments

Thyroid nodules are rare in children, but because of the higher risk for malignancy we tend to be more aggressive regarding biopsy and resection. Hot nodules are usually benign but not always, and FNA can be difficult or impossible in some children. Therefore, there is a very low threshold for recommending thyroid lobectomy. Although no imaging study is 100 % accurate, US has become invaluable in the assessment of the thyroid gland and the lymph nodes of the neck, with some experienced ultrasonographers able to distinguish benign nodules and lymph nodes from malignant ones. In some cases, a needle-core biopsy can be done for palpable lesions or with US guidance under general anesthesia. Bleeding is a risk but gentle pressure along the biopsy tract is an effective tamponade.

If the nodule is proven to represent malignancy, total thyroidectomy is usually recommended, even for small papillary carcinomas. This protects the patient from bilateral disease, allows more effective ablation of metastases with ^{131}I, permits the use of thyroglobulin as a marker for recurrence, and increases the sensitivity of postoperative scans. In experienced hands, the risk of recurrent laryngeal nerve injury or hypoparathyroidism after total thyroidectomy should be quite low. Nevertheless, depending on the available experience and expertise among endocrinologists and surgeons at a particular institution, the child might need to be referred to a tertiary care center or another institution with more experience and a safe track record.

The surgical technique for thyroidectomy is essentially the same as it is in adults. The cleaner planes of the child's neck allow the surgeon to maintain a plane of dissection essentially right on the capsule of the thyroid throughout the operation. The recurrent laryngeal nerve is usually easily identified and is frequently much larger than expected. Recurrent laryngeal nerve monitoring should be considered standard for most thyroidectomies, especially for reoperative cases, children with pre-existing unilateral vocal cord paralysis, and tumors that are infiltrative or invasive. The parathyroid glands can be difficult to identify but every attempt should be made to do so. A tiny piece of any questionable tissue should be sent for biopsy and, if it appears to be ischemic, should be placed on ice until the frozen-section diagnosis is returned. If confirmed to be parathyroid tissue, it should be implanted into the sternocleidomastoid muscle.

When dealing with any carcinoma, but especially medullary cancer, it is extremely important to perform a proper lymph node dissection. The surgeon should be familiar with all the anatomic zones of the neck including their borders and their contents and the details of the operation for staging purposes should be recorded with precision. For metastatic papillary carcinoma, removing all clinically positive nodes is usually sufficient and second or third operations to remove newly positive nodes are not unheard of. Even in the presence of metastases, papillary thyroid carcinoma is associated with a very good prognosis.

Parathyroid adenomas are rare but there should be a serious attempt to localize it preoperatively with US, sestamibi scan, or MRI. Surgical treatment of four-gland hyperplasia is somewhat controversial, but given the dynamic nature of a child's metabolism and unpredictable changes in endocrine status with growth and development, it seems prudent to remove all glands and place a portion in the muscle of the forearm while cryopreserving some extra tissue in the event more is needed in the future. To have to return to the neck for a second operation seems unnecessarily risky.

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Part V

Esophagus

Esophageal Atresia and Tracheoesophageal Fistula

30

Robert Baird and Jean-Martin Laberge

In 1974, N.A. Myers described the repair of esophageal atresia as "the epitome of modern surgery." More than 40 years later, innovations in neonatal care, improvements in instrumentation and minimally invasive techniques, and a better understanding of potential postoperative complications continue to make this statement true. With an incidence of approximately of 1 in 2000 live births, esophageal atresia (EA) with tracheaesophageal fistula (TEF), a previously fatal diagnosis, now has survival rates in excess of 90 %. The majority of patients will have a blind proximal esophageal pouch and a distal tracheoesophageal fistula—although alternative configurations must be recalled in the diagnostic workup. An unrecognized fistula to the proximal pouch (either alone or in conjunction with a distal fistula) can complicate the management and worsen the postoperative course.

Esophageal atresia should be suspected on prenatal ultrasound (US) by the absence of a gastric bubble, polyhydramnios, and distension of the upper esophagus during swallowing attempts by the fetus. The majority of patients, however, present only after birth with excessive salivation, mucus coming out of the mouth or nose, and noisy breathing with episodes of choking or cyanosis. These symptoms worsen if oral feedings are attempted. The diagnosis is confirmed when a 10-Fr Replogle tube inserted through the mouth or nose cannot be passed beyond about 10 cm. Smaller or more flexible catheters should be avoided because they can coil in the upper esophagus and give a false impression of esophageal patency. The tube is placed on suction to clear excess secretions. Anteroposterior and lateral radiographs that include the neck, chest, and abdomen ("babygram") should then be obtained while gentle pressure is maintained on the Replogle tube and 10 mL of air are injected through it. This delineates the location of the upper pouch in relation to the vertebral bodies. Routine contrast studies are not indicated and can lead to aspiration, although some centers still advocate their use, under careful monitoring, particularly to detect an upper pouch fistula.

The X-ray is crucial for several reasons: (1) The presence of abdominal gas confirms the presence of a distal fistula (~85 % of cases); its absence usually indicates a pure atresia, to be confirmed at bronchoscopy. (2) The Replogle tube tip should project over the C7 to T2 vertebral body. An abnormally high or low blockage could indicate pharyngeal or esophageal perforation rather than atresia, especially in a premature baby or when there is blood-tinged aspirate from the Replogle. In such circumstances, a contrast study is indicated, using 1 mL or less of a nonionic, isosmotic water-soluble agent. (3) Anomalies of vertebrae or ribs may be detected. (4) Cardiac malformations or a right aortic arch may be suggested. (5) The pattern of abdominal gas may suggest or exclude a concomitant duodenal atresia. (6) The lungs should be assessed for signs of pneumonia, which usually occurs in the upper lobes and is related to a delay in diagnosis.

The initial diagnosis may sometimes have been made at another hospital before the infant is transferred to a tertiary care pediatric center. During transfer, it is important to keep the baby warm, to keep the head elevated with the Replogle tube on continuous suction, and to maintain good oxygenation. The physical examination should assess the pulmonary status and look for signs of associated malformations such as cardiac, anal, limb, and chromosomal anomalies. A scaphoid abdomen suggests the diagnosis of a pure atresia. 35 to 50 % of infants with EA have other anomalies (Table 30.1). In about 10 %, these occur in associations such as VACTERL (vertebral, anal, cardiac, tracheoesophageal, renal, limb) or less frequently CHARGE (coloboma, heart defects, choanal atresia, growth retardation, genitourinary anomalies, ear abnormalities/deafness) association.

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Table 30.1 Associated anomalies

System	Percentage
Cardiovascular	20–30
VSD, ASD, tetralogy of Fallot, PDA, coarctation, R aortic arch	
Gastrointestinal	15–25
Imperforate anus, duodenal atresia, malrotation, Meckel's diverticulum, distal esophageal stenosis	
Genitourinary	10–20
Hydronephrosis, renal agenesis, hypospadias, undescended testis	
Musculoskeletal	10–15
Extremity malformations (radial ray defects), vertebral anomalies, hip dysplasia	
Craniofacial/CNS	5–10
Cleft lip/palate, dysmorphism, eye anomalies, spina bifida, hydrocephalus	
Chromosomal	3–5
Trisomy 21, Trisomy 18, Turner's syndrome	
Respiratory tract (excluding tracheomalacia)	3–5
Lung hypoplasia/agenesis, choanal atresia, laryngeal web, laryngotracheoesophageal cleft	
Miscellaneous	1
Omphalocele, CHARGE	

Note: Only the most frequently associated anomalies are listed; many others have been described

Preoperative Preparation

After a complete physical examination, routine blood work including a crossmatch should be performed. Preoperative echocardiogram is also indicated to assess for major structural abnormalities of the heart, the position of the aortic arch, and if possible the sidedness of the descending aorta. In our experience, EA in an infant with a right-sided arch is still best approached from the right provided the proximal descending aorta descends to the left; the surgical approach should be dictated by the location of the proximal descending aorta rather than by the arch itself. Further VACTERL workup (skeletal survey, renal ultrasound) should be continued postoperatively.

If life-threatening anomalies are suspected (Trisomy 13 or 18, anuria, complex cardiac malformation) it is wise to postpone surgery until appropriate investigations and consultations are obtained. In cases of extreme prematurity, there is a theoretical argument to delay operative repair 24–48 h to allow for germinal matrix stabilization after birth and reduce the risk of intraventricular hemorrhage. On the other hand, babies with EA/TEF who develop respiratory distress syndrome (RDS) and require intubation should be operated early, since the lungs can become less compliant with worsening RDS, and ventilation then preferentially passes through the fistula into the stomach. If extreme gastric distension occurs, not only might it become impossible to achieve adequate ventilation, gastric perforation could ensue. In such cases, catheter decompression of the distended stomach or pneumoperitoneum may temporize the patient until an emergent procedure can be performed.

Operative Technique

The operative steps to repair a typical EA with distal TEF are well established (Table 30.2). We strongly advocate performing a rigid bronchoscopy for conventional EA/TEF before proceeding with repair. The same applies to suspected pure atresia at the time of gastrostomy creation. While several different anesthetic options exist, we prefer performing the bronchoscopy while the neonate is spontaneously breathing and the vocal cords sprayed with local anesthetic. In patients with EA and distal TEF, the bronchoscopy is useful to (1) eliminate a proximal TEF, which could be missed during repair; (2) eliminate other airway malformations such as a laryngotracheoesophageal cleft (LTEC), laryngeal web, or subglottic stenosis; (3) ensure normal preoperative vocal cord movement; (4) evaluate for the presence of tracheomalacia (although this usually only becomes clinically apparent in the postoperative period); and (5) evaluate the site of the distal TEF—if one sees a "trifurcation" (a TEF at the carina) and if the Replogle tube ends at C7 on the radiograph, the surgeon knows that it will be a long-gap esophageal atresia and can prepare for it accordingly.

Once the bronchoscopy is complete, the patient is formally intubated and positioned. The whole procedure takes <5 min and should be recorded for later review. The only situation in which the risk of bronchoscopy might outweigh the benefits is in a premature baby with severe RDS, but even in this situation, the bronchoscope can be used to deliver surfactant directly in the mainstem bronchi, as opposed to losing part of it through the TEF.

A Word of Caution Anesthesia textbooks often recommend intubating beyond the fistula to avoid ventilating through it. The problem is that this is impossible with a very low or trifurcation fistula, and even with the usual distal tracheal fistula, there is a risk that the tube could slip into it when positioning the patient for thoracotomy. Having done the bronchoscopy at the beginning, everyone can see the site of the fistula. During the operation, the rigid bronchoscope should be kept in the room in case ventilation becomes problematic. The quality of image even with small flexible bronchoscopes has also improved and makes this another useful tool to have during surgery. If a patient desaturates and does not have a pneumothorax or massive gastric distension and the anesthesiologist is convinced the tube is going through the vocal cords, the likelihood is that its tip is in the fistula. *Take it out* and use the rigid bronchoscope to ventilate the patient—this maneuver can be lifesaving.

Table 30.2 Summary of operative steps for open repair of esophageal atresia with distal TEF

Operative step	Rationale
Rigid bronchoscopy	Assess position of fistula; check for proximal fistula
Muscle-sparing thoracotomy	Minimize the risk of scoliosis
Extrapleural dissection	Avoid empyema if the anastomosis leaks
Divide the azygos (optional) Gentle distal dissection	Improve visualization Avoid devascularization
Fistula ligation close to trachea	Avoid postoperative diverticulum
Check for tracheal leak with Valsalva maneuver	Repair immediately before proceeding
Pass catheter via distal esophagus	Rule out distal stenosis
Anesthesia to manipulate Replogle tube	Aids in upper pouch visualization and dissection
Assess gap length	May require "lengthening maneuvers" (see text)
After back wall, pass soft feeding tube	May begin early postoperative enteral feeds
Complete end–end anastomosis (with tension)	Alternative configurations have higher complications
Check for anastomotic leak	Repair immediately before proceeding
Interpose viable tissue (azygos, pleura)	Minimize postoperative refistulization rate
Chest tube placement (optional)	Minimize consequence of leak (benefit not been proven)
Loosely approximate ribs	Minimize the risk of scoliosis/ rib fusion

After bronchoscopy, the patient with EA and distal TEF is placed in left lateral decubitus (right side up) with the right arm extended and a roll placed under the left chest. Many anesthesiologists prefer to have the patient spontaneously breathing—with some assistance—until the fistula is encircled, in order to minimize gastrointestinal distension that would occur with positive-pressure ventilation. We use a limited posterolateral thoracotomy incision along the skin lines just below the tip of the scapula, with the aim of entering the chest in the fourth intercostal space. In most cases, entry into the chest can be achieved by mobilizing and retracting the latissimus dorsi posteriorly and the serratus anterior forward. Others prefer dividing the latissimus dorsi; at this level, this has no sequelae as intramuscular nerve regeneration occurs and function is preserved. The surgeon's finger can then slip under the scapula and count rib spaces. The intercostal muscles should then be carefully divided to keep the pleura intact. This extrapleural dissection aids in sealing any postoperative anastomotic leak and is best performed with a wet peanut dissector followed by slowly introducing a moistened gauze sponge to develop the extrapleural space. A small pleural tear can usually be ignored, as it will seal rapidly after surgery. It should be noted that, throughout the operation, desaturations sometimes occur, requiring the anesthesiologist to re-expand the right lung from time to time.

We usually divide the arch of the azygos vein between ties. The distal esophagus can usually be found just deep to this structure, and it enters the trachea just above it in most instances. Some surgeons prefer to keep the azygos vein intact, suggesting that it decreases mediastinal edema and anastomotic leak. Identification of the vagus nerve and observation of air distending the distal esophagus confirms its position. Palpation is important to confirm the position of the trachea, main stem bronchi, and aorta. A Silastic vessel loop is passed around the distal esophagus near its junction with the trachea after meticulous blunt dissection. Care is taken to avoid damage to the vascular and nervous supply to the lower esophagus. With a small amount of cephalad dissection and more fingertip palpation, the junction between the fistula and trachea becomes clear. The fistula is divided stepwise and closed with interrupted 5-0 synthetic resorbable sutures (we use PDS). This should be done close enough to the trachea to avoid leaving a diverticulum, while not causing tracheal stenosis (a rare event since the membranous part of the trachea is wider than normal in EA/TEF patients). The area is then checked for air leaks and the distal esophagus should be intubated with an 8-Fr tube down to the stomach to ensure patency and an adequate caliber.

With the fistula addressed, the surgeon may then proceed with identification of the proximal pouch. If the patient is extremely premature or unstable, closing the distal esophagus and tacking it to the prevertebral fascia under some tension for later repair might be appropriate. If the surgeon elects to continue, a figure-of-eight stay suture should be placed on the apex of the proximal pouch. It is mobilized with a sharp and blunt dissection and gentle use of the cautery. It often seems to share a common wall with the posterior part of the trachea in its lower portion. After the first 1–2 cm, the dissection usually becomes easier, unless there is a proximal fistula. The upper pouch being thicker and better vascularized than the lower esophagus can be dissected as far as the pharynx, if necessary.

The anastomosis is usually performed under mild or moderate tension, defying traditional surgical dogma, yet heals adequately in the majority of patients. The distal esophagus is inspected and gently dilated with a fine mosquito or Jake forceps to ensure an adequate lumen. There can be cartilage remnants in the wall of the lower esophagus close to the trachea as well as poor blood supply; many surgeons advocate resecting a few millimeters of esophageal end. A transverse opening is then made in the upper pouch, and the distal esophagus can be spatulated if necessary. Two corner full thickness sutures of 4-0 or 5-0 synthetic resorbable sutures are placed in both ends, so that the knots will be on the outside, but these are not tied yet. The posterior row of 3–4

sutures is placed such that the knots will be inside the lumen to facilitate placement and tying. One must be careful to avoid trauma to the esophageal wall during placement of the sutures and to include all layers, as the mucosa tends to retract. Once the posterior row is in place, gradual tension is applied on all sutures, while the proximal and distal esophagus are brought in apposition with DeBakey forceps. The posterior and corner sutures are tied and a 5- or 6-Fr Silastic nasogastric tube can then be passed for postoperative feeding. The anastomosis is completed with four or five interrupted sutures with the knots on the outside.

If the two esophageal ends cannot be approximated after full mobilization of the upper pouch and constant traction maintained for 20–30 min in the operating room, the next steps available are careful mobilization of the distal esophagus while maintaining its blood supply, upper pouch flap, and circular or spiral myotomy (allows a gain of up to 1.5 cm).

Once the esophageal anastomosis is complete, air is injected through a proximal Replogle tube after the anastomosis is placed under saline in order to detect leaks. Mediastinal tissue, pleura, or azygos vein should then be used to cover the tracheal side of the fistula. A small extrapleural chest tube may then be placed close to the anastomosis—this is connected to a sealed drainage system but not placed to suction. The thoracotomy is closed in layers, avoiding tight pericostal sutures that can lead to overlapping or fused ribs.

Thoracoscopic Repair

Thoracoscopic repair has been successfully performed since 1999, with several large series now described in the literature. There are advantages and drawbacks of this approach, though the short-term complication rates (anastomotic leak or stricture) appear to be comparable (Table 30.3).

The main arguments of its proponents are the morbidity and scarring associated with thoracotomy, with the added benefit that the anastomosis appears under less tension than with open repair. While this approach appears safe in the hands of the pioneers and minimally invasive surgical experts who have described it, those unfamiliar with the details of the technique should be assisted or mentored during the early stages of their individual learning curve.

Table 30.3 Summary of advantages and disadvantages of thoracoscopic EA/TEF repair

Advantages	Disadvantages
Magnification; improved visualization	Requires lung isolation
Improved cosmesis	Pneumothorax may raise CO_2
Less incisional pain	Eliminates the security of extrapleural approach
Reduced musculoskeletal sequelae	Requires advanced minimally invasive surgery (MIS) technical skills
	Well-documented learning curve (surgical and anesthetic)

Postoperative Care

The patient should be managed by a team approach that includes surgeon, neonatologist, nurses, and respiratory therapists. In a term baby with an uncomplicated anastomosis, extubation should typically be achieved within 24 h. Some prefer to keep the child heavily sedated or even paralyzed for a few days, especially when the anastomosis has been done under a lot of tension, in which case extubation may be delayed for up to 6–7 days. Neck flexion has also been advocated to decrease tension on the anastomosis, although these practices are unproven. We keep the tip of the Replogle tube above the anastomosis as marked intraoperatively and under continuous suction. Some remove the Replogle tube after a few days if there is minimal drainage, indicating passage of saliva through the anastomosis. Parenteral nutrition is started as soon as possible and enteral feedings are initiated through the Silastic feeding tube.

If an extrapleural chest tube has been placed in the operating room, it should be kept on underwater seal drainage and gentle (10 cm H_2O) suction may be added for the first 24 h. Usually only a minimal amount of serous drainage is noted. We obtain a contrast esophagram and upper gastrointestinal contrast study (UGI) under fluoroscopy 5–7 days postoperatively, to identify any anastomotic leaks and prognosticate the development of a stricture using the Esophageal Anastomotic Stricture Index (EASI)—a ratio of the narrowest site of the anastomosis to the distal esophagus (Fig. 30.1). As long as there is no leak and the child demonstrates a normal swallowing reflex, feedings should be initiated and the child gradually weaned from supplementary tube feedings.

The infant may be discharged when feeding well and gaining weight, occasionally with the feeding tube still in place to ensure adequate intake. Parents should be warned about the signs of complications such as gastroesophageal reflux, tracheomalacia, anastomotic stricture, and recurrent fistula; all babies should be discharged on acid-suppression therapy.

Patients should be followed up frequently in the first year of life and then once or twice a year at least until school age and preferably until adulthood. We recommend pureed food up to 12–18 months and then only minced food until 5 years of age when the child has learned to chew well before swallowing and has adequate teeth to do so. Ideally, the long-term care of survivors of esophageal atresia should be transitioned to adult specialists for regular endoscopic esophageal surveillance—these patients have a well-documented increased risk of esophageal cancer.

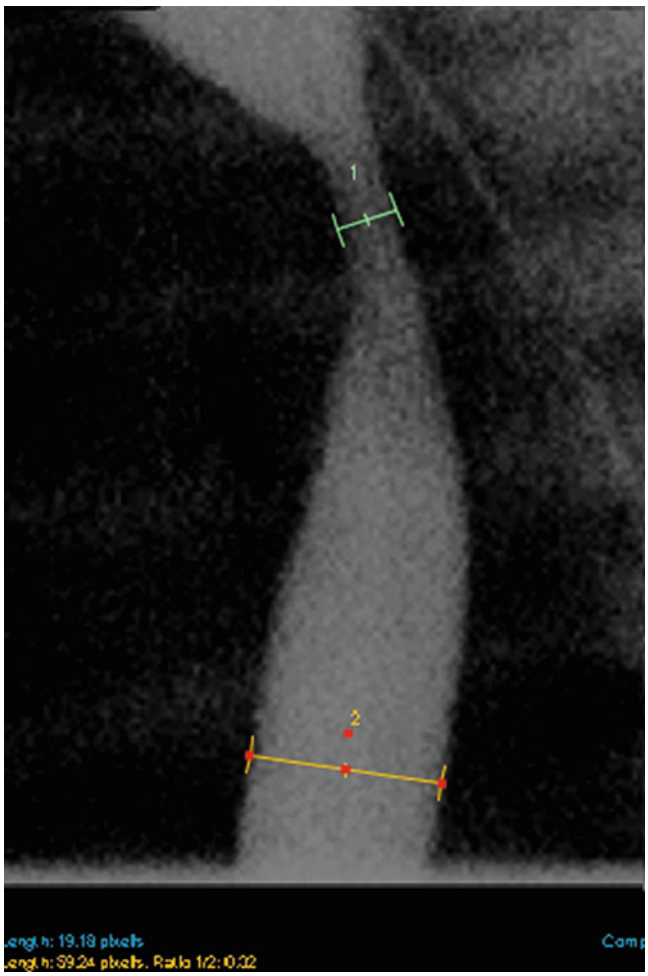

Fig. 30.1 Example of a postoperative esophagram (lateral projection) demonstrating the esophageal atresia stricture index (EASI), which is "easily" calculated by dividing the diameter at the narrowest point by the diameter of the distal esophagus (Reprinted with permission from: Sun LY, Laberge JM, Yousef Y, Baird R. The Esophageal Anastomotic Stricture Index (EASI) for the management of esophageal atresia. J Pediatr Surg. 2015 Jan;50(1):107–10)

Complications

Complications after EA repair can be divided roughly into early (<30 days), intermediate (1–3 months), and late complications (Table 30.4).

Anastomotic leaks occur in 5–10 % and can be suspected by the presence of frothy saliva in the chest tube drainage. The early esophagram is typically diagnostic. Small extrapleural leaks that are well drained by the tube are treated with continued upper pouch suctioning, antibiotics, and a delay in oral intake; these usually seal spontaneously. A complete hemithorax "white-out" or a massive pneumothorax is usually caused by a major leak or a total anastomotic disruption. Breakdown of the tracheal suture line should also be considered. A contrast study will usually confirm the suspected diagnosis, although this should not unduly delay operative care if a patient is rapidly deteriorating. When thoracotomy is required, it is sometimes possible to simply repair the dehiscence if the tissues appear healthy and the repair can be performed under minimal tension. Otherwise, options include the creation of a cervical esophagostomy and gastrostomy or simply closing the upper pouch, draining widely, and planning for a delayed repair.

Patients who develop recurrent coughing, choking, apneic episodes, pneumonia, and vomiting or regurgitation present a diagnostic challenge. These are symptoms common to several of the complications. Choking during feedings may indicate esophageal stricture, a recurrent or missed TEF, tracheomalacia, a laryngeal cleft, or uncoordinated swallowing with aspiration. Choking after feedings, with or without vomiting, is usually a manifestation of gastroesophageal reflux disease (GERD). The contrast esophagram with video fluoroscopy is the first and most important investigation (Fig. 30.2). While the focus is usually on the esophagus, attention should also be paid to the tracheal diameter on lateral views during inspiration and expiration and with a bolus

Table 30.4 Complications of esophageal atresia repair

Type	Timing	Rough incidence of significant/symptomatic complication
Anastomotic leak (+/− pneumothorax, empyema)	Early	5 %
Anastomotic dehiscence	Early	1 %
Recurrent fistula	Early/intermediate[a]	3–8 %
Anastomotic stricture	Early/intermediate	20–30 %
Swallowing incoordination, aspiration, poor suck	Early/intermediate	5 % + higher in prematurity
Tracheomalacia	Early/intermediate	5–10 %
Gastroesophageal reflux disease	Early/intermediate/late	10–25 % require surgery, >50 % medical treatment
Recurrent pneumonia/bronchitis/asthma	Intermediate/late	10–30 %
Failure to thrive	Intermediate/late	10–20 %
Scoliosis and chest wall deformities	Late	<5 %

[a]A recurrent fistula may not be recognized until months or sometimes years later

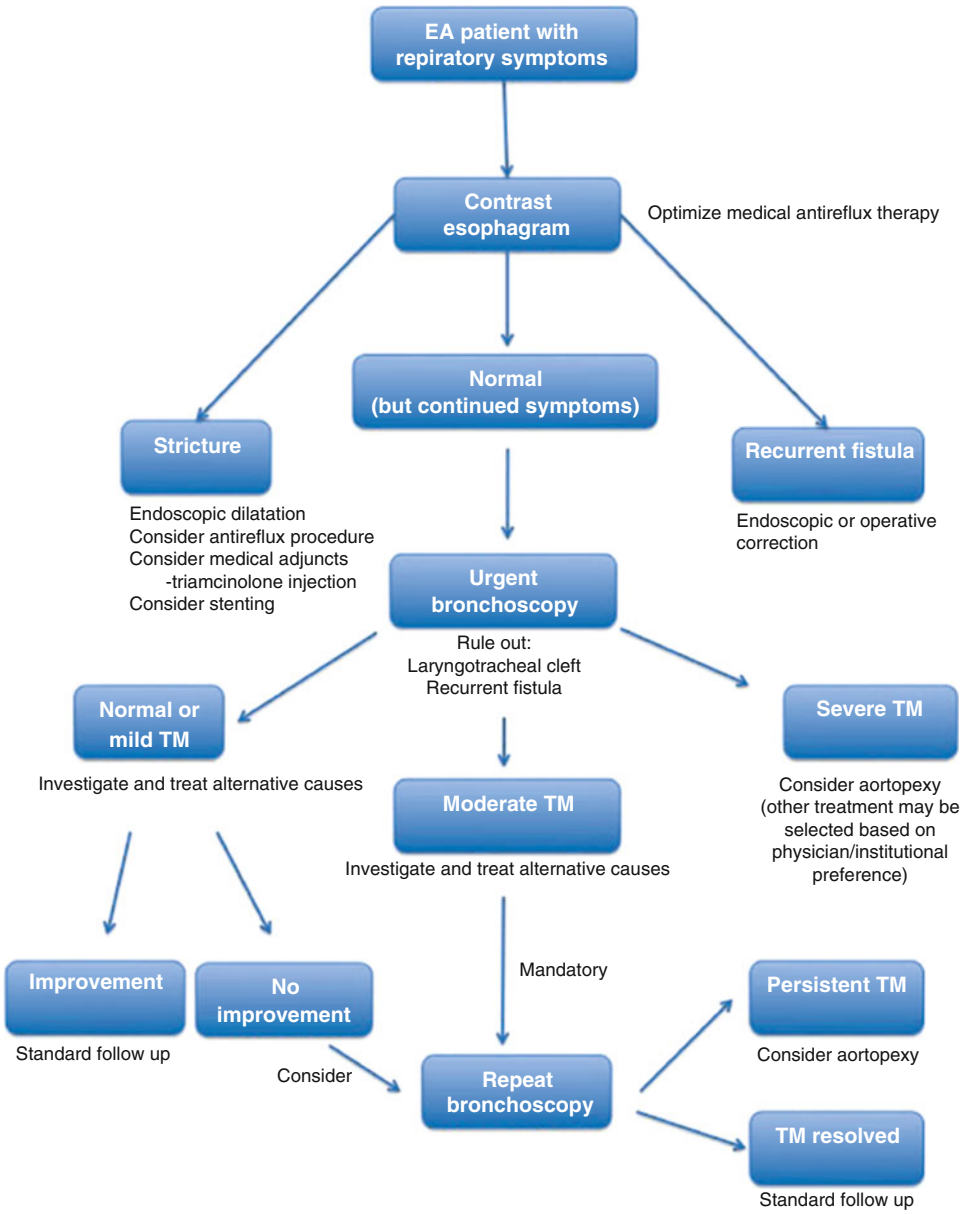

Fig. 30.2 Algorithm for patients who experience respiratory difficulties after esophageal repair (also applicable to patients experiencing feeding difficulties). *EA* esophageal atresia, *TM* tracheomalacia (Reprinted with permission from: Kay-Rivest E, Baird R, Laberge J-M, et al. Evaluation of aortopexy in the management of severe tracheomalacia after esophageal atresia repair. Dis Esophagus. 2014 Jan 22)

of contrast material. With severe tracheomalacia, the tracheal lumen may appear completely collapsed between the aortic arch and the distended esophagus, especially during expiration or crying.

Symptomatic *anastomotic stricture* often results from a leak, although it certainly can arise de novo. This typically presents with feeding difficulty, choking episodes, and regurgitation. We use a stepwise treatment algorithm for patients with stricture (Fig. 30.3). All patients should have optimal GERD treatment as this frequently exacerbates stricture formation. Most patients respond to a course of endoscopic dilatation; adjunctive agents like triamcinolone and mitomycin C have proven effective in difficult cases. In those patients whose stricture does not respond to these measures, consideration should be given to performing a fundoplication. Presence of a stricture thereafter can be managed with an esophageal stent—although catastrophic episodes of erosion into a great vessel have been reported. Another option remains resection and esophageal reanastomosis. Although mediastinal scarring complicates reoperation, by this time the esophageal ends are in apposition and better vascularized, increasing the likelihood of success.

When *tracheomalacia* is severe and is associated with "dying spells" (apnea and cyanosis during feeding or following a crying spell), aortopexy is indicated. Bronchoscopy is useful before, during, and after this procedure to assess the tracheal lumen. To confirm tracheomalacia, the tracheoscopy is done with the patient breathing spontaneously under light general anesthesia, since the collapsed lumen is most obvious during expiration. Rare patients with diffuse tracheobronchomalacia may require more than a simple aortopexy. The incidence of severe tracheomalacia requiring aortopexy varies

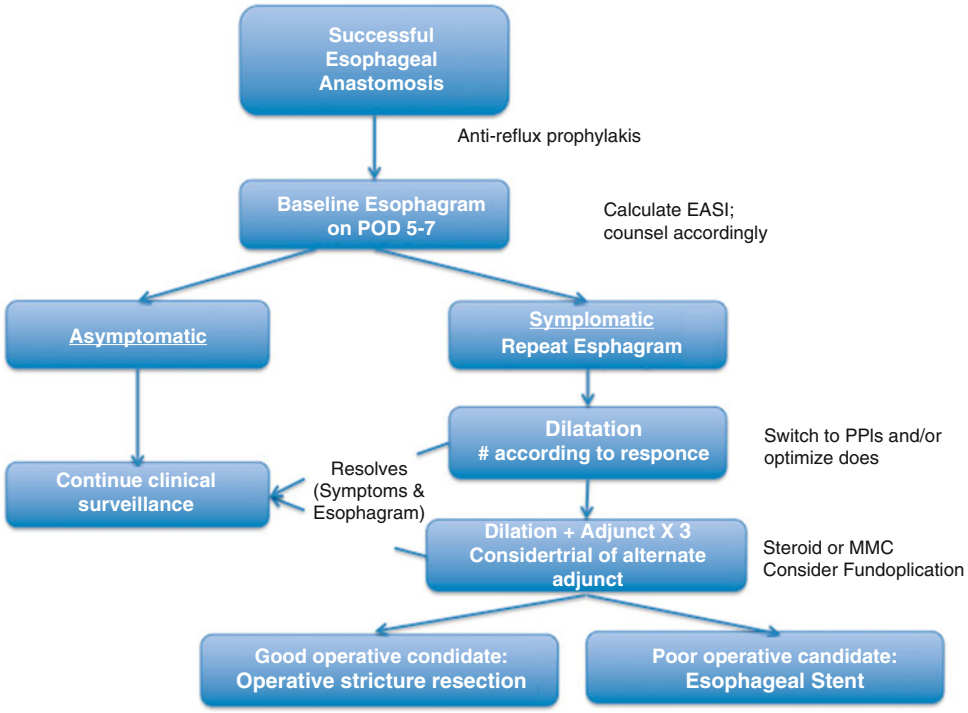

Fig. 30.3 Algorithm for the management of anastomotic stricture after esophageal repair. Adjuncts commonly used are intralesional steroids and mitomycin C. *POD* postoperative day, *PPIs* proton pump inhibitors (Reprinted with permission from: Baird R, Laberge JM, Lévesque D. Anastomotic stricture after esophageal atresia repair: a critical review of recent literature. Eur J Pediatr Surg. 2013 Jun;23(3):204–13, © Georg Thieme Verlag KG)

from 2.5 % to more than 10 % in some series. This wide variation is explained in part by the fact that some patients in the past died without a diagnosis or were treated by prolonged intubation or tracheostomy awaiting spontaneous improvement. Surgeons are now more aggressive in doing an aortopexy, which has proven to be safe and effective. It is interesting to note that tracheomalacia is unusual in cases of pure esophageal atresia, but there is no clear explanation for this observation. Another important point is that tracheomalacia may manifest itself early by the inability to extubate or CO_2 retention as the child starts to breathe spontaneously.

Fistula recurrence is a serious complication that can lead to death; therefore aggressive investigation with fluoroscopy and bronchoscopy is essential. A recurrent TEF can be difficult to demonstrate. The imaging study is best done with the patient in the prone position, injecting the contrast through a feeding tube under pressure as it is gradually withdrawn from the lower esophagus. Nonetheless, false-negative studies may occur; bronchoscopy is the best procedure to evaluate fistula recurrence, especially when combined with esophagoscopy and injection of methylene blue. Bronchoscopy can also detect the presence of a tracheal diverticulum at the fistula site. The bronchoscopy can be done simply as a diagnostic procedure or as part of the definitive operation if the problem has been identified by the contrast study.

Noninvasive ways to obliterate the fistula by bronchoscopy with laser, electrocoagulation or synthetic glue, and sclerosing agents were initially associated with a higher recurrence rate. However, the use of fibrin glue, sometimes applied after the fistula is cauterized, has gained in popularity and may be the ideal first-line treatment in a stable patient. Repeated attempts may be required to achieve successful closure. One must be careful not to use excessive pressure when applying the glue since an excess amount could spill over into the trachea with disastrous consequences.

Should nonoperative methods of fistula closure prove unsuccessful, surgical management is required. The identification and the surgical repair of a recurrent fistula can be facilitated by the insertion of a ureteral catheter or soft guidewire at bronchoscopy. The classic approach is a repeat right thoracotomy, transpleural division of the fistula, and interposition of healthy tissue such as an intercostal pedicle or a pericardial flap. Some surgeons have approached this problem through a left thoracotomy or by means of a transtracheal repair.

GERD should most accurately be viewed as an associated condition rather than a complication of EA. It results from a combination of disruption at the gastroesophageal junction at the time of surgery (from traction on the distal esophagus) as well as the associated esophageal dysmotility, which is likely both a consequence of the original malformation as well as acquired during esophageal mobilization. GERD might present with reflux, recurrent pneumonia and asthma, failure to thrive, or stricture of the lower esophagus or at the site of anastomosis. All EA patients require aggressive medical antireflux therapy (typically H_2 blockers). In patients presenting with symptoms while on H_2 blockers, we optimize

the dose, add proton pump inhibitors, and use motility agents in some patients. Evaluation may include an extended pH probe study; esophageal impedance studies are being reported with increasing frequency but their utility for clinical decision-making remains undetermined.

Fundoplication is required in 10–25 % of patients after esophageal atresia repair. The indications include life-threatening symptoms, recurrent esophageal stricture refractory to dilations, and failure of medical treatment. Fundoplication is more complicated in these patients. The esophagus is often short due to the gastroesophageal junction having been pulled up into the chest at the time of esophageal repair. Because of abnormal esophageal peristalsis, the wrap has more risk of causing a mechanical obstruction. For this reason, some surgeons have advocated the use of a partial fundoplication. Despite these complicating factors and the fact that the long-term failure rate has been high in some series, fundoplication remains an important tool in the management of these patients.

A *distal congenital esophageal stenosis* might be difficult to differentiate from an acquired one due to reflux. When not responding to balloon dilatation (persistent waist on fluoroscopy), it is more likely to be congenital and is very likely to require resection. Cartilaginous remnants are often confirmed after resection. This may be suspected on endoscopic US if the technology is available. This associated anomaly is more often diagnosed later than typical anastomotic strictures, when the child starts eating solids; rarely, it may be suspected at the time of esophageal anastomosis, when an 8-Fr tube passed in the distal esophagus appears to block.

Often several complications coexist and the treatment sequence is based upon a judgment of which is most life threatening. Most infants after esophageal atresia repair have abnormal esophageal peristalsis, some degree of GERD, and tracheomalacia. When life-threatening symptoms are present, a careful history and appropriate investigation will help decide what should be addressed first. Faced with a child with severe hypoxic spells associated with feeding or crying and radiographic evidence of both GER and tracheomalacia, we would perform a bronchoscopy to exclude a recurrent or missed fistula and be prepared to perform an aortopexy during the same anesthesia if severe tracheomalacia was confirmed (apposition of the posterior and anterior tracheal walls during expiration).

Long-Term Considerations

Patients who are discharged from the hospital after successful restoration of esophageal continuity should not be considered cured. There is a general impression that feeding and respiratory problems completely disappear after a few years. Although it is true that most patients tend not to complain and are reluctant to return for yearly follow-ups, one must be aware of the potential problems. Late mortality can occur from associated anomalies and from complications of the disease or its treatment. In infants with a smooth initial course, unexpected death has resulted from tracheomalacia or food impaction in the esophagus. A surprisingly high incidence (>1 %) of sudden infant death syndrome is noted in several large series, which gives some support to the theory of an immaturity of vagal reflexes in these patients. Tracheomalacia and GERD may also contribute to these deaths.

Late morbidity can be related to the esophageal anastomosis, to abnormal esophageal motility, to GERD, and to respiratory problems. GERD is probably the most troublesome since it can result in anastomotic or lower esophageal strictures and may be accompanied by Barrett's esophagus, a precursor to adenocarcinoma. *Esophageal carcinoma* has now been reported in nine patients, 20–46 years after esophageal atresia repair; interestingly, most of these are squamous cell carcinomas. Because most children grow up with symptoms from an abnormally functioning esophagus, they tend not to realize that they have a problem. It was formerly thought that reflux improved with time, but several studies have now shown that GER and esophagitis persist in a significant number of older children and adults, even when they are asymptomatic. Closer follow-up and more aggressive treatment of GERD are therefore required. Since reflux and esophagitis do not necessarily correlate with symptoms, surveillance esophagoscopy every 3–5 years has been recommended. Reflux has also been linked to respiratory problems such as recurrent pneumonia, bronchitis, and asthma.

The anastomotic scar and abnormal esophageal motility contribute to long-term *dysphagia* in about half the patients, although most do not complain about it. This often leads to swallowing difficulties and to food impaction requiring esophagoscopy for its removal. Patients are counseled to eat slowly, take small bites, and drink a lot while eating.

Respiratory problems in the first year might be related to recurrent fistula, GERD, tracheomalacia, or associated anomalies such as LTEC. Any of these may lead to serious morbidity and even mortality if not promptly recognized and treated. Later in life, the respiratory symptoms tend to improve. In contrast to classical teachings, however, it has been suggested that 40 % of adults still have the typical barking cough of tracheomalacia and 25 % have intermittent respiratory problems such as asthma, pneumonia, and bronchitis. This finding is more common in patients who had these problems in early childhood. A daily cough is associated with symptoms of reflux and dysphagia.

Long-term growth and development have been considered within the normal range in most reviews. *Scoliosis* may be secondary to vertebral or rib anomalies, anastomotic leak with pleural scarring, or an unnecessary long thoracotomy with rib excision. A musculoskeletal examination during

long-term follow-up should be considered mandatory, with imaging performed if indicated and prompt referral to appropriate specialists as needed.

Isolated Tracheoesophageal Fistula (H Type)

Choking and coughing in association with feedings and repeated pneumonia (especially right upper lobe) suggest the possibility of an isolated congenital TEF. In some cases, asthma or impressive chronic abdominal distention are the predominant signs of the disorder. Excessive mucous or hypersalivation might also be noted. In most cases, the symptoms start from birth, but the diagnosis is often delayed because of failure to investigate the problem or falsely negative initial studies. The presence of other anomalies, such as laryngeal or tracheal atresia or stenosis, may obscure the diagnosis. In distinction to the findings in babies with esophageal atresia, a history of polyhydramnios is rare, and low birth weight is less common. Associated malformations may occur, but they are generally not as frequent and as severe as those associated with EA.

The first step in establishing a diagnosis should be a dedicated contrast esophagram with video fluoroscopy. This should be performed in the prone or lateral decubitus position, injecting thin barium or nonionic water-soluble contrast material under pressure through a feeding tube, starting in the lower esophagus. The catheter is gradually withdrawn and boluses of contrast are injected at various levels. This eliminates confusion with aspirated contrast from swallowing incoordination or a LTEC. This technique, by distending the esophagus, also facilitates opacification of the fistula since the tracheal opening is usually proximal to the esophageal opening.

In patients with persistent symptoms and a negative esophagram, a rigid bronchoscopy should be performed urgently. Special attention is paid to the posterior larynx to avoid missing LTEC. This is followed by a thorough examination of the entire posterior tracheal wall to search for a TEF. Sometimes a small catheter is necessary to "probe" the posterior wall of the trachea, although in most instances a small dimple indicating the fistula site will easily be seen.

The operative steps for the repair of a tracheaesophageal fistula are less standardized (Table 30.5). Rigid bronchoscopy is an essential part of the operation. With the patient's neck extended, a roll under the shoulders, the bronchoscope just above the fistula, and the operating room lights dimmed, one can visualize the telescope light through the skin in the lower neck, confirming that the TEF can be approached through a cervical incision (up to 90 % of cases). The fistula may then canulated with a small Fogarty catheter, a ureteral catheter, or a soft guidewire passed through the instrument channel. This step is essential to facilitate intraoperative identification of the fistula and minimize dissection, thereby decreasing the risk of recurrent laryngeal nerve damage. Esophagoscopy should be used to either confirm that the Fogarty balloon catheter is up against the fistula or to retrieve the soft guidewire or ureteral catheter back out the mouth to aid in intraoperative fistula identification. The ventilating bronchoscope is removed and the patient intubated by the anesthesiologist.

Table 30.5 Summary of operative steps for repair of H-type fistula

Operative step	Rationale
Rigid bronchoscopy	Confirm fistula position; placement of incision
Bronchoscopic fistula intubation	Greatly aids intraoperative fistula identification, minimizes extent of tracheoesophageal mobilization
Approach via right neck	More consistent recurrent laryngeal nerve course, avoids thoracic duct
Fistula ligation close to trachea	Avoid postoperative diverticulum
Check for leak with Valsalva maneuver	Repair immediately before proceeding
Interpose viable tissue (omohyoid, portion of sternomastoid)	Minimize postoperative refistulization rate

With the head kept in hyperextension, it is now turned to the left and the right neck should be prepared and draped. Even with a fistula at the thoracic inlet, it is easier to pull it cephalad with the help of the Fogarty catheter than to work at the apex of the pleural cavity from a thoracic approach. Through a lower transverse incision along a skin fold, the sternocleidomastoid and the carotid sheath are retracted laterally. Below the right lobe of the thyroid, the tracheoesophageal groove is exposed by blunt dissection. Palpation of the Fogarty catheter or guidewire is facilitated when gentle traction is applied by the anesthesiologist. The right recurrent laryngeal nerve must then be identified and preserved, avoiding traction to it. The fistula is carefully dissected and encircled with a Silastic vessel loop. Extensive esophageal mobilization and retraction should be avoided as this may result in contralateral recurrent laryngeal nerve traction injury. Absorbable stay sutures on the tracheal side of the cephalad and caudal ends of the TEF aid in completing the fistula division and ligation. The fistula should then be sequentially divided close to the trachea as would be done in EA/TEF. Interrupted sutures are used to complete the tracheal closure, followed by esophageal closure. The tracheal suture line should then be covered with well-vascularized tissue to minimize the risk of recurrence—omohyoid muscle is typically easily mobilized and interposed.

When a thoracic approach is required, a right transpleural exposure through the fourth interspace usually gives the best

exposure, although thoracoscopic repair is an excellent option given the proximal position of the TEF. Again, the presence of the Fogarty catheter or guidewire is invaluable. Attempts at closing a congenital TEF using nonoperative adjuncts like fibrin glue or cyanoacrylate are less successful than with a recurrent TEF after EA/TEF repair since the congenital fistula is always lined with mucosa.

Intraoperative and early postoperative complications are commonly reported after H-type TEF repair. They include accidental extubation, tracheal perforation, bradycardiac and cardiac arrest, laryngeal edema, unilateral and even bilateral recurrent laryngeal nerve damage with vocal cord palsy, missed or recurrent fistula, mediastinitis, pneumothorax, and even phrenic nerve palsy. Many of these complications can be avoided or minimized by identification and catheterization of the fistula before dissection. Most of the reported complications have been due to operations on patients who only had a clinical diagnosis or those in whom the fistula was not catheterized. One should not perform a cervical exploration for presumed TEF if the fistula cannot be visualized by bronchoscopy. Minimal dissection with preservation of the recurrent nerves, precise suturing of the trachea and esophagus, and verification of vocal cord movement at the end of the operation are important. Postoperative intubation may be required for vocal cord palsy or airway edema; in the latter situation, racemic epinephrine and steroids may be useful. Late complications are uncommon, but a recurrent fistula may become apparent after several months. GERD and abnormal esophageal peristalsis are reported but uncommon.

Editor's Comment

Successful repair of EA/TEF can be one of the most pleasing and satisfying procedures in our field and patients typically enjoy normal growth and development. The repair however can be challenging and complications are common; thus surgeons must be prepared in the OR and postoperatively to manage all aspects of care. Fetal detection of EA/TEF is possible with the widespread use of prenatal US, and this allows for prenatal consultation with a pediatric surgeon who can influence the delivery plan and site of delivery to a center capable of managing potential respiratory issues that might occur. Polyhydramnios with the absence of a gastric bubble and a distended upper esophageal pouch with fetal swallowing should raise the suspicion of an isolated EA. The VACTERL workup should be pursued in all patients. Duodenal atresia and imperforate anus can complicate the management fairly rapidly and should also be ruled out.

When the two ends of the esophagus cannot be easily brought together, this usually straightforward operation can turn into a nightmare. The key in these situations is to have a backup plan and to avoid irrevocable errors: excessive mobilization of the distal esophagus, which can compromise its blood supply; multiple attempts to approximate the ends under excessive tension, which results in loss of length when the sutures tear through; and creation of a cervical esophagostomy, which often commits the patient to esophageal replacement and is associated with multiple complications.

In most cases, repair can be considered a semi-elective operation, but when a patient with a distal fistula requires positive-pressure ventilation, it should be considered an emergency—regardless of the position of the endotracheal tube, positive pressure inevitably results in massive abdominal distension and respiratory embarrassment. The thoracoscopic approach holds some promise, and while it is important that there are pioneers who are advancing the field, it is also clearly a very advanced minimally invasive operation with many pitfalls and a long learning curve, suggesting it needs to be tested and significantly more refined before it becomes standard. For most patients, a small, posterolateral, muscle-sparing thoracotomy and extrapleural approach are preferable. Occasionally one encounters a variation of the major vascular anatomy, such as double aortic arch or aberrant subclavian artery. It is usually possible to work around these structures, but it is important to be vigilant to avoid injury to the vagus nerves and thoracic duct, whose anatomy might be altered. When a right aortic arch is encountered, it is usually best to proceed as per usual; however if a right-sided descending aorta gets in the way, then it might be best to close the chest and start again on the other side.

While the back-row sutures are being tied, ring forceps work well to bring the ends together and are less traumatic than DeBakey forceps. The choice of suture material for the repair is individual, but absorbable suture is better than nonabsorbable, which can cause foreign body reaction, granulation tissue, and fistulas. The trachea should be oversewn with an absorbable or nonabsorbable monofilament suture. All patients with EA have GER, but only those with failure to thrive, recurrent stricture or significant complications need a fundoplication. A loose Nissen fundoplication performed over a bougie works just as well as a partial fundoplication in these patients.

Aortopexy should be strongly considered for patients who are difficult to extubate or who have other signs of severe tracheomalacia. It is a safe operation with excellent results when done with bronchoscopy and a meticulous technique. The most effective, safe, and durable way to dilate an anastomotic stricture at any age is with balloon dilation under fluoroscopic or endoscopic guidance. Patients with recurring strictures, especially if they need repeated dilation every few weeks or months, should undergo fundoplication, as in some cases this can make the strictures stop recurring immediately.

Suggested Reading

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Long-Gap Esophageal Atresia

31

Pietro Bagolan, Andrea Conforti, and Francesco Morini

"To anastomose the ends of an infant's esophagus, the surgeon must be as delicate and precise as a skilled watchmaker. No other operation offers a greater opportunity for pure technical artistry"

Willis Potts, 1950

Esophageal atresia is a rare congenital anomaly that occurs in 1:4500 live births. The expected outcome is close to 100 % survival, though this varies depending on birth weight, degree of prematurity, and associated anomalies (especially cardiac). Ideal surgical management consists of a primary end-to-end esophageal anastomosis and division of the tracheoesophageal fistula if one is present. The vast majority can be corrected without difficulty soon after birth. However, this goal is not always easily achievable. The management of the long-gap esophageal atresia remains a major challenge for pediatric surgeons and affected patients. Attempts to bridge the gap to allow a primary anastomosis have led to the introduction of several interesting techniques, none of which are considered standard.

Traditionally, long-gap EA was synonymous with pure EA (Gross type A) or EA with a proximal TEF (Gross type B) that usually have a wide separation between esophageal stumps. However, more recent surveys suggest that more than half of patients operated on for long-gap EA, defined as the inability to perform a primary esophageal anastomosis because of the gap, had EA with a distal TEF (Gross type C or D). In addition, a number of patients who are managed with a primary esophageal anastomosis may develop a "secondary" long gap as a result of complications of the primary procedure, often followed by cervical esophagostomy, closure of the distal stump and gastrostomy, or development of refractory gastroesophageal reflux and persistent long stricture, requiring subsequent resection. For these reasons, neonates with EA should be referred to experienced, tertiary-care neonatal/pediatric surgical units.

The gap between the esophageal ends can be measured in centimeters or vertebral bodies. Since the measurement is done in patients with a wide range of body weight (from below 1.5 kg to more than 3 kg) and because an absolute measure does not take into account the patient's size, the distance between the stumps is best expressed in terms of vertebral bodies. The diagnostic criteria for what constitutes a long gap differ among different surgeons. Some define 2 cm as a cutoff point; others classified the gap into short (1 cm), intermediate (2.5–3 cm), and long (>3 cm.); and others define a gap more than 3–3.5 cm as long, while still others recommend an esophageal replacement if the gap exceeds the length of six vertebral bodies. In summary, the definition of a "long gap" is somewhat subjective: what is amenable to primary anastomosis for one surgeon may be deemed impossible for another. Thus, a long gap could be (and often is) defined as any gap one cannot bridge. There is also a lack of uniformity in the methods and timing of gap measurement (before or after dissection of the esophageal stumps, whether or not under tension). We use the cutoff of 3 cm or three vertebral spaces to define a long gap, and we apply a standardized protocol to measure the distance between the two esophageal stumps, based on the fact that there is a higher complication rate associated with gaps over this distance.

Diagnosis

In most patients, esophageal atresia is diagnosed after birth, though in a few cases it may be suspected antenatally by an experienced ultrasonographer. The detection of a blind upper pouch at prenatal ultrasound may harbinger an esophageal atresia, while the absence of a stomach bubble suggests a Gross type A or B EA. Although these findings suggest EA, false-positives occur in up to 50 % of cases.

Postnatally, failure to advance a nasogastric tube beyond 10 cm from the nose or mouth confirms the diagnosis of EA, and a gasless abdomen at plain X-rays suggests the absence of distal fistula. Since all types of EA can present with a long gap, esophageal gap should be addressed in all patients with esophageal atresia. Therefore, in addition to the classic questions of anatomic type and associated anomalies, the

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diagnostic work-up should also answer the question of gap distance. After diagnosis, the upper pouch is continuously aspirated with a Replogle tube. Chest X-rays are taken with a feeding tube deeply inserted into the esophagus to confirm the diagnosis of esophageal atresia and to define, as exactly as possible, the level of the upper pouch. An echocardiogram is performed to look for associated cardiac anomalies and, importantly from a surgical point of view, to define the side of the aortic arch, which indicates the side of thoracotomy. Broad-spectrum antibiotics are initiated.

In all patients with EA, we perform bronchoscopy as the first procedure. Bronchoscopy allows one to define the presence of an upper pouch fistula (3–4 % of patients), to confirm the presence and determine the level of a distal tracheoesophageal fistula, to gather information about vocal cord motility, and to exclude associated and more complex laryngotracheoesophageal anomalies, such as wide laryngotracheal (or tracheobronchial) cleft or communicating bronchopulmonary foregut malformation, which would modify the approach. In our personal experience, of 219 consecutive patients with EA, regardless of the gap, 6 of 31 with a gasless abdomen had a proximal fistula which would have been missed without bronchoscopy; 2 had a laryngotracheoesophageal cleft, dictating a different approach; and 1 had a communicating bronchopulmonary foregut malformation. We perform bronchoscopy with a 3.5 mm flexible endoscope. In the case of a proximal fistula, we pass a guide wire through the fistula into the esophagus and pull it out through the mouth to allow the definition of the level of the fistula by fluoroscopy (Fig. 31.1), indicating the best route to close it, cervical (usually) or thoracic (15–20 %), to make the fistula easier to identify intraoperatively, to minimize necessary dissection, and to allow its proximal traction at the neck during the operation, if necessary. When a wide carinal fistula is found, we cannulate it with a 3.5 Fr Fogarty catheter (the balloon is inflated with 0.2 mL of saline solution) through the rigid ventilating bronchoscope (Fig. 31.2). This is done to occlude the fistula, thereby making mechanical ventilation easier and avoiding intraoperative gastric overdistension and possible aspiration.

Gap Measurement

In the treatment of EA, the definition of the gap takes on great importance in planning the operative approach, making necessary adjustments and explaining to parents what to expect. Therefore, this part of the diagnostic work-up should follow a strict and repeatable protocol to give detailed information that may turn out to be valuable for subsequent management. The definition of the gap follows different pathways depending on whether a distal fistula is present (type C/D) or not (type A/B). In patients with a distal fistula, we measure the gap at the first operative approach with bronchoscopy performed together with fluoroscopy. We insert a radiopaque tube of adequate diameter (usually 10 Fr) to push down the upper esophagus. We then place the tip of the bronchoscope at the level of the opening of the distal fistula (to mark the distal esophagus), and we measure by fluoroscopy the number of vertebral bodies between the radiopaque tube in the upper pouch and the bronchoscope (Fig. 31.3). Alternatively, the gap can be measured intraoperatively (less useful, since an unbridgeable gap could be a surprise), both with and without tension on the esophageal ends, after division of the fistula.

In patients without distal TEF, we do not measure the gap length at first operation, since we do not have access to the distal esophagus. The first procedure is then a gastrostomy (without cervical esophagostomy when possible), followed by gap measurement 2 weeks later. In these patients, the gap is measured either by injecting sufficient radio-opaque contrast into the stomach to allow it to reflux into the distal pouch or by passing a radio-opaque instrument, such as a bougie, Hegar dilator, urethral sound, or flexible endoscope, through the gastrostomy into the distal stump. At the same time a radio-opaque tube is advanced in the upper pouch. For the lower esophagus, we prefer a rigid sound passed through the gastrostomy, which allows us to measure the gap both under passive tension (not pushing on the rigid instrument) and with active stretch (pushing on the instrument), giving us a more precise estimate of the true gap thanks to the natural elasticity of the esophagus (Fig. 31.4).

We also apply a dynamometer to the Hegar dilator in the lower pouch to measure objectively the thrust applied to the lower esophagus (our standard pressure is 250–300 g to avoid the risk of perforation) and to anticipate the degree of tension after anastomosis. A gap under tension of two vertebrae or less, usually, will allow immediate one-step primary anastomosis. For a gap of three or more vertebrae, we plan a delayed primary anastomosis, usually in 4–8 weeks. Like any post-atretic intestinal loop, perhaps due to lack of exposure to amniotic fluid, the lower esophagus and stomach are hypoplastic at birth. After gastrostomy, regular bolus feeding induces progressive gastric growth and esophageal lengthening thanks to hydrostatic pressure induced by gastroesophageal reflux.

Other methods of inducing esophageal pouch growth have been proposed: proximal pouch bouginage once/twice daily, electromagnetic bouginage with metallic bullets placed in the two esophageal ends, the placement of silver olives in the blind pouches that are then gradually approximated through an attached thread, and hydrostatic stretch-induced growth through an indwelling balloon catheter. The gap is measured serially (every 2–3 weeks) to determine the optimal time for the delayed one-step primary anastomosis. Esophageal reconstruction may be delayed for 8–12 weeks

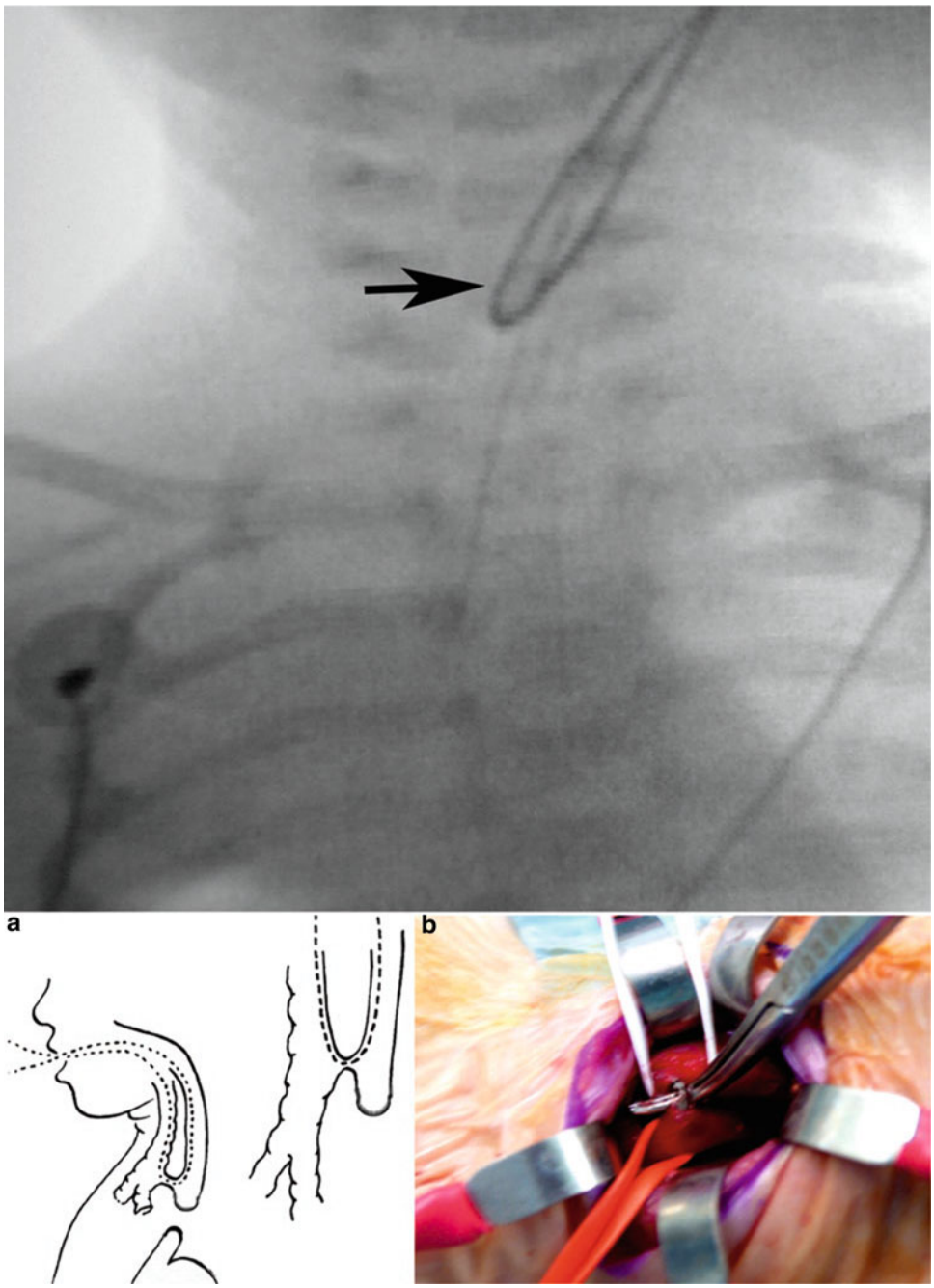

Fig. 31.1 Chest X-rays of an infant with a proximal tracheoesophageal fistula and a radiopaque guide wire passed through it (*arrow*). (**a**) Diagram showing the guide wire passing through the fistula and *in* and *out* from the mouth. (**b**) The fistula is microdissected and the guide wire is visible elevated on a dissector

because it has been noted that maximal esophageal growth occurs during this period.

Gap measurement is also of paramount importance before proceeding with esophageal anastomosis in patients referred after a previous failed attempt. These patients often have a cervical esophagostomy and a gastrostomy, and we measure the gap with the same technique as for type A/B, as the previous distal fistula is already closed. For the fluoroscopy, we mark the cervical esophagostomy either with contrast (usually barium as it coats the esophagostomy mucosa) or with a radiopaque instrument and instrument the gastrostomy as previously noted (Fig. 31.4).

Surgical Repair

In children with long-gap EA, opinions differ significantly about the best solution. Preserving the native esophagus has been reported as a challenging surgical goal, and a primary anastomosis is often described as impossible, though this is often based on the skill and experience of the surgeon. But no consensus has been accepted on esophageal gap measurement, even though standardized and comparable methods have been reported. Many type C patients should be included in this challenging group since there is often a long gap

discovered at the time of initial thoracotomy for distal fistula control but that was not expected preoperatively. In addition, patients referred after a failed attempt of primary anastomosis are an additional source of secondary long-gap EA and are often even more challenging to manage.

Various creative techniques have been developed to bridge a long gap and attempt to preserve the native esophagus. Most esophagus-sparing techniques consist of graduated traction applied to the esophageal segments progressively, inducing growth and reducing the gap between the ends over time. Other surgical refinements such as esophageal flaps and myotomy have been developed to reduce the anastomotic tension. We believe primary esophageal reconstruction is achievable in most long-gap patients. Since surgeons may face many different variants, we developed a flow chart to describe our approach (Fig. 31.5).

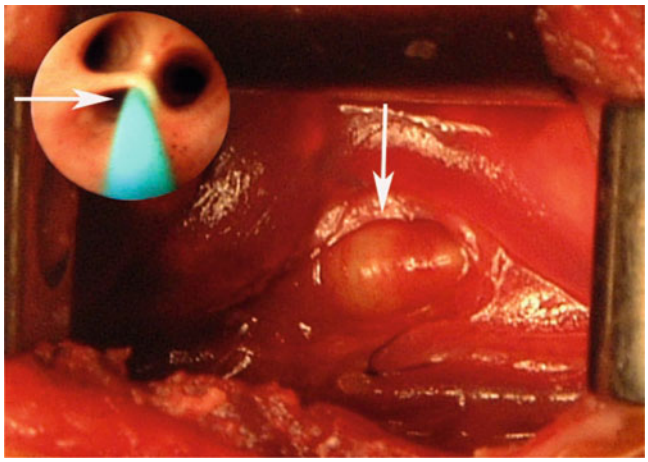

Fig. 31.2 Intraoperative picture of a Fogarty catheter placed through the distal fistula in the lower esophagus. *Arrow*: the balloon inflated in the lower esophagus. **Inset**: endoscope view of the catheter (*arrow*) into the distal tracheoesophageal fistula

Simple Delay: Gastrostomy

In type A/B esophageal atresia, in which the lower esophagus and stomach are hypoplastic, time is commonly used to allow the segments to grow. Therefore, a Stamm gastrostomy is performed through a periumbilical laparotomy, closing the proximal tracheoesophageal fistula, if present, usually through a cervical approach. Bolus gastrostomy feedings are

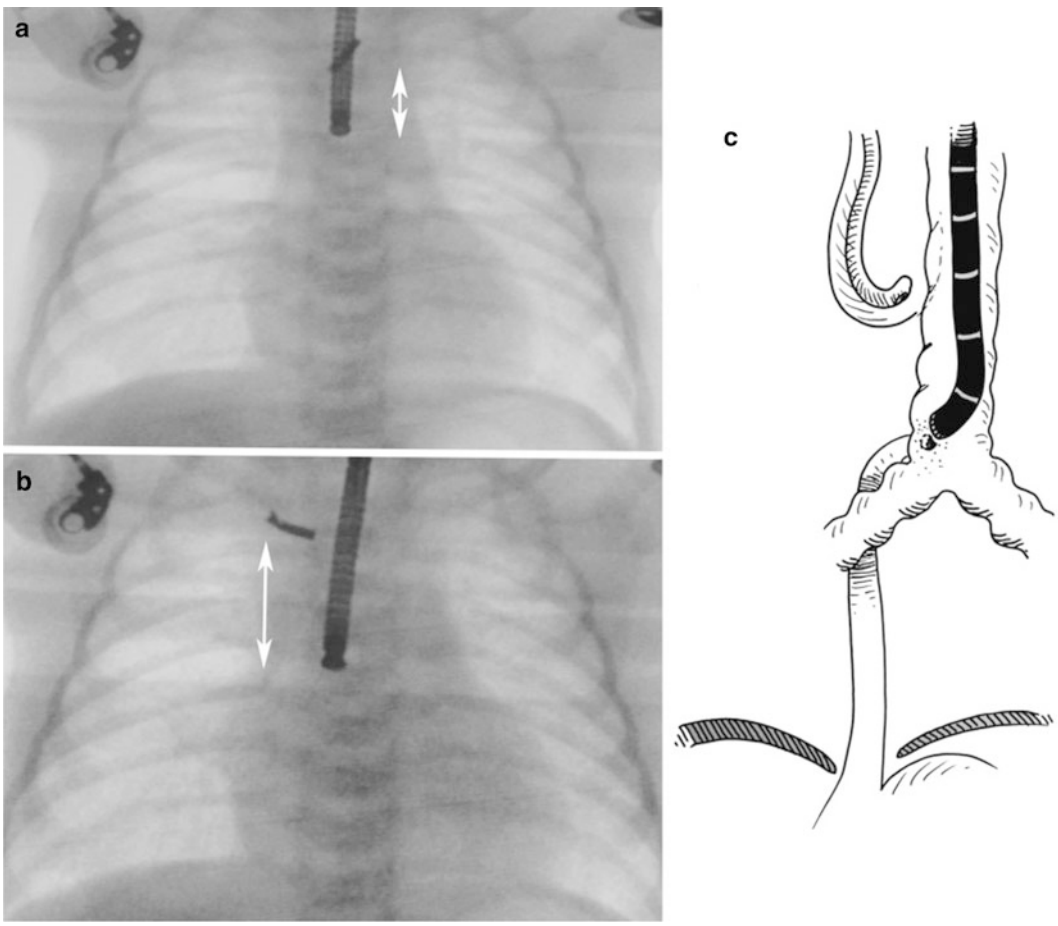

Fig. 31.3 Radioscopic measurement of the gap (*double arrow*) in type C esophageal atresia. (**a**) 1.5 vertebral bodies. (**b**) >3 vertebral bodies. (**c**) Diagram showing the tube in the upper esophagus and the endoscope at the level of the tracheoesophageal fistula (Courtesy of Dr. Fabio Ferro)

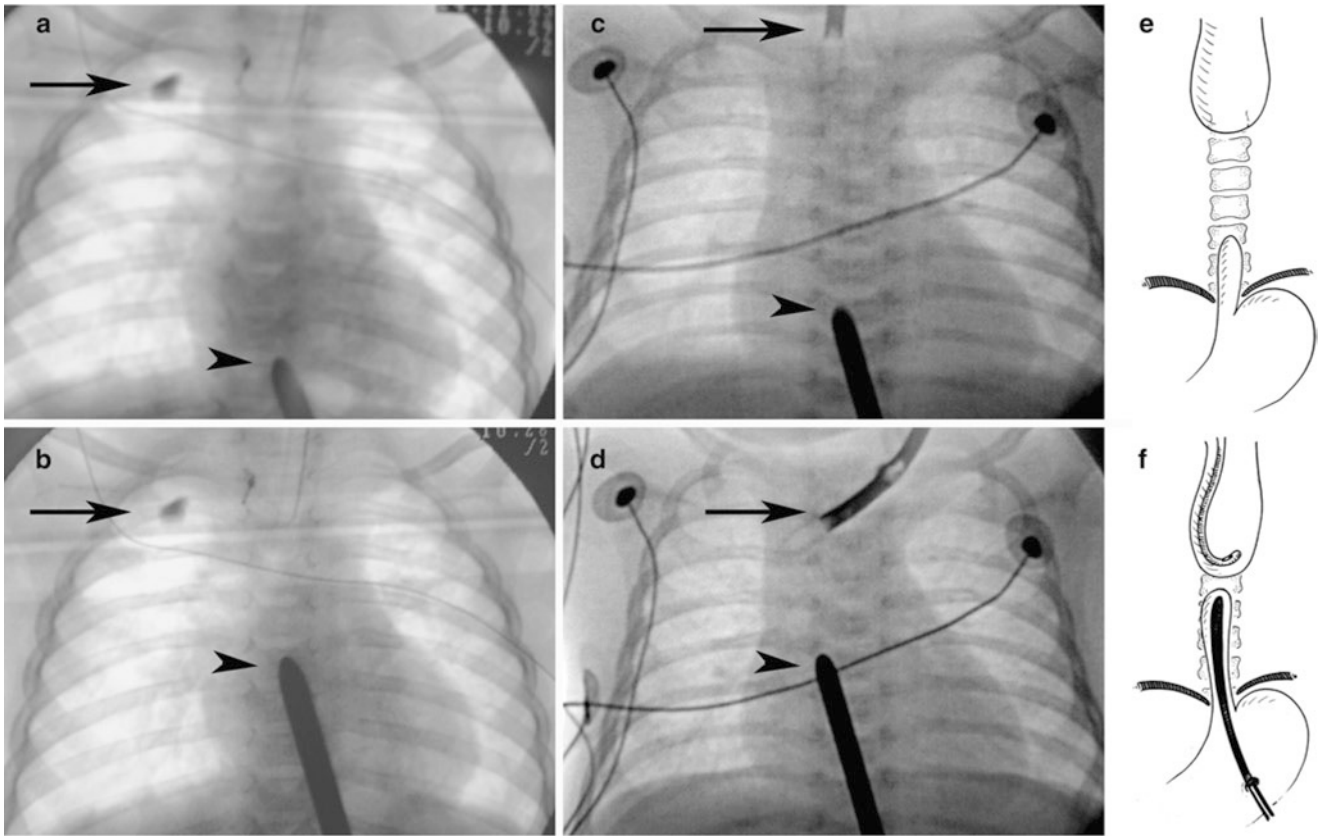

Fig. 31.4 Gap measurement (gapogram) in type A esophageal atresia. (**a**) Gapogram without tension of a referred patient with a cervical esophagostomy. *Arrow*: contrast media at the level of the cervical esophagostomy. *Arrow head*: Hegar dilator passed through the gastrostomy. (**b**) Gapogram of the same patient as "A" under tension. *Arrow*: contrast media at the level of the cervical esophagostomy. *Arrow head*: Hegar dilator passed through the gastrostomy. Note the reduction of the gap under active tension on the lower esophagus. (**c**) Gapogram without tension of a naïve patient. *Arrow*: tip of the radiopaque tube inserted in the upper esophageal pouch. *Arrow head*: Hegar dilator passed through the gastrostomy. (**d**) Gapogram of the same patient under tension on both esophageal pouches. *Arrow*: tip of the radiopaque tube inserted in the upper esophageal pouch. *Arrow head*: Hegar dilator passed through the gastrostomy. Note the reduction of the gap under active tension. (**e–f**) Diagram showing a type A esophageal atresia without tension on the pouches (**e**) and after a Hegar dilator is passed through the gastrostomy and active tension is applied on both esophageal pouches (**f**) (Courtesy of Dr. Fabio Ferro)

given to promote spontaneous growth of the stomach and distal esophagus. Spontaneous growth of the esophageal segments seems to occur during the first 3 months, but there are almost no data to inform this decision. A time interval of 4–8 weeks or until the infant is approximately 3.5–4 kg is considered as an appropriate period of time for wait-and-see program. We perform serial gap measurements, every 2 weeks, to decide on delayed anastomosis, which in our experience is usually possible as a one-step procedure when the gap is ≤ 2 vertebral bodies. We do not consider gastrostomy in patients with type C long-gap EA as they can usually be successfully managed with primary repair.

Cervical Esophagostomy

In the last few years, we managed many patients referred to our center with a cervical esophagostomy created after a failed primary repair attempt. Previously we avoided cervical esophagostomy, also limiting its use to manage postoperative complications or after failed primary attempts but have learned the cervical esophagostomy can be used to progressively elongate the proximal pouch, alone or in combination with lower pouch external traction. Therefore, cervical esophagostomy creation could be considered to shorten the hospital stay in cases of type A/B long-gap EA before definitive surgery. Moreover, it should be considered when there are other challenging clinical problems such as extremely low birth weight or severe cardiac defects.

Repair

Central venous access is secured in an anatomical site compatible with the surgical procedure (left internal jugular or femoral) for intraoperative and postoperative care. Total body preparation is then undertaken to allow a cervical approach to the upper pouch, if needed, and the thoracotomy,

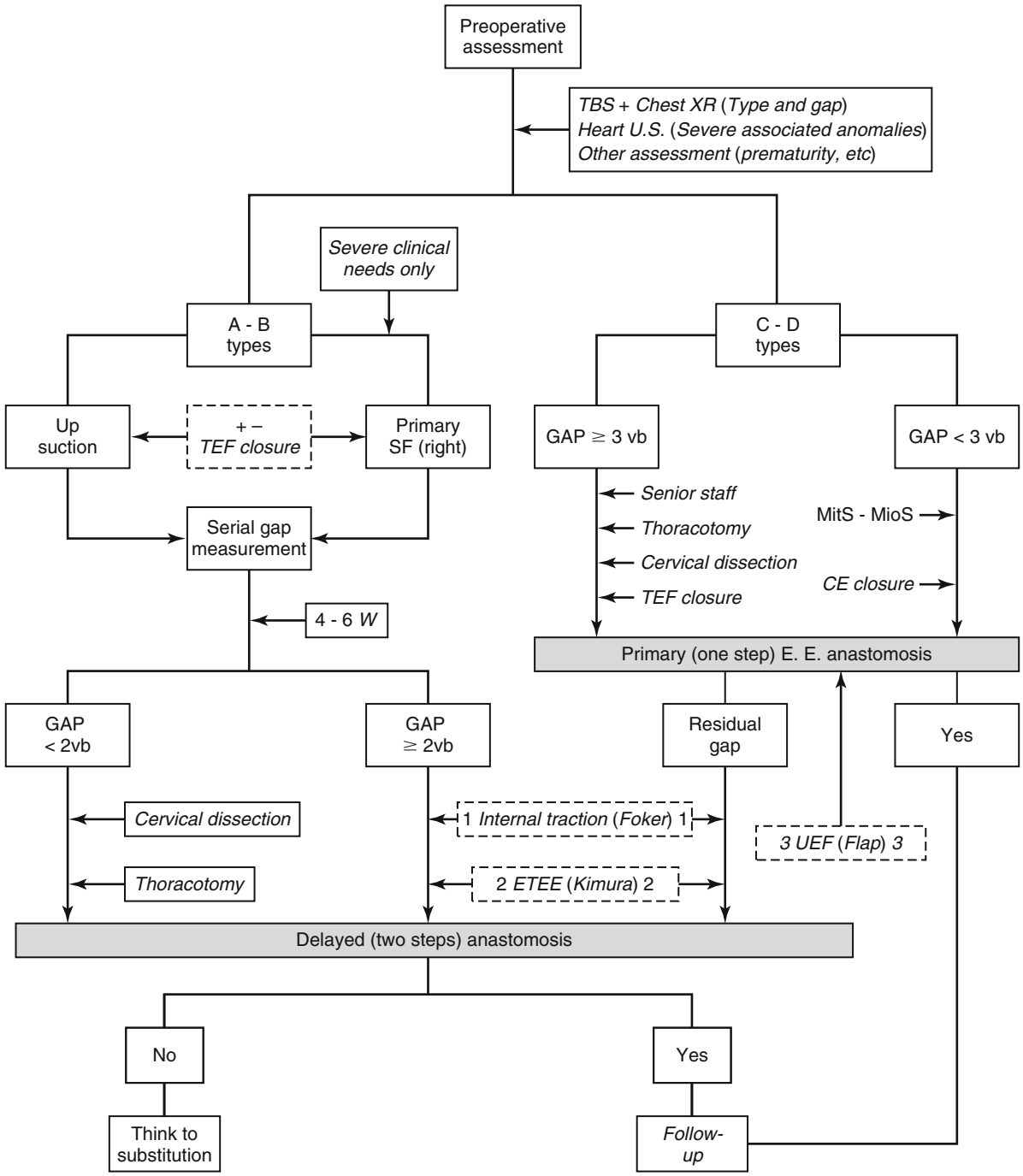

Fig. 31.5 Algorithm for the assessment and treatment of esophageal atresia. Legends—*CE,* cervical esophagostomy; *E–E,* end to end; *ET*, external traction; *ETEE*, extrathoracic esophageal elongation; *UEF*, upper esophageal flap; *MiTS*, minimally invasive thoracoscopic surgery; *MiOS*, minimally invasive open surgery; *TBS*, tracheobronchoscopy; *TEF*, tracheoesophageal fistula; *Up*, upper pouch; *US*, ultrasound; *vb*, vertebral bodies; *W*, weeks; *xR*, X-rays

centered on the appropriate intercostal space under the guide of the previous gap measurement. When a gastrostomy is present, a Hegar dilator is passed through the gastrostomy into the lower pouch and secured at the skin level to facilitate intraoperative identification and upward thrust of the lower esophagus (Fig. 31.6). The muscles are split, not divided, and the posterior mediastinum is accessed through a subperiosteal (to prevent chest/muscular deformities and costal synostosis) extrapleural approach, when possible. Both esophageal pouches are identified and extensively mobilized with gentle meticulous dissection and minimal manipulation using 4× magnification and 6–0 silk stay sutures to avoid tissue damage from forceps (Fig. 31.6). In reality, extensive dissection of upper and lower esophagus can be perfor-

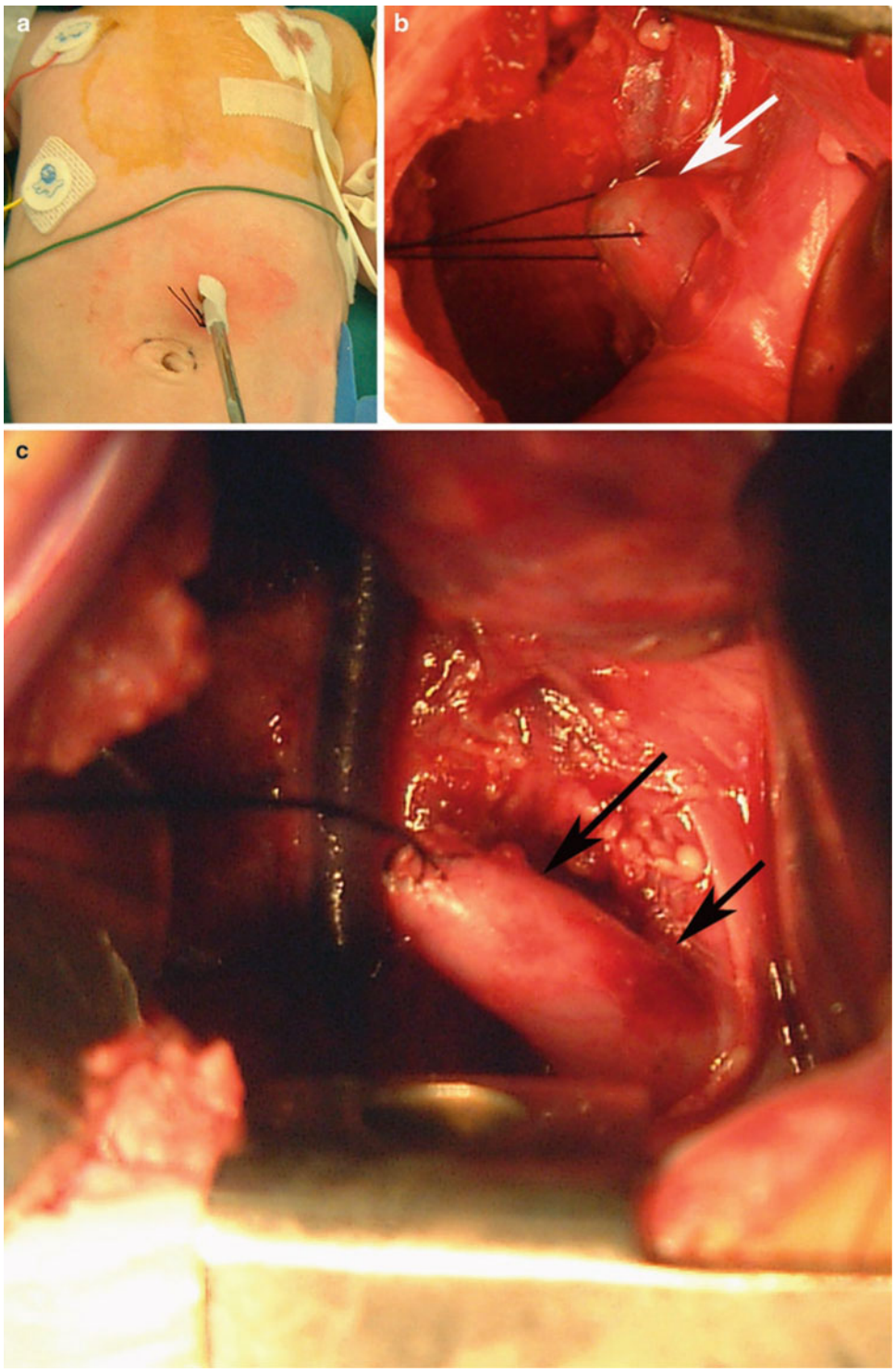

Fig. 31.6 Type A esophageal atresia repair. (**a**) After total body preparation, the Hegar dilator is passed through the gastrostomy and secured at the skin level. (**b**) Intraoperative picture. Pushing on the Hegar dilator, the lower pouch (*arrow*) comes into the operative field and stay sutures are placed on the pouch. (**c**) After extensive dissection of the lower pouch and pushing on the Hegar dilator, extra length of lower pouch (*arrows*) is obtained

med safely, without vascular compromise. Extended gentle dissection is better than performing an anastomosis under extreme tension. When the remaining gap is deemed too long to bridge, despite extensive mobilization, further dissection of the upper pouch is possible through a cervical incision, possibly giving an extra 1–1.5 cm.

Once the esophagus has been fully mobilized, the gap is measured again. Only when the anastomosis is felt feasible are the upper and lower pouches opened. The posterior row of sutures (5–0 or 6–0 polypropylene) is placed but not tied until all sutures can be tied simultaneously to decrease disruptive traction forces of tying individual sutures (Fig. 31.7). The anastomosis is performed over an 8–10 Fr nasogastric tube left as a trans-anastomotic stent. In long-gap EA we always leave a para-anastomotic chest drain. If the anastomosis is felt not possible at this moment, a few technical refine-

ments may help: (1) Progressive intraoperative traction for 15–60 min can be applied through the stay sutures placed on the upper and lower esophageal segments. (2) The cushion underneath the patient's chest can be removed, often permitting a gain of up to one additional cm (Fig. 31.8). (3) A slide of the upper pouch posterior esophageal wall is achievable by a longitudinal incision and offset repair of the anterior aspect of the blind pouch (Fig. 31.9). (4) An anterior flap can be used to lengthen the upper pouch though a combination of partial transverse and longitudinal incisions to allow inferior flap rotation and tubularization repair of the anterior aspect of the proximal pouch stump (Fig. 31.10). If we do not believe the technique will work or we do not feel comfortable with it, the next step to bridge the gap is traction and growth.

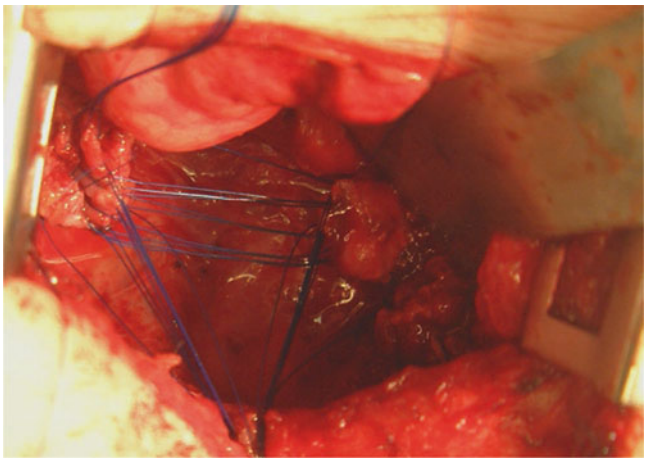

Fig. 31.7 Intraoperative picture: the *posterior row* of sutures is placed and left untied

Traction and Growth

When the residual gap is still not bridgeable, most authors recommend the application of traction and growth procedures. Traction has been considered a good system to induce esophageal growth and elongation. In a rat animal model of esophageal atresia, continuous traction on the esophagus has

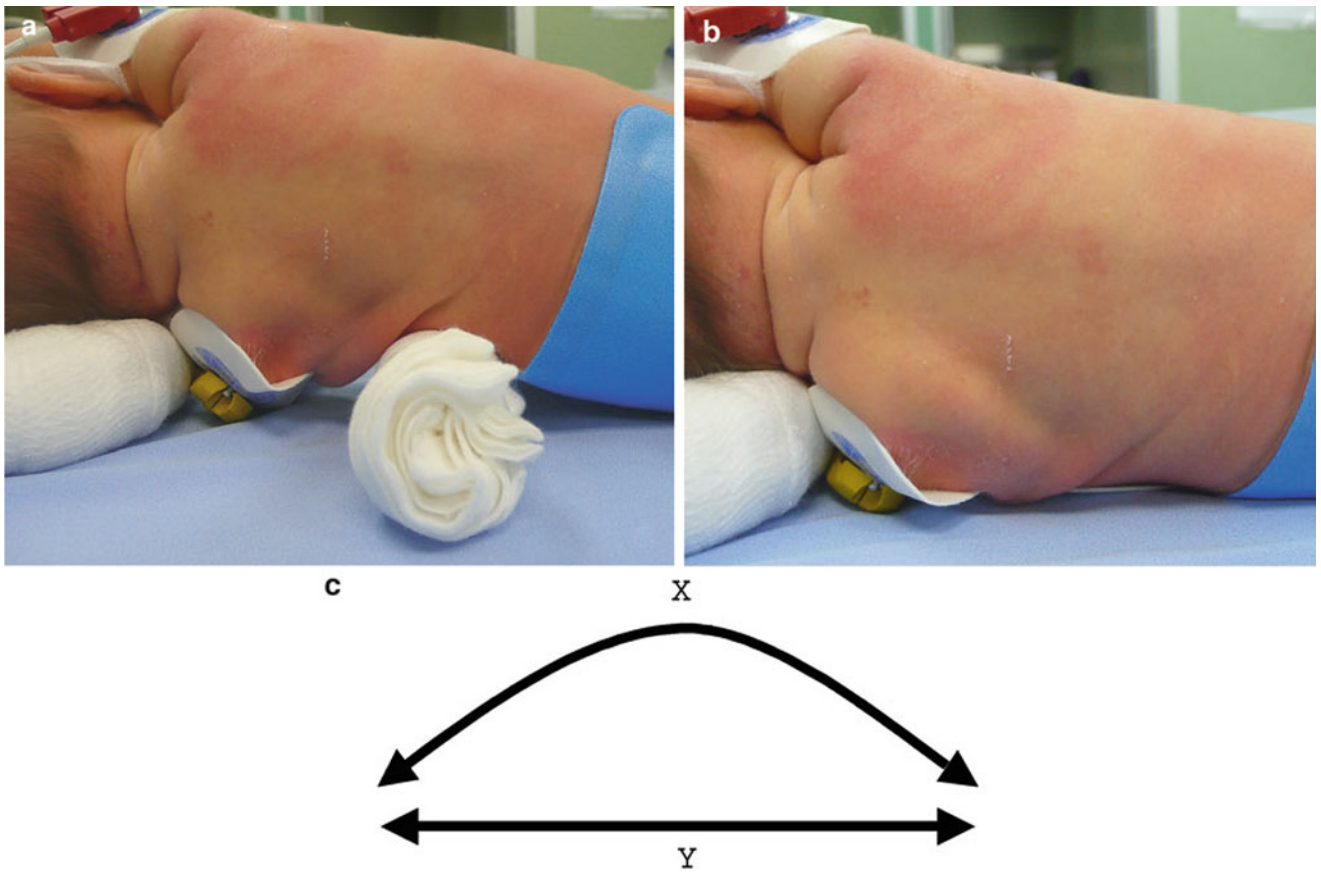

Fig. 31.8 The back of a patient with (**a**) and without (**b**) the cushion underneath his *left chest*. The removal of the cushion makes the spine, previously bent, rectilinear. (**c**) Diagram illustrating the effect on the gap of the straightening of the spine: the gap with (X) and without (Y) the cushion is exemplified. The entity of gap reduction can be calculated as the difference between the length of an *arc* (X) and its *chord* (Y)

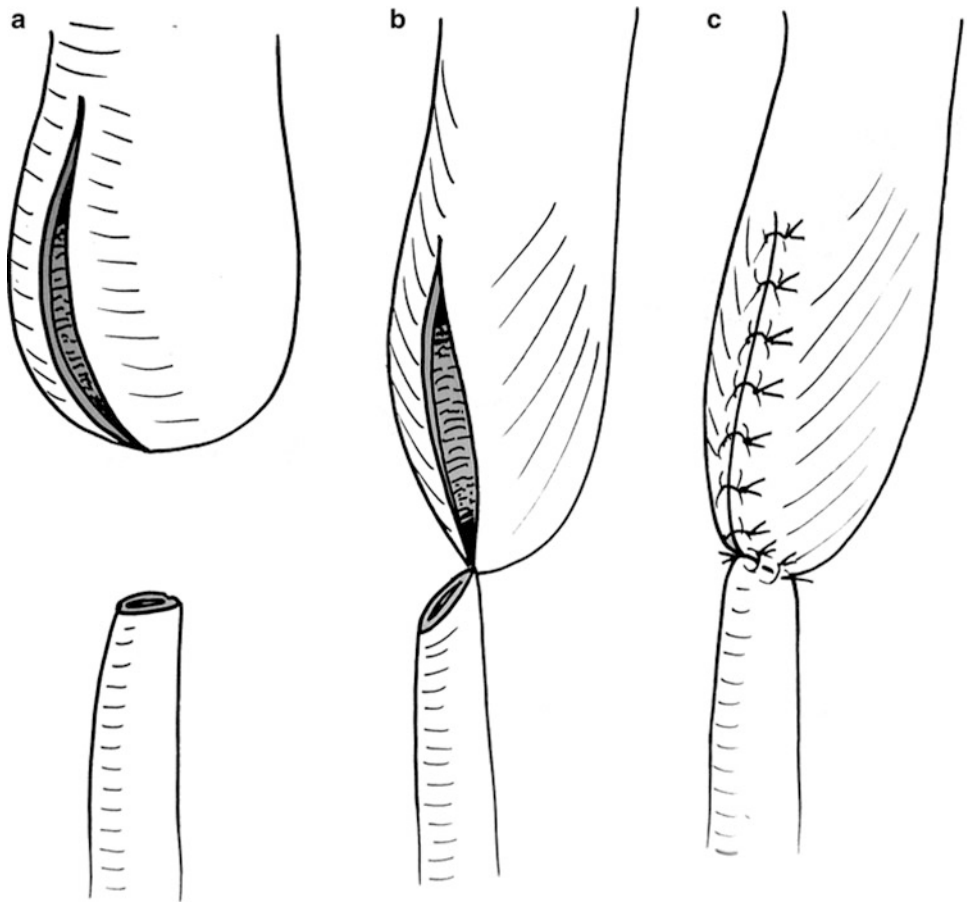

Fig. 31.9 Diagram illustrating the principle of the esophageal slide (Courtesy of Dr. Fabio Ferro). (**a**) An incision is made on the anterior aspect of the esophageal wall of the upper pouch. (**b**) Caudal stretching on the incised blind upper pouch leads to caudal skew of the circular muscle fibers, and an extra upper pouch length may be gained. (**c**) Esophageal anastomosis is completed and the incision is sutured

been shown to increase esophageal mass preserving histopathological morphology of the esophagus without major tissue damage. Two main esophageal lengthening techniques are commonly applied in newborns with a long gap.

Extrathoracic Esophageal Elongation (Kimura Technique)

This technique may be applied only to the upper esophageal pouch and is based on multistage extrathoracic esophageal elongation. The proximal esophagus is translocated to the subcutaneous tissues of the anterior chest wall, essentially a thoracic esophagostomy. After 30 days the procedure is repeated—the esophagostomy is dissected, mobilized, and exteriorized a few centimeters below the previous one. Extrathoracic elongation can be repeated until esophageal length is considered sufficient to allow restoration of esophageal continuity (Fig. 31.11).

Extrathoracic esophageal elongation is usually used in patients who have been treated with primary cervical esophagostomy or as an esophageal "rescue" procedure for babies in whom an esophagostomy had been performed because of a previous failed attempt. Advantages of this technique include the ability to maintain the native esophagus, to allow early oral sham feeding, and to shorten the hospital stay while waiting for the final esophagoesophagostomy. Preferably, the esophagostomy is created on the right side of the neck. The upper pouch is dissected as proximal as possible and brought to the skin. To make the subsequent dissection of the upper esophagus easier, this should be wrapped with a polytetrafluoroethylene patch (Fig. 31.11). At each elongation step, the neck is flexed and the esophagus gently stretched caudally and anchored to the pectoralis major fascia with 2 or 3 absorbable stitches. Thoracotomy, prolonged sedation, and muscle paralysis are not needed.

External Traction (Foker Technique)

After extensive mobilization of both upper and lower pouches, 5–0 polypropylene sutures placed in the upper and lower segments are brought out to the skin surface below and above the incision, and the thoracotomy is closed. Over the following 4–7 days, the sutures are pulled 2–3 mm daily. When the two ends are in proximity by fluoroscopy, esophageal anastomosis is performed. This technique requires additional 7–10 days of sedation, muscle relaxation, mechanical ventilation, and redo thoracotomy. We insert a

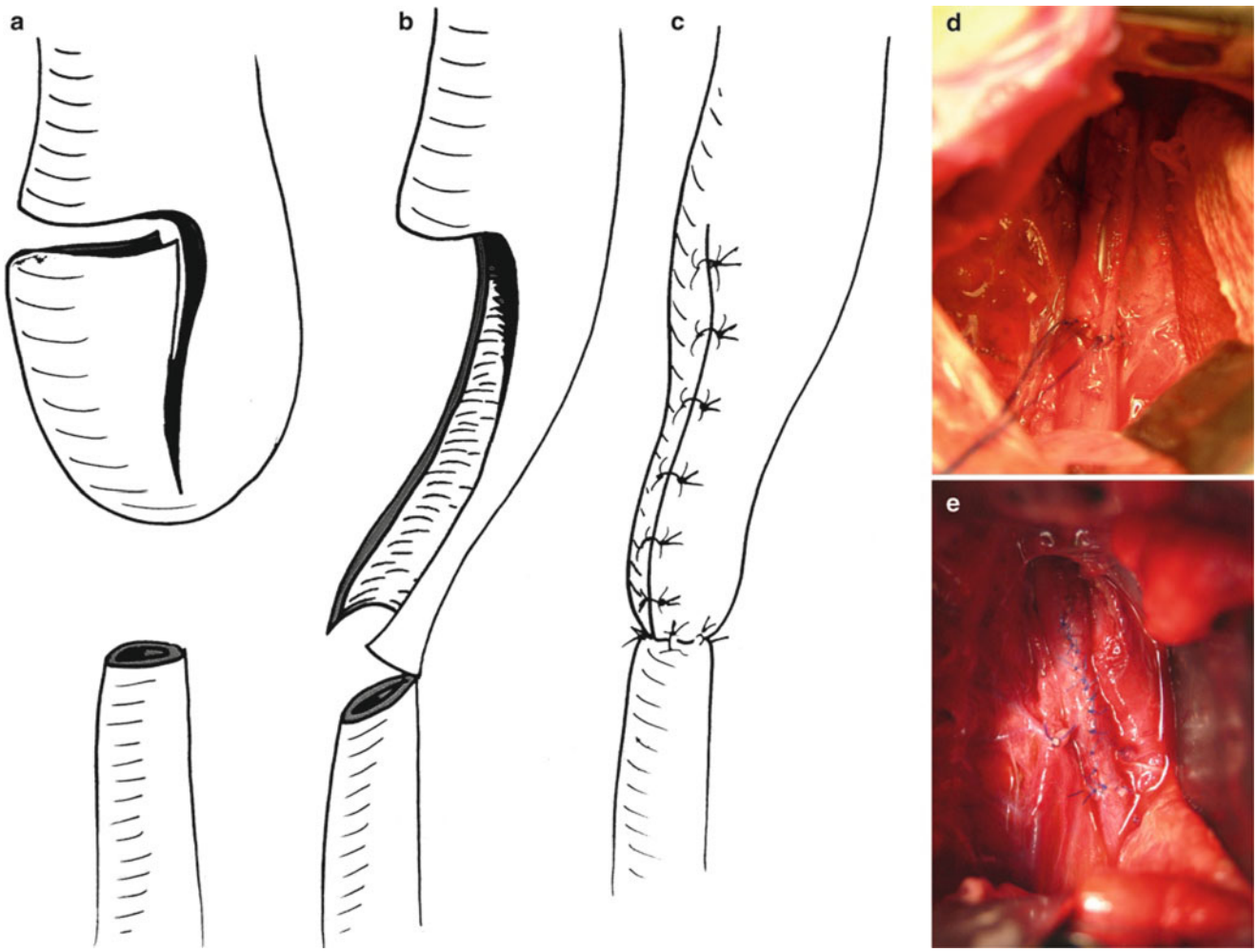

Fig. 31.10 Upper esophageal flap. (**a**–**c**) Diagram showing the principle of the esophageal flap (Courtesy of Dr. Fabio Ferro). After anterior horizontal incision of the upper pouch prolonged caudally on both sides (**a**), the flap is reversed, brought down (**b**), and anastomosed to the lower pouch (**c**). (**d**) Intraoperative picture. The flap has been reversed, the anastomosis completed, and the suture of the longitudinal incision begun. A VY-plasty of the resulting defect on *upper* (transverse) part of the incision may be needed. (**e**) Intraoperative picture. Final appearance of the esophagus after complete closure of the longitudinal incision

Goretex® sheet between the visceral and parietal pleura to reduce pleural adhesions, thereby making redo thoracotomy easier.

Failures and complications have been reported after external traction. Early complications include leaks in up to half of patients, which are mostly minor and seal spontaneously. Major disruption and failure of conservative management with need for drainage or reoperation is reported in up to 15 % of series. Lastly, esophageal replacement for unsatisfactory results after delayed anastomosis is reported in nearly 15 %.

Since delayed primary anastomosis with either gastrostomy feed and grow or with traction-induced growth provide good short- and long-term functional results, a concerted and rigorous effort to achieve an end-to-end native esophageal anastomosis should be made before considering esophageal substitution.

Minimal Invasive Surgery

The reported advantages of the thoracoscopic approach are less pain, minimal muscle damage with less shoulder asymmetry and scoliosis, and better cosmesis. In contrary, thoracotomy presents the specific advantage of an extrapleural approach, with the potential benefit in these difficult cases with increased risk of leaks due to the high anastomotic tension of keeping the leak confined to the extrapleural space as opposed to the right pleural cavity.

Postoperative Care

Postoperatively, we keep the infant paralyzed, sedated, and mechanically ventilated to minimize disruptive forces on the anastomosis (crying, hiccup, retching). The duration of

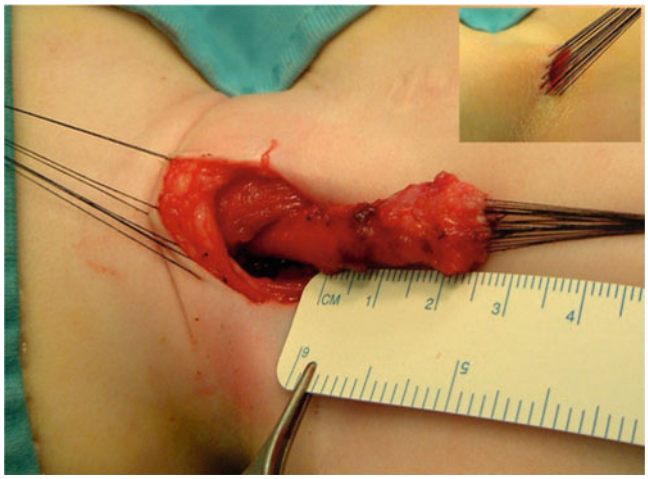

Fig. 31.11 Intraoperative picture of the upper esophageal pouch after wide esophageal dissection through a cervical approach. This was a referred patient with a cervical esophagostomy (see inset). A Goretex® sheet is wrapped around the upper esophagus to help subsequent dissection. Note the elongation obtained after wide dissection of the upper pouch

muscle paralysis ranges from 3 to 6 days, depending on the tension on the anastomosis. As soon as bowel movements resume, we start minimal enteral feeding through the trans-anastomotic tube or gastrostomy.

Before attempting oral feeds, we perform a contrast esophagram, on the 6th or 7th day. If there is no leak, the chest drain and the trans-anastomotic tube are removed and oral feeding is started. If the swallowing reflex is not yet effective, feedings are progressively increased through a nasogastric tube or a gastrostomy. If a minor anastomotic leak is detected, we postpone oral feeding, the chest drain is left in place, and minimal enteral feedings are continued. One week later, we perform a second esophagram to confirm resolution of the leak and oral feedings are started.

In the presence of either an anastomotic disruption or persistent leak, a second-look operation should be performed. At this point, depending on the condition of the esophageal ends, options might include revision of the anastomosis, cervical esophagostomy, and lower pouch closure with delayed attempt at new anastomosis or esophageal substitution.

One month after anastomosis, we perform another esophagram and esophagoscopy looking for a stricture (esophageal diameter < 5 mm) and to assess the impact of gastro-esophageal reflux (GER). When necessary, we carry out dilatations under general anesthesia with Savary bougies, over a guide wire. In the presence of significant GER, specific diagnostic studies are performed. When GER disease (GERD) is confirmed, aggressive treatment, including an early anti-reflux procedure (floppy Nissen fundoplication is our preference), should be considered, due to the strong correlation between GER and severe respiratory symptoms, recurrent esophageal stricture, and the risk of Barrett's esophagus.

As more than a few of these patients may present with persistent swallowing difficulties and GER-associated disorders, we follow them in a dedicated multidisciplinary follow-up clinic that includes a pediatric surgeon, a pediatrician, and a swallowing specialist. At 1 year of follow-up, we repeat pH monitoring and esophagoscopy because of the high rate of GER, esophagitis, and stricture.

Complications

The prevalence of early complications such as minor leaks, recurrent tracheoesophageal fistula, infections, esophageal stenosis, and GERD is related to the adequacy of blood supply to the esophageal ends, gentle handling of tissues, the degree of tension on the anastomosis, and careful postoperative care and paralysis. The incidence of complications is higher—not all of them major complications—compared to patients with short-gap esophageal atresia.

Late complications include oral aversion, which depends on the length of intubation and withholding of oral feeds, and vocal cord paralysis, due to recurrent laryngeal nerve injury following extensive upper esophageal pouch dissection or cervical esophagostomy. Despite these complications, the long-term quality of life seems no different from that of their short-gap counterparts. Mortality, which is strongly associated with complications, certainly tends to be higher in patients operated on for long-gap EA than in patients with a short gap.

It is our opinion, shared by many pediatric surgeons, that the long-term results of primary esophageal anastomosis are better than those with esophageal replacement. Irrespective of the type of replacement chosen, there appears to be less morbidity and more manageable long-term problems. However, there are no randomized controlled studies that compare the outcomes of primary anastomosis with that of esophageal replacement. But in small series of patients treated for long-gap EA, treated only with primary or delayed esophago-esophageal anastomosis, some authors have concluded that all of these babies can be treated successfully with primary anastomosis. Strictures and GERD represent the most frequent postoperative problems, and the additional procedures often required (dilatations, fundoplication) are an acceptable trade-off to maintain the patient's own esophagus and avoid replacement, which should be reserved only for cases in which a previous attempt of esophageal reconstruction failed.

In our experience and that of others, primary and delayed anastomosis for long-gap EA is nearly always possible if one follows a systematic and well standardized approach. Esophageal anastomosis in this challenging anomaly may cause short-term problems. Esophageal dysfunction is evident early after repair of a long gap but swallowing usually improves, esophageal stricture and GER can usually be managed with only minor

difficulties, and the function of native esophagus continues to improve over time, making it the procedure of choice.

Individualized Approach

Using our techniques, the most important patient characteristics that can change the treatment paradigm include birth weight, prematurity, and associated anomalies such as severe cardiac malformations (Fig. 31.5).

A Long Gap in an Otherwise "Standard" Patient

For Type A/B patients with a long gap, we recommend: (1) gastrostomy (± upper pouch fistula closure) and upper pouch suction; (2) serial measurements of the gap every 2 weeks for up to 6 weeks; (3) if the gap is <2 vertebral bodies, proceeding with anastomosis with cervical dissection, if necessary; and (4) if the gap is ≥2 vertebral bodies, performing either external traction or create an upper pouch flap and anastomosis.

For Type C/D patients we would: (1) perform a cervical dissection and proximal fistula closure; (2) close the distal TEF; (3) if the gap is <3 vertebral bodies, perform a primary anastomosis; and (4) if the gap is ≥3 vertebral bodies, proceed with either an external traction or create an upper pouch flap and anastomosis.

A Long Gap the Patient Referred After Cervical Esophagostomy and Gastrostomy

If the gap is <2 vertebral bodies, we would proceed with primary anastomosis (with cervical dissection). If the gap is ≥2 vertebral bodies, we would consider the Kimura procedure or an internal/external traction and anastomosis.

Editor's Comment

Retaining the native esophagus, even if imperfect, is almost always preferable to any of the various esophageal replacements that have been described. With experience, patience, and good judgment, we should be able to preserve the esophagus in most patients with long-gap EA. The critical element is usually time—the esophageal ends will grow, but it can take months. There should be no rush to try and bridge a long gap unless the plan has been thought out very carefully and the advice of experienced surgeons has been sought. A series of procedures are required and we need to help the parents prepare for a long process. It is very important not to burn any bridges and to try to preserve and retain the native esophagus at all costs, at least initially.

Once the work-up is complete and cardiac disease has been eliminated, the next steps are bronchoscopy to rule out a proximal fistula, gastrostomy for subsequent feedings, and measuring the initial gap. Almost every baby with pure EA has microgastria, which requires a gentle approach and usually a more traditional tube rather than a balloon device that occupies the gastric lumen. From above and through the gastrostomy, the proximal and distal pouches can be interrogated under fluoroscopy with contrast and instrumentation and the gap measured in vertebral bodies. Ultimately, periodic gap measurement with rigid instruments will be required. The esophageal ends will grow, most notably in the first few weeks; however, ultimately it might take months to bring both ends into closer proximity. Until such time, a proximal suction tube must be maintained in the proximal pouch to prevent aspiration. It is usually safe, under careful nursing or speech therapy observation, to allow early small volume sham feedings to help promote oral motor neurodevelopmental milestones.

The cervical esophagostomy has been frowned upon of late as it can shorten the proximal esophageal pouch available for ultimate anastomosis. One can only hope that this staple of pediatric surgical history will soon become a banished relic. This gruesome operation should only be performed under extraordinary circumstances or as part of a staged lengthening operation, not as primary therapy.

At thoracotomy, upper and lower pouch mobilization can be performed and the anastomosis achieved under tension. The careful technical aspects of laying the posterior row of sutures and tying the knots consecutively with the two esophageal ends held in proximity under traction should help prevent individual sutures from tearing through, which results in the loss of a precious centimeter or more of length. Ringed bowel forceps work well to grasp each esophageal stump above and below and to push the ends together so that the entire posterior row of sutures can be tied down under no tension. Intraoperative tricks to help bring the two ends closer together include maximally flexing the neck and removing shoulder rolls. Up to three circumferential myotomies or a spiral myotomy can be performed on the upper pouch, providing a significant amount of length. Upper esophageal flaps can be used as described to lengthen the proximal pouch but careful preservation of blood supply is critical.

A small nasogastric tube can be passed through the anastomosis to allow gastric decompression and enteral feeds in the postoperative period, though a tube that is too large can create radial tension and ischemia at the anastomosis, leading to breakdown or stricture. The technique of gradual lengthening by use of external traction sutures popularized by Foker clearly has been a major advance in the field, but we have also seen it fail miserably in inexperienced hands. It is not as easy as it seems and should be guided by someone with extensive experience in the technique.

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Managing the Complex Esophagus

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Edward Hannon, Lewis Spitz, and Paolo De Coppi

Managing complex esophageal injuries in children is challenging and requires institutional and individual surgical experience. Whether the result of caustic ingestion, iatrogenic injury, or failed surgical management of esophageal atresia, it is important that cases are carefully considered, with adequate investigation and planning regarding the most appropriate option for repair, and that the operation is performed by an experienced surgeon.

Complex esophageal injuries or conditions are rare in the pediatric population in contrast to the large workload the adult surgeon faces from malignant disease. This is mainly the result of improved legislation in the developed world around caustic materials and their packaging, which have led to a much lower incidence of caustic injuries. In the developing world, unfortunately such injuries are still a frequent occurrence. The management of esophageal atresia has also improved, resulting in lower morbidity and fewer failures requiring esophageal replacement.

At our institution the majority of complex esophageal work and subsequent replacement is a result of referrals from other UK centers and from overseas. Around a quarter of patients are managed from diagnosis exclusively at out institution. We therefore manage a full spectrum of cases from the first presentation of long-gap esophageal atresia or caustic injury through to the failed esophageal replacement cases from our and other centers.

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Initial Management

The acute management of different complex esophageal diseases in the pediatric patient is variable and individualized, depending on whether there was a caustic injury or a congenital esophageal problem.

Caustic Injury

Caustic injuries are increasingly rare in developed countries but are still seen and most commonly include household cleaner ingestion and swallowed button batteries lodged in the esophagus. Batteries should obviously be removed from the esophagus as an emergency as cases of esophageal perforation and aortic fistula have been described with batteries left in situ more than 6 h. Batteries tend to cause focal strictures at the site of impaction in the esophagus as opposed to liquid caustic ingestion where long circumferential burns can be very difficult to manage in the medium and long term.

Following early primary assessment of airway, breathing, and circulation, initial management of these types of liquid caustic injuries involves a conservative approach with no attempts to induce vomiting or promote dilution. Early endoscopy is performed at less than 48 h post-ingestion to confirm that the caustic substance has in fact entered the esophagus and to reduce the theoretical risk of perforation with more delayed assessment. At this point, accurate and detailed "grading" of injuries as often described can be difficult, but endoscopy gives a good indication of the depth and severity of injury, and it is important to note circumferential burns and the length of esophagus affected. A nasogastric tube can also be passed under direct vision to allow early feeding. Evidence for use of steroids and antibiotics is limited.

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The next stage of investigation is a contrast swallow, not usually performed for several weeks, to allow time for initial esophageal injury to heal and acute inflammation to resolve. During this period oral feeding is encouraged if tolerated but nasogastric feeding can be used if necessary. Worsening obstructive symptoms necessitate earlier investigation. At this point the longer-term significance of the injury to the esophagus can usually be assessed in terms of the degree and length of stricturing seen. Depending on the severity of the stricture, a program of esophageal dilatation can then be initiated.

Esophageal Atresia

The initial management of long-gap esophageal atresia obviously depends on the presence of associated tracheoesophageal fistula. While this is usually known radiographically before surgery, rigid esophagoscopy and bronchoscopy at induction can be useful to confirm the diagnosis, to exclude an upper pouch fistula and to evaluate the trachea for tracheomalacia—although these should not be undertaken in unstable, ventilated, or low birth-weight infants as the risks of increasing respiratory difficulties may outweigh the benefits.

In type A EA a gastrostomy is performed and Replogle tube left in the upper pouch. Given the often small size of the stomach, the gastrostomy may be not sutured up to the anterior abdominal wall to preserve stomach area for later surgery. Delayed gap assessment can then be performed after several weeks of gastrostomy feeding and definitive surgery planned. In cases of type C EA, following ligation of the TEF, an estimation of gap length is performed. The definition of gap length is variable and ability to perform primary anastomosis is obviously the judgment of the operating surgeon. More than three vertebral bodies are generally considered a long gap. Primary anastomosis under tension with elective paralysis and mechanical ventilation is safe and very successful; however, if in doubt a delayed repair under less tension may be better in inexperienced hands than a very tight and possibly unsafe primary anastomosis and the potential morbidity this brings.

Gap assessment is performed after at least 6 weeks and involves the use of urethral dilators, contrast, or a flexible endoscope being passed retrograde through the gastrostomy into the lower esophageal pouch, while the Replogle tube is pushed under tension in the upper pouch. Again, three vertebral bodies under moderate tension are considered long gap, and those patients would not be considered for immediate esophageal anastomosis but for further delay for up to 6 weeks and repeat gap assessment and then primary anastomosis or esophageal replacement. Obviously there are many other factors taken into account when making these decisions such as associated abnormalities, especially cardiac and the nutritional state of the patient.

This outlines our standard early management of the common primary complex esophageal patient we manage. However, the more complex esophageal patients we manage, many of whom are external referrals, previously managed elsewhere need more careful assessment and work-up to ensure the decision on further management strategy is fully informed. Patients may be referred early in their treatment progress if other centers do not have experience of performing long-gap esophageal repairs or managing difficult caustic injuries or may as is more commonly be referred after failed management elsewhere. These patients have often had multiple surgeries and may have had the native esophagus abandoned and esophagostomy already performed.

Clinical Assessment

Assessment of these complex pediatric esophageal cases involves a detailed multidisciplinary approach, and accurate investigation of patients is key for correct decision making. Accurate history and importantly operative history is essential to understand the nature of the underlying esophageal injury. Where available operative notes and imaging from referral centers are important, it is our practice to fully reinvestigate patients in order to have as much up-to-date information as possible on which to base decisions for management and surgery in children who have often undergone extensive multiple surgeries. This strategy has led in many cases to the discovery of previously missed and clinically significant abnormalities.

Echocardiography

Detailed transthoracic echocardiography is essential for the assessment of associated cardiac anomalies.

Upper GI Contrast Study

UGI is performed using water-soluble contrast and gives good anatomical information regarding the extent of esophageal disruption and presence of other contributing factors often seen in these cases such as gastroesophageal reflux, the presence of hiatus hernia or previous fundoplication, and some estimation of gastric emptying. Contrast can be given orally, by nasogastric tube or by gastrostomy (Fig. 32.1).

Microlaryngobronchoscopy

A close working relationship with ENT surgeons is essential when providing a complex esophageal service. MLB is an important investigation in complex cases of EA/TEF. It is

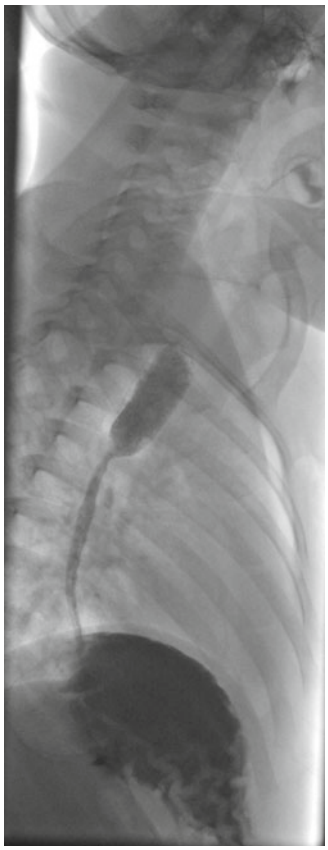

Fig. 32.1 Long distal esophageal caustic stricture. This patient failed serial dilatations and stent insertion and required esophageal replacement

essential to ensure there is no recurrent or missed upper pouch fistula or a missed fistula in patients with presumed type A (pure EA). The degree of tracheomalacia can also be assessed. This can be important for surgical planning when considering esophageal replacement. Bringing a large conduit (stomach or colon) into the chest with an anastomosis in the neck can have significant effects on respiratory dynamics, which can be more significant in those with tracheomalacia or cardiac disease. Consideration to correction or improvement of tracheomalacia with aortopexy should be considered, although this would preclude a retrosternal approach for esophageal replacement. Importantly MLB should be performed in the presence of the general pediatric surgeon.

Contrast CT

CT scan has more recently become part of our routine assessment of complex esophageal patients. It serves to identify associated abnormalities in thoracic vasculature (especially aortic arch position), to identify the best route within the chest for esophageal replacement, and to look for background lung disease. This is usually performed without a general anesthetic.

Esophagogastroduodenoscopy

While contrast esophagram gives a good anatomical picture of the complex esophagus and associated strictures, EGD completes that picture. It allows more understanding of the luminal anatomy and the nature of any stricturing and can assess the effects of reflux. Unlike the contrast esophagram, EGD performed early in the work-up can help characterize the stricture further, such as whether it might be safe to proceed with dilation or not. Biopsies are also useful, especially of the distal esophagus to assess for signs of mucosal injury from chronic reflux, which can make efforts to dilate strictures futile.

Esophageal pH, Impedance, and Manometry

These studies are useful in cases of intractable stricturing and ongoing dysphagia. In esophageal strictures where early recurrence of symptoms after dilatation is seen, reflux must be considered and investigated. In EA/TEF patients with ongoing dysphagia, manometry plays an important role in confirming a dysmotile pattern of swallow. While dysmotility is difficult to treat, knowledge that it is contributing to symptoms may spare further unnecessary investigation.

All of these studies form an integral part of a systematic work-up for children with complex esophageal disease (Fig. 32.2).

Surgical Management

The functional preservation of the child's native esophagus is the main aim of managing patients with complex esophageal conditions. The main obstacles to this are structuring, usually the result of caustic injury or failed anastomosis, and insufficient length of native esophagus, which may necessitate replacement surgery.

Strictures

The mainstay of stricture management is serial esophageal dilatation and treatment of reflux. The efficacy of dilatation is related to the length, degree, and type of stricture. We favor the use of balloon dilatation under radiological guidance. A guide wire is passed through the stricture and balloon passed over the wire. The balloon is then inflated with contrast and imaged until the waist on the balloon, representing the stricture, is obliterated (Fig. 32.3). Balloon dilatation avoids the sheering effect of bougie dilatation and allows the procedure to be performed under vision, and perforation is usually recognized early. Those with tight and recurrent strictures, especially after

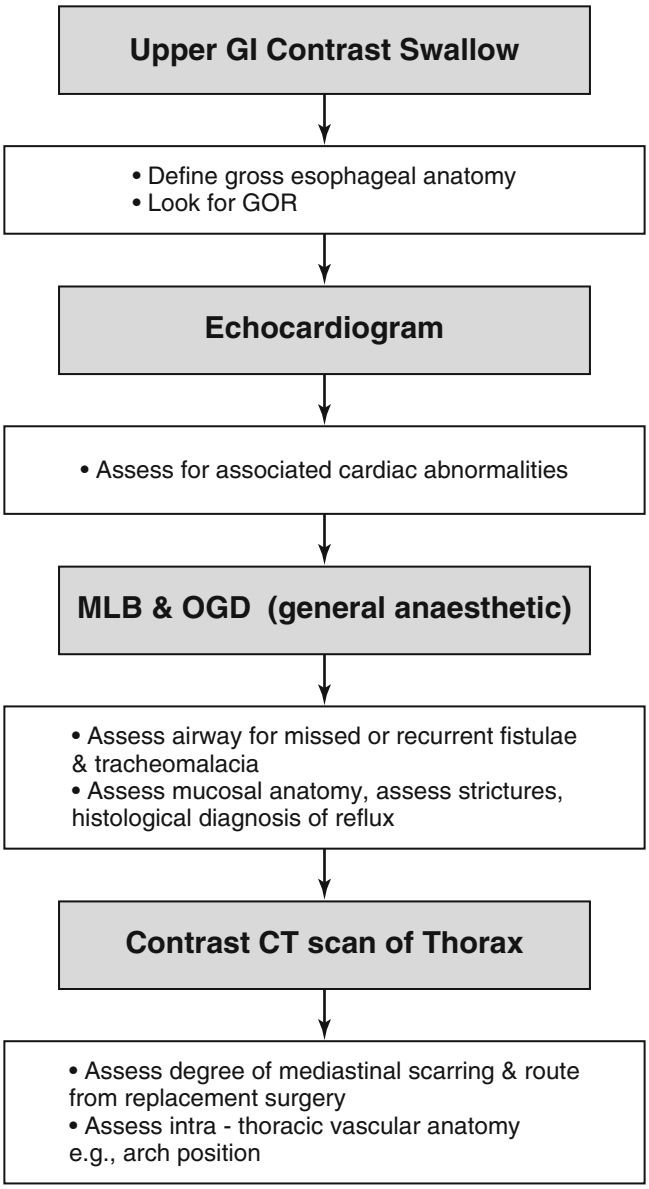

Fig. 32.2 Investigation strategy for complex esophageal cases

caustic injury, benefit from serial elective dilatation as opposed to waiting until symptomatic. These can be performed every 2–3 weeks. Pinhole strictures, which are difficult to access even using endoscopy and direct vision to pass the guide wire, can be approached retrograde through the gastrostomy.

Stricturing is also seen following esophageal replacement, especially at the anastomosis between the native upper esophagus and the conduit, which is often brought up to the neck under some degree of tension. Again, balloon dilatation is the best way to manage such strictures.

Stenting

Esophageal stenting is a technique translated from adult esophageal cancer care and is now reported in the management of caustic injuries in children and for the management

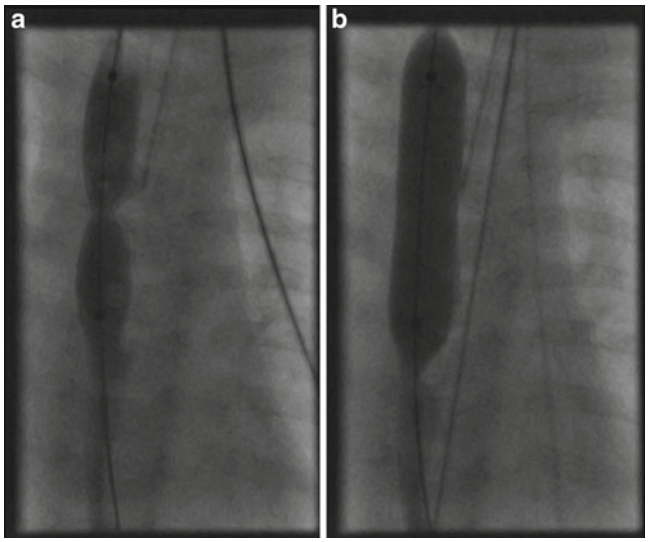

Fig. 32.3 (**a**) Balloon dilatation 1—"waist" on balloon demonstrating esophageal stricture. (**b**) Balloon dilatation 2—"waist" on balloon has been eliminated during dilatation

of some strictures. Different expanding stents are available depending on material (metal or plastic) and whether covered or uncovered. More recently absorbable plastic stents have also been used. Metal stents have the benefit of strength and less displacement but have a higher risk of erosion and perforation and hence are now covered. Plastic stents are gentler but are more likely to move, while the absorbable stents integrate well—not needing to be covered, they have less strength and need replacing regularly. All stent types can be difficult to tolerate. We have used both metal and absorbable stents for intractable strictures in those patients where further surgery is not immediately possible due to the nature of their esophageal injury, or significant comorbidities prevent surgery proceeding (Fig. 32.4).

Resection and Anastomosis

Although rare, cases of short caustic strictures and isolated anastomotic strictures that are resistant to dilatation and have adequate esophageal length can be considered for resection and redo anastomosis. This can be approached via a right thoracotomy, and the main difficulty faced is mobilizing enough length of healthy esophagus for a tension-free anastomosis in an already-scarred posterior mediastinum.

Gastroesophageal Reflux

Alongside dilatation the management of reflux is also crucial to successful treatment of strictures, especially in the distal esophagus. UGI swallow and pH/impedance monitoring are useful here, and the use of proton pump inhibitors should be considered in all patients empirically until reflux has been ruled out.

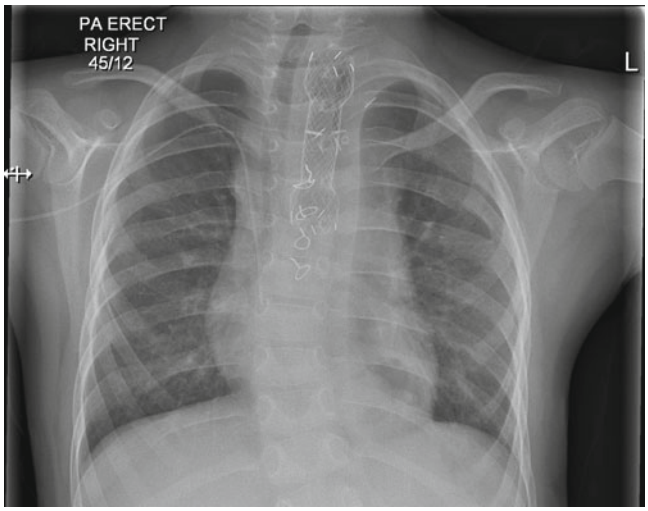

Fig. 32.4 CXR showing a metal-covered stent—stenting an anastomotic stricture in the cervical anastomosis of a complex gastric transposition

In severe cases of reflux, fundoplication should be considered, and a floppy Nissen wrap can be performed laparoscopically with repair of any associated hiatus hernia. The results of fundoplication in complex cases with poor esophageal function are poor, especially when there is some degree of tension from an esophageal anastomosis, with failure rates of up to 40 %. In these cases consideration of gastrojejunal feeding may need to be considered.

Special attention needs to be paid to those patients in whom the probability of needing an esophageal replacement is high. Fundoplication can make gastric transposition and hiatal dissection difficult, and if replacement is anticipated, patients should be fed through the jejunum and treated with high-dose PPIs to manage reflux. Patients with severe dysmotility also have poor results from fundoplication, and there is an important role for esophageal manometry in cases where dysmotility is suspected.

Esophageal Substitution

In many centers, *cervical esophagostomy* in patients with long-gap EA is routine to allow sham feeding. This feeding benefit is balanced against the risk of esophagostomy in the neonatal period and associated risk of damage to recurrent laryngeal nerves and some loss of length of upper pouch esophagus. We therefore do not routinely perform esophagostomy in the neonatal period but recognize its benefit in some selected cases where early anastomosis or replacement surgery is not possible, often due to comorbidities. It allows patients to be discharged and benefit from sham feeding but is a lower risk than when performed as a neonate. It also has a role in those patients with significant long-term injuries whether iatrogenic or caustic, often referred from other centers in which case it gives the patient a break from repeated hospitalizations for dilatations to try to salvage the esophagus, which will in the long term need replacement. Patients can have gastrostomy and esophagostomy placed and then be discharged to grow and get well nourished in preparation for replacement surgery.

The decision to abandon the native esophagus and perform replacement surgery is an important one and needs to be a well-informed decision, based on the results of the correct investigations made by experienced surgeons in discussion with a multidisciplinary team. The morbidity associated in the long and short term with esophageal replacement is significant, and all options at more conservative approaches must have been considered. However, the benefit of replacement is also easily seen in those patients with a long and complicated previous surgical history, requiring either multiple recurrent dilatations for strictures or who have an esophagostomy where the quality of life may be poor. In our experience *early recognition of those needing replacement* is also key in limiting the morbidity of multiple surgeries and achieving the best functional outcome. The indications for replacement include inability to perform an anastomosis (long-gap EA), repeated leaks, recurrent TEF, and intractable structuring, all of which are made more pertinent by recurrent hospitalizations and poor quality of life.

There are four well-described methods used for esophageal replacement in children: gastric transposition, colon interposition, jejunal interposition, and gastric tube. The most commonly used techniques are gastric transposition and colon interposition, and both have large series reported compared to the jejunal interposition and gastric tube.

Gastric Transposition

Gastric transposition, first described in the adult population for esophageal malignancy, was adapted and popularized for pediatric esophageal replacement mainly by the work of Spitz at Great Ormond Street Hospital and continues to be our procedure of first choice for esophageal replacement.

The technique involves initial closure of the existing gastrostomy, transhiatal resection of the distal esophagus, and oversewing or stapling of the gastroesophageal junction. In redo cases or caustic injuries, the native esophagus may need to be resected fully, in which case thoracotomy is required. The stomach is then mobilized on the right gastric and gastroepiploic vessels. A Heineke-Mikulicz pyloroplasty is performed. A channel is created in the chest to deliver the mobilized stomach into position. This is usually in the normal esophageal position in the posterior mediastinum but can be retrosternal, especially when the posterior mediastinum is scarred from multiple previous surgeries or significant caustic injury. This

dissection is usually blunt from the neck and hiatus until the space in the chest is large enough to accommodate the stomach, which is orientated and passed into the chest and anastomosed to the proximal esophagus in the neck (Fig. 32.5).

As with all esophageal replacement, careful dissection in the neck to preserve blood supply to the anastomosis and avoid injury to the recurrent laryngeal nerves is important. Finally a temporary feeding jejunostomy is inserted in those children who have never fed orally.

The excellent blood supply of the stomach in gastric transposition theoretically reduces the risk of leak and stricture, but these complications are still seen in 12 % and 20 %, respectively, at our institution. Therefore, close observation in the postoperative period is important and investigation of new symptoms with early contrast study is essential. Most leaks can be treated conservatively and strictures can usually be dilated.

The size of the stomach can affect respiratory dynamics in the early postoperative period and gastric emptying can be slow despite pyloroplasty (9 %). Rarely (3 %) dumping syndrome is also seen in those feeding orally. Reflux is also a problem and the long-term affect of gastric secretions on the proximal esophagus is unknown; therefore, all patients should stay on a PPI.

In our institution minimally invasive techniques now mean the procedure can be performed safely laparoscopically. The patient is positioned as for fundoplication with legs in lithotomy. A 5 mm umbilical camera port is used and two lateral working ports positioned. The procedure is performed as the open technique. Dissection of the hiatus and distal esophagus can be difficult, and if necessary thoracoscopy can also be used to aid in distal esophageal resection.

Colonic Interposition

First described in 1921 in children, the colon interposition takes advantage of the length of colon available without causing significant morbidity and ease of mobilization through the hiatus and into the chest. The interposed colon can be from the right, transverse, or left, mobilized on ileocolic, middle colic, or left colic vessels, respectively. The most commonly used is the left transverse and upper left colon. The specific segment of colon to be used is decided following inspection of the vascular anatomy of the colon and estimation of the length of graft required.

As for all esophageal replacement, the diseased esophagus is usually excised and a conduit in the chest created for the interposed colon. This can be either in the posterior mediastinum or, less frequently, retrosternal. The esophagocolonic anastomosis is then performed in the neck, and anastomosis of the colon to the distal esophageal stump is performed with anti-reflux wrap and pyloroplasty (Fig. 32.6).

Minimally invasive techniques have been described for colonic interposition to help minimize morbidity of this procedure. Laparoscopic-assisted interposition involves initial mobilization of the stomach, transhiatal-esophagectomy and mobilization of the colon, and subsequent exteriorization of

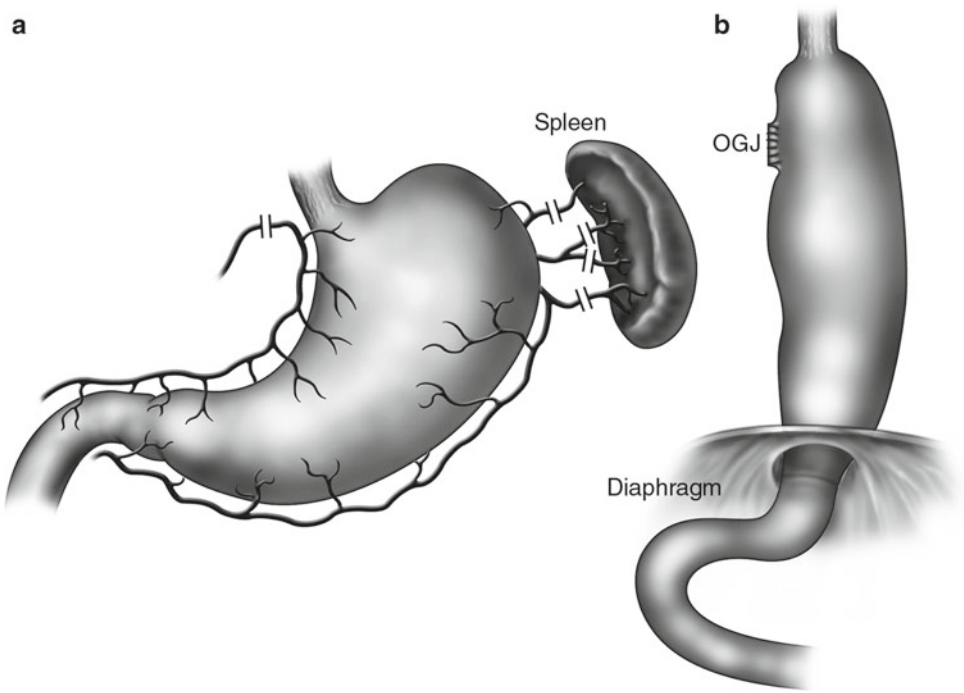

Fig. 32.5 Colon interposition. (**a**) *Segment a* based on *right*/*middle colic* vessels or ileocolic vessels. *Segment b* based on ascending branch of *left colic* vessels. (**b**) Colon graft passed retrosternally or transhiatally to posterior mediastinum or left thoracic cavity. (**c**) Distal anastomosis to distal esophageal stump or to stomach

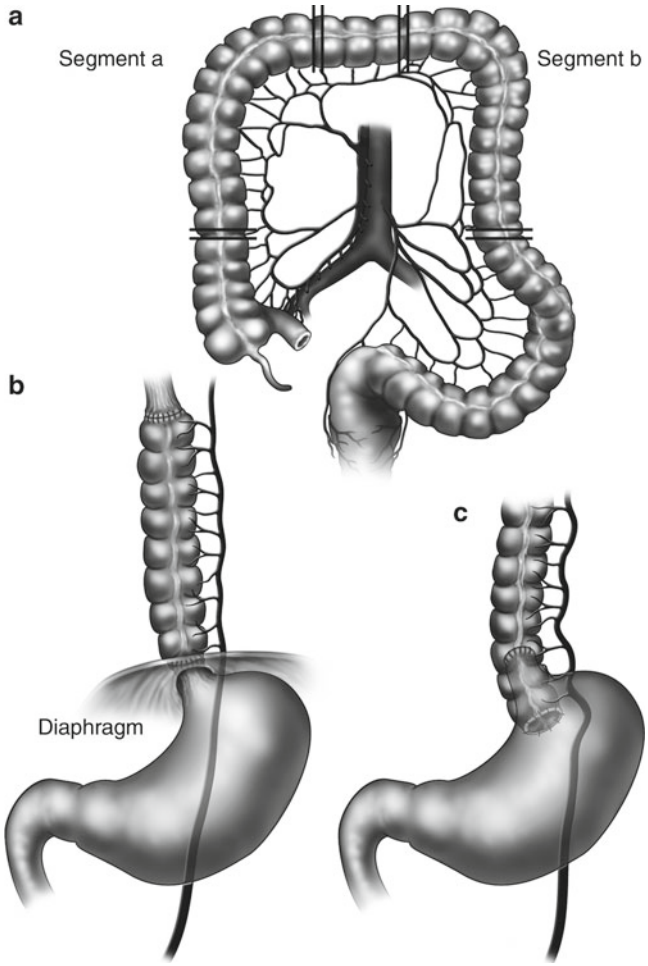

Fig. 32.6 Colon interposition. (**a**) *Segment a* based on *right/middle colic* vessels or ileocolic vessels. *Segment b* based on ascending branch of *left colic* vessels. (**b**) Colon graft passed retrosternally or transhiatally to posterior mediastinum or left thoracic cavity. (**c**) Distal anastomosis to distal esophageal stump or to stomach

the colon for the colocolic anastomosis and distal coloesophageal anastomosis. Finally the colon is delivered into the chest and anastomosed in the neck.

Colonic interposition is a popular choice for esophageal replacement in the USA and large series are reported in Egypt and Spain. Commonly reported morbidity includes anastomotic leaks and strictures and in the long term redundancy of the distal colon. Colonic interpositions appear to have a lower risk of reflux, and the ability to perform an anti-reflux wrap is obviously beneficial from this point of view.

We rarely use colonic interposition and reserve it for cases of failed gastric transpositions or in those patients with a small stomach making gastric transposition impossible.

Jejunal Interposition

Jejunal interposition is less commonly used for replacement due to a more precarious blood supply, but proponents of the technique like its similarity in caliber to the esophagus and report it maintaining its peristalsis well. We have used free jejunal interposition grafts, with microvascular anastomosis, in cases of intractable anastomotic strictures following gastric transposition.

Gastric Tube Replacement

The gastric tube procedure involves the formation of a tube of stomach using a stapling devise based on the greater curvature of the stomach and its vasculature. The advantages of good blood supply, graft length, and peristalsis are countered by the long staple lines and high risk of leak.

Complex esophageal conditions and replacement surgery are rarely necessary in children. In esophageal atresia, more than three vertebral bodies are generally considered a long gap, which is rare. The evidence behind any of the management strategies discussed is limited. Both gastric transposition and colonic interposition have the largest series in the literature, and the two comparative retrospective studies and one meta-analysis are contradictory when comparing the risk of leak, stricture, and graft failure between gastric transposition and colonic interposition but do agree that there is a similar morbidity to each procedure. Given that this procedure is rare and the literature equivocal regarding outcome between the two most commonly performed techniques, we conclude that good outcomes may be better achieved by centralization of services to centers with surgeons with large experience of esophageal replacement—irrespective of which technique they perform. There are no good long-term follow-up data for esophageal replacement into adulthood, and therefore the long-term effects such as function, nutrition, and respiratory function as well as the risk of malignant change are unknown at present and need further investigation.

Future Considerations

Given the significant morbidity and mortality of current esophageal replacement strategies, it is important to also look forward to the opportunities that tissue engineering may offer in the future. Tissue engineering involves the implantation of anatomical scaffolds seeded with cells destined to become the mature cells of all layers of organ to be replaced. Scaffolds for the esophagus may be synthetic in origin or decellularized grafts, which would be then reseeded with patient-derived cell lines, which have been cultured, expanded, and differentiated. This has been successfully achieved using decellularized cadaveric allografts in tracheal replacement in both adults and children, and while the esophagus offers a bigger challenge in terms of the functional outcome, it is hoped a tissue-engineered esophagus may be the procedure of choice in the future for esophageal replacement.

Editor's Comment

When several different operations are described for a single clinical problem, we can be fairly certain that not one of them is the ideal solution for every patient. Nevertheless, it is clearly important for the pediatric surgeon to have confidence and experience with one or more of the several imperfect operations used to replace the esophagus and have some familiarity with the other options that are available so that patient care can be individualized and optimized.

Historically in the USA, the colonic interposition has been the most popular. It is probably the easiest to perform and patients generally do quite well for several years. The problem is that over time, the colon continues to grow in length and diameter, so that eventually it becomes huge, tortuous, and poorly functioning. This has led to fairly widespread dissatisfaction with the technique and a corresponding increase in popularity of the gastric transposition ("gastric pull up"). It is safe and technically straightforward, and though the initial postoperative phase can be trying, the long-term results appear to be quite acceptable. Most surgeons prefer to perform a pyloroplasty. It is also preferable, though not mandatory, to place the graft in the posterior mediastinum and if possible to avoid a thoracotomy. Regardless of the approach, it is essential to preserve the blood supply of the stomach and to create a tension-free anastomosis. Leaks are relatively common but usually easily managed, especially when the anastomosis is in the neck.

The jejunal conduit is the most appealing option in that the diameter of the graft approximates that of the esophagus; transit should be better since peristalsis is preserved, and the long-term issues seen with the other types of graft should be eliminated. However, the operation is technically challenging and the blood supply to the cephalad portion of the graft is often quite tenuous.

Suggested Reading

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Esophageal Injuries and Replacement

33

Inna N. Lobeck and Daniel von Allmen

Injury to the mucosa of the esophagus can occur as a result of ingestion of caustic substances including alkalis and acids. While ingestion of acidic substances usually results in coagulation necrosis and denaturation of tissue proteins, alkaline ingestion tends to generate liquefactive necrosis through fat saponification and protein solubilization. Injury from acidic substances is limited in severity due to eschar formation. Alkaline substances, however, penetrate deeper into the mucosal surface and impede blood flow through vessel thrombosis, resulting in more severe injury. Although caustic ingestion may result in systemic injury, the esophageal sequelae of these substances are the most severe, including long-term feeding disability and risk of esophageal carcinoma.

The type and amount of substance ingested govern the degree of injury and play a large role in patient treatment modalities and outcomes (Table 33.1). In Western populations, alkali ingestion accounts for the majority of esophageal injury, while in developing countries, injuries from hydrochloric acid and sulfuric acid are relatively more common due to easier access to these substances.

The ingestion of caustic agents displays a bimodal age distribution, with peaks in the less than 5 and greater than 65 years, believed to be due to accidental ingestion. Roughly 50 % of toxic exposures occur in children <5 years of age.

Although improved child safety protocols, child safety caps, and public awareness campaigns have significantly decreased the incidence of caustic esophageal injury, ingestion of corrosive substances remains a serious public health concern with 5000–15,000 caustic ingestions occurring in the USA every year.

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Presentation and Diagnosis

Clinical presentation depends on the type and amount of substance ingested as well as the timing of the ingestion. While early symptoms may be minor, they do not correlate well with the severity and extent of injury. Patients may present with burns to the lips, mouth, and oropharynx. This however is not indicative of the degree to which the esophagus is harmed, as 70 % of patients with these burns do not display esophageal injury. The most common symptom of esophageal injury is dysphagia, which may occur even with mild esophageal injury. This is due to an impaired esophageal motility and, later, stricture formation. Other symptoms include drooling, stridor, hoarseness, and dyspnea. The presence of severe chest or abdominal pain suggests esophageal or gastric perforation. Patients presenting later may exhibit signs of mediastinal abscess, sepsis, or empyema.

The diagnosis of esophageal injury is multimodal. Chest radiography may display signs of esophageal perforation in the form of mediastinal air or effusion. Although radiologic contrast studies are sometimes useful in the assessment of late complications such as strictures, they are not recommended in acute situations as they have 30–60 % false-negative diagnostic rates. Water-soluble contrast studies are used initially if esophageal perforation is suspected. The most effective and widely used method of diagnosing esophageal injury and determining its extent is esophagoscopy, performed with either a rigid or flexible endoscope, which allows grading of the esophageal injury (Table 33.2). The flexible endoscope may be advanced past a mild injury, allowing for visualization of the stomach, though this should not be attempted if the injury is a circumferential grade 2 or 3 burn due to a heightened risk of perforation.

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Table 33.1 Commonly ingested caustic substances

Type	Examples
Acid	Sulfuric: batteries, industrial cleaning agents, fertilizers *Hydrochloric*: toilet and drain cleaners, swimming pool disinfectants *Oxalic*: paint thinners and strippers
Alkali	*Sodium hydroxide/potassium hydroxide*: button batteries, liquid oven and drain cleaners, washing powders *Calcium hydroxide/lithium hydroxide*: hair relaxers *Ammonia*: household cleaners
Detergents, bleaches, disinfectants	Dish detergent *Sodium hypochlorite*: household bleach *Potassium permanganate*: disinfectants, hair dye Mildew remover

Table 33.2 Endoscopic grading of esophageal injury (reproduced based on Zagar's classification)

Grade	Characteristics
0	Normal mucosa
1	Mucosal edema
2a	Superficial mucosal ulcerations, exudates, erosions
2b	Deep discrete or circumferential ulceration
3a	Transmural ulceration with focal necrosis
3b	Transmural ulceration with extensive necrosis
4	Esophageal perforation

Early endoscopic evaluation should encompass an assessment of the entire length of the esophagus and stomach if possible. Recent recommendations have advised waiting no longer than 24 h to evaluate the esophagus endoscopically, as beyond this time frame the progressive weakening of the esophageal wall increases the risk of perforation.

Treatment

Initial steps in management of esophageal injuries include hemodynamic stabilization with continuous evaluation of the airway and prevention of emesis and aspiration. The patient with airway compromise might require endotracheal intubation or tracheostomy, depending on the complexity of injury. Neutralization of the corrosive agent or induction of vomiting is contraindicated as this results in further esophageal damage. Once the patient has passed the early resuscitation phase and injuries to the airway have been ruled out or managed, early efforts should be directed toward evaluation of the extent of the injury. Button batteries should be removed emergently when identified on preoperative chest X-rays as damage to the esophageal tissue can be severe within 3–4 h of ingestion.

Mild injury, in which the esophageal mucosa is irritated but intact, should be managed symptomatically with early resumption of oral intake and discharge from the hospital. However, endoscopic evaluation that reveals diffuse mucosal eschar should be approached with care and the endoscopy limited to the proximal esophagus. Repeat endoscopy within 48–72 h is helpful to reassess the extent of damage both in terms of depth and length. If possible in severe cases, gentle passage of a soft tube into the stomach provides feeding access and preserves the esophageal lumen.

Subsequent management is based on the extent of esophageal injury. Follow-up endoscopy may show remarkable improvement with return of normal esophageal appearance within days to weeks even when the initial evaluation appears severe. However, most severe patients enter a cycle of chronic dilations and recurrent strictures. Many patients ultimately respond to long-term conservative measures lasting several months before allowing resumption of a normal diet.

Even in cases where it is clear that the native esophagus will not be salvageable, it is crucial to allow the process to evolve completely and injury to mature before attempting any esophageal replacement procedure. The surgical options will ultimately depend on the extent of the injury and span of the spectrum of local resection with primary anastomosis, segmental interposition, gastric pull-up, or colonic interposition.

Aggressive protocols of early endoscopic evaluation, close follow-up, esophageal dilations, and a philosophy to preserve the native esophagus at all costs have markedly reduced the need for esophageal replacement due to injury. However, caustic ingestions are far from eliminated and new risks including ingestion of button batteries continue to make severe esophageal injuries a common clinical problem.

Surgical Options

If surgery becomes necessary, there are several options, the choice of which is tailored to the individual patient and the type and extent of injury (Table 33.3).

Table 33.3 Modalities of esophageal replacement utilizing various conduits

Conduit	Advantage	Disadvantage
Colon	Superior length	Elongation, redundancy
Jejunum	Better caliber	Tenuous blood supply
Gastric tube	Good caliber	High leak/complication rate
Stomach	Single anastomosis, robust conduit	GERD, gastric dilation

Primary Resection

Short segment damage to the esophagus caused by battery ingestions or limited caustic ingestion may occasionally be treated by segmental resection and primary anastomosis. Surgeons with an appropriate skill set and experience can attempt the procedure thoracoscopically. The risk of this approach lies in the difficulty of preoperative evaluation regarding the extent of damage. Esophageal injury frequently extends farther than expected making primary anastomosis impossible or subject to leak or recurrent stricture. When multiple attempts at restoration of esophageal continuity are made, further efforts may prove futile and be detrimental to patient's welfare. In these cases, esophageal replacement must be pursued.

Gastric Transposition

Gastric transposition was first described in the pediatric population by Sweet in 1948, though it did not gain popularity until reintroduced by Ahmed and Spitz in the 1980s when other replacement modalities did not display satisfactory outcomes. This operation involves mobilization of the stomach on a vascular pedicle and placing it in the mediastinum through creation of a single cervical anastomosis (Fig. 33.1). If the proximal esophagus is relatively spared and depending on the length of usable proximal esophagus, the stomach can be mobilized and pulled up to meet the cervical esophagus using either an Ivor-Lewis approach or trans-hiatal esophagectomy. The esophagectomy portion of this procedure may be quite challenging in cases of lye ingestion, where the full-thickness injury can cause dense adhesions to surrounding mediastinal structures. In these instances a thoracotomy is required to safely remove the esophagus. However, in most cases a transhiatal esophagectomy is preferred, alleviating the need for a thoracotomy. And some surgeons with advanced laparoscopic skills can employ minimally invasive techniques.

Studies of this replacement modality have displayed a low complication profile and satisfactory long-term functional results. Other advantages are that is a relatively

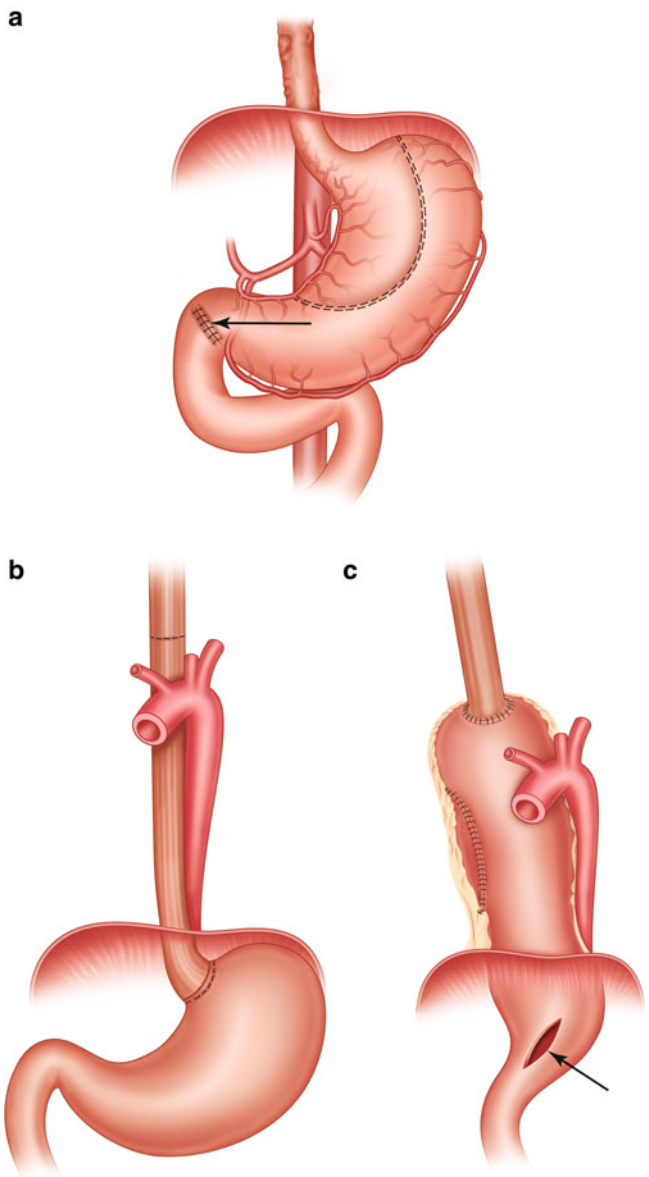

Fig. 33.1 Gastric transposition for esophageal replacement. (**a**) The stomach is mobilized and gastrohepatic ligament is divided to preserve the right gastric artery. (**b**, **c**) A pyloromyotomy is typically performed and the stomach is pulled up into the chest and divided. A gastroesophageal anastomosis is then created

straightforward operation with a well-vascularized graft and a single anastomosis in the neck or mediastinum. In addition, the inclusion of a pyloromyotomy and pyloroplasty may be performed to prevent delayed gastric emptying. Long-term outcomes and patient nutrition have also proven satisfactory. The stomach acts as a conduit rather than a reservoir for solids and liquids. Height and weight are generally satisfactory in these patients in the long term.

Complications include stricture, leak, and GER. Respiratory complications have also been reported in the short-term postoperative period due to edema caused by the extensive dissection and in the long term in patients who report reduced lung capacity, presumably due to the mass effect of the stomach in the chest.

Gastric Tube

The gastric tube is developed from the greater curvature of the stomach with left gastro-epiploic blood supply. Although originally described as a reversed or antiperistaltic conduit, the technique has been modified to allow for an isoperistaltic tube. To create a gastric tube, the gastro-epiploic arcade is divided and an incision is created in the greater curvature of the stomach. This portion of the greater curvature is then tubularized and pulled up into the chest on a vascular pedicle. A cervical proximal esophageal anastomosis is then performed (Fig. 33.2).

Alternatively, the Scharli technique employs elongation of the lesser curve of the stomach, allowing for end-to-end esophageal anastomosis. This technique is more commonly used in infants with pure long-gap esophageal atresia, but can be used in children who require extensive resection of the esophagus. Advantages of this conduit include reliable blood supply, resistance to ulceration from GER, and low rates of redundancy. Recent studies have determined this procedure to have good functional outcomes as well, with 70 % of children having normal weights and 50 % with normal height following 3-month- to 20-year follow-up. However, although it preserves portions of the native esophagus including the esophagogastric junction, it does have a less favorable complication profile. The extensive suture line results in high incidence of leaks and stricture. Also, continued production of acid by the tube has resulted in acid reflux into the cervical esophagus, resulting in Barrett's esophagitis.

Colon Interposition

The use of the colon as a conduit for esophageal replacement was first described by Sandblom in 1948 and has remained a popular modality for esophageal replacement. It is the treatment of choice for esophageal replacement at our institution. Replacement of the entire esophagus using a colonic interposition can be performed using either the right or the left colon on its vascular pedicle and can be done in either an antiperistaltic or isoperistaltic fashion. Typically, an intraoperative assessment of the mesenteric vessels is performed and the segment of the colon with the most robust perfusion is selected for the conduit. Removal of the damaged esophagus can usually be accomplished using a trans-hiatal technique, avoiding the need for thoracotomy. A two-team approach with one surgeon proceeding caudally from the neck and the other cephalad from the abdomen improves efficiency and facilitates accomplishment of the trans-hiatal approach. If inflammatory changes make this too dangerous, a thoracotomy is required.

Once the esophagectomy is complete, the distance from cervical region to the stomach is measured and the colon is divided in the appropriate position. The site from which the segment was measured adjacent to the middle colic artery is then divided and the mesentery mobilized down to the retroperitoneum to provide length. The graft is passed behind the antrum of the stomach to the esophageal hiatus. Using care to maintain the orientation of the vascular pedicle, the conduit is then passed up to the neck where an end-to-end anastomosis is performed. The distal end of the graft is anastomosed to the antrum of the stomach, and the procedure is completed with a pyloroplasty to facilitate emptying and a colocolostomy to reestablish continuity of the colon.

Contained leaks at the proximal anastomosis are not uncommon and usually occur with 3–5 days. Management of these proximal leaks is expectant with the vast majority resolving spontaneously. Subsequent strictures at the proximal anastomosis typically respond to endoscopic dilation. Surgical revisions are necessary if the strictures are resistant to multiple dilations. Postoperative GER can cause vomiting and exacerbate strictures, so concomitant antireflux wraps may be performed. Graft necrosis is rare, especially when particular attention is paid to ensure adequate blood supply and vasculature that is free of kinks. More challenging is the long-term complication of elongation of the interposition with poor emptying and stasis due to redundancy of the colon in the chest. This is believed to occur due to negative thoracic pressure and emptying by gravity. Dilation and elongation of the conduit increases the risk of aspiration and regurgitation. Avoiding a breach in the pleura and resecting the excess colon in the neck prior to anastomosis might reduce the frequency of this complication. If elimination of the redundant conduit is required, a new anastomosis may be constructed with particular attention paid to not disturbing the graft's blood supply.

The nutritional status of children after colon interposition has been reported to be satisfactory. Children with caustic esophageal injuries generally fall into a normal growth curve after replacement. Many achieve full oral intake while others

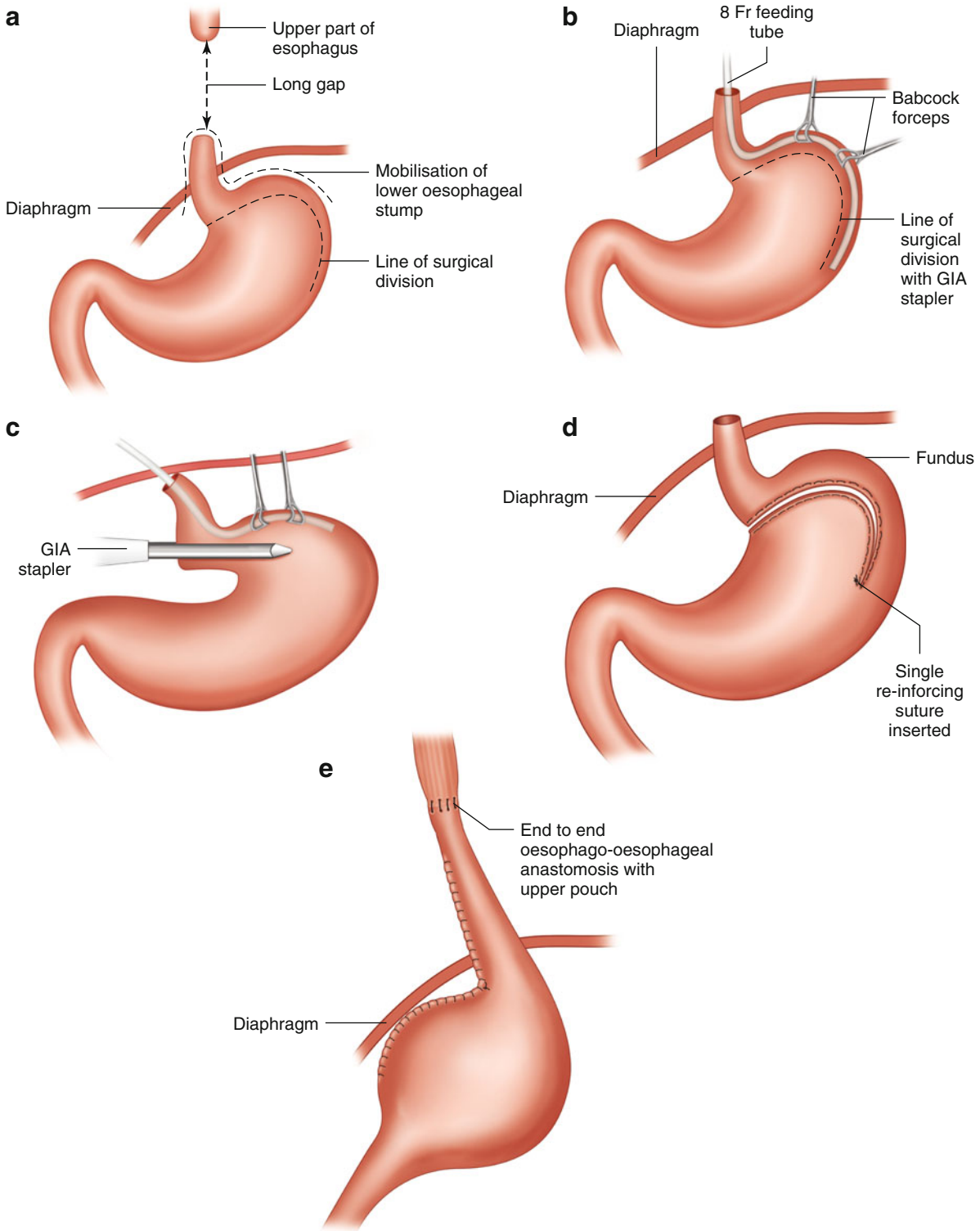

Fig. 33.2 Gastric tube for esophageal replacement. (**a**) The left gastric artery is divided and stomach fundus mobilized. (**b**) A feeding tube is inserted into the opened lower esophagus, through the gastro-esophageal junction and along the gastric fundus. (**c**) The feeding tube is held in place by Babcock forceps and a GIA stapler is used to divide the stomach across the lesser curvature, against the feeding tube. (**d**, **e**) A gastric tube is now formed, acting as a neo-esophagus

require supplemental gastric or jejunal tube feeds during the night. It has also been noted that children with colon interpositions suffer from iron deficiency and or B_{12} deficiency, but in our experience this has not been an issue.

Segmental Colon Interposition

Replacement of the entire length of the esophagus using the colon is a common technique. It has the advantage of allowing for excellent length that can reach all the way to the pharynx in severe injuries when there is little or no residual normal esophagus. Disadvantages include the need for three anastomoses and the risk of elongation of the graft over time.

In order to avoid the risk of elongation and a tortuous conduit that does not drain well, a segmental colon interposition might be considered. Patients who present with segments of the normal proximal and distal esophagus, but a damaged portion too long for primary anastomosis, are ideal candidates for segmental interposition. A suitable length of the colon is harvested based on the middle colic artery pedicle with the distal end of the graft of sufficient length to reach the neck. The conduit is then tailored to the appropriate length by removing the bowel from what will become the distal margin using great care to preserve the marginal artery. The bowel is then passed into the chest adjacent to the esophageal hiatus and anastomosed in the neck to the proximal end of the esophagus and in the chest to the distal margin to bridge the gap created by resection of the damaged segment (Fig. 33.3). The advantage of this technique is a reduction of graft length, thereby reducing the risk of significant elongation over time. This method also preserves the normal esophagogastric junction, reducing the incidence of significant gastroesophageal reflux (GER). The disadvantages of segmental colon interposition are its technical challenges, often requiring incisions in the neck, chest, and abdomen.

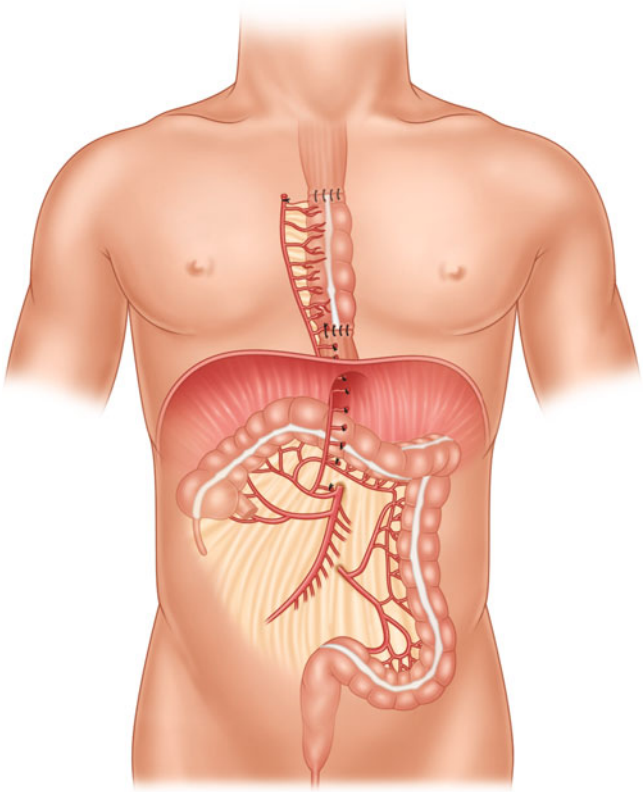

Fig. 33.3 Segmental colon interposition utilizing the right colon

Jejunal Interposition

The use of jejunal conduits for esophageal replacement has been employed for over a century. Although used in adults between 1907 and 1942, Humphreys and Ferrer first employed this technique in children with esophageal atresia in the early 1940s. Several surgical methods exist for using the jejunum as replacement for the esophagus, including utilization of the jejunum on its pedicle or as a free graft. The most widely utilized approach is a jejunal pedicle graft where the jejunum is transected distal to the ligament of Treitz, and the first two mesenteric artery branches are divided centrally to preserve the peripheral arcades. A second transection is performed at the third branch of the superior mesenteric artery (SMA). The distal segment of the upper jejunum is removed, so the upper most portions with their pedicle can be transferred behind the stomach and through the posterior hiatus (Fig. 33.4). Two esophago-enteric anastomoses are then carried out in the neck to the proximal esophageal margin and in the chest to the distal margin. A jejuno-jejunal anastomosis restores intestinal continuity. An alternative technique uses a free jejunal graft with microvascular anastomoses to the carotid artery and jugular vein (Fig. 33.5).

Preservation of the peristaltic activity of the jejunal segment and its comparable caliber of the bowel in comparison to the native esophagus reduces the risk of dilation and elongation of the conduit. Also, through preservation of the lower esophageal remnant, GER is greatly reduced. As in all grafts, leaks and strictures can occur and persist, requiring additional surgical revisions. Also, due to a tenuous blood supply, ischemia and graft necrosis may occur.

Complications

Complications associated with all modalities of esophageal replacement are common, and the long-term consequences of esophageal replacement remain poorly characterized (Table 33.4). These complications must be balanced with the

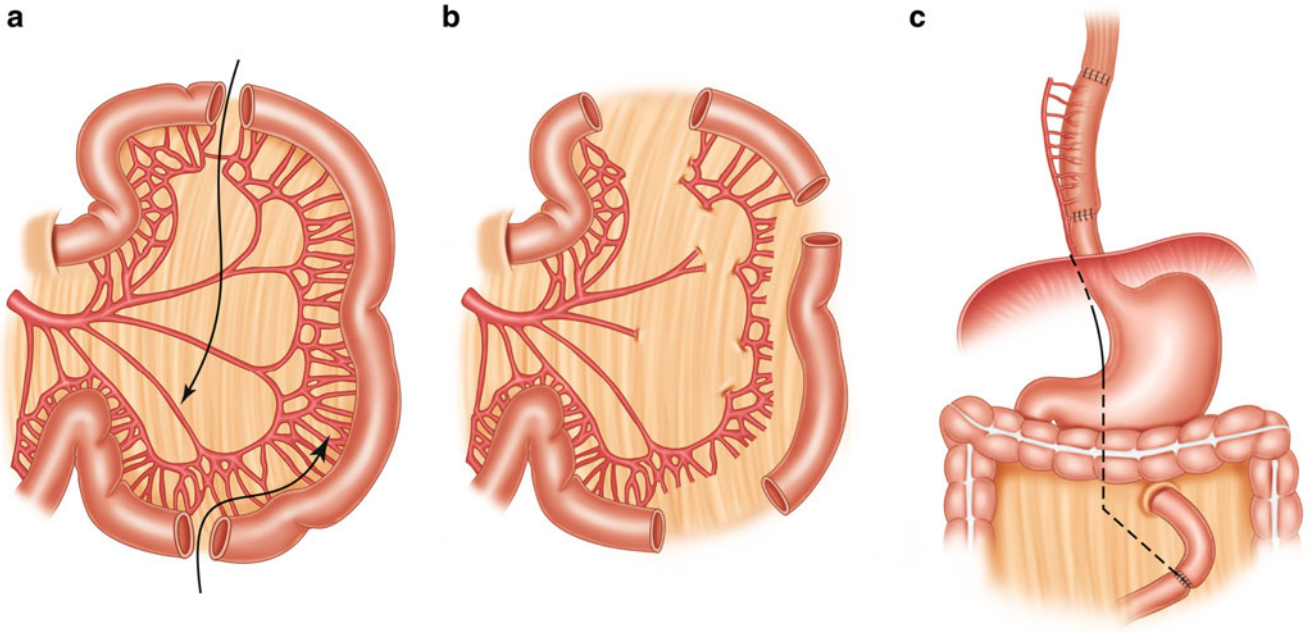

Fig. 33.4 Pedicle jejunal interposition for esophageal replacement. (**a**) The jejunum is first transected near the ligament of Treitz. The first two mesenteric artery branches are centrally divided, salvaging the peripheral arcades. The jejunum is then again transected at the third mesenteric artery branch and mobilized, leaving the vascular pedicle intact. (**b**) The distal portion of the upper jejunum is removed, leaving the upper portion for transfer into the chest. (**c**) The uppermost portion of the jejunum is transferred behind the stomach through the posterior hiatus into the chest where two entero-esophageal anastomoses are created

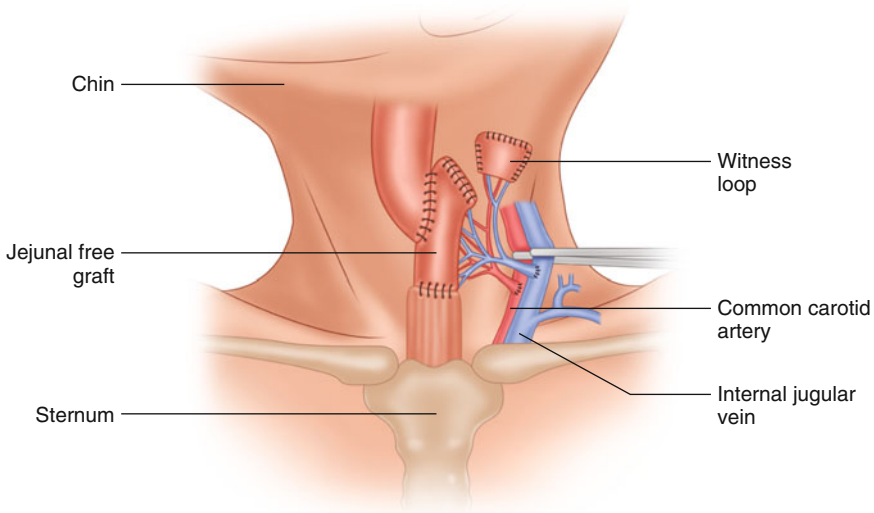

Fig. 33.5 Free jejunal graft for esophageal replacement

Table 33.4 Complications of esophageal replacement

	Complication rate (%)	Leak (%)	Stricture (%)
Colonic interposition	55–60	25–30	15–40
Jejunal interposition	70–75	60	40
Gastric tube	10–15	0	10–15
Gastric transposition	20–80	20–35	10–50
Primary anastomosis	20–35	15–20	30–40

long-term risk of malignant degeneration of the damaged esophagus. The risk of developing an esophageal malignancy in a patient with a history of a caustic ingestion has been estimated to be 1000 times higher than for a normal esophagus. However, most studies are case series with no controls and select patient populations, making the exact level of risk unclear. Esophageal cancers have been reported after both acid and alkaline ingestion. Due to this heightened risk of malignancy, esophageal replacement or aggressive long-term surveillance is indicated in cases of severe damage.

Future Considerations

Outcomes are generally satisfactory with esophageal replacement procedures despite morbidities and long-term complications associated with GERD, aspiration, feeding intolerance, and the risk of cancer in the residual esophagus. There simply is no optimal esophageal replacement. However, advances in tissue engineering promise novel approaches. Tissue-engineered body parts have been developed and implanted successfully in humans. Also, the ability to grow functional intestinal organoids from a single cell has been developed, and it is only a matter of time until an autologous replacement esophagus becomes a reality.

Editor's Comment

Esophageal foreign bodies can remain in place for a surprisingly long time before coming to the attention of a clinician. By then, the object can become deeply embedded in the wall of the esophagus, often surrounded by a considerable mass of granulation tissue and phlegmonous reaction. Lately the most common is the button battery injury, which can create full-thickness injuries of the esophagus within hours. These must be treated as a true emergency, and the surgeon should be prepared to perform an emergency thoracotomy for aortic-esophageal fistula or other life-threatening emergencies.

Removing the foreign body that has eroded into the mediastinum requires thoracotomy, though in some cases thoracoscopy might also be a reasonable option. A preoperative CT scan helps with planning the approach and anticipating complications. The key elements of such an operation, as always, include wide exposure, protection of adjacent structures (especially nerves and vessels), primary repair of the esophagus, and, most importantly, adequate drainage. The wall of the esophagus itself can rarely be identified; rather, suture repair simply involves approximating layers of inflammatory tissue.

Most esophageal injuries will heal spontaneously if adequate drainage is achieved, essentially creating a controlled fistula. This means a large sump-type nasogastric tube to continuous suction in addition to a well-placed chest tube. Antibiotics that cover oral flora are usually continued until the fistula has closed. After 5–7 days of NPO, a contrast esophagram is obtained and, if no leak is identified, the patient may resume oral intake. A leak will usually heal after another week or so of fasting. A cervical esophagostomy should almost never be required, except perhaps in the extremely rare case of uncontrolled mediastinal soiling and life-threatening sepsis.

Children with esophageal atresia and TEF are at lifelong risk of esophageal foreign body and food impaction due to either an actual stricture or an area of relative narrowing created by an inelastic ring of scar. Many pediatric surgeons will therefore continue to follow these patients into adulthood and prefer to perform foreign body removal and esophageal dilatation themselves. Caustic injuries of the esophagus have thankfully become rare in most developed countries but remain a huge public health dilemma in developing countries. The worst offenders are sodium hydroxide-based drain cleaners, as they are viscous and strangely palatable to young children. All patients, regardless of symptoms or severity of clinical presentation, should undergo a careful esophagoscopy by an experienced endoscopist, who should conclude the examination as soon as a severe injury is identified. Nearly every patient should receive a gastrostomy tube, which is placed in a location on the stomach that does not preclude the its use as a replacement should this become necessary. The very rare full-thickness esophageal injury with mediastinal extension is associated with a high risk of death and therefore mandates urgent esophagectomy. Nearly all other injuries can be observed and allowed to heal, which can take up from 4 to 6 weeks. Superficial injuries will usually heal without sequelae, while deeper burns inevitably result in strictures. Corticosteroids should be administered with caution, if at all, while antibiotics are probably of some benefit.

All esophageal replacement operations are huge undertakings with a high incidence of early complications and long-term problems, making retaining a damaged native esophagus almost always preferable to replacing the esophagus. For isolated strictures of the esophagus, balloon dilation under radiographic guidance is the safest and most effective technique. For long or multiple strictures, bouginage using tapered dilators passed over a wire or heavy suture that loops into the nose and out through a gastrostomy is still probably the best approach.

Esophageal replacement operations are chosen mostly on the basis of the surgeon's experience. Colonic interposition is the easiest, safest, and until recently the most popular operation; however the problem of long-term redundancy and stasis remains an unresolved issue—nearly every patient will develop recurrent symptoms and require multiple surgical revisions as an adult. Gastric pull-up and gastric tube operations are popular in some centers, but are also fraught

with complications and the need for further surgery in the long term. The most anatomic replacement in terms of size and function appears to be the jejunum, but issues related to the blood supply of the graft and the relatively high risk of ischemia make it another less-than-perfect choice. Self-expanding wire stents have been tried but are associated with life-threatening complications (septic mediastinitis, esophago-aortic fistula) and are extremely difficult to remove once they become incorporated into the soft tissue of the esophageal wall. Their use outside of a carefully designed study and truly extreme circumstances should be condemned.

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Foregut Duplication

34

Brian G.A. Dalton and Shawn D. St. Peter

The first report of alimentary tract duplications is attributed to Calder in 1733. Enterogenous cyst, ileum duplex, giant diverticula, and unusual Meckel's diverticula are some of the many names that have been applied to cystic malformations of the gastrointestinal tract. The most commonly used term of alimentary tract duplication was coined by William Ladd in 1937. In his description, three findings were consistently present: (1) well-developed smooth muscle in the wall of the lesion, (2) epithelial lining consistent with gastrointestinal origin, and (3) attachment to some portion of the gastrointestinal tract.

Alimentary tract duplications can occur anywhere from the mouth to the anus. They may be cystic (80 %) or tubular (20 %). The incidence is 1:4500 live births with about one third of these occurring in the foregut. The primitive foregut is the progenitor for the pharynx, respiratory tract, esophagus, stomach, and the duodenum to the ampulla of Vater. The laryngotracheal groove first appears around the third week of gestation. The dorsal portion differentiates into the esophagus and the ventral portion into respiratory tract. Given this common embryologic origin, the term foregut duplication currently encompasses all bronchogenic cysts, esophageal duplications, lesions mixed of esophageal and respiratory origin, and duplications of the stomach or duodenum.

Several theories have been proposed to explain the occurrence of foregut cysts, but there is not currently a unifying and widely accepted theory. Aberrant luminal recanalization, failure of regression of embryonic diverticula, environmental factors such as trauma or hypoxia, and partial twining have all been theorized. The split notochord theory is suggested by the association of vertebral abnormalities with thoracic and thoracoabdominal duplications. The important relationship between the notochord and foregut formation of thoracic duplications is further supported in an experimental animal model. None of these theories completely explain the variation in location, associated anomalies, and variety of mucosal types found in different duplication cysts. Additionally, foregut duplications are associated with esophageal atresia, tracheoesophageal fistula, congenital diaphragmatic hernia, and malrotation, which points to a multifactorial source of development.

Many foregut cysts are found on routine imaging and are asymptomatic. The majority are discovered in the first 2 years of life. When these lesions are symptomatic, the presentation depends on the anatomic level of the cyst, mass effect of the cyst, and the presence of acid-secreting cells of the mucosal lining. The diagnosis and management of these lesions also differ depending on the level of the duplication (Table 34.1).

Thoracic Duplications

Intrathoracic foregut cysts are often first suspected on chest radiograph due to the presenting symptoms and the convenience of the imaging modality. The presence of vertebral anomalies increases the chance that a lesion seen on chest radiograph is a foregut cyst. All patients with suspected thoracic foregut cyst and vertebral anomalies should be further imaged with a cervical and thoracic MRI to clarify the existence of a neurenteric cyst. Neurenteric cysts consist of a foregut cyst with extension into the spinal canal and are the least common type of foregut cyst. These lesions are found incidentally or present with a variety of neurologic symptoms from pain to hemiparesis.

Neurenteric cysts should be resected in an expeditious fashion to avoid the need for urgent laminectomy or laminotomy when neurologic symptoms develop. A combined neurosurgical and thoracic surgery team is needed for operative planning and resection. Often the entire lesion can be resected through a thoracic approach, but a laminectomy

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Table 34.1 Foregut duplication cysts diagnosis and treatment

Type	Diagnostic method	Differential diagnosis	1^0 treatment	2^0 or 3^0 treatment
Bronchogenic	CT/MRI	Pulmonary sequestration, CPAM	Resection	None
Esophageal	CT	Abscess, leiomyoma	Resection	Marsupialization with mucosal stripping
Neurenteric	MRI		Resection	Laminectomy/laminotomy
Gastric	CT/US	Abscess, splenic cyst	Resection	Cystogastrostomy with mucosal stripping
Duodenal	CT/MRCP	Choledochal cyst	Resection	Cystoduodenostomy with mucosal stripping, endoscopic unroofing, pancreaticoduodenectomy
Pancreatic	CT/MRCP	Pseudocyst, cystic neoplasm	Resection	Cystogastrostomy, cystojejunostomy, pancreaticoduodenectomy

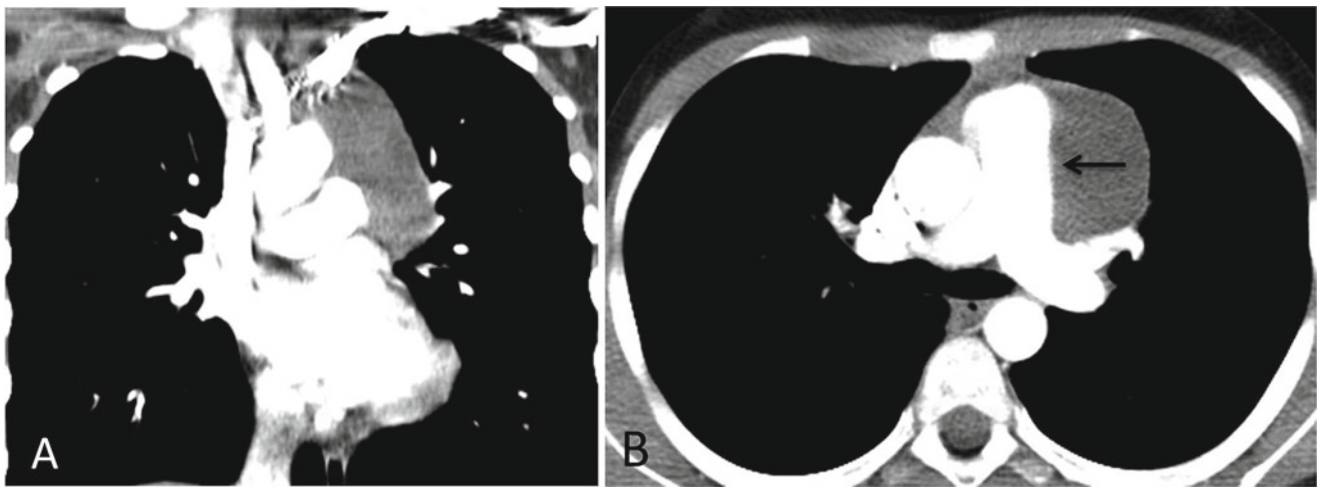

Fig. 34.1 CT of the chest showing a bronchogenic cyst near the left pulmonary hilum. (**a**) Coronal view, (**b**) Axial view. The *arrow* demonstrates the long segment where the lesion was adherent to the left pulmonary artery requiring slow thoracoscopic dissection

or laminotomy might still be needed depending on the extent of spinal canal involvement. If severe neurologic symptoms are the presenting feature, the patient will likely need urgent or emergent laminectomy or laminotomy for decompression of the spinal cord. The patient may then have delayed resection of foregut duplication by thoracoscopy or thoracotomy.

Bronchogenic and esophageal cysts can cause wheezing, dyspnea, hemoptysis, and recurrent pneumonia due to airway compression and dysphagia due to esophageal compression. The cyst can also become infected and present with chest or back pain and fever. Esophageal duplications are the most common foregut cyst representing 20 % of all duplications. Up to one half of these cysts contain ectopic gastric or pancreatic mucosa, and this can lead to bleeding, ulceration, perforation, or stricture formation as the presenting symptom.

Esophageal duplications and bronchogenic cysts should be further investigated with cross-sectional imaging. CT is our preferred method of preoperative imaging unless a neurenteric cyst is suspected, in which case MRI is most useful. This imaging modality allows for characterization of vascularity and relationship to the airways. An abdominal CT should be included since about 25 % of thoracic duplications have a concomitant abdominal enteric duplication. CT often reveals a rim-enhancing cystic structure that can be confused with an abscess. However, without a clinical picture consistent with abscess, duplication is a more likely diagnosis. Left-sided bronchogenic cyst in the pulmonary hilum sometimes demonstrate a long segment of attachment to the left pulmonary artery (Fig. 34.1).

Our preferred method of resection for both esophageal and bronchogenic cysts is thoracoscopy on the side of the lesion or from the right for posterior mediastinal duplications. Preoperative antibiotics are indicated. An attempt is always made for complete resection without violation of the esophageal or bronchial lumen. If there is an extensive bed of dissection where fluid drainage is expected, a 10–15-Fr closed-suction drain is left to bulb suction, which can typically be removed on the first postoperative day. Standard chest tubes are almost never required.

If the duplication is intimately associated with the esophagus, careful inspection during passage of a bougie is

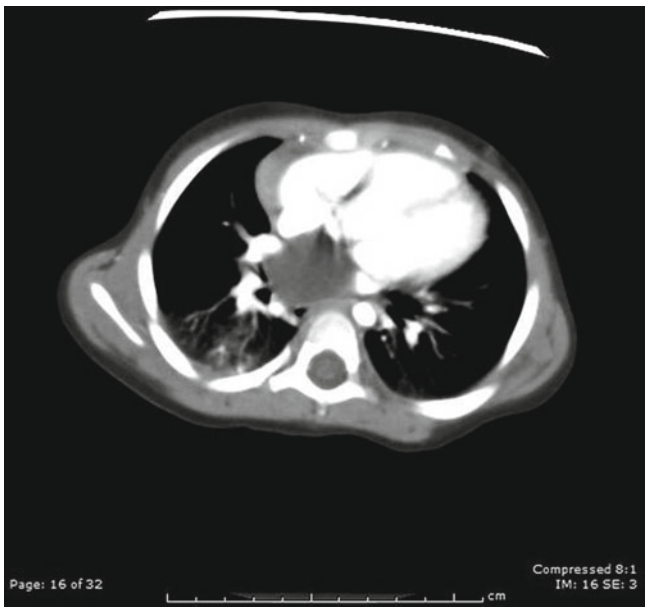

Fig. 34.2 CT demonstrating a central bronchogenic cyst where no safe window for resection exists from either side; thus a median sternotomy was performed. The excision required dissection of the main pulmonary trunk off the lesion. After this was freed up, we retracted the vessels to gain exposure until the blood pressure dropped requiring release of the retractor, so the dissection was completed in small intervals. A small defect in the anterior trachea was noticed after resection where a small common wall existed. This was closed with absorbable monofilament suture

usually adequate to rule out a full thickness defect, making a subsequent esophagram unnecessary. If the esophagus is entered and requires closure, a drain should be considered, and an esophagram prior to initiating a diet is prudent, though most surgical esophageal leaks can be managed nonoperatively. If complete resection is not feasible or safe, the lesion can be managed by resecting as much of the cyst as possible and stripping the mucosa from the remaining lesion. In this situation, dissection can be performed with electrocautery through the submucosal plane. If this is too difficult or incomplete, the remaining mucosa can be destroyed with electrocautery or Argon beam coagulation.

Occasionally cysts will occur in the central mediastinum confined within the great vessels, essentially preventing a safe approach from either a right- or left-sided thoracoscopic approach. Resecting these lesions often requires median sternotomy (Fig. 34.2).

Thoracoabdominal duplications are rare, representing about 2 %. They arise from foregut structures in the chest, pass through the esophageal hiatus, and connect to the distal alimentary tract at the level of the stomach, duodenum, jejunum, or ileum. A common presentation for these lesions is respiratory distress in the neonate due to fluid accumulation in the cyst. The lesion often communicates with the distal bowel but not with the thoracic foregut resulting in compression of thoracic structures. These patients often have vertebral anomalies. Further imaging by CT or MRI should be performed to define the extent and connections of the cyst. Our approach to resection of these duplications is combined laparoscopy and thoracoscopy with closure of any diaphragmatic defect that may occur with this type of duplication.

Abdominal Duplications

Gastric duplications account for about 5 % of all duplications. Presentation is most often emesis with a palpable epigastric mass. Hematemesis and melena may also be present, but perforation can rarely cause the presenting symptoms. Most gastric duplications are attached to the greater curvature, but can be completely separated from the stomach in the retroperitoneum. Gastric duplications do not usually communicate with the gastric lumen (Fig. 34.3). The goal of surgery is complete resection. Our preferred approach is laparoscopic excision. If a safe plane cannot be established between the duplication and native gastric wall, then a partial gastrectomy can be performed by stapling off a wedge of the stomach where the duplication is attached (Fig. 34.4).

Duodenal duplications represent about 2–5 % of alimentary tract duplications. They occur posteromedially in the second and third portions of the duodenum and most often are noncommunicating. The most common symptoms are vague abdominal pain, early satiety, and failure to thrive. They can also present with jaundice or pancreatitis due to mass effect and are sometimes confused with choledochal cysts. They often contain heterotopic gastric mucosa and are subject to peptic ulceration or bleeding secondary to acid secretion.

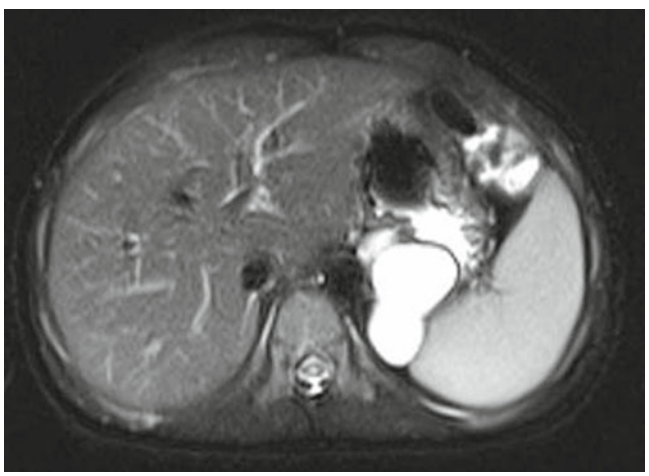

Fig. 34.3 MR showing enteric duplication intimately associated with the stomach as demonstrated by the *arrow*. The lesion was resected by identifying the plane separating the gastric wall from the cyst

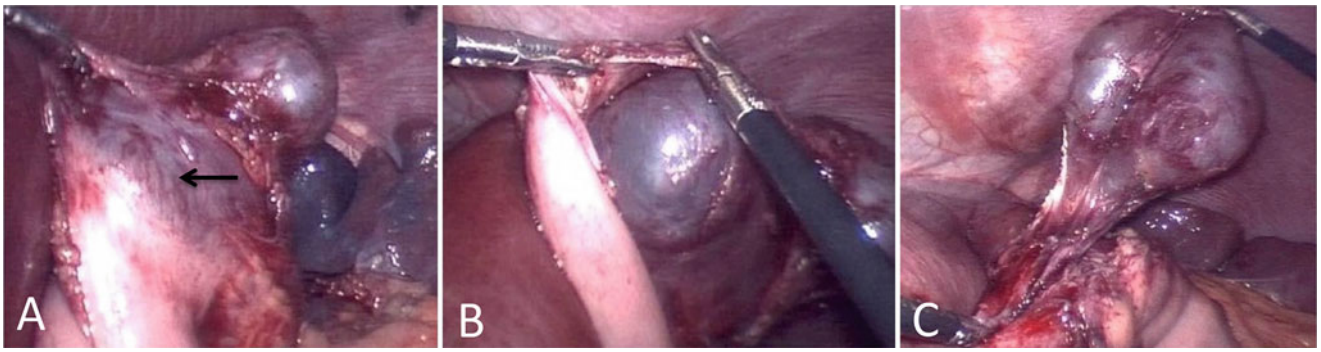

Fig. 34.4 Laparoscopic excision of gastric duplication showing (**a**) the initial appearance with a subtle transition from stomach to cyst (*arrow*) then (**b**) the subsequent dissection, which identifies the plane to allow (**c**) simple complete resection

If a duodenal duplication is suspected, a CT or MRCP should be performed preoperatively to determine the relationship of the cyst to pancreatic and biliary ductal system. As with all foregut duplications, resection is the preferred treatment, which can usually be handled laparoscopically. If concomitant duodenal resection is required, then upper GI study may be performed prior to the initiation of an oral diet depending on the integrity of the closure, and drains are generally unnecessary. If complete resection would result in significant morbidity, internal enteric drainage and mucosal stripping are options. Intraoperative cholangiogram is sometimes needed to ensure the integrity of the bile and pancreatic ducts.

Pancreatic duplications are the rarest foregut duplication. The presentation is similar to duodenal duplications in that most symptoms are nonspecific. CT and MRCP should be used to define the relationship between the ductal system and cyst. The goal of intervention is complete resection. If the cyst resides in the distal pancreas, a distal pancreatectomy with splenic preservation can be done laparoscopically without too much difficulty. The pancreas can be divided with an endostapler.

Pancreatic cysts involving the head of the pancreas present a significant management challenge. Knowing the status of the duct is especially important and may need to be assessed intraoperatively. Enucleation of the cyst is the preferred treatment, if this is possible. A closed-suction drain is left in place and removed when drainage is minimal. Internal drainage and pancreaticoduodenectomy are secondary surgical options if the cyst involves the head of the pancreas and the main pancreatic duct.

Antenatal Diagnosis

Fetal diagnosis is increasingly common and occurs in as many as 50 % of all alimentary tract duplications. Detection is possible as early as 12 weeks, but most are found by routine US at around 20 weeks. Two sonographic signs are indicative of a duplication cyst: the double-wall sign, indicating an inner hyperechoic layer of mucosa-submucosa and an outer hypoechoic layer consistent with muscularis propria, and peristalsis of the cyst wall. Once these are identified, they should be followed with serial US due to the possibility of foregut cyst mass effect causing hydrops. Although this is a rare occurrence, therapeutic fetal intervention has been reported. Fetal MRI and echocardiography are also recommended if the diagnosis of foregut cyst or enteric duplication is made.

In almost all cases of prenatally diagnosed foregut duplication cysts, the patient can safely be delivered outside of a tertiary referral center and resection of the foregut cyst performed electively. However, given the association with malrotation and the potential for obstruction, antenatally diagnosed foregut cysts should be resected within the first 6 months of life. Parents should also be counseled on the signs and symptoms of perforation or obstruction and to seek treatment immediately if these arise.

Principles of Management

Due to the risk of symptom development, complication, and malignancy, all foregut duplications should be resected after diagnosis. Expectant management is not recommended because carcinoma arising from a duplication cyst, while a rare occurrence, has an almost universally poor outcome, and it appears that the vast majority of adults with duplication cysts have symptoms or complications of the cyst. There is a 10–15 % intraoperative complication rate in adults who require cyst excision. Chances are very high that a duplication cyst will become symptomatic or cause a complication during the lifetime of a patient and therefore should be resected near the time of diagnosis.

Partial resection carries an unacceptably high recurrence rate. Mucosectomy is a less attractive option due to a high recurrence rate and the risk of a remnant forming the nidus for malignant degeneration or symptoms related to retained

gastric or pancreatic mucosa. However, mucosal resection should be performed when complete resection is not feasible to minimize the sequelae from acid-producing mucosa. Drainage procedures such as cystogastrostomy, cystoduodenostomy, or Roux-en-Y cystojejunostomy are also options, but patients will need lifelong monitoring due to the risk of malignancy. Recent reports have shown internal drainage by endoscopy to be a treatment option, but this method does include complete resection of the cyst.

A minimally invasive approach is our preferred method for resection when feasible. Retrospective series in both adults and children have shown the safety of thoracoscopic, laparoscopic, or a combined approach in thoracoabdominal duplication while maintaining the general benefits of minimally invasive surgery over open surgery.

MRI avoids ionizing radiation and is the best modality for imaging of concomitant spinal abnormalities. The principal drawback is that young children often require general anesthesia or sedation to obtain a satisfactory study. CT can provide detailed imaging of the bronchial tree and its relationship to the lesion as well as characterize the vascularity of the lesion when performed with intravenous contrast. An upper GI contrast study can provide information about connection of the duplication to the enteric system, but this information is not vital prior to surgical intervention. All patients with a foregut duplication should have a diligent search for associated anomalies and second duplications. Ultrasound can be diagnostic of abdominal foregut cysts, but those cysts adherent to the duodenum and pancreas will likely require further imaging in the form of MRCP, CT, or ERCP. Technetium-99m pertechnetate scans are sometimes useful for small duplications with heterotopic gastric mucosa, but if duplications can be localized by other means, resection should be the treatment with or without ectopic gastric mucosa. Endoscopic ultrasound has been shown effective for diagnosis of foregut cysts in adults, but there is little experience in children.

Editor's Comment

Foregut duplications in the chest include bronchogenic cysts and esophageal duplications. Nearly all can and should be excised thoracoscopically. Exceptions include some that communicate with or involve a long segment of the esophagus or airway and those that were infected at one time and are therefore likely to be extremely difficult to excise. As with all operations performed in the mediastinum, careful attention to avoid injury to adjacent structures (especially the phrenic and vagus nerves and the thoracic duct) is paramount, though fortunately these lesions typically separate from all important structures with gentle blunt dissection, until, of course, you reach the organ of origin, when patience and meticulous technique are critical.

Spillage of the sterile contents of the cyst does not appear to increase the risk of recurrence or infection and is often performed deliberately to aid in the dissection of a large cyst or to remove it from the chest. When dealing with an especially adherent or fibrotic cyst wall, it is acceptable to enter the lumen and to strip the mucosa completely, leaving the fibrotic wall behind, but it is especially important to identify and repair communication with the lumen. Except when a lumen has been breached or frank infection is present, routine placement of a drain or chest tube is unnecessary.

Long, tubular thoracoabdominal esophageal duplications can also be approached thoracoscopically, by mobilizing the thoracic portion first and then completing the dissection in the abdomen by laparoscopy or laparotomy. Extensive preoperative imaging with three-dimensional reconstruction is very useful in planning these challenging operations. Because retained mucosa places the patient at lifelong risk of complications and cancer, every effort should be made to excise it, though it is probably safe to leave the outer fibrous wall. Marsupialization or creation of an enteric communication is not a definitive treatment and should only be done under extreme circumstances. Likewise, it is impossible to completely destroy an enteric epithelium with any energy source, including the argon beam coagulator; this should not be relied upon for definitive treatment of an enteric duplication.

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Achalasia

35

J. Duncan Phillips

Achalasia is an uncommon disorder of esophageal dysmotility, with an annual incidence of only 1 in 100,000 individuals. Although usually thought of as being simply a failure of normal relaxation of the lower esophageal sphincter (LES) during swallowing, it is actually part of a more diffuse disease of esophageal function. Because treatment for diminished or absent esophageal peristalsis is so poorly developed at this time, clinicians tend to focus on the LES, which is the only part of esophageal anatomy that lends itself to intervention.

Normal swallowing is a complex process that involves antegrade propulsion of ingested liquids and solids by coordinated peristaltic contractions of the esophageal body and a transient relaxation of the LES from its normal resting pressure. In patients with achalasia, this normal relaxation fails to occur. Although the precise etiology of achalasia is uncertain, the primary cause is likely an abnormality of the esophageal myenteric plexus. Patients with achalasia often have a reduced number of ganglion cells and the ganglion cells are surrounded by an inflammatory infiltrate. Unlike Hirschsprung disease, which is thought to be due to failure of normal migration of ganglion cells during fetal life, the etiology of achalasia might involve an autoimmune mechanism, with progressive partial destruction of the ganglion cells and the inhibitory neurons that normally mediate LES relaxation.

Achalasia in children has been associated with trisomy 21, triple-A syndrome (achalasia, alacrima, ACTH insensitivity), and familial dysautonomia, but most are sporadic. Although the disease has rarely been described in toddlers, the typical pediatric patient is a teenager between the ages of 13 and 17.

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Diagnosis

Patients typically present with a history of progressively worsening dysphagia that begins with solid foods and then progresses to soft foods and eventually even liquids. Most describe food getting stuck in the cervical region and point to the base of the neck. They usually discover that they can propel that food into the stomach by swallowing liquids frequently throughout their meals. Most also experience intermittent regurgitation of undigested food that occurs immediately or up to a few hours after meals. They and their parents frequently describe this as "vomiting" but careful questioning usually reveals that the vomitus is nonbilious and composed of only chewed-up food.

Substernal chest pain is another very common symptom. This pain is typically described as "heartburn" and often incorrectly attributed to gastroesophageal reflux disease, leading to empiric treatment with acid blocking medications or promotility drugs. These agents are typically of no benefit in patients with achalasia. Most children with achalasia will experience weight loss that ranges from mild to severe (10–20 % of body weight). The weight loss is gradual and often subtle.

The initial diagnostic test in the child with dysphagia is usually a contrast esophagram. It is important that the study be performed in both the supine and upright positions, to properly assess esophageal emptying. It is also helpful to take video recordings with emphasis on the pattern of esophageal contractions. Classic findings include a dilated, dysmotile esophagus and a "bird's beak" deformity at the gastroesophageal junction (Fig. 35.1). Early in the course of the disease, the radiographic findings can be subtle, while, in cases of long-standing disease, the progressively redundant esophagus can adopt a sigmoid shape. Careful observation by the radiologist will usually reveal the absence of relaxation of the GEJ.

Probably because GERD is so much more common, most children with achalasia are initially thought to have lower

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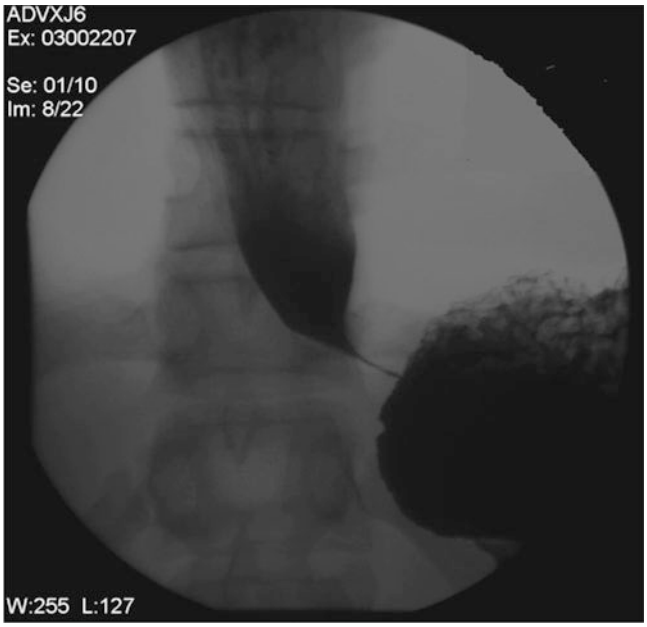

Fig. 35.1 Esophagram demonstrating the "bird's beak" deformity at the gastroesophageal junction, indicating long-standing esophageal achalasia. This 16-year-old girl had dysphagia for over 1 year. Resting lower esophageal sphincter pressure was 42 mmHg

esophageal spasm or stricture due to GERD. Following the esophagram, most physicians will usually then recommend a flexible esophagogastroduodenoscopy. Endoscopy may demonstrate pooling of retained fluid within the esophagus and esophageal inflammation related to stasis. The endoscopist might encounter mild resistance but can usually pass the endoscope into the stomach, essentially ruling out a fibrotic stricture.

The standard test for esophageal achalasia remains esophageal manometry. Pressure recordings show absent or diminished peristalsis in the upper esophagus, elevated LES pressures, and minimal or absent LES relaxation. It is important to note that these pressure differences are typically not as impressive as they might be in adults, affected children having resting LES pressures only about two-thirds that of adults.

Preoperative Preparation

Current treatment strategies for achalasia are directed specifically at the LES. Balloon dilatation of the LES under general anesthesia is the most common nonoperative technique utilized in children. Symptomatic relief is unfortunately almost always transient and thus repeated dilatations are required. Dilatation also carries with it the risks of general anesthesia and approximately a 3 % risk of esophageal perforation. It is useful mostly as a diagnostic tool to help children and their parents understand the potential benefits of Heller myotomy.

An alternative nonsurgical treatment for esophageal achalasia is endoscopic intra-sphincteric injection of botulinum toxin, which lowers LES pressure by inhibiting acetylcholine release from nerve endings. This effect is also transient, requiring repeated injections for long-term success. Several investigators have found that a repeated botulinum toxin injection induces scarring within the wall of the distal esophagus. As a result, the risk of esophageal perforation during subsequent Heller myotomy is increased. For this reason, many pediatric gastroenterologists do not advocate botulinum toxin injections for their patients and most experienced pediatric laparoscopic surgeons are recommending against it.

The occasional patient with achalasia will present with severe weight loss and malnutrition. These children benefit from preoperative supplemental feeds delivered by nasogastric tube. Positive nitrogen balance is associated with decreased perioperative morbidity but can take several weeks to achieve.

Treatment

Esophageal myotomy, originally including longitudinal incisions on both anterior and posterior sides of the LES, was described by Ernest Heller in 1913. Since essentially all authors now utilize a single anterior myotomy, a more accurate term for the operation as it is performed today is the modified Heller myotomy. Nevertheless, most authors consider "the Heller" the procedure of choice for the surgical treatment of children with achalasia. Excellent results have been reported with long-term follow-up of children treated with this procedure.

Controversy regarding specific technical aspects of the Heller myotomy include (1) whether it is better to approach the LES through the chest or the abdomen, (2) to what degree balloon dilatation or botulism toxin injection increases the complication rate of the operation, (3) whether one should also perform an antireflux operation, and (4) whether minimally invasive techniques are as good as the traditional open approach.

Heller originally performed the myotomy through a left thoracotomy, as he felt this allowed better visualization of the esophagus and that the myotomy could more easily be extended superiorly to the level of the inferior pulmonary veins. In fact, until the late 1980s, this was the standard approach at most centers. More recently, however, most have found that the abdominal approach allows for an adequate myotomy, is associated with less perioperative pain and morbidity, and makes fundoplication easier to perform.

Nonoperative treatments such as balloon dilatation and injection of botulinum toxin offer at best a transient improvement in symptoms and are associated with a small risk of significant complications. In addition, extensive scarring within the wall of the esophagus can make subsequent myotomy difficult or even dangerous. Therefore, most pediatric surgeons experienced with the laparoscopic technique recommend against both dilatations and injections.

After disruption of the LES by myotomy, many patients develop GERD, which may or may not be clinically apparent. Most surgeons therefore advocate a concomitant antireflux operation when performing the Heller procedure. This is mainly due to the concern that long-standing GERD places the patient at risk for Barrett's esophagus and esophageal carcinoma. No single technique is clearly favored and various authors have advocated the Nissen, Dor, Toupet, and Thal procedures.

Both laparoscopic and thoracoscopic Heller myotomy have been described. The thoracoscopic approach was initially more popular, but it soon became clear that up to 60 % of patients have significant gastroesophageal reflux. Since most surgeons felt that concomitant fundoplication was exceedingly difficult to do thoracoscopically, there was interest in developing a practical laparoscopic approach that would accommodate both operations.

Surgical Technique

The patient is positioned in the supine position with the surgeon standing to the patient's right side and the assistant on the left. Older children may have the legs extended on stirrups with the knees flexed 20–30° so that the surgeon can stand between the legs. We prefer to place a Foley catheter to evacuate the bladder and a nasogastric tube to decompress the stomach. A single dose of intravenous antibiotic is given prior to incision.

Five trocars are standard, with initial access at the umbilicus. We use a 5-mm trocar and a 5-mm 30° telescope but initial access with a larger trocar is preferred by some. We then place four more trocars under laparoscopic view. We have found it best to insert these trocars fairly high, along the costal margins, for optimal advantage.

A trocar along the right anterior axillary line allows for introduction of a liver retractor. We use a "snake" retractor to elevate the left lateral segment, exposing the anterior gastric wall and GE junction. A telescope holder can be attached to the operating room table to hold this liver retractor, thus freeing up the surgeon and assistant to each use both hands during the remainder of the procedure.

The three additional trocars are usually inserted in the right midclavicular line for insertion of a grasper, in the left anterior axillary line for the assistant's grasper, and in the left midclavicular line. The assistant can move the laparoscope to the left midclavicular trocar and control the camera with the left hand. This allows the surgeon, standing at the patient's right side, to operate with the left-hand instrument inserted via the right midclavicular trocar and the right hand to control instruments via the umbilical trocar.

The dissection is typically started by incising the gastrohepatic ligament to expose the right crus of the diaphragm. We then incise the peritoneum overlying the intra-abdominal esophagus, just superior to the phreno-esophageal fat pad. One can use the hook cautery or Harmonic Scalpel for most of this dissection. As during a Nissen fundoplication, we typically also incise the peritoneum along the anterior surface of the right crus. The anterior and poster vagus nerves are usually visible on the surface of the esophagus and should be carefully protected. If one has chosen to perform an anterior fundoplication, the posterior esophageal attachments may be left intact.

The myotomy is typically performed with the monopolar hook cautery at the 10 or 11 o'clock position, just to the right of the anterior vagus nerve (Fig. 35.2). We usually start this just cephalad to the phreno-esophageal fat pad, which is sometimes quite thick, and extend this cephalad for about 5 or 6 cm. The surgeon typically uses the left-hand instrument to grasp the right edge of the myotomy and the assistant typically uses a gentle grasper to control the left edge of the myotomy so that the muscle edges can be gently separated. We find that 5-mm Hunter bowel graspers work quite well for this step. To avoid thermal injury to the underlying esophageal submucosa, it is important to not set the current too high and avoid arcing of the current. The myotomy incision must be carried through the outer longitudinal muscle and also through the inner circular muscle, exposing the

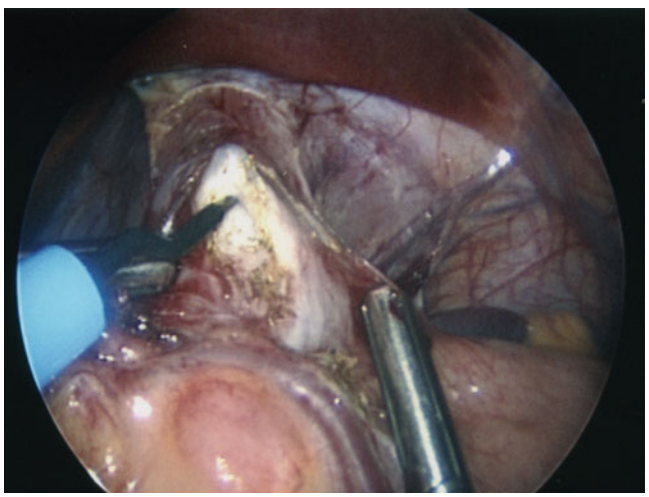

Fig. 35.2 Laparoscopic Heller myotomy. Peritoneum overlying the intra-abdominal esophagus has been divided. The hook cautery is used to begin the myotomy on the anterior surface of the esophagus

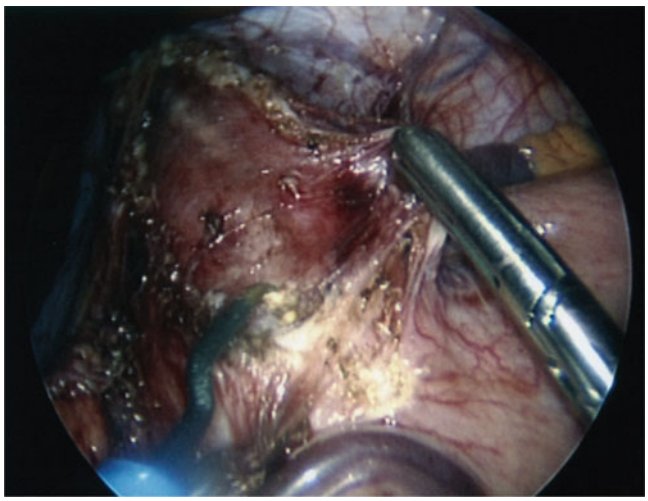

Fig. 35.3 Laparoscopic Heller myotomy. The myotomy of the distal esophagus has been completed and is being extended onto the stomach for 1–2 cm

submucosal vascular plexus. Gentle downward traction on the cut muscle edges allows the surgeon to extend the myotomy well up into the lower mediastinum. The myotomy is then extended 1–1.5 cm onto the anterior gastric wall (Fig. 35.3). In anticipation of the fundoplication, we typically divide the short gastric vessels at this point, using either cautery or the Harmonic Scalpel.

Due to the risk of causing significant dysphagia, most surgeons prefer to avoid creation of a 360° Nissen fundoplication in patients with disorders of esophageal motility. To create an anterior 180° fundoplication (Dor), two rows of permanent sutures are used. We prefer to use 2-0 braided nylon or a similar multifilament coated suture. To help the needles pass through the 5-mm trocars, they need to be straightened slightly into a canoe or ski shape.

The first row of sutures secures the gastric fundus to the left edge of the myotomy. Three or four interrupted sutures are typically needed (Fig. 35.4). The stomach is then "folded over" the myotomy site (from patient's left to right) and a second row of interrupted sutures secures the fundus to the right edge of the myotomy. The uppermost stitch on each side usually includes the crus. We typically place one or two additional sutures between the fundus and the diaphragm anteriorly.

Many authors have described the intraoperative use of a flexible esophagoscopy to aid in myotomy assessment and suture placement. As an alternative, we pass a 6 Fr Fogarty catheter by mouth, inflate the balloon with air or water, and pull it retrograde from stomach to esophagus under laparoscopic visualization. This allows assessment of myotomy completeness. Some authors inject dilute methylene blue dye to exclude occult inadvertent esophageal perforation.

If one has chosen to perform a posterior 180° (Toupet) fundoplication, one must make sure that the posterior esophageal attachments at the esophageal hiatus have been completely divided during the initial esophageal dissection. Following completion of the myotomy, the surgeon reaches posterior to the esophagus with a left-hand instrument to grasp the mobilized fundus and pulls it from the patient's left to right toward the caudate lobe of the liver. If the short gastric vessels have been properly divided, there should be no significant tension on the fundus and it does not snap back toward the patient's left.

Three rows of interrupted sutures are typically placed to complete the Toupet: an interrupted row securing the fundus to the right edge of the myotomy, a second row securing the fundus to the right crus of the diaphragm, and a final row securing the stomach to the left edge of the myotomy. In the Montupet modification of the Toupet, a crural stitch is placed posterior to the esophagus, to approximate the crura in the midline.

To perform the Heller myotomy using an open approach, most surgeons prefer an upper midline incision, beginning at or just to the side of the xiphoid process and extending to just above the umbilicus. A Thompson or Buckwalter retractor is extremely helpful for improved exposure of the GEJ. The left lateral segment of the liver can be detached from the undersurface of the left hemidiaphragm using electrocautery and retracted to the patient's right with a smooth blade of the retractor. The remainder of the intra-abdominal portion of the procedure is similar to that described above.

A thoracoscopic approach may useful in certain circumstances. For left-sided thoracoscopic procedures, single lung ventilation can often be achieved via right mainstem intubation or by the use of a bronchial blocker. In older children, a double-lumen endotracheal tube can be used. An alternative is the use of valved trocars and gentle CO_2 insufflation with pressures of 5–8 mmHg.

Typically, a four-trocar technique is utilized: in the sixth intercostal space in the midaxillary line, in the fourth intercostal space approximately 2 cm posterior to the posterior axillary line, in the fifth intercostal space in the anterior axillary line, and in the eighth intercostal space in the posterior axillary line. With the lung retracted anteriorly and superiorly, the inferior pulmonary ligament may be divided as high as the inferior pulmonary vein. The mediastinal pleura is incised to expose the distal thoracic esophagus. This can be facilitated by the placement of a flexible esophagoscope.

The myotomy is then performed in a fashion similar to that described for the laparoscopic procedure, using 5-mm hook cautery. The myotomy is typically extended just beyond the GEJ. A chest tube is usually placed through one of the port sites.

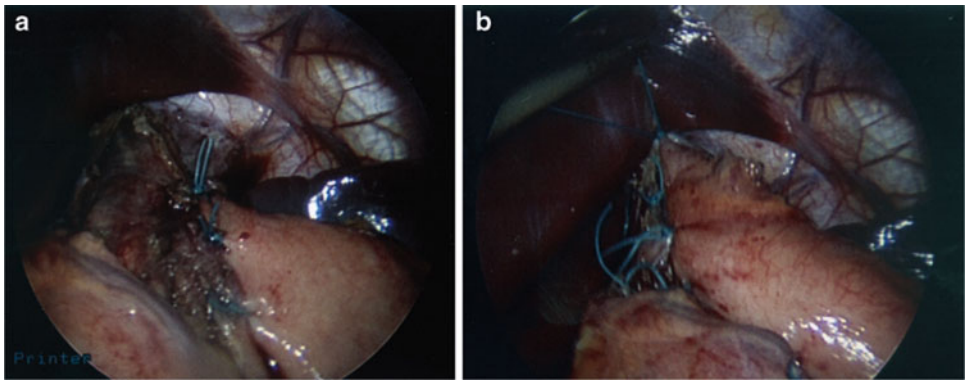

Fig. 35.4 Laparoscopic Heller myotomy with Dor fundoplication. (**a**) The first row of sutures (*arrows*) secures the fundus to the left edge of the myotomy. (**b**) The second row of sutures (*arrows*) helps to "fold" the fundus over the anterior wall of the esophagus at the level of the myotomy to secure the fundus to the right edge of the myotomy

Postoperative Care

Most surgeons at our institution obtain an esophagram on the first postoperative day prior to beginning oral feedings to verify proper esophageal emptying and to rule out the presence of a leak. It should be noted that the esophagram will not reveal any significant change in esophageal dilatation and often shows a rather long area of apparent esophageal narrowing at the myotomy site. This is often quite confusing or even alarming to those unfamiliar with the typical early postoperative radiographic appearance.

Following minimally invasive surgery, diet can usually be resumed immediately following the esophagram. Intake of soft foods is preferable to hard foods, such as crusted breads. Some authors recommend a "no-chunk" diet for 2–4 weeks after surgery. Most surgeons continue empiric acid blocking medications for a period of approximately 6 weeks, though there is little evidence that this is necessary. Most patients can be discharged home within 1–2 days of the minimally invasive operation.

Since achalasia is just one part of a more diffuse esophageal disorder, affected patients should be followed indefinitely by an experienced gastroenterologist. The association between long-standing achalasia and esophageal carcinoma is well-established. Surgical treatment of achalasia during childhood would be expected to reduce this risk but long-term follow-up data are lacking.

Editor's Comment

Achalasia is rare in children and the clinical presentation, though often insidious, is distinctive: dysphagia, chest pain, and regurgitation of undigested food. Nevertheless, patients frequently present for surgical consultation only after many months of misery, failed interventions, and ineffective medical therapy. This is unfortunate, not only because the patient suffers needlessly, but because there is a safe and effective operation available that becomes more difficult and more dangerous when the patient presents late after having been dilated or injected. Primary physicians and gastroenterologists should be encouraged to refer these patients to an experienced surgeon early in the course of the disease rather than as a last resort.

Laparoscopic Heller myotomy is an advanced minimally invasive technique but is generally safe in the hands of an experienced laparoscopist. The operation can be done safely with the patient in the supine position and the surgeon standing to the right, which avoids the inherent delay and added risk of placing the patient in stirrups. Some have touted the use of intraoperative adjuncts like manometry or endoscopy to assess the adequacy of the myotomy, but these are unproven and probably unnecessary. To protect the exposed submucosa and to avoid unnecessary dissection posterior to the esophagus, most recommend an anterior fundoplication, but this is certainly open to debate. A postoperative esophagram is admittedly overkill but avoiding even a single rare case of unrecognized perforation seems like adequate justification for this generally harmless exercise.

The robotic-assisted approach seems very well suited to Heller myotomy—visualization and the ability to manipulate instruments and suture are all superior to the laparoscopic approach. It seems likely that this will become the standard surgical approach in years to come.

The key to the success of the Heller myotomy, like most complex operations, is proper management of expectations. Patients naturally expect instantaneous relief of their symptoms and the ability to eat anything and everything immediately after the operation. In most cases, this is unrealistic and patients should be counseled to expect that some degree of dysphagia will persist for some time after the operation. This is because the disease affects the motility of the entire esophagus, the chronically dilated esophagus is ineffective at peristalsis, and there is a partial functional obstruction at the LES after myotomy. Their esophagus will empty principally by gravity and pressure from the advancing bolus of swallowed food or liquid. These symptoms resolve gradually over the course of several weeks or months, but in the meantime patients should be encouraged to avoid food with large chunks (meat, bread crust), to chew their food well, and to drink fluid frequently during meals. Some patients can

develop intermittent painful episodes of esophageal spasm that usually eventually cease. This has been treated with variable results using calcium channel blockers and medications that counter smooth muscle spasm.

Intraoperative perforations should be primarily repaired and then "patched" with the fundoplication, in which most patients should be able to tolerate oral intake after a brief (48–72 h) period of observation and a negative esophagram. The rare patient with an esophageal perforation noted on postoperative esophagram is treated initially with NPO, antibiotics, and careful observation. The leak usually seals spontaneously in 5–7 days but occasionally will require percutaneous drainage or reoperation for local or systemic sepsis. Perforation should be an extraordinarily rare event.

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Part VI

Thorax and Mediastinum

Persistent Ductus Arteriosus

36

Petros V. Anagnostopoulos

The ductus arteriosus is an important vascular structure of the fetal circulation. In the majority of the patients with a left aortic arch and normal branching of the great vessels, the ductus originates at or near the origin of the left pulmonary artery and connects to the undersurface of the distal aortic arch, at the level of the aortic isthmus. The ductus arteriosus forms from the distal portion of the left embryonic sixth arch. During fetal circulation, it serves as the main outflow for the right ventricle, shunting 80–85 % of right ventricular blood volume to the distal aorta. This bypasses the lungs, which are non-ventilated in utero and have high pulmonary vascular resistance. Patency of the ductus arteriosus in fetal life is maintained by the low oxygen tension in the fetal circulation and the presence of cyclooxygenase-mediated derivatives of arachidonic acid metabolism (prostaglandin PGE2 and prostacyclin PGI2). PGE2 and PGI2 are generated in the placenta, and levels rapidly drop after birth. Intramural smooth muscle cells contract and the ductus constricts, losing its patency. The resulting fibrous band becomes the ligamentum arteriosus.

Pathophysiology

The clinical presentation of PDA can range from the asymptomatic patient with a murmur to a florid heart failure. This depends on patient age, the size of the duct, and differences in resistance between the systemic and the pulmonary circulation. With the persistence of the ductus arteriosus after birth, the progressive postnatal decrease in pulmonary resistance results in blood shunting from the higher resistance systemic circulation to the lower resistance pulmonary circulation. This results in a left-to-right shunt that increases progressively after birth. Over time, the lungs become congested and left atrial pressure increases. The left heart becomes volume overloaded and distends. Initially, left-to-right shunting occurs during the systolic phase of the cardiac cycle.

As the pulmonary resistance drops, it extends into the diastolic phase resulting in a continuous left-to-right flow that forms the basis for the classic continuous "machinery" type murmur. This murmur is best heard in the left upper sternal border radiating to the back. Critically, a truly continuous murmur is only appreciated in a minority of patients who have a large PDA and low pulmonary resistance. In patients with a large duct, the bounding pulses that are sometimes appreciated are due to reversal of flow into the aorta.

Diagnosis

The surgeon who is asked to evaluate a patient for surgical ligation of a PDA should be aware that many of the findings associated with a symptomatic PDA in premature babies can also be seen in other disease states. These include chronic lung disease, prolonged ventilator dependency, and hemodynamic instability. Careful evaluation is therefore warranted, and the surgeon must first determine whether these findings are due to a symptomatic PDA and whether operative intervention is warranted.

Patients with symptomatic PDA will exhibit evidence of fluid overload on chest X-ray and moderate cardiomegaly. However, in some patients, the chest X-ray will demonstrate pulmonary congestion without cardiomegaly, in which case the surgeon must find additional evidence of hemodynamically significant shunting through the duct.

In all patients, an echocardiogram is obtained to rule out intracardiac lesions that could account for the patient's symptoms. In addition to confirming the presence of a PDA, the echocardiogram will provide important information regarding the direction of flow through the duct, the

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pulmonary resistance, and whether there is reversal of flow during the cardiac cycle. This information is essential because in a patient with predominantly right-to-left flow across the PDA, it is difficult to support heart failure as the main reason for the patient's symptoms.

An echocardiogram is also useful in preoperative planning. It can inform the surgeon about other anatomic anomalies that could alter the surgical approach. These include a right-sided aortic arch, vascular rings, coarctation of the aorta, and an aberrant right subclavian artery arising from the area of the isthmus of the aorta. It can determine if there is an area of narrowing of the duct ("neck") that would make the ligation technically easier. It can also determine whether there is adequate length to allow safe ligation, whether the aortic arch is of a normal size or hypoplastic, and whether there is a posterior aortic shelf. This information will help risk assess whether ligation of the PDA could result in coarctation of the aorta. Finally, echocardiography can determine whether the aortic isthmus is well developed. If there is any question that remains unanswered after the echocardiogram, the surgeon should not proceed to operative intervention before obtaining additional information from cross-sectional imaging with an MRI or cardiac CT. That said, most of the time the echocardiogram is sufficient to answer the relevant questions.

Indications for Treatment

The principal indication for treatment is congestive heart failure. However, the asymptomatic patient might require intervention if there is echocardiographic and early clinical evidence of a hemodynamic significant shunt resulting in volume overload of the left heart. Additional indications for closure of a PDA, especially in the older child and adult, include the prevention of bacterial endocarditis and pulmonary hypertension. Other rare indications are the presence of a ductal aneurysm that causes compressive symptoms (airway obstruction, recurrent laryngeal nerve dysfunction) and involvement of a PDA in the formation of a vascular ring.

In the preterm neonate, the need to ligate the PDA is a complex decision. When compared to selective ligation in symptomatic patients, preemptive PDA ligation (prior to the onset of symptoms) is associated with increased chronic lung disease, retinopathy of prematurity, and neurodevelopmental impairment. In the older patient with a large PDA, an assessment of the pulmonary vascular resistance by echocardiography or cardiac catheterization needs to precede the decision for surgical or interventional closure. The development of irreversible pulmonary hypertension must be ruled out before closure. In patients in whom the pulmonary vascular resistance exceeds 8 U/m^2, the duct is helping the outflow of the right ventricle, and the PDA should not be closed.

Pharmacologic Closure

In low-weight premature infant, the first line of treatment should be medical therapy. Indomethacin and ibuprofen have been approved by the FDA for pharmacologic closure of the PDA. These medications have significant renal toxicity and are associated with necrotizing enterocolitis, thrombocytopenia, and gastrointestinal bleeding. Acetaminophen has a significantly better risk profile compared with indomethacin and ibuprofen and has been recently used to close the PDA.

Transcatheter Closure

Since the initial description of transcatheter occlusion of a PDA in an infant by Raskin and Cuaso in 1979, interventional cardiologists have successfully utilized various devices and techniques. The conical configuration of most patent ductus arteriosus makes them amendable to relatively straightforward catheter closure procedures. In the current era, most small patent ductus (less than 1.5–2 mm) are closed with free or detachable stainless steel coils. Closure devices are recommended for patients larger than 5–6 kg; however, multiple clinical studies have documented safety and efficacy in smaller patients with a large ductus. The majority of all patients who require occlusion outside of the neonatal period are candidates for catheter-directed device occlusion.

Surgical Therapy

Surgical closure of a PDA is the preferred management option in preterm low birth weight infants when pharmacologic treatment has failed or when there are contraindications to medical therapy like renal insufficiency, intracardiac hemorrhage, or necrotizing enterocolitis. In older children and adults, surgical therapy is indicated when transcatheter therapies are not appropriate for anatomic reasons. Open surgical technique is more appropriate in the low-weight preterm infant, while in older patients, thoracoscopic ligation might be considered.

In preparation for surgical ligation, systemic infection needs to be ruled out. Operating on a premature patient in the face of an active infection increases the risk of operative morbidity and mortality. Elevated or decreased white blood cell count, thrombocytopenia, and temperature instability suggest infection in these patients. A useful preoperative test to assess the feasibility of the operation in a critically ill preterm baby is to try to position the baby in a lateral decubitus position the day before surgery for approximately 30 min. If

the stress of positioning is too severe for the patient, there is a good chance that the baby will not tolerate the operation.

With the patient in a lateral decubitus position, the spine is marked. A line is drawn parallel to the spine and in the middle of the distance between the posterior border of the scapula and the spine. A curvilinear incision is made between the tip of the scapula and this second line (left posterior thoracotomy). The latissimus is divided and the serratus is retracted anteriorly. The chest is entered in the third intercostal space. The most difficult part of the dissection in the small premature baby is the dissection between the superior border of the PDA and the undersurface of the aortic arch. The visualization and angle of dissection is easier when one chooses the third over the fourth intercostal space.

A self-retaining retractor is placed, and the assistant retracts the lung anteriorly with two malleable retractors. Good communication is paramount between the surgical and anesthesia teams as this maneuver can result in desaturation and hemodynamic instability. If this occurs, releasing the lung usually results in an improvement in the hemodynamics and the saturation.

With the area of the isthmus exposed, the next step is to identify the location of the distal, transverse aortic arch, and the left subclavian artery. The ductus inserts just opposite and distal to the left subclavian artery. The pleura in the inferior aspect of the PDA is opened. The recurrent laryngeal nerve is identified and protected. The space is developed with a mosquito hemostat by spreading gently along the long axis of the PDA. Next is the most difficult maneuver of this operation—the pleura between the distal transverse arch and the superior aspect of the PDA needs to be incised. Frequently, this angle is very acute and the dissection needs to be precise. The pleura may be hard to pick up and open. Once the pleura is opened, the space is developed with a mosquito hemostat as described above. The surgeon must understand the spatial relation of the PDA and the arch. Occasionally, the PDA is more anterior and the aortic isthmus is more posterior. Developing the space between the two will allow for safe placement of the ligation clip without the catastrophic complication of clipping the duct and part of the aortic isthmus. We have not found it necessary to encircle the PDA. This maneuver is not needed for complete ligation and may jeopardize the integrity of a friable duct.

After the duct is dissected, a clip size is chosen. A clip applier is tested to make sure that the clip will not scissor. Scissoring of the clip can rupture the PDA causing catastrophic hemorrhage. Using the same clip applier, the scrub technician loads a second clip in front of the operating surgeon. The surgeon then alerts the anesthesia team about the imminent ligation. The diastolic pressure immediately prior to ligation is noted. Then the surgeon retracts the isthmus towards him. This maneuver elongates the duct. The clip is applied in a firm but gentle fashion in the middle of the duct. The diastolic pressure after ligation is again noted. In hemodynamically significant PDAs, usually there is an increase by 8–10 mmHg. Lower extremity pulse oximeter reading should remain normal. The clip position is checked. The isthmus is palpated for a thrill and the operating field is assessed for hemostasis. Dampening of the distal pulse oximeter tracing or development of a palpable thrill after ligation may signify the development of a coarctation and should be investigated. The chest is copiously irrigated with antibiotic solution. A 10-mm JP drain is left in the pleural space and is removed on the first postoperative day. The chest is closed in a standard fashion.

In the older child, we encircle the duct. In order to do this safely, we perform a more extensive dissection to allow proximal and distal control of the aorta before we pass a right angle and a silk suture around the duct.

Postoperative Care

At our institution, the neonatology team assumes the postoperative care of infants. Standard periodic chest radiographs guide the removal of the chest drain, and postoperative antibiotics (first-generation cephalosporin) are administered. Ligation of the PDA can be a very stressful event for an extremely low birth weight premature infant. In addition, hemodynamic instability may result from the acute increase in the afterload to the left heart leading to transient ventricular dysfunction. The majority of the babies recover within 48–72 h, and significant morbidity and mortality is usually not observed.

Although common in premature infants, the indications for medical or surgical intervention for PDA remain physiological evidence of congestive heart failure or in some cases echocardiographic evidence of a hemodynamically significant shunt. The preemptive closure of a PDA in the absence of either of these indications is unwarranted. Approaches to closure are becoming increasingly less invasive and include medical treatment, transcatheter device closure, and more recently thoracoscopic ligation. Although there are increasing advances in imaging technology to assess the anatomy of the PDA to assist with operative planning, perhaps the best means of assessing whether an infant will tolerate open closure of the PDA is to simply position the baby in a lateral decubitus position for approximately 30 min the day prior to surgery.

Complications

PDA ligation should be considered a major operation, and as such parents should be informed of the indications, alternatives, anticipated benefits, and potential complications of the

operation in some detail. Risks include infection, bleeding, pneumothorax, chylothorax, recurrence, coarctation of the aorta, and injury to other structures such as the heart, major vessels, lung, and the phrenic or recurrent laryngeal nerve. They should also be told that there is a very small risk of death.

Chylothorax occurs when lymphatics crossing the parietal pleura overlying the duct and in the periaortic adventitia are divided. The risk is increased in patients with recent upper respiratory infections when lymphatics are engorged and more difficult to seal with electrocautery. Lymphatic leakage in the operative fields can sometimes be controlled with sutures or clips.

Bleeding from an injured ductus arteriosus can be heavy and due to the friability of the tissues difficult to control. A clip or stitch might be sufficient, but one might need to try and obtain proximal and distal control of the aorta. Alternatively, opening the pericardial space to control bleeding from the pulmonary artery is sometimes necessary.

Unintentional ligation of the aorta or left pulmonary artery is possible, especially if the ductus is large and is adjacent to the aortic arch. Monitoring of lower extremity blood pressure and oxygen saturation is critical. Interrupted pulmonary blood flow is sometimes noted on the postoperative chest X-ray.

Ligation of the PDA is expected to improve cardiac function and decrease excessive pulmonary blood flow. However, because these infants have other risk factors (intrinsic lung disease, surfactant insufficiency, primary pulmonary hypertension), lung function is not always improved by the operation.

Editor's Comment

Even in a small premature baby, PDA ligation is generally straightforward and safe, but there are significant risks including bleeding, recurrent laryngeal nerve injury, and erroneous ligation of a major vessel such as the left pulmonary artery. The operation is best performed with the patient in the NICU with full support and monitoring including an arterial line, good IV access, and at least one blood volume (80–100 mL/kg) of cross-matched blood warmed and ready to be transfused quickly if necessary.

The indications are well established, and there is usually consensus among the clinicians involved regarding the need for ligation. The patient should have an echocardiogram less than 48 h prior to ensure that the ductus still needs to be ligated. Indomethacin can make the ductus more friable and bleeding more difficult to control due to platelet dysfunction, but its recent use is not a contraindication to proceed. Despite success at some centers with thoracoscopic ligation, the open approach remains standard. A small left posterolateral muscle-sparing incision, rarely more than 3 cm in length, is made near the tip of the scapula, and the chest is entered through the third or fourth intercostal space. The more posterior the incision, the smaller it needs to be. An extrapleural dissection provides optimal exposure, allows easier containment of bleeding, and obviates the need for a chest tube. The lung is gently retracted anteriorly using a small malleable retractor bent at 90° and fixed to the Finochietto retractor with an Allis clamp. Although proximal and distal control of all major vascular structures is risky and unnecessary, the aortic arch, descending aorta, subclavian artery, pulmonary artery, and the ductus itself should all be clearly identified. Identification of the vagus and recurrent laryngeal nerves is also critical as it helps identify the ductus and avoid vocal cord paralysis, a disappointingly common complication of the procedure.

The ductus can usually be safely dissected circumferentially to allow passage of two 2-0 silk ligatures, though some have suggested that the risk of bleeding is minimized by only dissecting the ductus only enough to allow placement of a hemoclip. Accidental ligation of a vascular structure other than the ductus is surprisingly easy to do, but should be rare for the experienced surgeon. The risk is minimized by clearly identifying the vagus and recurrent laryngeal nerves and all vascular structures. It is also important to test clamp the structure to be ligated to confirm that post-ductal blood pressure improves, oxygen saturation remains high, and lower extremity perfusion is intact. Errant ligation can be lethal and therefore must be recognized and reversed quickly.

Bleeding from an injured ductus can be astonishingly brisk. It is important to maintain equanimity and to use a careful approach to control the bleeding. It is also important to have excellent suction, a second pair of hands, and good exposure. Blind placement of a hemoclip on the proximal ductus can be effective in slowing down the bleeding but must be done with care to avoid injury to aorta itself. Frantic attempts to control the bleeding almost invariably result in recurrent laryngeal nerve injury.

The infant's clinical condition will likely not improve immediately after ligation—they usually become fluid overloaded and require ongoing support until they can diurese. Most will begin to improve by the third or fourth postoperative day.

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Vascular Compression Syndromes

37

Mark L. Wulkan

Vascular compression syndromes include vascular rings, pulmonary artery slings, and innominate artery compression syndrome. Vascular rings cause the majority of vascular compression syndromes. There are no demographic predispositions to vascular compression syndromes. These anomalies occur equally in both males and females. Complete vascular rings encircle the trachea and esophagus causing compressive symptoms. Younger children tend to present with respiratory symptoms such as noisy breathing, stridor, cyanosis, apnea, respiratory distress, and a brassy cough. Patients might also have a history of reactive airways disease or recurrent pneumonias. It is not uncommon for children with complete vascular rings to have some feeding difficulty; however, formula and breast milk usually pass through the compressed esophagus. It is more common for older children to have symptoms of dysphagia and difficulty feeding. Patients with complete rings tend to present earlier and have more severe symptoms.

Aberrant left subclavian artery with right aortic arch is the most common type of vascular ring. The left subclavian artery takes its origin from Kommerell's diverticulum and encircles the esophagus and trachea as the aorta continues an abnormal descent on the right side.

Double aortic arch is the second most common type of vascular ring. It occurs when there is incomplete involution of the antecedent pharyngeal arch arteries (the sixth arch and the right-sided dorsal aorta). Although vascular rings are rare, left aberrant subclavian and double aortic arch together account for up to 90% of all vascular rings.

Pulmonary artery sling occurs when there is an abnormal takeoff of the left pulmonary artery from the posterior aspect of a normally positioned right pulmonary artery. A pulmonary artery sling can cause compression of the distal trachea and right mainstem bronchus. The left pulmonary artery then courses between the esophagus and trachea. Repair is usually accomplished with reanastomosis of the left pulmonary artery on cardiopulmonary bypass. Pulmonary artery sling is often associated with tracheobronchial abnormalities such as complete trachea rings.

Innominate artery compression is thought to occur when there is compression of the trachea by an abnormal leftward takeoff of the innominate artery. True innominate artery compression syndromes are rare. However, in tracheomalacia, the innominate artery can make an impression on the anterior trachea.

Diagnosis

Delays in diagnosis of vascular compression syndromes are not uncommon. Often they are discovered during a workup for respiratory symptoms or dysphagia. There can be suggestive findings on a plain radiograph of the chest, including an abnormal aortic knob or deviation of the trachea or esophagus. The diagnosis is often brought up during bronchoscopy for stridor or other airway symptoms. At bronchoscopy, tracheal compression or tracheomalacia can be seen. It is best to perform the bronchoscopy while the patient is breathing spontaneously, so as not to underappreciate the degree of collapse with inspiration when the airway is stented open by positive pressure.

Once the diagnosis is suspected on bronchoscopy, the next step is often CT angiogram or MR arteriography. CTA and MRA can usually provide a definitive diagnosis of a vascular compression syndrome. This is usually followed up with an echocardiogram to rule out intracardiac anomalies. Diagnosis of a vascular compression syndrome may also be made primarily by echocardiography. Echocardiography provides important functional information about blood flow in a vascular ring, especially a double aortic arch.

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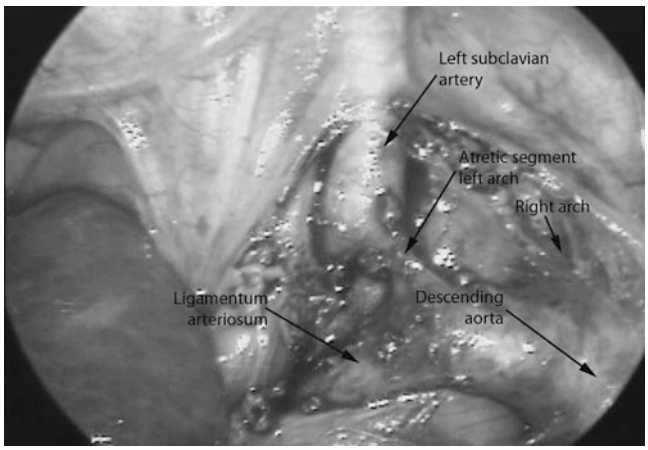

Fig. 37.1 Thoracoscopic view of a double aortic arch, with an atretic segment of the left arch between the left subclavian artery and the descending aorta

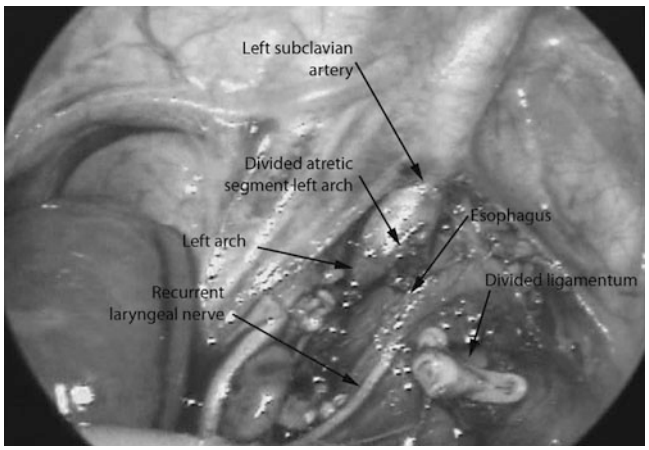

Fig. 37.2 Thoracoscopic view of the double aortic arch and ligamentum arteriosum divided. Note the space between the divided segments

Definitive diagnosis can also be made by contrast esophagram (Fig. 37.1). On esophagram, there are distinct impressions on the esophagus caused by adjacent vascular structures. An astute radiologist can often distinguish the various types of vascular compression syndromes based solely on the pattern of these impressions, although this may become a lost art with modern advanced imaging techniques.

Treatment

Once the diagnosis is made, the symptomatic patient should be considered for an operation. Nonoperative observation is sometimes warranted in patients who are asymptomatic. There is some evidence that patients who only have minor symptoms can eventually outgrow them. However, it is recommended that symptomatic vascular rings be divided.

Once the decision is made to surgically divide a vascular ring, many surgeons proceed with either a CTA or MRA. These studies are best to define the anatomy further, especially if a thoracoscopic approach is being considered. Monitoring of blood flow to the extremities is essential when dividing a vascular ring. This is typically accomplished with a *left* radial arterial line as well as a pulse oximeter on the left upper and lower extremities. The principles of the operation are the same whether one is using a thoracoscopic or open approach. Thoracoscopic division is considered for patients with a right aortic arch, aberrant left subclavian artery, and left-sided ligamentum arteriosum and for patients with a double aortic with an atretic or very small, low-flow segment to be divided. We currently do not recommend dividing true double aortic arches thoracoscopically due to the potential for catastrophic bleeding.

Right-Sided Arch with Aberrant Left Subclavian Artery

The goal of surgical repair of a right-sided arch with an aberrant left subclavian artery and a left ligamentum arteriosum is to divide the ligamentum arteriosum (Fig. 37.2). Complete dissection should still be done to verify that there is not an atretic double aortic arch, which, if left untreated, can leave the patient symptomatic. During the course of the dissection, the recurrent laryngeal nerve must be carefully identified and preserved (Fig. 37.3). Although the ligamentum theoretically has no blood flow, it should still be suture ligated or clipped. Again, care is taken to dissect the tissues overlying the esophagus in order to completely release the ring.

Placement of a chest tube is optional. The typical postoperative stay is 2–3 days for thoracotomy and 1–2 days for thoracoscopy. Patients are started on a diet immediately postoperatively. We do not routinely place patients in the intensive care unit.

While patients will commonly have immediate relief of their constricting symptoms, there is often residual tracheomalacia that can take some time to resolve. This is especially true of younger children with a double aortic arch. Symptoms of dysphagia may take some time to resolve as well. Of note, there still may be what appears to be vascular compression on an esophagram due to the presence of the blood vessels in an abnormal position.

Double Aortic Arch

The patient is approached through either a *left* thoracotomy or thoracoscopically. The pleura overlying the aorta is opened from the descending aorta to the level of the takeoff

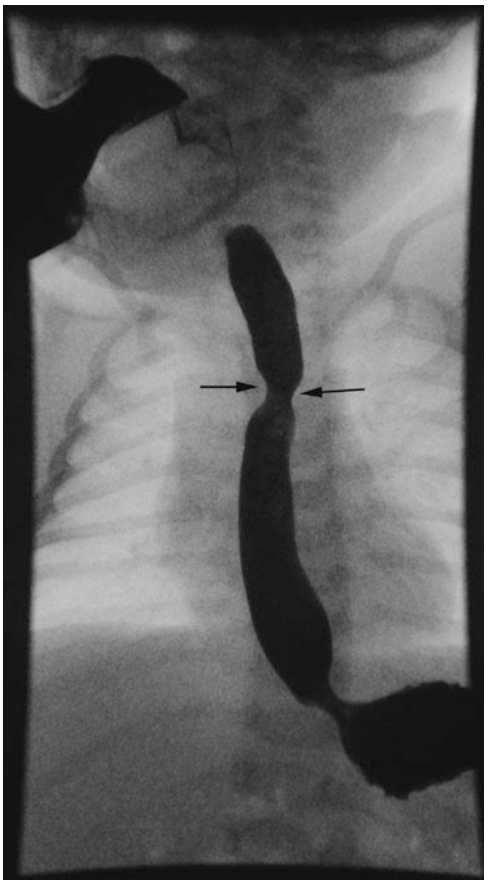

Fig. 37.3 Esophagram showing lateral and posterior indentations from a double aortic arch (*arrows*)

of the left subclavian artery. The pleura is reflected medially as the left arch and ductus arteriosus are identified. The left arch is dissected free from surrounding structures with particular attention paid to the area over the esophagus. The right arch is also identified. If there is an atretic segment of the arch as identified on preoperative studies, this area can be used for division. Otherwise, the arch is typically divided between the takeoff of the left subclavian arch and descending aorta. If there is a large size discrepancy between the arches, the smaller of the arches is divided. This may necessitate division of the right arch. Again, this is usually done at the junction with the descending aorta. Care must be taken when dividing a right posterior arch, as the right arch can retract and bleed quite briskly into the right mediastinum upon division. We typically oversew the aorta to prevent any accidents. Plastic interlocking clips are used for small atretic or stenotic segments if the double arch is approached thoracoscopically. The ligamentum is also typically divided. Once the arch is divided, the tissues overlying the esophagus are dissected free to make sure there are no constricting bands.

Complications

During the course of the procedure and especially when ligating the vessels, the surgeon should always be prepared for potential bleeding. Catastrophic bleeding should first be prevented. Survival is only likely if the surgeon has a plan already formulated for control. Initially, this includes proximal and distal control of the vessels prior to division. In the case of thoracoscopic division, a thoracotomy tray should be readily available for rapid entry into the chest.

Other potential complications are injury to the vagus nerve or recurrent laryngeal nerve and chylothorax. The course of the nerves should always be identified before dividing any structures. Should chylothorax develop, it is usually treated conservatively. It is rare to have injury to the thoracic duct proper.

Editor's Comment

In most tertiary care centers, cardiac surgeons are responsible for the care of the child with a vascular compression syndrome. Nevertheless, pediatric surgeons need to be aware of the signs and symptoms of these uncommon anomalies and should be familiar with the basic anatomy and principles of management. It is not uncommon to encounter a vascular anomaly during a thoracotomy or thoracoscopy being performed for esophageal atresia or other mediastinal lesion, in which case it is important to know what to do and, perhaps more importantly, what not to do. Such a finding usually prompts an immediate review of available imaging to see if something was missed on the initial reading and a call should be made to the appropriate surgical consultant for assistance. The next step is to carefully dissect and define all structures, including those on the opposite side of the mediastinum, being very careful not to injure important adjacent structures. No vessel should be divided unless it is clear that a true ring exists and that there is brisk flow in the descending aorta after test occlusion of the vessel in question.

Certain vascular anomalies can safely be repaired with a thoracoscopic approach by experienced minimally invasive surgeons. Vessels can be ligated with a variety of techniques, and most surgeons prefer to use at least two for added safety. In small children, most vessels can be clipped and then divided with advanced bipolar electrocautery or ultrasonic scalpel. Other options include simple suture ligation and oversewing the end with a running permanent monofilament suture. Stapling devices would probably work well, but there is not always enough space to manipulate the device and fire it properly without fear of inadvertently incorporating an important adjacent structure or nerve.

Bleeding is the most feared complication as these are large, high-flow vessels that have a tendency to retract and

become extremely difficult to control. Even when the bleeding is stopped, much to the relief of all present, the risk of injury to other structures (recurrent laryngeal nerve) is significant. A contingency plan must be prepared in advance, especially if the procedure is being performed thoracoscopically, with the ability to perform a rapid thoracotomy at a moment's notice. Proximal and distal control of all vessels can be difficult and time-consuming, but it is time well invested.

Chylothorax is a particularly distressing complication and one that is often frustrating to manage. It is best prevented by using meticulous technique and staying close to all vessels being dissected. At the conclusion of the operation, one should take a moment to observe the operative field closely for signs of a chyle leak and place sutures to repair a leak if one is found. Some have suggested that application of a commercially available fibrin sealant works well to help small chyle leaks to seal. If a chylothorax occurs, management includes establishing drainage with a small chest tube, initial bowel rest, and a great deal of patience. If the leak persists after 3 or 4 weeks, operative management should be considered, which can be difficult given that this entails a redo operation in the chest.

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Congenital Lung Lesions

38

Adesola C. Akinkuotu and Oluyinka O. Olutoye

Congenital lung lesions (CLL) represent a wide array of developmental anomalies of the respiratory tract including congenital pulmonary airway malformation, bronchial atresia, congenital lobar emphysema, bronchopulmonary sequestration, and bronchogenic cyst. The majority of these lesions are now diagnosed prenatally. Fetal intervention, ranging from the use of maternal steroids to open fetal surgery, may be necessary for lesions that produce hydrops or cardiac failure. In the remainder of patients not requiring fetal intervention, postnatal management of CLL involves observation, or resection which can be performed in most instances with minimally invasive techniques.

Advances in imaging have led to improvements in the prenatal diagnosis of congenital lung lesions. Congenital lung lesion (CLL) is used to describe developmental anomalies arising from the respiratory tree. These include congenital pulmonary airway malformation (CPAM), bronchial atresia, congenital lobar emphysema (CLE), bronchopulmonary sequestration (BPS), and bronchogenic cyst (Table 38.1). Although there are certain radiographic findings that can help to differentiate between them, they all have overlapping features. As such, practitioners should be cautious about making clinical decisions based only on imaging.

Histologically, CPAMs are characterized by abnormal alveoli and an overabundance of terminal respiratory bronchioles. CPAMs can be further divided into microcystic and macrocystic lesions based on the size of cysts that are present. CLE is a progressive overinflation of one or more lobes of the lung that typically affects the upper lobes and might be associated with a defect in bronchial cartilage. BPS describes a portion of the lung that does not communicate with the tracheobronchial tree and thus is nonfunctional. BPS lesions are characterized as extralobar if the lesion has its own separate pleural covering or intralobar if it is invested within the pleural of adjacent normal lung. They are typically found in the lower chest, related to the lower lobes. BPS receive arterial blood supply from a systemic vessel, but their venous drainage can be into either systemic veins (extralobar BPS) or pulmonary veins (intralobar BPS). Bronchial atresia results when the airway to one or more bronchopulmonary segments is obstructed, resulting in segmental accumulation of lung fluid in utero. Most of these regress as pregnancy continues, as lung fluid production decreases and the rest of the lung grows around the lesions. These are peripheral bronchial atresias that are to be distinguished from main-stem bronchial atresia. Main-stem bronchial atresia is a rare lesion caused by obstruction of the main-stem bronchus (more frequently the right), leading to a marked overdistension of the affected lung in utero. The mass effect results in contralateral pulmonary hypoplasia, mediastinal shift, cardiac compression, and hydrops. To date, there have been no long-term survivors even with fetal surgical intervention.

Pleuropulmonary blastomas are rare, malignant lesions of the lung that by imaging may be difficult to distinguish from a CPAM. They were initially thought to the result of malignant transformation of a CPAM. However, fetal and neonatal diagnoses of these lesions now suggest that they arise de novo but are sometimes erroneously thought at first to be a CPAM. The definitive diagnosis of each lesion is usually only made by histologic examination after resection.

Diagnosis and Prenatal Management of CLL

Nowadays, CLL are often diagnosed by ultrasound. A CPAM volume ratio (CVR) is calculated. The CVR is based on the volume of the lesion as determined by the volume of an ellipse. The product of the widest length, width, and depth are

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Table 38.1 Concepts of the management of congenital lung lesions

Prenatal diagnosis of congenital lung lesion	• Measure CVR (CVR > 1.6 = high risk) • Fetal MRI • Baseline fetal echocardiogram • Genetic counseling • Monitor closely with serial ultrasound during period of rapid growth (20–26 weeks) for fetal compromise
Indications for fetal intervention	• Hydrops • Cardiac failure • Significant mediastinal shift – Steroids may be useful in large, macrocystic lesions with hydrops
Fetal intervention options	• Decompressive thoracentesis • Thoracoamniotic shunt • Open fetal surgery
Large lesions not requiring fetal intervention	• EXIT-to-resection
Management of lesions not requiring fetal intervention or EXIT-to-resection	• Chest CT at 6–8 weeks of life • Resection via thoracotomy or thoracoscopy • Long-term monitoring for compensatory lung growth, recurrence, and chest wall deformity

multiplied by 0.52 and divided by the head circumference in cm [$(L \times W \times D \times 0.52)$/HC]. Lesions with a CVR greater than 1.6 are considered high risk.

We routinely use fetal MRI to further characterize the lesion. In experienced hands, subtle findings on fetal MRI may also help to characterize these lesions and distinguish them from others with similar appearances such as congenital diaphragmatic hernia and may help to identify communication with the GI tract. Once the diagnosis is made, we further evaluate the fetus with an echocardiogram, especially if the lesion is large. We obtain baseline cardiac parameters to compare with as the lesion enlarges and could cause cardiac compromise. As with any anomaly, genetic counseling and testing is offered as well. During the period of rapid lesional growth (20–26 weeks gestation), the fetus is monitored closely for signs of compromise. After 26 weeks' gestation, the somatic growth of the fetus increases faster than the growth of the lungs, such that the mass often now appears relatively smaller as the fetus grows around it, or it might actually regress in size. Some lesions will continue to grow with the fetus, but because of the faster growth trajectory of the fetal chest compared to the lungs, the mass rarely exhibits sufficient mass effect to cause hydrops after 28 weeks. Thus, the frequency of follow-up is liberalized after 28 weeks.

Corticosteroids

Recently, there has been an increase in the use of maternal corticosteroids to decrease the size of the CLL especially those that are large and microcystic with hydrops. Steroids are thought to act by decreasing lung fluid production and increasing reabsorption of fluid within the lung lesion. At this time, it is unclear whether steroids actually make a difference in the progression of these lesions or merely allow for the evolution of the natural course of the lesion. Randomized controlled trials are needed to prove efficacy, however considering the current widespread use of corticosteroids' equipoise might already be lost.

Fetal Intervention

The major indications for fetal intervention are hydrops and cardiac failure (Fig. 38.1). It is the known natural history of these lesions that fetuses with CLL who do not have signs of cardiac dysfunction can be managed expectantly with subsequent definitive management after birth. Nonimmune hydrops, defined as the accumulation of fluid in two or more body compartments, had been used as a surrogate for cardiac failure in the past. At our center, we rely on actual cardiac assessment by echocardiography. We have found that some fetuses with lung lesions (especially those on the right side) have ascites and a pleural effusion, yet have preserved cardiac function. The accumulation of fluid could be due to impaired lymphatic or venous return. In the past these would have met the definition for fetal hydrops and been eligible for fetal intervention. However, we noted that as long as the cardiac function remains adequate, we could expectantly manage these lesions and the fluid accumulation usually resolves after about 28 weeks as the fetus outgrows the mass.

Fetal intervention is indicated when the CLL demonstrates an increase in size (even with steroid therapy) that is associated with cardiac deterioration as evidenced by fetal echocardiogram, hydrops, or significant mediastinal shift in fetuses less than 30 weeks' gestational age. Options for fetal intervention include decompressive thoracentesis, placement of a thoracoamniotic shunt, or open fetal surgery for microcystic lesions.

For each case that is evaluated for fetal intervention, the patient undergoes multidisciplinary counseling, during which we review the medical and psychosocial factors that might affect the care of the mother or fetus. Preoperatively, the mother and family are counseled about the anticipated benefits of the procedure as well as the potential for serious complications including hemorrhage, infection, preterm delivery, fetal demise, and impact on long-term fertility. When there is a large dominant cyst, we perform either a decompressive thoracentesis or thoracoamniotic shunt.

For microcystic lesions not amenable to fluid decompression, we perform open fetal surgery with resection of the affected lobe. This is performed under deep general anesthesia. A low transverse abdominal incision is made and is

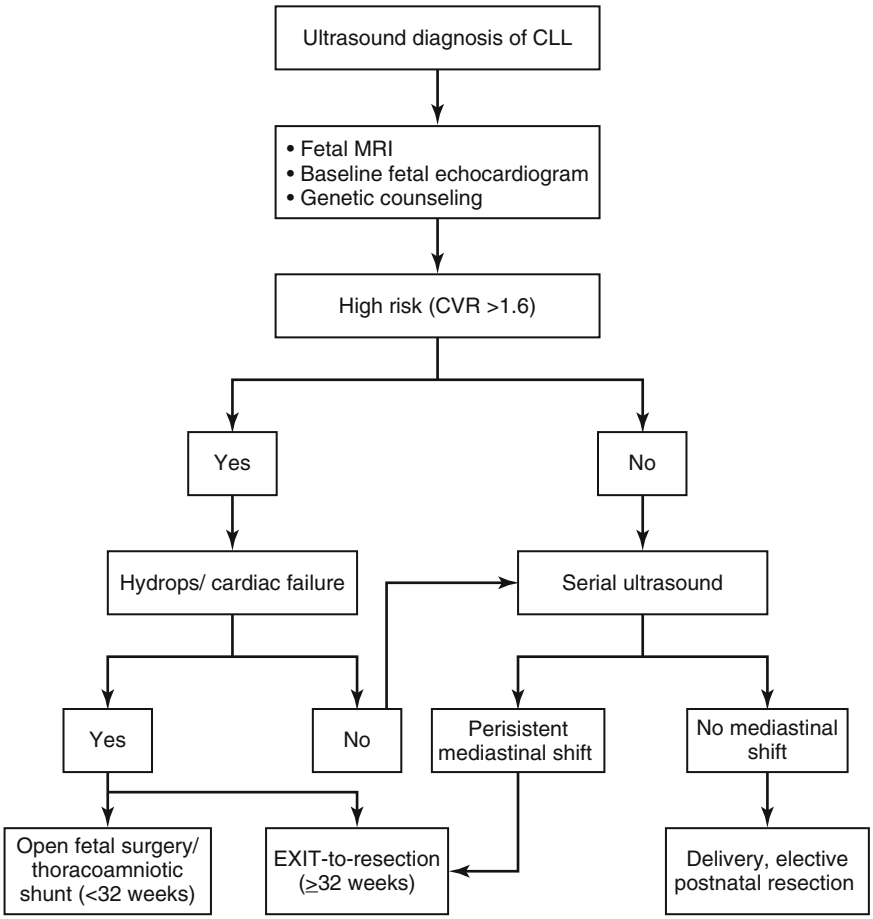

Fig. 38.1 Management of prenatally diagnosed congenital lung lesion

followed by a hysterotomy and exposure of the fetus on the side with the lesion. Peripheral venous access is obtained and supplemental anesthesia and analgesia administered to the fetus. The fetus is volume loaded in anticipation of a decompressive thoracotomy. The site of the lesion is verified by ultrasound, and a generous thoracotomy incision is made with access into the chest cavity in the fifth intercostal space. The lesion is delivered gently with careful suture ligation of feeding vessels. The hilum is typically stretched and can be stapled en masse. The fetus is resuscitated as needed and the chest is closed in layers. This is followed by replacement of the amniotic fluid with warm lactated Ringer solution and closure of the uterus and the abdomen. Continuous fetal echocardiographic monitoring takes place during the entire operation. The mother and fetus are monitored closely postoperatively and for the remainder of gestation. Hydrops typically resolves within a few days, and compensatory growth of the remainder of the lung is observed on serial imaging. The pregnancy is allowed to progress as close to term as possible with eventual delivery by cesarean section.

Ex Utero Intrapartum Treatment

For lesions that do not require fetal intervention but still remain large in the third trimester, we perform repeat imaging at 32–34 weeks to assess for the risk of perinatal cardiorespiratory distress. The size of the lesion (CVR > 2.0), persistent mediastinal shift, cardiac compression, and a suggestion of cysts that would increase in size with positive pressure ventilation are all factors taken into consideration. Such patients are offered an EXIT-to-resection procedure. The concern is that after delivery the compressed uninvolved lung of a fetus with a persistent large mass might not provide sufficient ventilation. Positive pressure ventilation could then increase the size of the cystic lesions (especially CPAMs) and increase the mass effect on the normal lung and heart, further worsening heart and lung function.

To avert this vicious cycle, which in the past has proven fatal, an EXIT-to-resection is performed as close to term as possible (Fig. 38.2). Using fetal surgical techniques, under deep general anesthesia, a lower segment-stapled

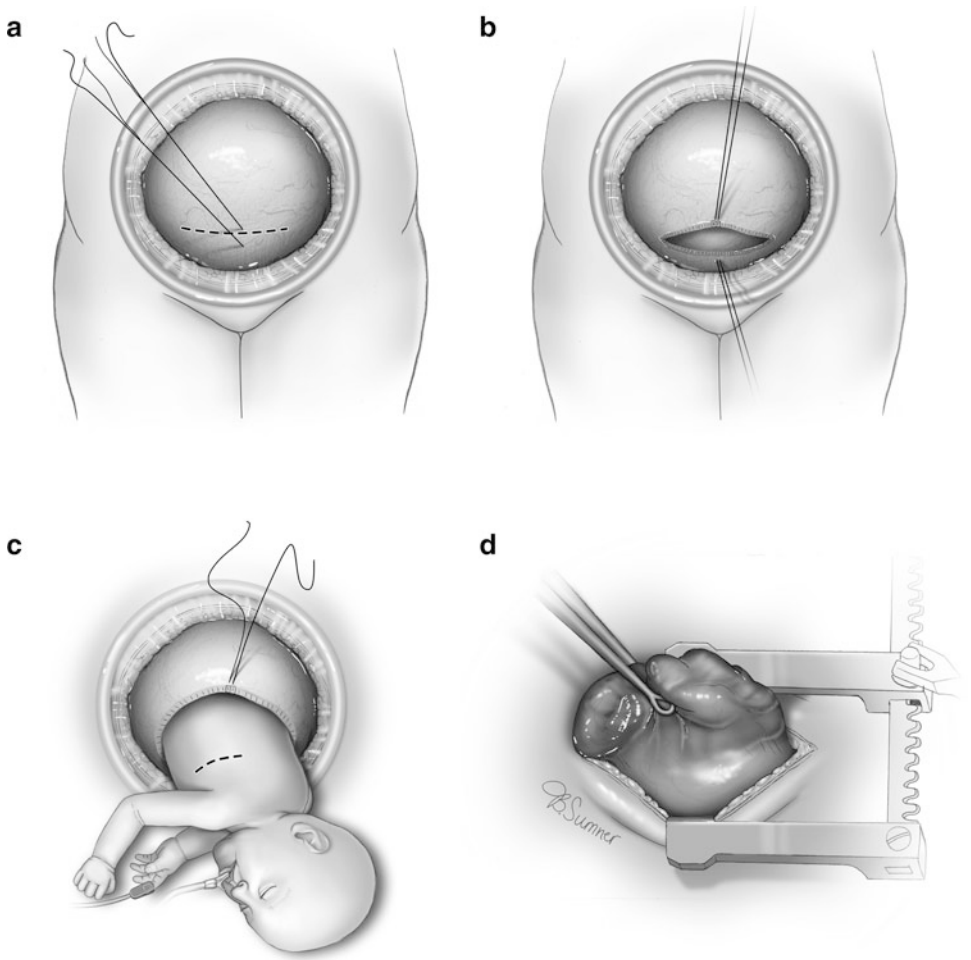

Fig. 38.2 EXIT-to-resection of congenital lung lesions. (**a**) A lower abdominal/Pfannenstiel type incision is made followed by (**b**) the creation of a hysterotomy. (**c**) The fetus is delivered and intubated, and intravenous access is obtained while on placental support, and then, (**d**) a posterolateral thoracotomy is made on the fetus and the lesion is exteriorized from the chest cavity. Ventilation is attempted and the fetus is delivered and transferred to an adjacent operating room for completion of the lobectomy, if there is adequate gas exchange (Printed with permission from Texas Children's Hospital)

hysterotomy incision is made and the fetus partly delivered, maintaining placental support. Supplemental analgesia and anesthesia are given. Venous access is then obtained through a peripheral upper extremity vein and a pulse oximeter is placed on the fetal hand. The fetus is intubated with an endotracheal tube that is sutured to the alveolar ridge. At this point, ventilation is avoided so that we preserve fetal circulation and avoid expansion of the lesion. A posterolateral thoracotomy is made and the lesion is exteriorized. At this point, we attempt to ventilate, and if gas exchange is adequate, the fetus is delivered and transferred to an adjacent operating room for completion of the lobectomy. In the event that gas exchange is inadequate, the fetal lung lesion resection is completed on placental support.

Management of Lesions Not Requiring Fetal Intervention

In the majority of cases of CLL, there is progressive decrease in size of the lesion without evidence of cardiac dysfunction or mediastinal shift. In these cases, there is very little concern for perinatal distress and thus the mother is given the option of delivering the baby at the hospital of her choice. No imaging would be needed in the immediate newborn period, and the neonate would be expected to be asymptomatic and discharged home with the mother. For asymptomatic infants, we follow the lesion with a chest CT at 6–8 weeks of life. The advantage of obtaining the chest CT at this time point is to allow for better distinction of cystic versus solid lesions. There will have been sufficient time for any residual lung fluid to be absorbed and any areas of hyperlucency within the lung to be better defined. The chest CT is obtained with intravenous contrast and the sequences obtained to optimize visualization of systemic feeder vessels. Lesions with systemic blood supply are at increased risk of intrapulmonary shunting and high-output cardiac failure depending of the size of the vessels.

Although most CLLs are benign, there is a risk of recurrent infection in cystic lesions that communicate with the airway. Also the inability to effectively differentiate some cystic lesions from the much rarer pleuropulmonary blastoma (PPB) might prompt surgical resection. Further confounding the management of asymptomatic lesions is the

inability to follow most of them with serial chest radiographs. The lesions are best seen on CT. The lungs continue to grow and develop until about 8 years of age. A lung resection would be accompanied by compensatory lung growth if performed in infancy or early childhood. It is our practice to carefully evaluate the imaging characteristics of the lesion and discuss with the parents the potential risk of infection or PPB.

Small lesions consistent with peripheral or segmental bronchial atresia can be managed nonoperatively. CPAMs and cystic lesions at risk for mucus trapping and infection and those that cannot be distinguished from PPBs are offered surgical resection. The pros and cons of observation and surgical resection are discussed with the family. Surgery can be performed as early as 8 weeks of age or at the convenience of the family. Efforts are made to perform the procedure prior to the onset of recurrent respiratory infection that may make the subsequent resection more technically challenging.

Resection can be performed either with an open, muscle-sparing mini-thoracotomy or with a thoracoscopic approach. When a thoracotomy is employed, our practice is to create a small lateral incision over the fifth intercostal space, elevating and reflecting the latissimus dorsi and serratus anterior muscles without dividing them. Two self-retaining chest retractors are used, one to widen the intercostal space and the other placed at right angles to the first to keep the chest wall muscles retracted. The incision is made just big enough to permit visualization of the hilar vessels that are readily seen in the major fissure. The disadvantage of this small incision is that it could limit access to a systemic feeder vessel arising through the diaphragm. The systemic feeding vessels can retract into the abdomen when disrupted, and thus we prefer to dissect, occlude, and divide this vessel prior to carrying out further dissection of the lung parenchyma.

Children with imaging suggestive of BPS are preferentially done thoracoscopically. In general, our practice has gradually transitioned to performing most of the elective lung resections thoracoscopically regardless of age. Appropriate-sized ports are used (3 mm or 5 mm). We prefer to use advanced bipolar cautery to seal the vessels in two areas and cut in between with the scissors to confirm that the vessel has been sealed prior to being divided. In younger children, we have used the advanced bipolar cautery to divide the bronchus deep within the lobe and then place two endo-loops proximally. This technique ensures control of the bronchus at all times and allows suture closure of the bronchial stump. In older children, an endo-stapler is used to divide the bronchus. We perform a test for air leak with airway pressures increased up to 40 cm H_2O. We expand one of the port sites (preferable the posterior one) to accommodate a 10 mm specimen bag and retrieve the lung within the bag. Patience to carefully maneuver the specimen through the opening (which may need to be extended up to 1.5 cm but using the specimen bag as a wound protector) is needed to deliver a specimen that is intact and can be subjected to proper pathologic evaluation.

Intercostal local anesthetic blocks are performed at each port site. The anesthesiologists placed a thoracic epidural catheter for those undergoing thoracotomy. We place a pleural drain connected to water seal, and all patients are extubated at the conclusion of the procedure and do not usually require management in a high-acuity setting. The chest tubes are removed within 1–2 days based on the presence or absence of an air leak. The patients are discharged thereafter.

Complications

Early complications include bleeding, persistent air leak, and infection. Since the portion of the lung that is removed is typically nonfunctional, worsening of the respiratory status is rarely a concern. If a substantial portion of normal lung is included in the resection, reduction in pulmonary reserve might then be a concern. We see these patients as outpatients a few weeks after surgery where posterior-anterior and lateral chest radiographs are obtained. The pathologic findings are also discussed at this visit and long-term plans outlined. It is our practice to monitor these patients long term to assess for compensatory lung growth, recurrence, chest wall deformity, and adequacy of lung function.

Summary

Congenital lung lesions are usually benign developmental anomalies that are typically asymptomatic in the perinatal period. The majority are identified by routine antenatal US. These lesions have a fairly predictable course with the most significant growth occurring in the second trimester followed by significant regression or stabilization of the lesion. Prenatal imaging is essential for planning management. Fetal MRI can be used to further characterize CLL, and the team managing these patients needs to assess the fetus for concomitant congenital anomalies. A subset of fetal lung lesions that are large (CVR > 1.6) deserve close observation during the period of rapid fetal lung growth (22–26 weeks gestation). Fetal echocardiography to monitor for evidence of cardiac dysfunction would help select those in need of fetal intervention. Administration of maternal corticosteroids is increasingly used to treat fetal lung lesions but warrants proper studies to ascertain its efficacy. When indicated due to hydrops, fetal intervention options include thoracoamniotic shunt, thoracic decompression, open fetal surgery, and EXIT-to-resection. If the lesion is small and can be managed postnatally, a CT is obtained at 6–8 weeks of life

and ultimately followed by resection. The indications for resection include respiratory difficulty, infection, concern for malignancy, and parental reassurance. Postnatal lung resection can be safely performed with minimal access techniques even in young infants.

Editor's Comment

Every congenital lung lesion should be excised, but depending on the clinical circumstances the timing varies: in utero, at birth using an EXIT strategy, urgently in the newborn period or electively after several weeks of close observation. A CPAM might regress in the third trimester and for a time after birth, but they never disappear—although some centers recommend watching asymptomatic CPAMs indefinitely, there is always the risk that a child lost to follow-up could develop a complication or malignant transformation. Most cases of congenital lobar emphysema will present acutely in the newborn period and need to be removed urgently. For a CLE under tension, a bedside decompressive thoracotomy can be lifesaving. A segment orlobe of the lung that appears to be enlarged and filled with fluid on antenatal imaging could have a CLE because of course they do not fill with air until birth.

The thoracoscopic approach is an advanced MIS procedure that is increasingly being performed with excellent results and few complications. For elective cases, parents should be offered the option of having their baby's care transferred to a center where this technique is offered. In preparation for any operation that involves lung lobectomy, it is always sensible to review the relevant anatomy ahead of time. The operation itself should be done with single-lung ventilation, usually best accomplished in an infant by mainstem intubation under fluoroscopic guidance. The biggest hurdle to successful thoracoscopic resection is an incomplete major fissure, the dissection of which frequently results in intraoperative bleeding and stubborn air leaks after surgery. Because the tissues are so delicate and vessels prone to tearing, the most important technical aspects of the operation are extreme patience and an absolutely meticulous dissection. The surgeon needs to resist the temptation to use aggressive blunt dissection, which is the trademark of the accomplished laparoscopist but can quickly lead to exsanguinating hemorrhage.

Suggested Reading

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Lung Biopsy and Resection

39

Charles W. Archer Jr. and Daniel J. Ostlie

Thoracoscopic pulmonary resection was initially described in the 1970s; however, it did not become widely utilized until the 1990s when it became apparent that it was a superior technique for lung resection. Thoracoscopic lung biopsy gained acceptance more rapidly than lobectomy due to ease of technique and low risk associated with biopsy alone. Acceptance of thoracoscopic lobectomy was slower, primarily because it required advanced thoracoscopic techniques that were difficult to obtain given the infrequency of the procedures and the progression of minimally invasive surgery during that time. With improved technology and experience, the thoracoscopic approach is increasingly preferred over thoracotomy for lung surgery, even in pediatric patients. The minimally invasive technique, although technically more demanding, has the advantages of improved cosmesis, less postoperative pain, shorter recovery times, and decreased length of hospital stay.

Indications

In the adult population the most common indication for segmental resection or lobectomy is neoplastic disease; in the pediatric population, indications for surgery are much more diverse. They can be divided into congenital and acquired pulmonary disease. Congenital lesions include congenital lobar emphysema, congenital pulmonary adenomatous malformation, and intralobar and extralobar sequestration. With the exception of extralobal sequestrations, which are separate from the lung itself and therefore require simple excision, most congenital lung lesions require lobectomy.

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Acquired lesions include pneumonia and other infectious processes, suspected or known malignancy, bronchiectasis, blebs, and right middle lobe syndrome. As with congenital lesions, the extent of resection of these acquired lesions varies and can range from wedge resection to formal lobectomy.

Contraindications to thoracoscopic lung resection include tumor or cystic size too large for safe visualization, which will vary depending on the size of the patient, inability to tolerate single-lung ventilation, and previous thoracotomy with obliteration of the pleural space. Previous pulmonary infections and significant hilar lymphadenopathy can make the thoracoscopic approach difficult, necessitating conversion to thoracotomy. Finally, patient characteristics such as size and other congenital anomalies, such as congenital heart disease, might preclude thoracoscopic resection.

Diagnosis

All patients require some form of imaging. In general, most congenital lesions are found on prenatal ultrasound and confirmed on definitive studies postnatally. Acquired lesions can be found incidentally, during evaluation for symptoms, or on surveillance imaging.

Most patients with a congenital lesion will have a plain chest X-ray, which may or may not reveal the abnormality (Fig. 39.1). Prior to considering resection, all patients should undergo more advanced preoperative imaging. Generally, a CT scan will be the initial study for most patients, although an MRI may be indicated for certain patients where CT may not be able to adequately characterize a lesion. The purpose for advanced three-dimensional imaging is to fully evaluate the lesions with regard to lesion size, cyst size, and location and to assess the underlying anatomy specifically the vascular supply, bronchial anatomy, and lobe, or lobes, that are involved (Figs. 39.2, 39.3, and 39.4). With regard to extralobar sequestrations, the arterial supply usually arises from the descending aorta, which the advanced imaging will nearly

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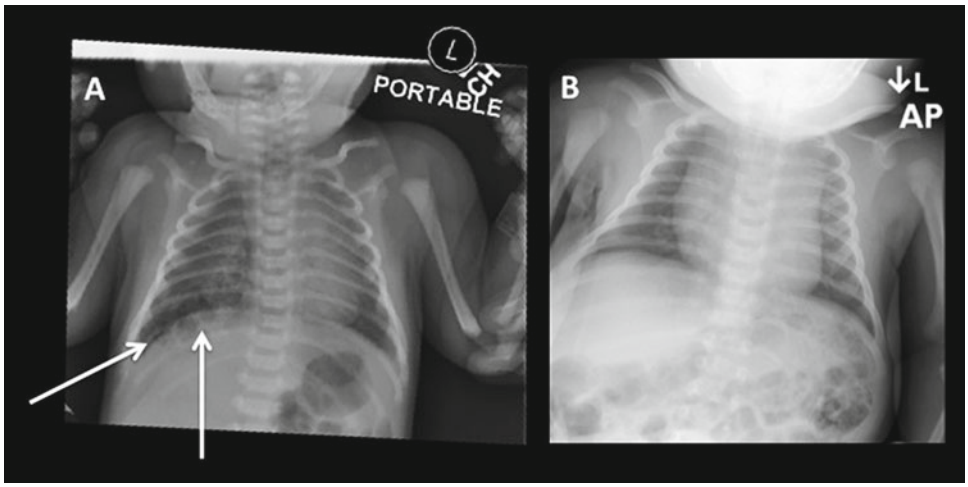

Fig. 39.1 The chest radiograph in patients with congenital pulmonary adenomatous malformations (CPAM) may be abnormal or appear normal: Image A shows a right-sided CPAM, while image B appears normal despite a known left-sided lesion

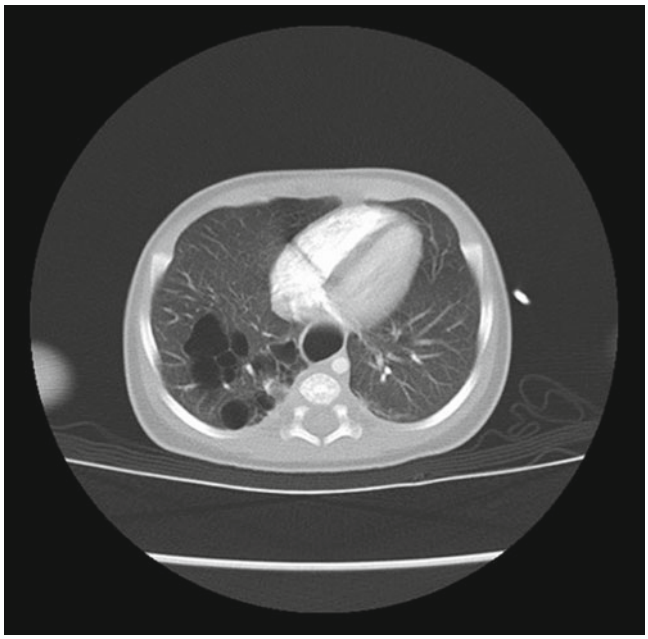

Fig. 39.2 Complex right lower lobe CPAM with cystic changes of variable sizes ranging from more than 3 cm to smaller than 1 cm. This child underwent a thoracoscopic right lower lobectomy at 6 months of age

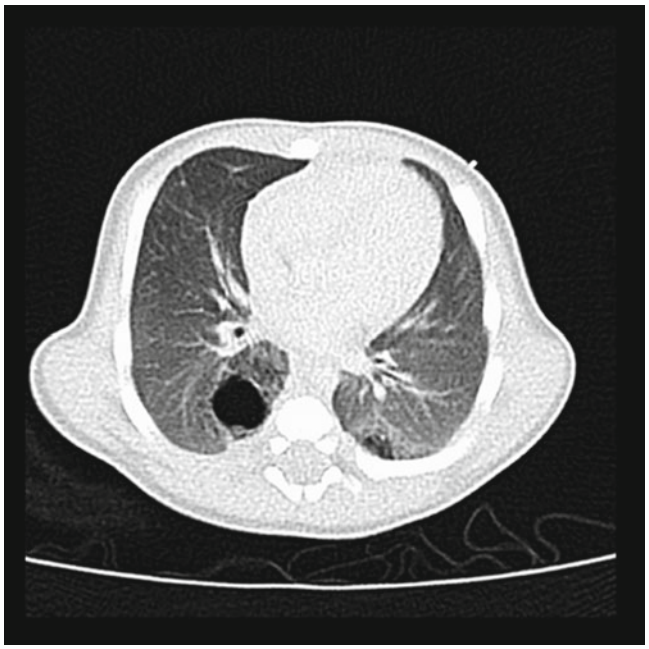

Fig. 39.3 This figure shows a complex right lower lobe CPAM with cystic changes of variable sizes ranging from more than 3 cm to smaller than 1 cm. The child underwent a thoracoscopic right lower lobectomy at 6 months of age

always be able to identify to identify and confirm the diagnosis (Fig. 39.5). Often the differentiation of intralobar versus extralobar sequestration can be determined based on the CT (Figs. 39.6, 39.7, and 39.8), important for both operative planning and counseling of the family.

Acquired lesions are usually found at the time of surveillance imaging or during evaluation for symptoms. A CXR is generally the initial diagnostic test in patients with new symptoms, while a CT is more commonly used for surveillance. Although CXR may identify an abnormality, it is often read as normal. In most cases, a chest CT should be obtained to fully evaluate the lung parenchyma. As with the congenital lesions, MRI can be used if there is concern about the adequacy of CT. However, CT is highly sensitive in identifying and characterizing most acquired parenchymal lesions.

If necessary, preoperative bronchoscopy should be performed to further delineate bronchial anatomy or potential obstruction.

Operative Technique

Preoperative antibiotic prophylaxis is normally indicated, unless the patient is already on antibiotics, in which case those should be continued as scheduled. If the patient has known colonization with MRSA, the addition of vancomycin

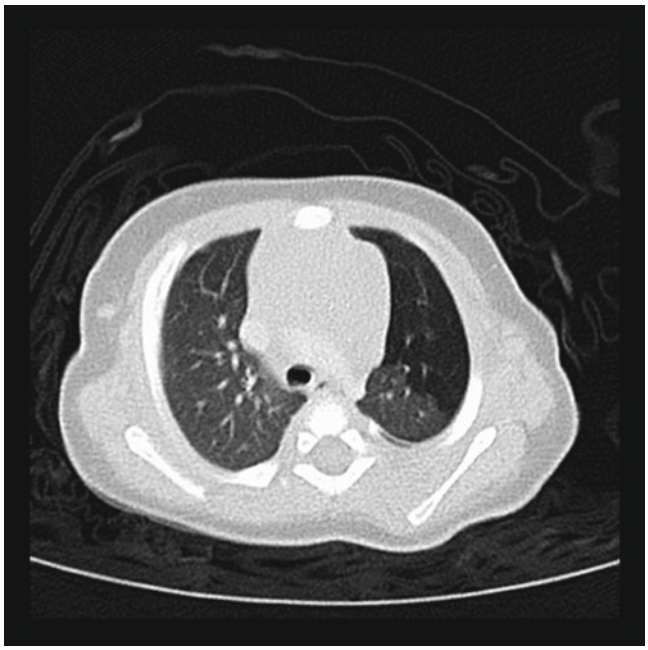

Fig. 39.4 Bilateral congenital cystic disease is identified in this chest CT. This child underwent right upper lobectomy at 3 months of age for the larger, more significant disease. The left-sided disease is much less severe with cyst size of less than 1 cm. Surveillance CT is being performed on a 4–6-month basis to follow the lesion with regard to growth or other abnormal developments

Fig. 39.5 A 3-D arteriogram reconstruction from a chest CT in a patient with a right pulmonary sequestration. The arrow indicates the aberrant arterial blood supply arising from the infra-abdominal aorta

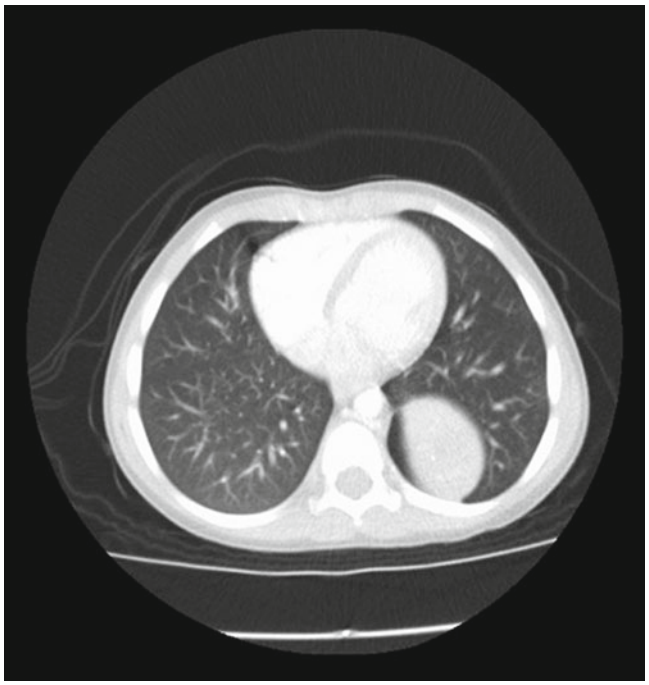

Fig. 39.6 This chest CT shows a large left-sided extralobar pulmonary sequestration in a 3-year-old female. Note the solid nature of the lesion

is recommended. If the patient has a known penicillin allergy, clindamycin can be used as an alternative, or, because the cross-reactivity with cephalosporin is very low, and unless the patients penicillin allergy is anaphylaxis, a cephalosporin might still be appropriate.

Pulmonary resections are performed with the patient in lateral decubitus position. The patient is usually best rotated approximately 30° anteriorly, and based on the patients size, a pneumatic bean bag, gel rolls, or towels are used to ensure the patient maintains position throughout the case (Fig. 39.9). The arm on the operative side is well supported to avoid brachial plexus tension. An axillary roll is placed under the chest to reduce pressure on the down arm. Depending on the patients' size, the patient can be positioned so that when the operating table is flexed, the rib spaces open. The operating surgeon and assistant stand in front of the patient with a monitor positioned posterior to the patient.

Incisions and port sites depend on the location of the lesion and anticipated lung resection. The operating telescope should be placed in the mid-axillary line at the level of the sixth or seventh intercostal space to provide exposure of the entire pleural cavity and identification of the lesion to be resected (Fig. 39.10). Location of other incisions and ports is dictated by the location of the fissure, with working ports or incisions placed along the anterior axillary line between the fifth and ninth intercostal spaces. In smaller children and infants, instruments can be inserted through small stab incisions without a port.

Depending on the size of the patient and the specimen being removed, a port site incision might need to be enlarged for extraction of the specimen. Enlarged port site incisions

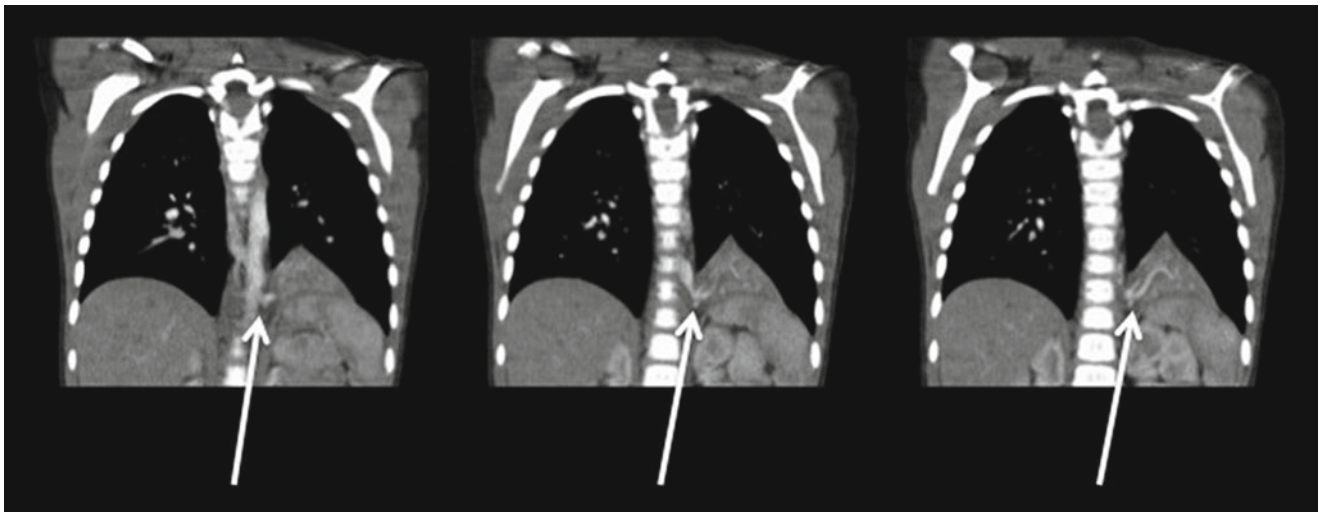

Fig. 39.7 Sequential images from the chest CT of the patient referred to in Fig. 39.6. The *arrows* show the course of the aberrant artery arising from the descending aorta

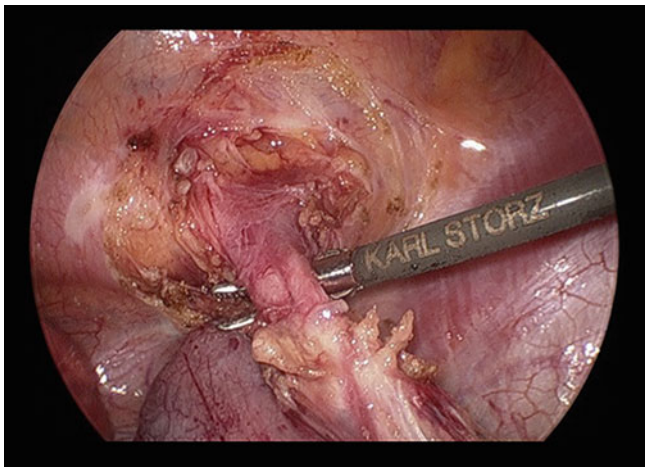

Fig. 39.8 An intraoperative photograph of the patient described in Figs. 39.6 and 39.7 is shown. The artery has been dissected and is being prepared for division with a vessel-sealing device

should be closed with deep and superficial layers using absorbable suture. 5-mm port sites can be closed in a subcuticular fashion; stab incisions require steri-strips only. Infiltration of local anesthesia into the wounds and intercostal nerve blocks can be used as adjuncts for postoperative pain control.

Anesthesia

Optimal surgical exposure in thoracoscopy is accomplished with single-lung ventilation, which should be used whenever possible. A variety of techniques are available. For patients weighing 40 kg or more, single-lung ventilation can be obtained using a 28, 32, or 35 Fr double-lumen endotracheal tube. Because there are not appropriately sized double-lumen endotracheal tubes for patients weighting 20–40 kg, a balloon-tipped bronchial blocker, which has a high-volume low-pressure balloon, placed in the trachea alongside the endotracheal tube can be used to block ventilation to the operative lung. Another option for these patients, as well as patients less than 20 kg, the endotracheal tube can be advanced into the mainstem bronchus of the contralateral lung to achieve single-lung ventilation. When using a mainstem intubation to accomplish single-lung ventilation, an endotracheal tube a half size smaller than normal is used for ease of endobronchial placement. Limitations of mainstem intubations include incomplete collapse of the operative lung and the possibility of obstructing the upper lobe bronchus, especially on the right, which can affect oxygenation. When single-lung ventilation is not available, high-frequency oscillating ventilation provides excellent decompression and visualization of the lung, and has the advantage of superior ventilation when compared to conventional ventilators, thus limiting hypercapnia.

The chest should be insufflated with CO_2 during thoracoscopy if lung collapse is inadequate for surgical exposure. The insufflation pressure is generally kept between 3 and 5 mmHg to limit the adverse effects of higher pressure on hemodynamics; however, pressure and flow can be increased if there is significant loss of the pneumothorax due to leaks from the incisions. The anesthesiologist might need to be aggressive in increasing respiratory rate and tolerate moderately elevated PCO_2 (40–60 mmHg).

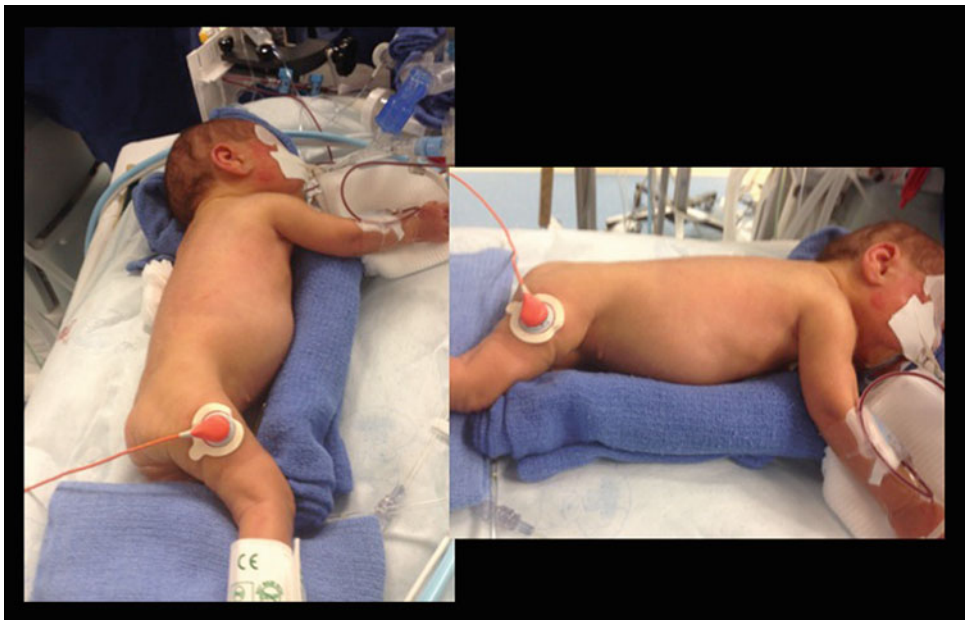

Fig. 39.9 Operative positioning for a right-sided pulmonary resection. Note the anterior positioning of approximately 30°, which allows for improved visualization of the posterior mediastinum. The right arm is supported with *towels*, and a towel has been used as an axillary roll

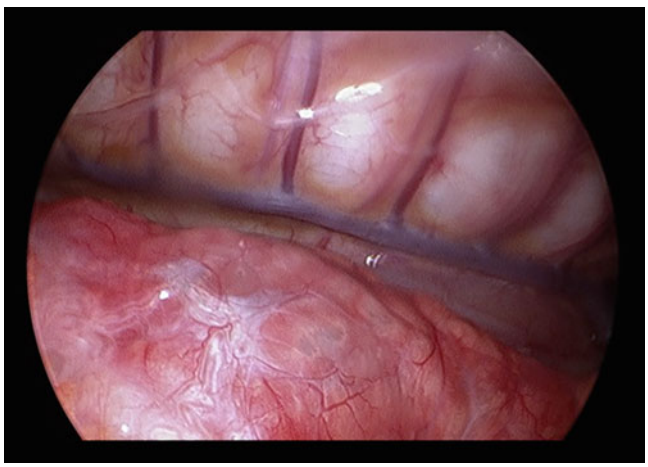

Fig. 39.10 The operating telescope has been placed into the chest cavity, and the congenital pulmonary adenomatous malformation is clearly seen

Lung Biopsy or Wedge Resection

Pulmonary wedge resection has become standard of care for diagnosis and resection of small, indeterminate nodules, including suspected malignancy or fungal infection. It has also been used to obtain lung parenchyma for histologic evaluation when a primary lung disease is suspected. For intraparenchymal lesions that are likely to not be visualized at the time of thoracoscopy, preoperative localization with either a wire or tattooing should be performed (Fig. 39.11). After insertion of the camera, lesions located on the periphery of the lung are located, and additional ports and instruments are inserted. The entire lung is inspected, looking for other abnormalities. If the lesion has been localized, the wire or tattoo is assessed to ensure that the suspected biopsy site is going to be included in the resection. Having identified the appropriate biopsy site, the wedge resection is performed in one of two methods. If the lesion is located on the periphery near a fissure, or if a lung biopsy for suspected primary lung disease is being performed, the lesion or adjacent lung parenchyma is grasped with an atraumatic grasper. After ensuring adequate mobility of the parenchyma, an endoloop can be placed and positioned proximal to the biopsy site, using the grasper to ensure proper positioning. Once the surgeon is comfortable with the adequacy of the biopsy, the endoloop is secured. A second endoloop is sometimes necessary. The biopsy specimen is then divided from the lung sharply, placed in a specimen bag and removed through a slightly enlarged port site.

The second technique for wedge resection is to utilize an endo-stapler with a vascular cartridge to seal and divide the lung parenchyma after identification of the area for biopsy. This approach is necessary for lesions that are located deeper within the lung parenchyma or on the periphery away from a fissure and therefore not mobile enough to allow for the use of an endoloop. This technique is also used for bleb resection in patients with spontaneous pneumothorax. When using a stapler to perform the biopsy, the surgeon should anticipate the need for multiple firings of the stapler in order to obtain an adequate biopsy (Fig. 39.12). Once the specimen has been removed, the endoloop or staple line is inspected for hemostasis and no air leak is present. If there is no evidence for an air leak, a chest drain is probably not needed. However, if there is concern for an air leak, a small closed-suction drain can be left for 24 h.

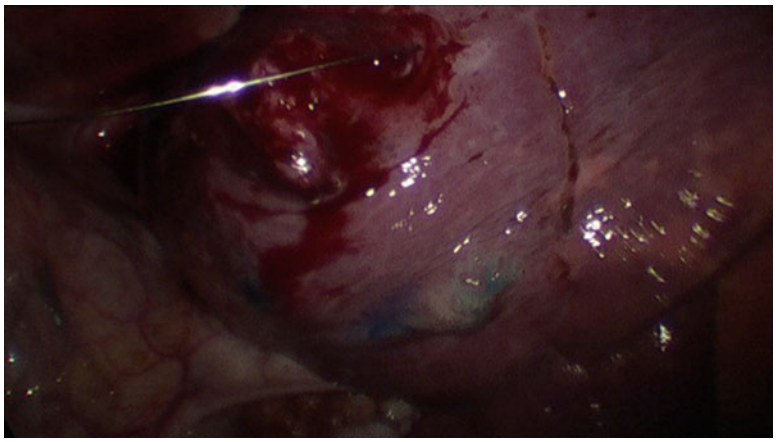

Fig. 39.11 A CT-guided wire localization has been performed for a lesion not located on the periphery. The wedge resection was performed ensuring that the entire wire was included within the biopsy specimen

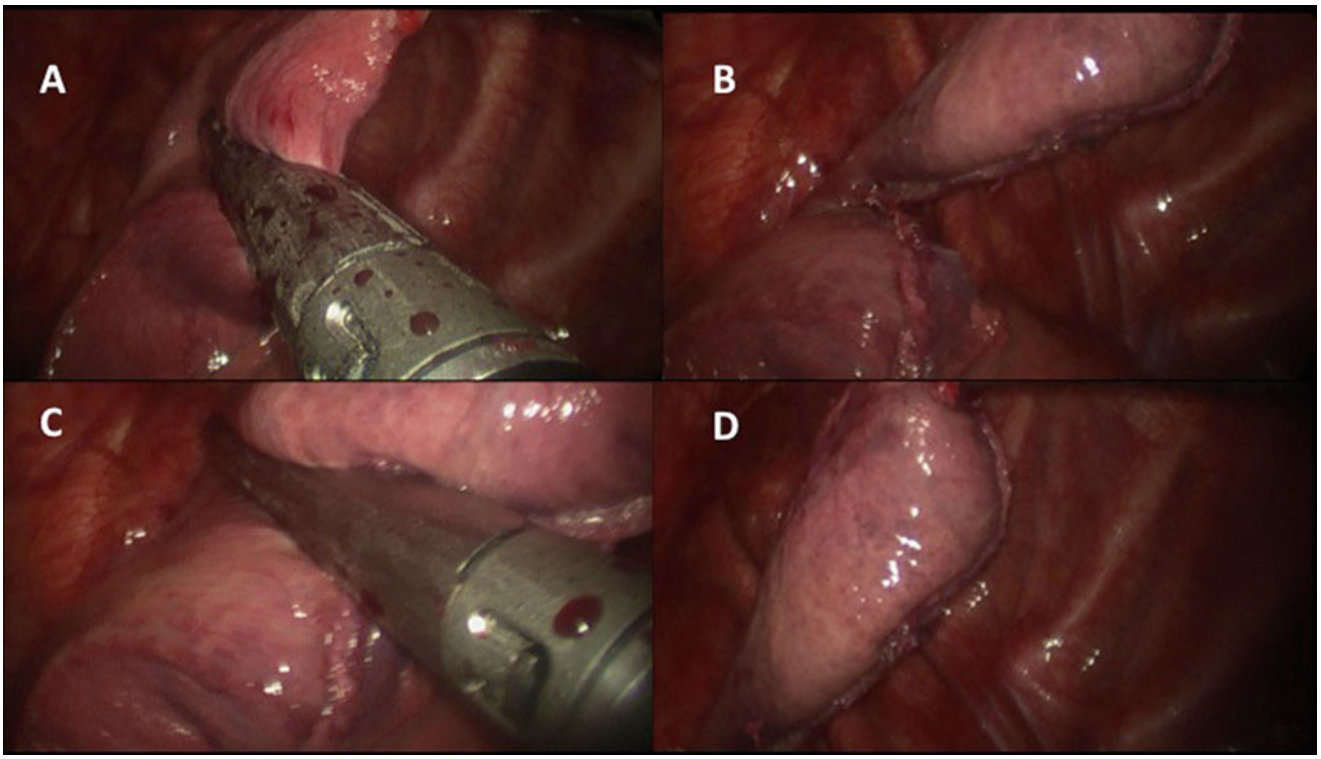

Fig. 39.12 The technique for a stapled pulmonary wedge resection is shown. (**a**–**c**) depict the sequential firing of a laparoscopic staple with a vascular load across the pulmonary parenchyma. (**d**) shows the free specimen. The staple line is irrigated with saline while inflating the lung to ensure no air leak is present

Right Upper Lobe

Right upper lobe resections are technically demanding thoracoscopic procedures due to the short length of the vein and the anatomic relationship requiring the lobe to be brought down from the main pulmonary artery. Key aspects of right upper lobectomy that increase difficulty include: the major fissure is often fused and crossed by posterior venous branches; the superior vein and truncus anterior are sometimes in close proximity necessitating ligation and division of the lobar bronchus first; and securing the interface of the middle lobe to the lower lobe can be difficult.

An understanding of the endobronchial and vascular anatomy is important for the safe completion of any lobectomy. For the right upper lobe, the arterial supply is from the truncus anterior pulmonary artery and the ascending artery. The truncus anterior supplies the apex and anterior aspect of the lobe, while the ascending artery supplies the posterior aspect of the lobe. The superior pulmonary vein is the most anterior structure and lies in close proximity to the truncus anterior

artery. The dissection separating these two vessels can be difficult. Also, the position of the right middle lobe vein must be known prior to dividing any of the upper lobe segmental branches. The right upper lobe bronchus arises from the right mainstem bronchus and is accessed by dividing the posterior segmental artery.

The operation is initiated by first retracting the upper lobe posteriorly and incising the mediastinal pleura away from the phrenic nerve to expose the superior pulmonary vein. An incomplete fissure is often encountered and must be completed in order to proceed with the vascular dissection. The parenchyma can generally be divided using electrocautery or a vessel-sealing device. Ligation of the vein prior to the artery can lead to venous congestion. Exposure of the segmental branches of the truncus anterior artery is gained through mobilization of the superior pulmonary vein. If the dissection leads to adequate arterial length, the artery can be ligated. Generally, this is not the case, and the dissection proceeds to the interlobar portion of the pulmonary artery from within the major fissure. Once identified, the ascending branches are dissected from the interlobar artery. Stretching the lobe forward exposes the posterior mediastinum and allows the pleura to be opened using electrocautery or blunt dissection. The ascending arteries are then controlled with a vessel-sealing device.

Once the arterial and venous structures have been divided, the upper lobe bronchus will be encountered. Pulling down and forward on the upper lobe exposing the bronchus will aid in dissection. The bronchus is ligated using either a stapler or clips and then divided. Once the bronchus is controlled, the remaining parenchyma is divided. The lobe is then placed into a bag and brought out through one of the port incisions, which might need to be enlarged slightly.

Right Middle Lobe

Regarding right middle lobe anatomy, there are two arteries that arise separately from the main right pulmonary artery to supply the lobe: the medial and lateral segmental arteries. The middle lobe bronchus lies in the groove between the two segmental arteries and gives rise to segmental bronchi, which are not seen during middle lobectomy. The middle lobe vein is again the most anterior structure necessitating division to access the bronchus and medial segmental artery.

Operatively, the dissection is started in the minor fissure moving from anterior to posterior, and the middle lobe arteries are found at the intersection of the transverse and oblique fissures. The sheath of the pulmonary artery is incised to find the lateral segmental artery arising from the anterior aspect of the pulmonary artery which is then divided using clips or vessel sealer.

The anterior aspect of the oblique fissure is opened, and the lobe is then retracted posteriorly until the phrenic nerve is visualized. Posterior to this, the mediastinal pleura is incised and the vein is dissected free, and the lowest branch of the superior pulmonary vein is identified. Once this has been identified and the middle vein has been circumferentially dissected, the middle vein is elevated and divided using either clips, a vessel-sealing device, or stapler, depending on the size of the vein.

Division of the vein exposes the bronchus, which is dissected and stapled or clipped at the takeoff. The medial artery is then clipped or ligated using a vessel-sealing device. If there is remaining parenchyma, it is divided as noted previously.

Right Lower Lobe

Right lower lobe anatomy consists of two main arteries, the basilar trunk and superior segmental branch. Care must be taken to ensure that the posterior segmental artery to the upper lobe does not arise from the superior artery. The lower bronchus is the last element to be divided and should not be stapled prior to visualizing the origin of the middle lobe bronchus or using a reinflation test or bronchoscopy to ensure it is not included in the transection. The inferior pulmonary vein is found by dissecting the inferior pulmonary ligament free.

Lobectomy is initiated by completing the major fissure if necessary. Traction is first applied to the upper or lower lobe to facilitate dissection and completion of the major fissure until the artery is encountered. The sheath is entered, and the branch to the middle lobe and posterior segmental artery is identified. Occasionally, the apical artery and basilar trunk are divided together, although usually this is done separately. The posterior portion of the major fissure is divided by retracting the lower lobe and upper lobe anteriorly which allows better visualization of where the mediastinal pleural needs to be opened to complete the division. At this point, care must be taken to visualize the posterior segmental artery and preserve its path to the upper lobe.

The lobe is retracted cephalad to expose the inferior pulmonary ligament, which is divided, and the vein is ligated using a stapler, clips, or a vessel-sealing device. This exposes the bronchus and the surrounding peribronchial tissues and lymph nodes. The origin is dissected using blunt dissection and the lower bronchus is clipped or stapled, depending on patient size. If visualization of the middle lobe bronchus is incomplete, a reinflation test should be performed to confirm the middle lobe bronchus is not involved in the resection.

Left Upper Lobe

Arterial supply to the left upper lobe is variable compared to other pulmonary lobes, but generally arises from the truncus anterior, supplying the apico-posterior and anterior segments, and posterior arteries, originating in the fissure. As with the right upper lobe, the superior vein is the most anterior structure.

The surgical approach to left upper lobectomy begins with assessment of the fissure. If the fissure is fused, it must be separated. This can be accomplished with a combination of blunt dissection, electrocautery, vessel-sealing device, or a stapler. Once the fissure has been completed, the upper and lower lobes are spread apart to expose the pulmonary artery. The upper lobe is then retracted anteriorly, and dissection is directed cranially, dividing posterior vessels as encountered. The first segmental artery is dissected and controlled. Gentle traction and blunt dissection can expose the apical posterior segmental artery, which if difficult can be approached posteriorly. The truncus anterior is revealed as the posterior segmental arteries are divided, and the origin is bluntly dissected free. Care should be taken as very short arterial branches may be present.

With the upper lobe retracted posteriorly, the mediastinal pleura is incised posterior to the phrenic nerve deep to the superior pulmonary vein which is then divided after adequate dissection. This allows the upper lobe to be lifted up exposing the bronchus which is circumferentially dissected and stapled or clipped. Finally, the pulmonary ligament is divided to the inferior pulmonary vein and the specimen removed.

Left Lower Lobe

The arterial supply to the left lower lobe arises from the basal trunk and the superior segmental artery, which takes off from the posterior aspect of the left pulmonary artery. The left lower lobe bronchus arises from the upper bronchus and courses beneath the arterial branches. The inferior pulmonary vein is approached through the inferior pulmonary ligament, similar to the right lower lobe resection.

As with the left upper lobe, the fissure is opened, and the lobes are spread apart to expose the fissure where the pulmonary artery is visible. With the fissure divided, the reflection of the mediastinal pleura can be visualized between the two pulmonary veins and opened towards the pulmonary artery completing the division of the anterior fissure. The basilar trunk and apical lower artery are divided. The pulmonary ligament is incised to the lower vein, which is dissected free and ligated exposing the lobar bronchus, performing a reventilation test if necessary to ensure the upper bronchus is free.

Postoperative Care

Most healthy patients can expect to be extubated in the operating room and transferred to a general care floor. If there is any concern about the stability of the patient, it might be necessary to observe them in an intensive care setting. A chest tube or pleural drain, if placed intraoperatively, should be left to suction overnight and placed to water seal if no air leak is present. If there is no pneumothorax and drainage is appropriate (less than 2–3 mL/kg) the chest tube can be removed. Typical hospital length of stay for thoracoscopic pulmonary lobectomy is approximately 3 days. Discharge primarily depends on pain control for those patients undergoing lobectomy and biopsy and chest tube management for patients undergoing treatment for recurrent spontaneous pneumothorax with resection of blebs.

Patients should be seen back in a clinic setting in 2–3 weeks with a CXR to ensure that there has not been any change and to check surgical incision sites. We see patients back at 2 and 6 months for routine follow-up and at any time if there are concerns. Patients are generally discharged from surgery clinic after the 6-month follow-up visit.

Complications

Fortunately, surgical complications of thoracoscopic lung resection are infrequent and most commonly include persistent air leak or pneumothorax and prolonged chest tube drainage for pleural fluid or chyle. Treatment for these complications is conservative with continued chest tube drainage until the air leak closes or drainage decreases to an appropriate volume. Although very infrequent, pneumonia, surgical site infection, bleeding, and conversion to open thoracotomy can also occur.

Editor's Comment

In the small child with diffuse or miliary disease, a true "mini" anterolateral thoracotomy incision (2 cm, in the fifth or sixth intercostal space) can be used to gain access to the lingula or lower lobe. Done well, this is less invasive than a thoracoscopic procedure. In the absence of an absolute contraindication, most lung biopsies should be performed using a minimally invasive technique.

Thoracoscopy works best for patchy disease or when the nodules are peripherally located and large enough to be seen, but with one-lung ventilation, 5–8 mmHg CO_2 insufflation, and patience to let the lung become completely atelectatic (15–20 min), lung lesions as small as 2–3 mm in diameter and up to 1–2 cm deep to the pleura can usually be "visually palpated" at thoracoscopy. The trick is to use the smooth shaft of a 5-mm grasper or suction cannula to sweep the lung surface while applying gentle pressure until the instrument catches on the lesion. The parenchyma near the lesion is grasped and lifted so that the stapling device can pass deep to the lesion. The vascular cartridge should be used, and even if the device is being used extracorporeally, the endoscopic stapling device is superior to the standard handheld stapling device because it places three rows of staples instead of just two.

Most find that three incisions are best, one in the anterior axillary line in the fifth or sixth intercostal space (enter the chest with a hemostat as for a chest tube), a second 5-mm trocar posteriorly in the eighth or ninth intercostal space, and a 10/12-mm port in the mid-axillary line in the lowest transverse axillary skin crease. Placing the last port within the axilla might be better cosmetically, but the arm will prevent you from getting enough leverage to direct the stapler towards the diaphragm. It is important to minimize unnecessary grasping of the parenchyma as this creates small parenchymal hematomas that can mask the lesion or result in air leaks. The risk of an air leak at a staple line is minimal but increases with the number of staple lines, especially if they cross each other. We rarely leave a chest tube after simple thoracoscopic wedge resections. Instead, we use a soft catheter to evacuate the air under water seal with Valsalva. If we feel the need to leave a chest tube, we use 16 or 20 Fr tube, place it through the camera port site, and take it out on the first postoperative day while still on suction if there has never been an air leak. The tube does not always need to be sutured in place, and the incision, if properly Z tracked obliquely through the tissues, can be closed with cyanoacrylate glue or a small occlusive dressing when the tube is pulled. The other incisions are closed at the level of the deeper fascia and the skin and covered with cyanoacrylate skin adhesive.

The thoracoscopic approach should be used to sample suspicious nodules in children with cancer, but is not recommended for the careful and thorough search for small nodules needed with curative intent, such as in the rare patient with a small number of metastatic lung nodules due to osteogenic sarcoma who is still considered curable with surgery. In these situations, bilateral staged thoracotomy or sternotomy with bimanual palpation of each lung is recommended.

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Diseases of the Pleural Space

40

Charles L. Snyder

Chylothorax

Although chylothorax is relatively rare in children, it is the most common cause of pleural effusion in neonates. The incidence is 1.4 per 100,000. Three-quarters of chylothoraces are in infants under 12 months of age, with a median age at diagnosis of 2 months.

The lymphatic system develops in the embryo during weeks 6–9. Six primary lymphatic sacs are formed: two jugular, two femoral, one retroperitoneal, and the cisterna chyli. The cisterna chyli is located at L2 and represents the inferior portion of the thoracic duct. It is connected to the jugular lymph sacs by the right and left thoracic ducts. Lateralized segmental regression of the paired system results in persistence of the lower portion of the right thoracic duct and the upper portion of the left thoracic duct (Fig. 40.1). The thoracic duct is 2–3 mm in diameter with an adult length of 38–45 cm. The anatomy is quite variable. The typical anatomic configuration occurs in about 65 % of people, with a duplicated duct in 10–15 %.

The thoracic duct begins in the abdomen at the cisterna chyli ascending on the right behind the aorta through the aortic opening of the diaphragm between the aorta and the azygos vein. It lies just anterior to the vertebral column in the posterior mediastinum, angles to the left at about T5 and ascends behind the aortic arch between the left side of the esophagus and the left pleura to the thoracic inlet. It ends by emptying into the angle of junction of the left subclavian vein with the internal jugular vein, arching a few centimeters above the clavicle. There are terminal valves that prevent venous backflow. The thoracic duct does have a muscular layer, which exhibits spontaneous rhythmic contractions.

Digested fats flow into lacteals in the small intestine and are carried with lymph up through the thoracic duct. Nearly all ingested fat absorbed from the gut is transported through the thoracic duct in the form of chylomicrons. Loss of substantial amounts of chyle results in lymphopenia and impaired immune function. The system has surprisingly high flow, varied by diet, up to 50–200 mL/h (1.5–2.5 L each day) in adults. This dramatically increases after ingestion of fats, but even drinking water will increase flow by 20 %.

The lymphatic system does three things: transports lipids and lipid-soluble fats, collects and returns excess fluid and protein from the interstitial space to the circulation, and returns lymphocytes to the circulation. Chyle itself is bacteriostatic and alkaline. The protein content is high, usually more than 3 g/L, and the lymphocyte count ranges from 400 to 6800/mm^3 (most of which are T lymphocytes). The electrolytic composition is similar to serum.

Etiology

The causes of chylothorax are varied (Table 40.1). Neonatal chylothorax is usually congenital and idiopathic. Traumatic delivery was previously felt to be causative, but that hypothesis is currently discounted. Congenital variants (pulmonary lymphangiomatosis, lymphangiectasia) are often very difficult to treat. Most cases that occur outside the neonatal period are acquired, often as a post-cardiac surgical complication. Older children with chylothorax commonly have an underlying medical condition.

Large administrative database studies of congenital cardiac surgery patients suggest an incidence of chylothorax approaching 3 %. The vast majority do not require operative intervention. When medical management fails, thoracic duct ligation or pleurodesis is usually performed. Hospitals with the highest surgical volume have a lower incidence of chylothorax, and the incidence of chylothorax was increased with diseases and procedures associated with high venous pressure or more complex repairs. The incidence is higher in neonates and infants. These are also the patients more likely to undergo the complex procedures associated with chylothorax.

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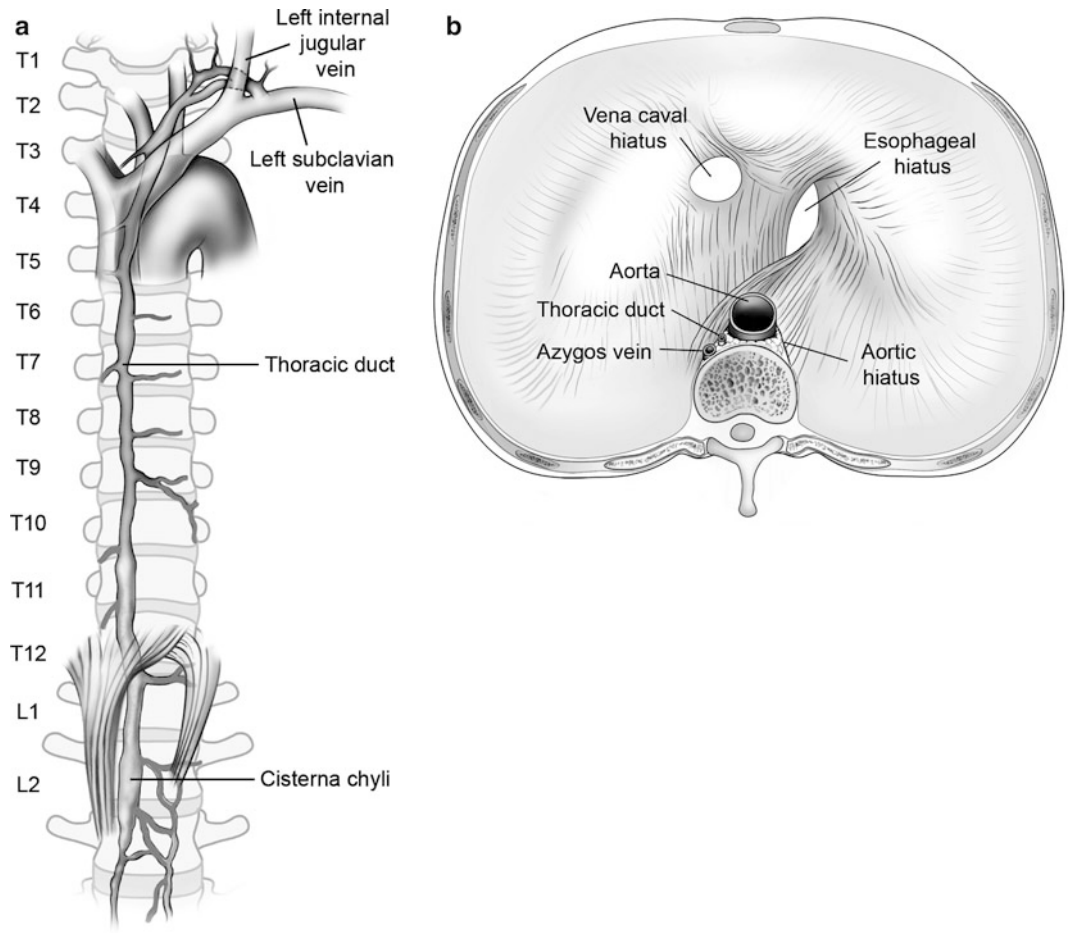

Fig. 40.1 (**a**) The typical course of the thoracic duct. (**b**) Orientation structures coursing through the aortic hiatus of the diaphragm

Table 40.1 Causes of chylothorax

Congenital (lymphangiomas and lymphangiectasias, syndromes such as Noonan, Gorham-Stout, Down, and Turner)
Traumatic (surgical procedures, IV access/procedures, or other trauma)
Elevated central venous pressure (venous thrombosis, congenital heart defect)
Malignancy (neurogenic, lymphoma, Kaposi sarcoma)
Miscellaneous (granulomatous infection such as tuberculosis or histoplasmosis, etc.)

Table 40.2 Characteristics of chylothorax

Triglyceride content ≥110 mg/dL
Total cell count ≥1000 cells μL
Lymphocyte predominance ≥80 %
Pleural fluid to serum cholesterol is <1.0
Presence of chylomicrons

Diagnosis

The symptoms are variable depending on the underlying cause, the age of the child, the size of the effusion, and the rapidity of onset. Congenital chylothorax is evident in 24 h in half of patients and by the end of the first week of life in 75 %. Typical findings are decreased breath sounds and dullness to percussion on the affected side and the presence of an effusion on a chest radiograph. Respiratory compromise is the most frequent presentation. Patients with gradual onset may present with signs of malnutrition, hypoproteinemia, fluid and electrolyte imbalance, metabolic acidosis, or immune compromise. A chest radiograph or US demonstrates an effusion, and thoracocentesis or tube thoracostomy allows analysis of the fluid. Although chylous effusions are typically described as "milky," nearly half are not.

Analysis of pleural fluid is often necessary to confirm the diagnosis (Table 40.2). A triglyceride level above 110 mg/dL and a ratio of pleural fluid to serum cholesterol of <1.0 are characteristics of chylothorax. Lipoprotein analysis reveals chylomicrons. Ancillary studies are sometimes necessary to elucidate an underlying cause.

Treatment

Tube thoracostomy (with a small pigtail catheter) is used to control the leak. The first therapeutic maneuver is dietary modification, consisting of either conversion to a medium-chain triglyceride (MCT) diet or NPO and parenteral nutrition. A MCT diet is used because saturated fatty acids of 8–12 carbon chain length are directly absorbed into the portal system, bypassing lymphatic drainage.

Large-volume leaks are often initially treated with complete cessation of oral intake and parenteral nutrition, since these measures result in the lowest volume of chyle. Lipid emulsions are given intravenously, do not travel through the lymphatic system, and thus do not increase chyle flow.

The somatostatin analog, octreotide, is used as adjunctive therapy to decrease the chyle flow. The mechanism of action is not completely understood. It reduces intestinal blood flow by splanchnic vasoconstriction, decreasing lymphatic fluid production. It also decreases the volume of gastric, pancreatic, and biliary secretions and decreases intestinal motility. There may also be receptors in the wall of the lymphatic vessels that are blocked by octreotide. High-quality evidence regarding the efficacy of these pharmacologic agents in the treatment of pediatric chylothorax is lacking, but available evidence does support their use. There is some speculation that positive end-expiratory pressure may help tamponade the ductal leak within this low-pressure system, although evidence is also sparse.

The volume of drainage per day is used to guide therapy. Output of 100 mL/year of age/day or 10 mL/kg/day, without slowing down after 10–20 days, are common end points. The definition of failure of medical management is variable. High flow, concomitant significant medical problems, the underlying cause, and the presence of a clearly identified leak may lower the threshold in terms of duration of medical therapy before proceeding to operative intervention. Our usual practice is 2–4 weeks of attempted medical management. Overall, nonoperative management of chylothorax is successful in more than 80 % of cases.

Surgical Approach

Surgical planning should include identification of the leak site if possible (Fig. 40.2). However, lymphangiography or lymphoscintigraphy is seldom done and may not even be possible in infants or very small children. Even in adults, successful identification of a thoracic duct leak is possible in only one-half to three-quarters of patients. There have been a few adult case reports of interventional radiology percutaneously accessing the cisterna chyli, using lymphangiography to identify the leak and then embolizing it successfully.

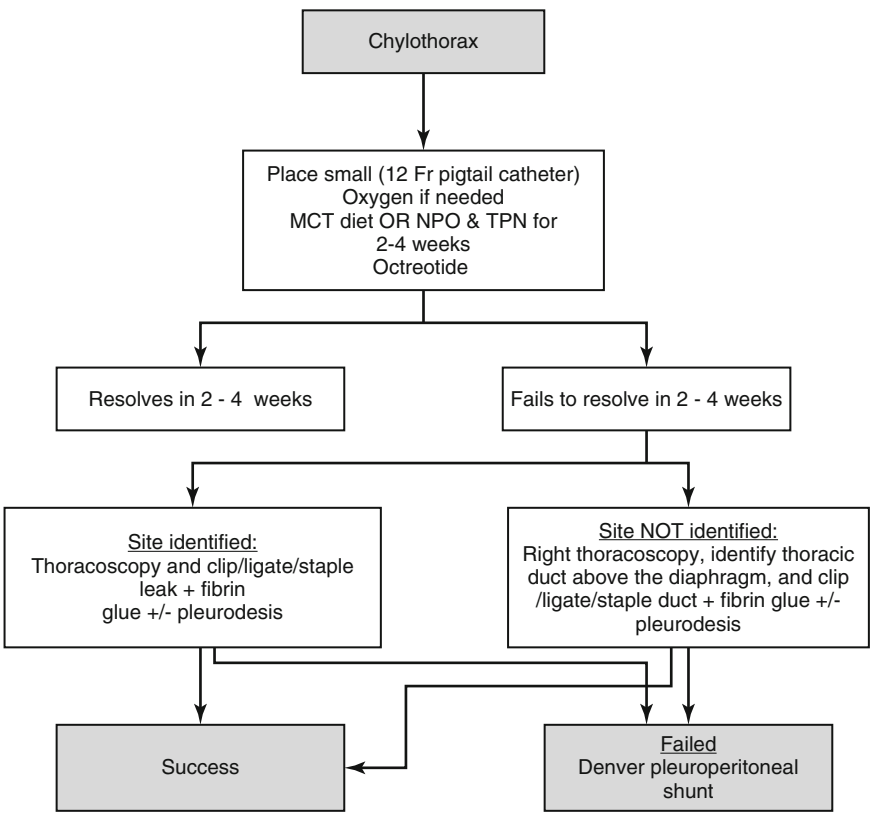

Fig. 40.2 The algorithm depicts an approach to the treatment of pediatric chylothorax

Magnetic resonance lymphography can be done with interstitial or IV injection of Gadolinium-based contrast, but there is very limited experience in children.

A thoracoscopic approach provides a wide field of view and magnification and often allows direct ligation of the site of the leak. Preoperative administration of 30–60 mL of whole milk or cream or intraoperative injection of 1 % Evans blue dye can help identify the site of the leak.

Identification of the precise origin of the leak is not always possible and mass ligation around the leaking site in combination with fibrin glue or local pleural or muscle flaps might be necessary. If no clear leak can be identified, the thoracic duct is ligated where it exits the abdomen through the aortic hiatus in the right chest. The posterior mediastinal pleura between the azygos vein and the chest wall is opened after mobilizing the inferior pulmonary ligament. The azygos vein is mobilized well below the inferior pulmonary vein and gently retracted, while the esophagus is retracted anteriorly. The thoracic duct can be found to the right of and lateral to the aorta, just behind the esophagus, and anterior and to the right of the azygos vein. Once identified, the duct is clipped securely (at least doubly on each side) and divided.

If the duct cannot be identified, all tissue in the normal anatomic location of the thoracic duct's location—anterior to the azygos vein, posterior to esophagus, between the aorta and right parietal pleura—is clipped, ligated or stapled, and divided. Application of fibrin glue and mechanical pleurodesis are sometimes performed, whether or not the duct was identified.

The chylothorax that persists despite maximal medical therapy and surgical attempts at closure, as well as those associated with lymphangiomatosis, can be treated with a pleural-peritoneal shunt. A modified Denver shunt works well as it allows one-way flow and can be equipped with an external pump mechanism. These often need to be specifically customized for a small infant or child.

Outcomes

The overall mortality rate for chylothorax is relatively high at over 10 %, reflecting the severity of the underlying cause rather than the chylothorax itself.

Pneumothorax

The normal intrapleural pressure is negative, and any communication to the external environment results in collapse of the lung and influx of air. Pleural gas can be absorbed by the pleura at a rate that depends on the solubility of the gas, the physical characteristics of the pleura, the pressure gradient, the contact surface area, and the temperature. Since the solubility of oxygen in water is higher than the solubility of nitrogen, increasing the concentration of oxygen in the blood will decrease the partial pressure of nitrogen (Henry's law). This reduces the total gas pressures in the pulmonary capillaries, increases the differential pressure gradient with the pleural cavity, and hastens reabsorption of the pneumothorax (as much as fourfold).

Pneumothorax can be classified as spontaneous or due to an external cause such as trauma or medical misadventure. It can also be categorized as *primary* (no lung disease) or *secondary* to a pulmonary disease process like cystic fibrosis. In infants, most are from external causes (barotrauma, intrinsic lung disease, iatrogenic). In adolescents and young adults, most are spontaneous. Bullae (>2 cm) and blebs (<2 cm) may be an end product of inflammation rather than a developmental problem (smokers have a markedly higher incidence of spontaneous pneumothorax). Pressure gradients lead to higher mechanical stresses on the alveoli in the apex of the lung, the site of almost all clinically significant blebs and bullae. This might also account for the higher incidence in adolescent males and patients with ectomorphic body shapes (taller with longer chest cavities). There is a male preponderance of about 2:1.

Causes of secondary spontaneous pneumothorax are legion. Chronic obstructive lung disease accounts for 70 % of adult cases. Tuberculosis, necrotizing pneumonia, pneumocystis carinii, malignancies, endometriosis, cystic fibrosis, and many other entities can be causative. Malignancy is a rare cause of pneumothorax in children, but when present, osteogenic sarcoma is the most common associated malignancy. Pleuropulmonary blastoma should be considered as well.

Clinical Presentation

Symptoms may be minimal or absent in spontaneous primary pneumothorax but are usually more significant in secondary spontaneous pneumothorax. The usual presentation is sharp chest pain, shortness of breath, and cough. Decreased breath sounds, tachypnea, and hyperresonance may be noted. Life-threatening tension pneumothorax can occur, although rarely in spontaneous pneumothorax. An upright PA chest radiograph is the best initial study (Fig. 40.3). Air in the cardiophrenic or costophrenic sulcus in a supine patient may be seen as a "deep sulcus sign." Although the diagnosis of pneumothorax is generally straightforward, the differential includes diaphragmatic hernia, lung and foregut cysts, and pneumatocele.

The size of the three-dimensional air collection can be difficult to estimate from the two-dimensional radiograph, which underestimates the size of the pneumothorax. However, the absolute size is not as an important as is the

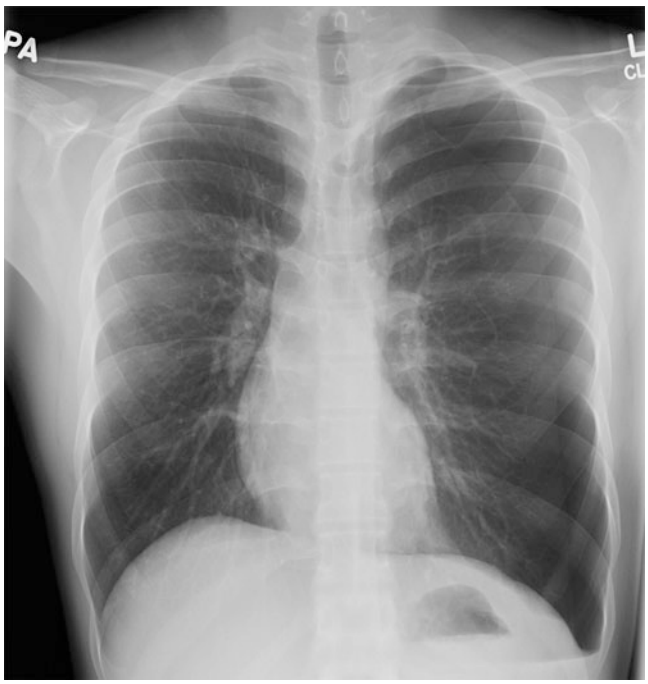

Fig. 40.3 A PA chest radiograph demonstrating a moderate-sized left pneumothorax

clinical presentation. CT will more accurately define the volume of the pneumothorax and has been used to identify causative or associated lesions such as bullae and blebs. However, since identification of blebs and bullae is not highly accurate and further treatment is not based on their presence or absence, we do not routinely obtain a chest CT in patients with spontaneous pneumothorax.

Treatment

Initial treatment depends on the clinical picture. Small air collections in asymptomatic children with primary spontaneous pneumothorax can be observed. The rate of resolution for a pneumothorax in adults is slow: 1.25–2.2 % of the volume of the hemithorax every 24 h. If the child is symptomatic, has a large pneumothorax, or has a secondary pneumothorax, then a small chest tube or pigtail catheter should be inserted. In adults, simple aspiration is an alternative to tube thoracostomy, with conflicting guidelines put forth by experts. In children, tube drainage is preferred. Almost all patients should receive supplemental oxygen. One must be aware of the possibility of re-expansion pulmonary edema, particularly in a large long-standing pneumothorax. Simple water-seal drainage without suction may allow a slow resolution in this scenario.

A commercially available suction canister is used until the air leak resolves, followed by a period of water-seal drainage (usually 12–24 h). If the pneumothorax does not re-accumulate, the tube is removed, and the patient is discharged.

Surgical Approach

Standard indications for operation in primary spontaneous pneumothorax include (1) second ipsilateral pneumothorax (recurrence), (2) first contralateral pneumothorax, (3) synchronous bilateral spontaneous pneumothorax, and (4) persistent air leak despite chest tube drainage (the definition of 'persistent' varies - we use 24 – 48 hours). In adults, pregnancy and high-risk occupations (divers, pilots) are added to the list. Children with secondary spontaneous pneumothorax are much less likely to respond to nonoperative management.

We use a thoracoscopic approach, with careful inspection of the lung, particularly the apices, for emphysematous-like changes. Partially filling the hemithorax with saline and insufflation of the lung may help to identify small air leaks. Resection of bullae or blebs (with a stapling device via a 12 mm port) and abrasive mechanical pleurodesis with a cautery scratch pad on a ringed forceps is our usual approach (Fig. 40.4). Air leaks are checked for prior to closure and a drain is left.

Postoperative recurrence rates are low. Open thoracotomy approaches are used much less frequently. Compared to thoracotomy, thoracoscopic repair is clearly associated with less pain and a shorter length of hospital stay, but perhaps a slightly higher recurrence rate (5 % vs. 1 %). Another option is a transaxillary mini-thoracotomy. Sclerosing agents are sometimes used in adults, but not as first-line therapy. These are often reserved for nonoperative candidates with secondary spontaneous pneumothorax. Many sclerosants have been used. Talc was perhaps the most common but it is now rarely used. The treatment is very painful, and pediatric experience is limited. Acute respiratory distress syndrome (ARDS) can occur, albeit rarely. Long-term recurrence rates are as high as 10–20 %, much higher than surgical methods of pleurodesis.

Complications

There are many potential yet infrequent complications of tube thoracostomy: injury to or perforation of intrathoracic or upper intra-abdominal structures, kinking or mechanical complications causing tension pneumothorax, infection, and injury to the lung itself. Impressive subcutaneous emphysema can sometimes be seen with chest tube drainage for pneumothorax, but is rarely clinically significant. Re-expansion pulmonary edema is a rare but potentially lethal complication (up to 20 % mortality) occurring when long-standing air or fluid collections are rapidly removed from the thorax.

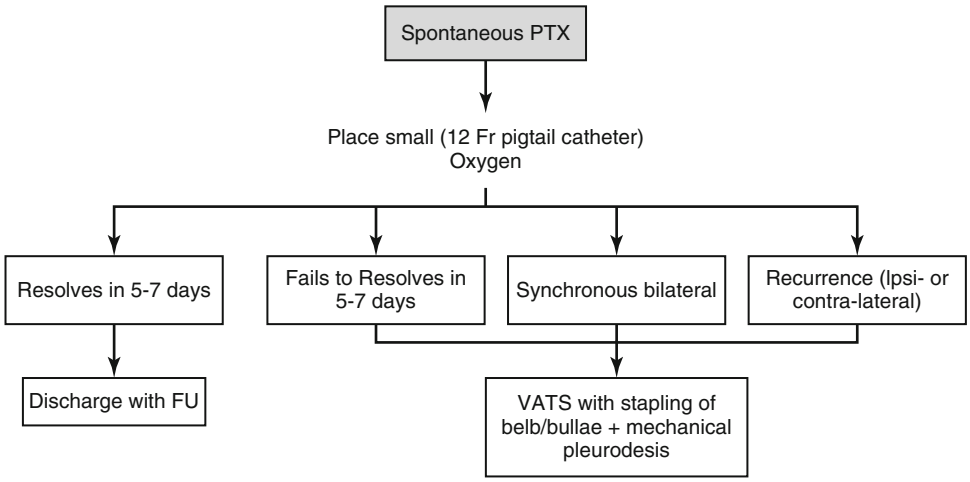

Fig. 40.4 The algorithm depicts an approach to the treatment of spontaneous pneumothorax in children

Chronic chest pain thought to be related to intercostal nerve injury, Horner syndrome, persistent effusions or air leak, and hemothorax are infrequent complications after Video-assisted thoracoscopic surgery (VATS) for pneumothorax. Reoperation for persistent air leak is required in <5 % of cases. Secondary spontaneous pneumothorax has a higher morbidity and mortality than does the primary form.

Outcomes

Although the incidence of blebs and bullae on the unaffected side is much higher, contralateral recurrence is seen in as many as 25 % of cases in adults. The recurrence risk might be even higher in children (up to 50 % in some series). Recurrences are usually early, within the first few months after treatment.

Although there is a higher risk of recurrence in adult or older adolescent patients who continue to smoke, there is no evidence that increased physical activity increases the risk of recurrence, and therefore limitations on activity are unnecessary.

Air travel is usually prohibited for a short period of time (1–3 weeks) after nonsurgical treatment of spontaneous pneumothorax and should not be undertaken by anyone with an untreated pneumothorax. There is no need for flight restriction in children who have undergone successful operative management. Scuba diving is usually proscribed permanently after a significant pneumothorax, even if treated surgically.

Cystic Fibrosis

Cystic fibrosis is a well-recognized cause of secondary spontaneous pneumothorax in children. It is estimated that about 3–4 % of patients with cystic fibrosis will develop a pneumothorax. It is more common in older patients, presumably because they have more advanced disease, and it is associated with high morbidity and mortality.

Up to 50 % have bilateral pneumothoraces. Chest tube drainage is usually required, but there is a recurrence rate of 50 % with drainage alone. Since response to nonoperative measures is poor, operation is indicated after the first occurrence.

Poor pulmonary reserve may limit surgical options, and the potential need for lung transplantation is a relative contraindication to chemical pleurodesis. VATS may not be technically possible in those who can tolerate operation. Good results with thoracotomy, bleb resection and mechanical pleurodesis, or pleurectomy have been reported in carefully selected patients.

Concern for compromising future lung transplantation (operation made more difficult or associated with a higher complication rate) may lead to avoidance of aggressive treatment for pneumothorax in cystic fibrosis, but there is some evidence that previous pleural interventions do not significantly adversely impact future lung transplantation.

Empyema

Empyema is pus in the thoracic cavity. The incidence is increasing in the developed world. Interestingly, there is evidence that recent widespread use of polyvalent pneumococcal vaccine has decreased the incidence of pneumonia but increased the incidence of empyema. About 1 in 150 children with pneumonia severe enough to require hospitalization will develop an empyema.

Most empyemas result from bacterial pneumonia. The most common cause in children in the developed world is *Streptococcus pneumoniae*. However, *Staphylococcus* is a more common cause in children under the age of 6 months. Empyema can result from a variety of other causes including

secondary infection of traumatic hematomas or lung contusions, esophageal perforation, and parasitic infection.

Three stages of empyema development are commonly described: the initial *exudative* stage, followed by a *fibrinopurulent* stage, and a final *organized* phase. These are not distinct entities but rather a continuum. In fact, the clinical utility of this categorization schema is dubious.

Initially, the infection of the lung leads to inflammatory changes, resulting in proteinaceous and cellular exudates in the area around the lung (parapneumonic effusion or exudative phase). Subsequently, elevated cytokines and inflammatory mediators lead to fibrin deposition and loculation, which is the fibrinopurulent stage (the most common stage treated by surgeons). Antibiotics are not very helpful at this point since penetration of the empyema cavity is poor. If untreated, fibrin is gradually replaced by fibrosis and the lung becomes trapped and encased by scar tissue (organized phase).

Diagnosis

Patients usually present with symptoms related to the underlying pneumonia: fever, cough, labored respirations, and pleuritic pain. Examination reveals nonspecific findings such as unilateral decreased breath sounds and dullness to percussion. Crackles or a pleural rub are sometimes heard on auscultation.

Acute phase reactants are usually elevated with empyema but do not discriminate between bacterial and viral infections and do not predict empyema formation in children with acute bacterial pneumonia. Furthermore, trends in their values do not correlate well with clinical progress.

Anemia is common in children with empyema. Blood cultures are usually obtained, but are only positive in about 10 %. Cultures of pleural fluid are often negative, probably because most children have already been on one or more antibiotics. Empyema fluid analysis is often performed as well (Table 40.3). The best correlate with fibrinous change is a low pH. In contrast, in children with a simple effusion, the pH is usually >7.2 and the glucose concentration higher than 2.2 mg/dL.

The initial study is usually a standard chest radiograph. This may show an effusion, pulmonary consolidation, or unilateral "whiteout" of the thorax (Fig. 40.5). However, plain films are poor at distinguishing between lung consolidation and fluid. The best radiologic study to evaluate an empyema is ultrasound, which can usually distinguish fluid from consolidation; identify loculations or layering of fluid; and allow ultrasound-directed aspiration of pleural fluid for culture and analysis. The accuracy is comparable to CT, it can be performed with a portable machine, there is no radiation exposure, and the cost is lower. A CT scan may be useful in more complex cases to demonstrate tumors, intrapulmonary abscess, and other pathology.

Table 40.3 Characteristics of empyema

Low glucose (<2.2 mmol/L or 60 mg/dL)
Low pH (below 7.2)
Elevated LDH (>1000 international units per deciliter)
High protein (>25 g/L)
High specific gravity (>1.018)

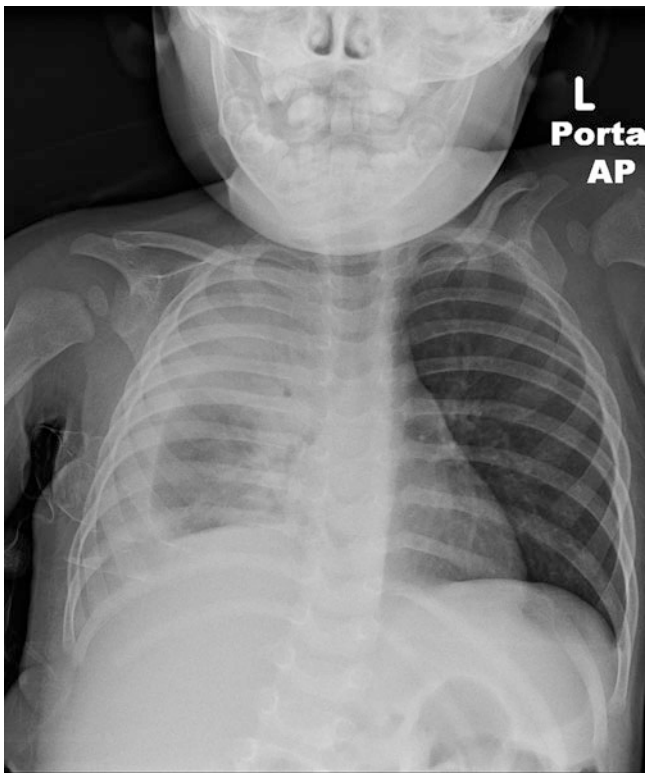

Fig. 40.5 A PA chest radiograph demonstrating a right-sided empyema with incomplete expansion of the lung

The differential diagnosis includes tumors, sequestration, congenital cystic lung disease, pulmonary abscesses, simple effusions, hemothorax, and necrotic infarcted lung. Pneumatoceles can occur as a result of necrosis of the lung. This is much more common in *Staphylococcus aureus* pneumonia. Most pneumatoceles will eventually resolve. Rare organisms can cause empyema and may suggest an immunodeficiency. In infants and toddlers, one should also be aware of the possibility of an aspirated foreign body, lodging peripherally and causing an empyema.

Treatment

Initial treatment of a parapneumonic effusion (exudative stage) empyema consists of broad-spectrum IV antibiotic coverage for the underlying pneumonia and support.

Supplemental oxygen may be needed. In the early stages, this may be sufficient therapy. Indications for aspirating a fluid collection early in pneumonia depend on the size, radiographic appearance, and the clinical picture. Free-flowing fluid might require a single thoracocentesis, but most require tube thoracostomy. We use small pigtail catheters inserted via a Seldinger technique in lieu of the large-bore chest tubes favored in the past.

A complex pleural effusion (an empyema with fibrinous changes, loculated fluid, or solid material) requires therapy beyond drainage and antibiotics (Figs. 40.6 and 40.7). Several randomized controlled pediatric trials have compared VATS to catheter drainage with intrapleural fibrinolytic therapy and have demonstrated comparable results, except for lower hospital charges with chemical debridement. Since the least invasive, least painful, and least expensive option is preferable, our current first-line therapy is catheter drainage and tPA (tissue plasminogen activator). A 12 Fr pigtail catheter is placed (with US guidance if necessary, but without a general anesthetic) and tPA (4 mg in 40 mL saline with 1 h dwell time) is infused daily for 3 days. Approximately 16 % are refractory (remain clinically ill and febrile, with persistent pleural disease on US or CT four or more days after treatment) and can usually be salvaged with VATS. It is important for the clinicians and family to understand that the chest radiograph remains abnormal for a long time. The mean hospital stay after successful chemical debridement for empyema is about 6–7 days.

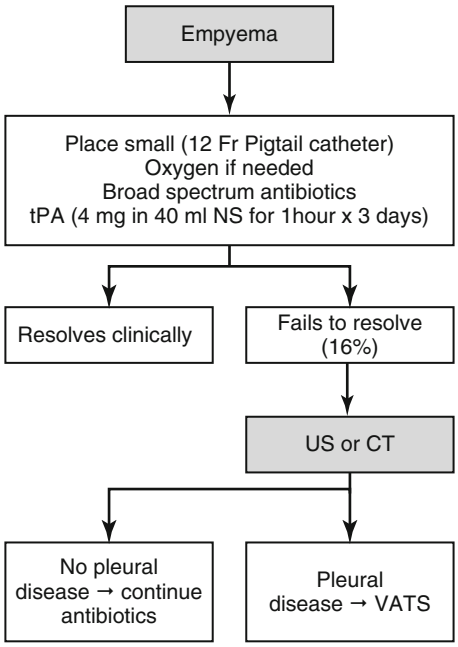

Fig. 40.6 The figure demonstrates our management algorithm for an established empyema

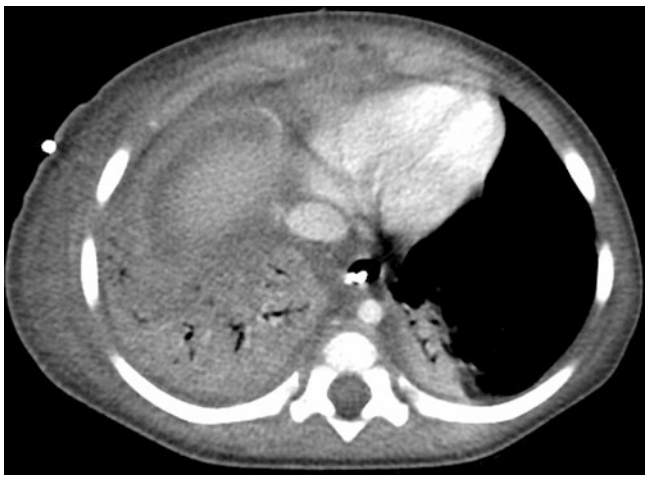

Fig. 40.7 The CT scan demonstrates consolidation of the right lung, pleural thickening, and an empyema collection anterosuperiorly

Surgical Approach

Thoracoscopic debridement is done under general anesthesia in a lateral position with the affected side up. Single-lung ventilation can be done but is not routinely necessary since the affected lung's ability to fully expand is already limited. The loculations are taken down, all fluid evacuated and cultured, and any rind or fibrinous material debrided. A chest tube is left in place postoperatively. A thoracotomy or mini-thoracotomy may be necessary in advanced disease (longer duration of illness, persistent high fevers, very thick pleural reaction).

Severe cases may be complicated by pulmonary parenchymal necrosis, identified on CT scan or at operation. These children have a poorer outcome and persistent air leak is more common. Bronchopleural fistula is a serious but infrequent complication. A variety of treatment options are available, including serratus anterior muscle flap closure. Long-term follow-up studies of children treated for empyema have shown an extremely low incidence of long-term sequelae.

Summary

Chylothorax is a rare problem in pediatric surgery; most are congenital or secondary to cardiac surgical procedures. Operation is only required in about 10 % of cases. Spontaneous pneumothorax typically affects adolescents and is usually initially treated with a small pigtail catheter. The chance of a recurrent pneumothorax after successful nonoperative treatment approaches 50 %. Recurrence after VATS (the procedure of choice in children) is 5–10 %. Empyema is increasing in incidence, but there has been a recent sea change in its management. Chemical debridement

with fibrinolytics has become the treatment of choice at many centers; most use VATS for failures of medical management, which constitute about 15 % of children. Long-term outcomes are excellent.

Editor's Comment

Ultrasound is sufficient to make the diagnosis of empyema in a child; CT should almost never be necessary. Progression can be rapid and very dramatic—a small effusion to near whiteout in 24 h is not uncommon; hence, imaging should be repeated in the event of clinical deterioration. The decision to recommend intervention is based on the clinical picture (tachypnea, fever, oxygen requirement) or the presence of a large loculated effusion. Minimally invasive approaches and randomized controlled trials have led to better outcomes and less morbid operations in pediatric surgery. Diseases of the pleura like empyema were associated with significant morbidity following surgery. The first randomized controlled trials that demonstrated the superiority of the tPA approach for empyema over thoracoscopy caused a philosophical shift in pediatric surgery that is leading to less invasive approaches for not only pleural disease such as pneumothorax but also for other diseases such as appendicitis.

On the other hand, thoracoscopy is safe and, if done properly, straightforward and quick. It takes <20 min, does not require lung isolation, and can be done with two small incisions: one 5 mm port for the camera (and chest tube) and one 10 mm incision in the axilla for alternate passage of a curve sponge clamp and large plastic Yankauer suction cannula. An attempt should be made to remove all of the fibrinous exudate from the parietal pleura and to break up all loculations (especially the subpulmonic effusion), but it is usually best to manipulate the lung as little as possible to avoid tears, bleeding, and a subsequent fistula. Despite an irrational fear expressed by some surgeons, bronchopleural fistula is exceedingly rare, and the presence of necrosis, pneumatocele, or even a pneumothorax on preoperative imaging is not a contraindication to a thoracoscopic debridement.

Chylothorax will almost always resolve spontaneously, but it can take weeks. Whether dietary changes, special formulas, octreotide make any difference is doubtful, but there is usually little risk to trying them. If the effusion persists for more than 3 weeks, it is usually time to consider surgical intervention, though parents need to be warned that it is a very tricky business and success is not automatic. The thoracoscopic approach is preferred. A small amount of dairy cream given by gastric tube intraoperatively improves localization of the leak. Even when clearly seen, repair can be difficult. Direct suture repair with fine monofilament suture using a precise technique is best, but hemoclips are an acceptable alternative. If the leak cannot be controlled with stitches or clips, ligation of the thoracic duct is safe and highly effective.

Asymptomatic children with a stable spontaneous pneumothorax should be observed and not given a chest tube. Most will resolve spontaneously, and at follow-up a decision needs to be made whether to recommend pleurodesis. It seems reasonable to offer pleurodesis after the second episode. CT is not useful in predicting recurrence or likelihood of success with surgery and is therefore only used in atypical cases to rule out tumor, infection, or a missed congenital lung lesion. Apical bleb resection and mechanical pleurodesis is a straightforward thoracoscopic procedure that should not require thoracotomy. It is helpful to resect the apex using at least three tangential firings of the stapling device, which recreates the conical shape of the apex. A flat top creates a larger air space when the lung is re-expanded, potentially compromising the effectiveness of the pleurodesis. Postoperatively, maintaining the chest tube to suction for 72 consecutive hours and pulling it on suction (skip the water-seal step) usually prevents that small stubborn apical pneumothorax that occurs frequently when the suction is broken too soon. The recurrence rate should be very low.

Suggested Reading

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Pectus Deformities

41

Allison L. Speer and Timothy D. Kane

Pectus Excavatum

Pectus excavatum is the most common anterior chest wall deformity resulting in a posterior depression of the sternum and the lower costal cartilages. The incidence is approximately 1–2 per 1000 children with a male to female ratio of greater than 3:1. Pectus excavatum occurs infrequently in African-Americans. The deformity may be noted within the first year of life and often progresses during puberty presumably due to rapid growth spurts. The condition varies significantly and is occasionally asymmetric or comprised of a mixed defect involving a pectus carinatum component as well.

The etiology of pectus excavatum remains unknown. Several potential causative factors have been proposed, all of which have been based upon the frequent association of pectus excavatum with other musculoskeletal conditions such as congenital diaphragmatic hernia, scoliosis, and Marfan syndrome. One theory proposes that abnormalities in diaphragm development are responsible for chest wall deformities, whereas others suggest that abnormal connective tissue, cartilage, or collagen formation plays a role. Despite the elusive pathophysiology, pectus excavatum does frequently convey a hereditary predisposition with a positive family history found in more than a third of patients.

Clinical Presentation

The majority of infants and young children with pectus excavatum are asymptomatic. With increasing age, patients develop symptoms that are especially pronounced with exercise. As the chest wall becomes more rigid as children age, the deformity progresses, often resulting in exercise intolerance. Decreased exercise capacity is the most common complaint and likely results from the inability to increase cardiac output or minute ventilation when there is increased metabolic demand. This results in many children deciding to discontinue participating in sports. Other common symptoms include chest pain, shortness of breath, dyspnea on exertion, and heart palpitations. Children with pectus excavatum also often have poor body image and are self-conscious about their deformity. Some withdraw from social activities that involve taking their shirt off, and this can lead to low self esteem, depression and, rarely, suicidal ideation.

It has been shown that individuals with pectus excavatum have similar cardiac function compared to normal controls at rest. However during exercise these patients demonstrate a significantly lower cardiac index seemingly due to an inability to increase stroke volume. The presumed etiology is probably related to cardiac compression or reduced end-diastolic filling volume. More recently, it has been shown that both cardiopulmonary exercise function and exercise pulmonary function are normalized or significantly improved following pectus excavatum repair. The specific indices evaluated following pectus repair are FEV_1 (%), maximum VO_2/kg (mL/min/kg), cardiac index (mL/min/m^2), and stroke index (mL/beat/m^2).

Preoperative Evaluation

A complete history and physical examination should be performed to evaluate for familial predisposition or signs of a connective tissue disorder. Mild to moderate pectus excavatum is typically asymptomatic and best managed with an exercise and posture program. Annual follow-up is recommended to assess for development of symptoms and progression of the defect and to reinforce the importance of the exercise and posture programs. Severe pectus excavatum is seen in approximately one third of the children and is usually

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symptomatic. The timing for considering surgical repair by the Nuss approach is ideally around 13–14 years of age. It is our practice that testing not be performed if the patient is ambivalent about having procedure, is under 12 years old, or adamantly declines to consider surgical repair under any conditions.

If the deformity is subjectively severe and the patient and family desire an evaluation, he or she should undergo pulmonary function testing, cardiac evaluation with electrocardiogram and echocardiography, and axial three-dimensional imaging such as CT or MRI. Generally, children are candidates for surgical repair if they meet two or more of the following criteria: (1) pulmonary function studies demonstrate restrictive disease, obstructive disease, or both; (2) cardiac compression as manifested by murmur, mitral valve prolapse, and dysrhythmias (first-degree heart block, right bundle branch block, or Wolff-Parkinson-White syndrome); (3) a Haller index (HI) greater than 3.25 or correction index (CI) greater than 10 %; (4) progression of the deformity; (5) recurrent pectus deformity after prior Ravitch or Nuss procedure.

The HI is defined as the ratio of the widest transverse distance of the chest to the shortest distance between the anterior spine and posterior sternum. This index was first described in 1987 and has remained the standard objective metric to assess the severity of a pectus excavatum (Fig. 41.1). An HI greater than 3.25 is characterized as severe and worthy of consideration for surgical correction. This was based on the observation that the controls in the original study all had an HI less than 3.25. Recently, the value of this index has been challenged. The original report included only 19 controls and 4 were younger than 6 years. Furthermore, the HI has failed to predict technical difficulty and outcomes after repair. The Children's Mercy Hospital group has proposed the CI as a more reliable and accurate assessment of pectus excavatum severity in children. The CI uses the shortest distance between the anterior spine and posterior sternum (AS to PS) and the longest distance between the anterior spine and most anterior portion of the chest wall (AS to ACW). The difference between these two is divided by the latter and multiplied by 100 to give the percentage of chest depth that the deformity represents or alternatively the percentage of chest depth to be corrected by surgery (Fig. 41.2):

$$\left\{\left[\left(\text{AS to ACW}\right)-\left(\text{AS to PS}\right)\right]/\left(\text{AS to ACW}\right)\right\}\times 100=\text{CI}\left(\%\right)$$

Interestingly, when studied, the Haller index has demonstrated a nearly 50 % overlap between normal controls and those with pectus excavatum, whereas the CI has demonstrated zero overlap. As calculated, the HI tends to be flawed in those patients with very narrow or very wide chests, where the measurement will decrease or increase the HI, respectively, regardless of the severity of the defect. The CI clearly and reproducibly distinguishes normal patients from those patients with pectus excavatum. Further studies are needed to determine if any correlation exists between the CI and postoperative outcomes.

If a patient meets criteria for repair, then preoperative metal allergy testing should be performed since 6–7 % of patients may demonstrate bar allergy. Allergy testing may be performed preoperatively by either the thin-layer rapid use epicutaneous (TRUE) test or application of a pectus bar sensitivity disk applied to the skin for 5 days (Fig. 41.3). If a patient develops a reaction using either method, then bar allergy is confirmed and a titanium bar(s) should be ordered for use in these patients. Titanium bars are manufactured according to the individual patient's preoperative CT or MRI imaging and are delivered pre-bent. We work directly with

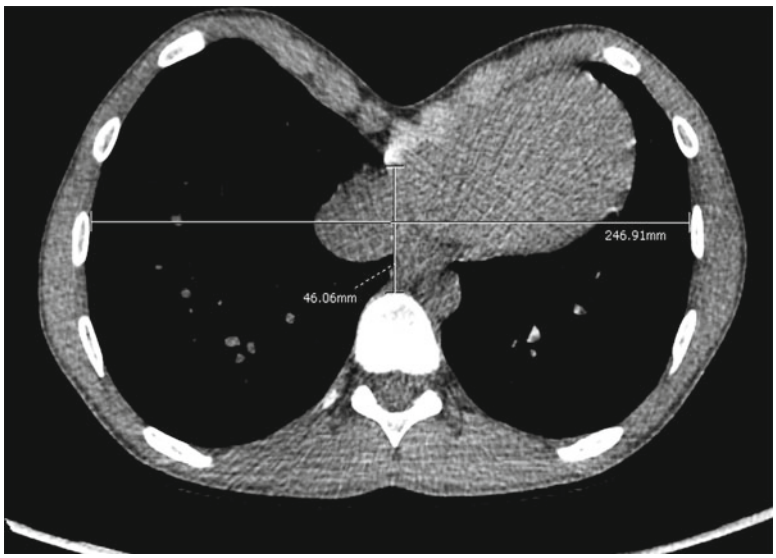

Fig. 41.1 Haller index (HI) = 246.91/46.06 = 5.4

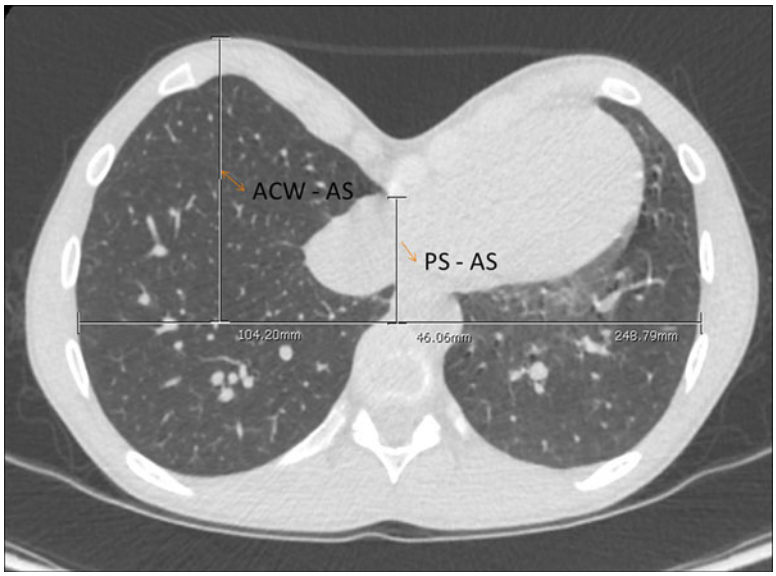

Fig. 41.2 Correction index (CI) = (AS to ACW – AS to PS)/ AS to ACW × 100 = 46.62 %

Fig. 41.3 Pectus bar sensitivity disk used preoperatively to assess for bar allergy

the company representative when ordering these bars since sometimes a longer bar (than the surgeon would normally implant) is produced based on the imaging.

Surgical Techniques

Several surgical techniques have been developed over the years including both open and minimally invasive pectus excavatum repairs. All techniques present a risk of recurrence. Thus, appropriate patient selection for a particular approach is paramount to a successful outcome. The Nuss procedure, a minimally invasive technique to correct pectus excavatum, was developed by Nuss in 1986 who first reported results in 1998. It involves placing a convex bar posterior to the sternum and anterior to the pericardium through lateral thoracic incisions. Since the seminal paper was published in 1998, over 1400 patients have undergone the procedure at Children's Hospital of The King's Daughters, and the technique has gained widespread popularity worldwide.

The safety and efficacy of the technique have been improved over the years with two major modifications: (1) routine use of thoracoscopy with CO_2 insufflation for better visualization and to prevent injury to the heart or mammary vessels and (2) stabilization of the pectus bar with lateral metal stabilizers and pericostal suturing to minimize the risk of postoperative bar displacement.

Although the majority of pectus excavatum repairs employ the Nuss technique, the open repair is still used when children have significant chest asymmetry or a mixed pectus deformities (pectus excavatum and carinatum), or for patients who do not want an in situ bar for 2–3 years. The Ravitch repair, originally described in 1949 and later modified in 1957 and 1958 by Baronofsky and Welch, respectively, is an open method to correct pectus excavatum. In this method, preservation of the perichondrial sheaths of the costal cartilage and intercostal muscle bundles and anterior fixation of the sternum is performed.

Another open repair method, the sternal turnover technique, originally described by Judet and Jung in France and utilized by Wada in Japan has fallen out of favor. The approach in effect requires a free graft of sternum that is

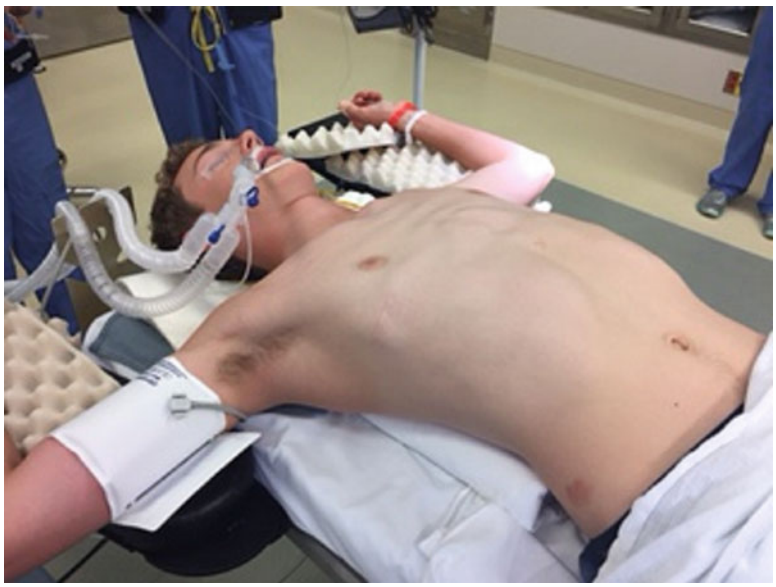

Fig. 41.4 Patient positioned supine with both arms abducted and elbows bent at 90° on *padded arm* boards for bar removal. Same position is utilized for bar insertion

rotated 180° and resecured to the costal cartilages. It is a radical approach with serious complications such as sternal necrosis and infection and has largely been abandoned given the availability of effective alternative techniques.

Nuss Procedure

We routinely use an epidural catheter placed by the anesthesiologist prior to surgery for postoperative pain control and general endotracheal anesthesia. Although some centers no longer use epidural analgesia, patient controlled analgesia (PCA) works as effectively for most patients in the postoperative period. This is especially important to know when the epidural is not working and a PCA can be used. The patient is then placed supine with both arms abducted and the elbows bent at 90° on padded arm boards (Fig. 41.4). This allows for adequate exposure of the chest wall bilaterally. Preoperative antibiotics should be given within 30 min of incision (cefazolin or clindamycin if penicillin allergic) and continued for 24 h. Chlorhexidine in alcohol is used to prepare the skin in the standard surgical fashion.

We begin by marking the deepest point of the pectus excavatum with a marking pen. This determines the horizontal plane for bar insertion. If the deepest point is inferior to the xiphisternum, then the inferior sternum is marked instead. The intercostal spaces within this horizontal plane are then marked with an X just at the edge of the pectus (costochondral) ridge. A 5 mm trocar is inserted two intercostal spaces below the incision site in the right lower chest. This is placed in a manner to avoid the lateral thoracic incision. A 5 mm 30° thoracoscope is then inserted into the right chest, and CO_2 is insufflated to a pressure of 6–8 mmHg with a flow of 6–8 L/min. The right lung will collapse and this improves visualization. The right chest and mediastinum are inspected to confirm there is no contraindication to repair.

For redo operations, we liberally place additional trocars to perform lysis of adhesions and create the retrosternal tunnel to accomplish this safely. Occasionally, an additional port in the left chest is helpful as well. The thoracoscope is used to ensure that the internal anatomy correlates well with the external markings by applying pressure with a finger at these sites or inserting a 25-gauge needle through the anterior chest wall. It is very important to examine the posterior aspect of the sternum adjacent to the intercostal space selected for bar passage. If there is a large cartilaginous projection in the area, then we will select another intercostal space in order to prevent bar instability due to the uneven posterior sternal table. Transverse lines for the bilateral chest wall incisions are then drawn or redrawn within this same horizontal plane at the midaxillary line bilaterally. If the patient is female, we attempt to make these incisions along the inframammary crease. If a second bar will be required, its horizontal plane is marked as well, usually one intercostal space above or below the original bar. A second bar should be considered if the deepest point of the pectus excavatum is inferior to the sternum. Generally the superior bar is placed first, followed by the inferior bar.

After confirming the internal anatomy by thoracoscopy, bilateral thoracic skin incisions are made. A deep subcutaneous skin tunnel is raised anteriorly toward the intercostal space marked with the X just at the edge of the pectus ridge using a Kelly or tonsil clamp. The chest should not be entered too far lateral to the pectus ridge since the strong posterior force on the bar will be borne by the ribs and intercostal muscles laterally rather than by the sternum centrally. This is

thought to be a common cause for bar displacement. If a tunneling site chosen is adjacent to the pectoralis major muscle, a subpectoral plane should be developed. Care should be taken to make these tunnels only the width of the bar and not wider. A subcutaneous pocket should also be developed for a lateral stabilizer on the either side.

A Lorenz introducer (Biomet Microfixation, Jacksonville, Fla.) is inserted in the subcutaneous tunnel from the right side. Under direct thoracoscopic vision, it is advanced through the right intercostal space at the edge of pectus ridge into the right pleural cavity. Using the introducer to dissect the pleura and pericardium off the posterior sternum creates a transthoracic substernal tunnel. The pulse oximeter volume should be turned up during transmediastinal dissection, so the heartbeat is clearly audible and arrhythmias may be detected. The tip of the bar passer should always face anteriorly and be in contact with the sternum but also be mindful of avoiding damage to the internal mammary vessels. Care should be taken to make small movements left and right during this dissection to avoid creating a large opening in the intercostal space where the bar is being passed. Once transmediastinal, the introducer is then pushed through the contralateral intercostal space at the marked X and advanced out of the left lateral thoracic subcutaneous tunnel and incision. If one is unable to see the transmediastinal dissection with a 30° scope, a towel clamp or bone hook can be used to pull the xiphisternum anteriorly, or a short transverse subxiphoid incision can permit the passage of a finger to guide the dissector between the sternum and pericardium. Additionally, a left-sided 5 mm trocar can be considered for the use of the thoracoscope in the left pleural cavity. We use a second bar passer on the outside of the body and juxtapose this to the internal one to determine how much farther the bar passer will need to be advanced. This prevents creating a longer transmediastinal tunnel than necessary.

Once the bar passer is passed through the contralateral intercostal space, we turn off the CO_2 insufflation as this will lead to unnecessary entrainment of CO_2 into the left chest which is difficult to remove later. We elevate the sternum repeatedly by lifting the introducer anteriorly on both sides simultaneously (surgeon right and assistant left). The lifting is performed until the sternal depression appears to be corrected. This maneuver is believed to prevent excessive sternal pressure on the pectus bar after placement. We then tie a one-inch-wide umbilical tape through the eyelet of the Lorenz introducer and the other end through the end hole of a 24 Fr chest tube.

The pectus bar to be used should be 1–2 in shorter than the distance between the right and left midaxillary lines. The pectus bar is then bent into a semicircular shape leaving a 2 cm slightly less convex but not entirely flat section in the middle to support the sternum with gentle convex curves on each side. If this central section of the bar is too flat or too long, the pectus excavatum will likely be under-corrected. Bars bent on the ends only with a rectangular shape should be avoided as they also result in under-correction of the defect. The surgeon should aim for a slight overcorrection of the defect to prevent recurrence once the bar is removed.

The pectus bar is then inserted into the distal end of the chest tube and secured with #0 silk suture through the hole in the pectus bar to secure the bar and chest tube together. The umbilical tape, chest tube, and bar are lubricated with water-soluble lubricant and the introducer is slowly withdrawn from the left to the right chest. Under thoracoscopic guidance, the bar passer and umbilical tape are then pulled through the substernal tunnel, followed by the chest tube and finally the pectus bar with the convexity facing posteriorly. We have found that the addition of the chest tube for this maneuver makes passage of the bar smoother. Once the bar is in position, a bar flipper is used to rotate it 180°.

Immediate correction of the pectus excavatum should be observed after bar turning. The pectus bar ends should rest comfortably against the chest wall musculature and lateral ribs. If the bar requires adjustment, it can be re-flipped 180°, remodeled, and turned back into position without removal. If there is residual sternal depression, placement of a second pectus bar should be considered one intercostal space above or below the first. This sometimes requires creation of a second lateral thoracic incision or may be achievable through the original incision. The bar passer-introducer is used to create a tunnel for the second bar as for the first. A second pectus bar should also be utilized if a single bar has been placed inferior to the body of the sternum as this location is unstable and can result in bar displacement. We have found that using two bars also results in better correction in older patients with more rigid chest walls. When using a second bar, we typically make it of a different length than the first bar to avoid clashing of stabilizers on the sides.

Bar stabilization and fixation are accomplished by first attaching a stabilizer to each end of the pectus bar and placing it in a subcutaneous pocket. The stabilizer and bar are then fixated with #0 Vicryl sutures through the eyelets in both sides of the stabilizer and the end of the bar, as well as around the bar to the underlying fascia. Next, a #1 polydioxanone suture on a CTX needle is used to place pericostal sutures around the bar to the underlying ribs in two places on the lateral aspect of each bar. Creating a hard bend in the middle of the needle using two needle drivers to make the sharp angle around the ribs helps accomplish this task. Care is taken not to damage the inferior intercostal bundles although this is not done under thoracoscopic guidance. The knot is then dragged underneath the bar and cut so as not to leave a large suture knot in the subcutaneous pocket.

The soft tissues and skin incisions are then closed in layers using interrupted absorbable sutures in the usual fashion. We do not use wires or multiple stabilizers for the bar, as there is no added benefit in strength. The correct positioning

of the bar and the pericostal sutures are the most important characteristics for bar stability. Attention is then turned to evacuating the pneumothorax in the right pleural cavity. The insufflation tubing is cut and the end is placed under water seal in a kidney basin of sterile water. The anesthesiologist gives several positive pressure breaths with a positive end-expiratory pressure (PEEP) of 5–6 cm H_2O until the CO_2 is evacuated and the bubbling stops. The lungs are then held in full inflation when the trocar is removed and the skin incision is closed. A smooth emergence from anesthesia is encouraged to decrease the risk of bar displacement. A chest X-ray is obtained in the post-anesthesia care unit (PACU) to confirm bar position and ensure no large pneumothorax is present.

Postoperative Care

Postoperative pain control consists of an epidural with fentanyl and ropivacaine with intravenous ketorolac and acetaminophen around the clock for 3–4 days. If an epidural is not possible or is not functional, then PCA with morphine or Dilaudid is utilized. When the patient is ready to transition off the epidural, oral oxycodone is started and the epidural medication held without removal of the catheter. If the patient's pain is not controlled, the epidural is restarted and this trial is attempted again 24 h later. After removal of the epidural catheter, pain is controlled with oral oxycodone and acetaminophen as well as intravenous ketorolac and morphine. In addition to narcotics and Non-steroidal anti-inflammatory drugs (NSAIDs), muscle relaxants such as diazepam are used. Patients are discharged to home with oral oxycodone, acetaminophen, ibuprofen, and methocarbamol for 2 weeks. Daily polyethylene glycol is also given to all patients to help avoid constipation. Diet is advanced as tolerated. Pulmonary toilet is encouraged postoperatively with incentive spirometry, out of bed to chair, and ambulation with physical therapy. Patients are typically discharged at 5 days postoperatively depending on pain control.

To minimize the risk of bar displacement, we recommend that patient sleep on their backs for the first 6 weeks, return to school by 2 weeks, and do not participate in aerobic sports for 6 weeks and competitive sports for 2 months. Patients may resume normal activities slowly and eventually aerobic sports like swimming, soccer, and basketball. We permit contact sports such as football, ice hockey, and lacrosse, but only after 2–3 months if the patient desires, and they are counseled regarding potential issues of bar displacement. However, we have not seen bar displacement after 2 months in our athletic patients who have participated in contact sports (including pole vaulting). The initial clinic follow-up visit occurs at 2–3 weeks and then again at 2, 12, and 24 months with planned bar removal at 24–48 months.

Bar Removal

Bar removal is an outpatient procedure. The bar should be left in place for at least 2 years and for 3–4 years in younger patients (10–12 years) to be certain there has been permanent chest wall remodeling. Teenagers who have experienced big growth spurts require monitoring as the decision may be made to leave the bars in place longer to avoid recurrence or remove the bars if there is impingement on the thoracic wall preventing outward growth.

General anesthesia is administered and the patient placed supine with both arms abducted and the elbows bent at 90° on padded arm boards. Preoperative antibiotics should be given within 30 min of incision. The previous scars are palpated to confirm the bar and stabilizers are close and accessible. If the hardware is not palpable, fluoroscopy can be used to determine their exact location. Ideally, the old incisions are incised and both sides of the bar are exposed. The bar and stabilizer are released from the surrounding scar tissue using electrocautery. This is occasionally challenging if heterotopic calcifications have formed around the bar in which case an osteotomy may be used to dissect the bar free. Positive pressure ventilation with PEEP is maintained throughout to decrease the risk of pneumothorax. Once the bar ends are free, the stabilizer is removed from the bar and a bar bender is used to straighten the bar ends bilaterally. The pectus bar is then removed with gentle traction using a vise-grip on the right end of the bar and close attention to the ECG monitor during bar extraction. The incisions are once again closed in layers and a chest X-ray obtained in the PACU.

Open Technique

The open repair for pectus excavatum is utilized for very severe defects or those with significant asymmetry (combination excavatum and carinatum). We use the Ravitch repair or some modification of this procedure. Since cartilaginous resection is performed during this procedure, the timing of operation should occur after full skeletal maturity is achieved to avoid the risk of acquired thoracic chondrodystrophy. Typically this is done between the ages of 15–17 years.

Preoperative preparation is the same as for the Nuss technique. We use an inframammary transverse incision just medial to the nipple-areolar complex bilaterally to develop exposure. Cutaneous muscle flaps are created superiorly and inferiorly. Next, pectoralis muscle flaps are created beneath the fascia to expose the anterior sternum and costal cartilages. Depending on the length of the depression, costal cartilages should be exposed from T2–T6. Removal of the abnormal costochondral cartilages is performed while

maintaining the perichondrial sheaths. Longitudinal incisions are made with electrocautery along the perichondrium and various lengths of cartilage removed according to the length of deformity. The perichondrial sheaths are re-approximated with absorbable suture at the end of the procedure to enable cartilage regrowth. The xiphoid cartilage will sometimes require removal or release if it projects too far anteriorly or posteriorly.

Once the sternum is released, an anterior wedge-shaped osteotomy is performed in the sternum at the point of transition from normal to depressed sternum. This is usually between T2 and T3. Elevation of the lowermost aspect of the sternum leads to a buckle fracture of the posterior table. We use braided polyester sutures to close the osteotomy. Next, a short, straight pectus bar is inserted beneath the sternum and extending anterior to the ribs laterally for a few centimeters to prevent the sternum from collapsing posteriorly prior to or during rib cartilage regrowth. The bar is attached laterally with absorbable sutures. Closed-suction drains are placed and the pectoralis muscles reattached to the sternum. Epidural or patient controlled analgesia analgesia are used for the open procedures although these patients tend not to have the constant pressure-type pain that patients experience after the Nuss operation. There should be no tension on the chest or sternum if an adequate release was done. The metal strut should be left in place until cartilaginous regrowth can be expected to have occurred, usually about a year. The strut is removed under anesthesia as an outpatient procedure.

Complications

In multi-institutional studies comparing the Nuss and Ravitch procedures, complications are shown to be similar. Early complications include pneumothorax, hemothorax, and pleural effusion requiring drainage, with hemothorax and pleural effusions occurring in less than 1 %. Surgical site infection occurs in approximately 1 %. Pericarditis and pericardial effusion are rare (less than 1 %), as is pneumonia. Late complications include overcorrection (1–2 %) and recurrence (1–2 %). The Norfolk group has demonstrated a 1 % recurrence rate after primary Nuss repair, and the Boston Children's group has shown a 2 % recurrence after Ravitch repair. Recurrence after the Nuss procedure can be due to malpositioned or displaced bars, but it is sometimes related to how the bar is bent or if the bar is removed too early. Recurrence after a Ravitch repair typically occurs in patients operated on at a young age (5–15 %). This type of recurrence can worsen during the pubertal growth spurt.

The group from Norfolk has demonstrated that the Nuss procedure is safe and effective for recurrent pectus excavatum. They note that patients who have had a redo pectus procedure can have significant pleural adhesions requiring decortication during the second repair. They also specified that some patients who had undergone Ravitch repair develop acquired thoracic chondrodystrophy requiring more than one pectus bar during the second repair. Despite these challenges, they reported a greater than 95 % success rate regardless of the original repair technique.

Complications unique to the pectus bar include bar displacement, bar infection, and bar allergy. Bar displacement was initially as high as 5–12 %, but after optimizing bar stabilization, placement, and fixation, this has decreased to less than 1 %. The majority of children with bar displacement require revision. Bar infection (not superficial surgical site infection) is a deep infection involving the bar and occurs in less than 1 %, occasionally requiring bar removal. Bar allergy occurs in approximately 6 % of patients and can almost always be avoided if preoperative allergy testing is undertaken. It presents as a rash or sterile abscess at the incision site and occasionally with a pleural or pericardial effusion. Bar allergy can be confirmed by checking C-reactive protein (CRP) and Erythrocyte sedimentation rate (ESR), and if elevated, the patient can be trialed on a 2-week course of prednisone 25 mg PO daily. If the bar allergy persists (CRP and ESR remain elevated), then the bar should be removed and replaced with a titanium bar.

Pectus Carinatum

Pectus carinatum or anterior protrusion of the sternum occurs less often than excavatum deformities by a ratio of 1:5. It is estimated that pectus carinatum deformities comprise only 5 % of chest wall defects but it seems to be much more prevalent in South America. Many of these patients are not recognized as having a deformity until puberty begins. The variety of configurations of pectus carinatum deformities is large and includes symmetrical protrusions, unilateral defects affecting only one side of the sternum, or mixed deformities with associated pectus excavatum defects. Patients typically do not have physiological symptoms with true pectus carinatum deformities but many complain of intrinsic chest wall pain or discomfort.

Treatment

Management of pectus carinatum includes noninvasive bracing, which is very effective in children less than 16 years of age with symmetrical defects who are compliant with wearing the brace. A Ravitch procedure may be offered in severe cases. We almost always offer bracing as the first-line treatment for pectus carinatum defects. We use the Calgary brace, which is fitted for the patient by an orthotics company. Others have shown success with dynamic bracing systems.

Surgical management of carinatum defects includes the Ravitch approach or some modification of this technique, which is guided by cartilage resection and posterior repositioning of the sternum. An alternative operative method for correction of carinatum is the Abramson procedure (also known as the "Reverse Nuss") in which no cartilage resection is performed and a pectus bar is placed anterior to the sternum and secured laterally to the ribs to compress the sternum.

Editor's Comment

Some of us perform the Nuss procedure without thoracoscopy. Based on the modifications developed by Ron Sharpe at the Children's Mercy Hospital in Kansas City, we instead make a subxiphoid incision to clear the space between the sternum and the pericardium. We have found that this approach simplifies the procedure, reduces OR time, and eliminates the need for thoracoscopy. We do not secure the bar around the ribs. We use bilateral stabilizers and secure them with #5 FiberWire, a thick woven suture. To avoid recurrence, we leave the bar in place in all patients for 3 years. While rare, bar infection can be treated with IV antibiotics, usually rifampin, for a year and will usually clear. Because a foreign body is being implanted in these patients, we routinely double glove for these cases.

The "Nuss" procedure has revolutionized the treatment of pectus excavatum. It is very effective, has a low complication rate, and is associated with minimal external scarring when compared to the Ravitch operation. The principal drawback is extreme pain, which is usually effectively managed in the immediate postoperative period with patient controlled analgesia (thoracic epidural catheters are effective but have fallen out of favor due to rare reports of paraplegia), and for the first 2–3 weeks with narcotic analgesics. Narcotic addiction is a significant concern but should be rare with ethical and appropriate pain management techniques and conversion to non-narcotic analgesics as soon as possible after the operation.

Pectus excavatum produces measurable deficits in cardiac and respiratory function but the true physiologic significance is controversial. Though some still believe it is purely a cosmetic defect, patients frequently describe significant symptoms before surgery, and many report considerable subjective improvement in their stamina and comfort after the operation. Especially in active teenagers, displacement of the bar remains a constant worry but is thankfully rare, especially with the routine use of bar stabilizers. It is customary to orient the lateral incisions transversely, probably to respect Langer's lines, but vertical incisions placed in the midaxillary lines heal nicely and should allow excellent exposure for the placement and stabilization of the pectus bar.

A well-done Ravitch repair is elegant and effective in its own right, but should only be offered when there are contraindications to the minimally invasive approach. Rather than removing the costal cartilages, Dr. Haller would instead cut the cartilages at an angle (anteromedial to posterolateral) and bring the medial half anterior to the lateral half, thus helping to push the sternum anteriorly. They need to be stitched in this position to avoid slippage and the perichondrium is closed over it. A bar is not always necessary but recommended for severe defects especially in older teenagers and adults.

In many respects, pectus carinatum is even more of a cosmetic concern than pectus excavatum. The operations described for correction of this defect are more invasive and perhaps less effective than those available for pectus excavatum. External bracing appears to be very effective; however, compliance remains a significant hurdle.

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Mediastinal Tumors

42

Sidney M. Johnson

As a group, mediastinal tumors are representative of a wide spectrum of disease. Approximately 40 % of mediastinal masses are benign (such as teratomas or cystic neoplasms) and 60 % are malignant, most of these being lymphoma. Nearly 40 % of mediastinal tumors occur in children under 2 years of age.

The anatomic classification of mediastinal tumors is important with respect to clinical symptoms and surgical considerations. Accordingly, mediastinal tumors are described according to anatomic location into anterior, middle, or posterior mediastinal compartments.

Practically speaking, the *anterior* compartment only becomes clinically apparent when occupied by tumor. Close to half of all mediastinal tumors arise within the anterior compartment. This compartment is bounded by the sternum anteriorly, the pleura laterally, and the pericardium, trachea, and great vessels posteriorly. The anterior mediastinum contains the thymus, lymph nodes, vessels, lymphatics, fatty tissue, and occasionally thyroid or parathyroid tissue. Common tumors in the anterior mediastinum include lymphoma (T-cell, B-cell, Hodgkin); teratoma; thymic cysts, tumors, or hyperplasia; thyroid masses or goiter; and, rarely, vascular or lymphatic malformations. Accordingly, lesions occurring in the anterior mediastinum are often recalled by remembering the "four T's": thymoma, teratoma (terrible), lymphoma, and thyroid.

The *middle* mediastinal compartment is bounded by the posterior limits of the anterior compartment and the anterior border of the spine. This compartment contains the proximal tracheobronchial tree, the heart and great vessels, major thoracic nerves, and hilar lymph nodes. Common malignant tumors of the middle mediastinum include both Hodgkin and non-Hodgkin lymphoma. Common benign tumors in this compartment include lymphatic tumors, vascular anomalies, and bronchogenic or pericardial cysts.

The *posterior* mediastinal compartment is bounded anteriorly by the middle compartment, laterally by the paravertebral sulcus, and posteriorly by the chest wall. It contains the esophagus, aorta, thoracic lymphatics, and sympathetic chain ganglia. Common posterior mediastinal masses include foregut cysts, ganglioneuroma, and neuroblastoma.

Presentation

Tumor location correlates with clinical symptoms at presentation and, often, the acuity of symptoms (Fig. 42.1). Accordingly, anterior mediastinal masses are the most likely to present acutely. This is because many lymphomas exhibit rapid tumor growth but also dramatic involution with therapy (Fig. 42.2). Although some patients are asymptomatic, anterior mediastinal masses can present with symptoms associated with mass effect or compression including stridor, wheezing, chest pain, new onset cough, dyspnea, and orthopnea. Systemic symptoms sometimes include weight loss, fever, fatigue, and night sweats. In infants and children, mediastinal tumor growth can range from very rapid to slowly progressive; symptoms may not become apparent until overt respiratory distress develops. In rare cases of thymoma, anterior masses can present with a paraneoplastic syndrome such as myasthenia gravis.

Dyspnea and orthopnea are the most ominous signs and should raise suspicion of an anterior lesion. These symptoms should warn caregivers to be both cautious and expeditious with diagnostic interventions, including imaging. Progressive symptoms should be viewed with high suspicion and evaluation should not be delayed.

Important findings on physical examination include weight loss and signs of respiratory distress such as wheezing or stridor. Some patients will refuse to leave a sitting position because of difficulty breathing. Others will exhibit signs of vascular congestion such as jugular venous

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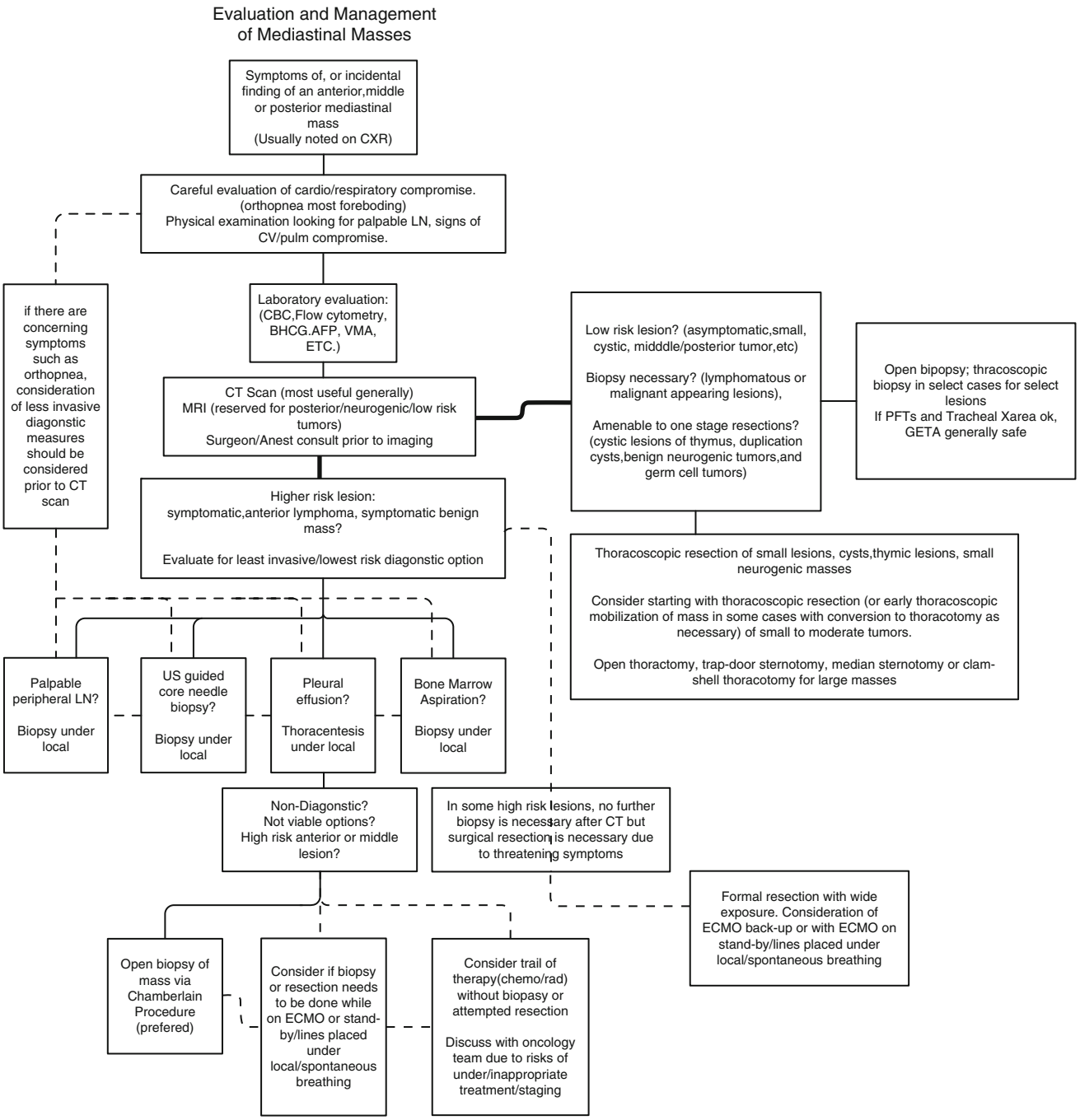

Fig. 42.1 Clinical pathway algorithm for the evaluation and management of mediastinal masses

distention, pulsus paradoxus, or hepatomegaly. Obviously, the evaluation should include a thorough search for lymphadenopathy in the neck, axilla, and inguinal region—peripheral lymph node biopsy under local anesthetic is a much safer alternative to direct biopsy of the mediastinal mass, but a suitable node can be easily missed on cursory examination by an inexperienced clinician.

Middle mediastinal masses should be also viewed with suspicion until symptoms are carefully assessed by experienced personnel. On the one hand, benign masses of the middle compartment, like posterior masses, tend toward a more chronic presentation. On the other hand, malignant middle mediastinal lesions can present with acute life-threatening symptoms similar to those seen with anterior masses. Thus, clinical symptoms always trump anatomic considerations and tumor type in terms of careful preoperative planning.

Posterior compartment masses are perhaps the most varied in their presentation. Posterior mediastinal lesions are the

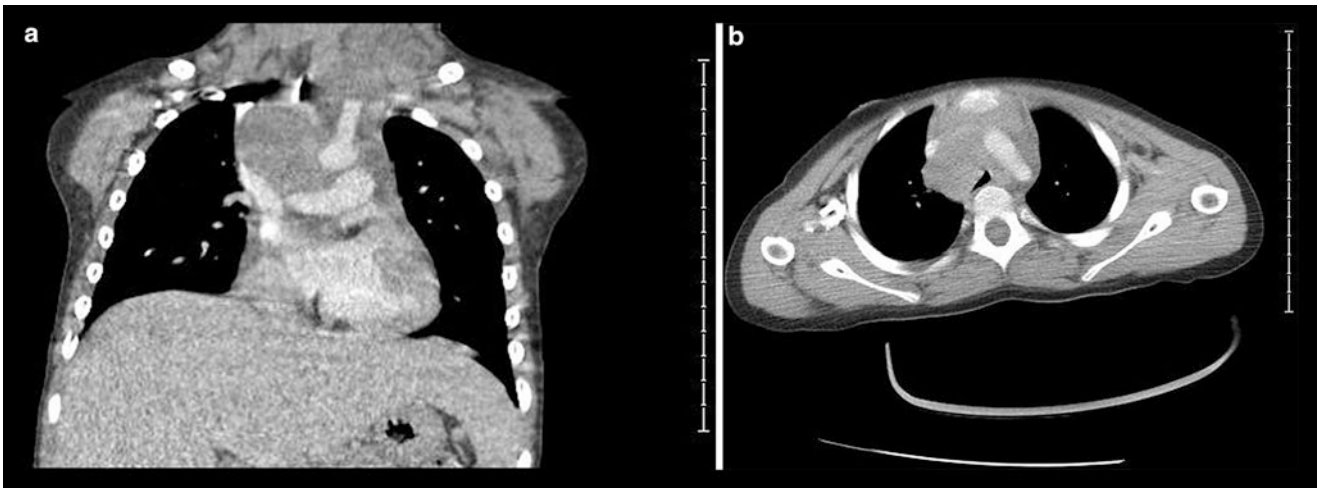

Fig. 42.2 Anterior mediastinal T-cell lymphoma

least likely to present with acutely life-threatening symptoms. Enteric duplication cysts of the posterior mediastinum are now often diagnosed by prenatal imaging before they become symptomatic. Neurogenic tumors are often found incidentally in patients with chronic respiratory symptoms on chest radiograph; others may present with neurogenic symptoms such as Horner syndrome or recurrent nerve or phrenic nerve palsies. Rarely, neurogenic tumors can present with progressive paralysis in infancy. Though these symptoms may not be as acutely life threatening, acute neurogenic symptoms at presentation can be devastating because of tumor invasion of the spinal cord.

Diagnosis

The workup nearly always starts with simple AP and lateral chest radiographs. In fact, the majority of mediastinal masses are discovered incidentally when children are under evaluation for nonspecific respiratory symptoms.

If a mediastinal mass is found on chest X-ray, pediatric surgeons should be aggressively involved in the early evaluation, diagnostic testing, and management of these lesions. This is not simply because the majority of these masses will require surgical biopsy or formal excision, but because the clinical judgment that comes from experience is essential in the evaluation of these masses. It is common practice at many institutions to lightly sedate children for CT scans, and less experienced practitioners may not understand that common diagnostic tests under light sedation or supine positioning can be disastrous. There are numerous reports of children suffering cardiovascular collapse after being sedated for diagnostic CT scans when under evaluation of mediastinal pathology.

That said, CT is generally the most useful diagnostic adjunct to characterize mediastinal lesions and distinguishing cystic, vascular, and lymphatic tissue. CT is helpful in judging mass effect and the relationship of the tumor to critical structures. In conjunction with formal pulmonary function test (PTFs), it can also be useful in obtaining predictive physiologic information for anesthetic planning. In the majority of anterior and middle mediastinal tumors, simple chest radiography and CT will provide sufficient information for surgical planning.

Patients with neurogenic tumors may benefit from other studies such as MRI. MRI studies yield little additional information for anterior and medial mediastinal masses but should be strongly considered in the evaluation of posterior mediastinal lesions. For posterior mediastinal tumors, MRI provides critical information about the anatomic relationship between the tumor and the spinal cord. Thus, MRI should be considered when evaluating posterior lesions.

Laboratory studies can be obtained in parallel with the radiographic studies and should be directed toward common tumors for age. CBC with peripheral smear and a basic chemistry profile should be obtained. If there is a high suspicion for a neurogenic tumor, tumor markers such as VMA, HMA, HVA, and urine metanephrines should be evaluated. In lesions with the typical appearance of a teratoma (cystic areas, fat, calcifications), testing should also include quantitative β-hCG and alpha-fetoprotein to rule out malignant degeneration of a germ cell tumor.

Pre-anesthesia Evaluation

Surgeons should work in conjunction with the anesthesia team to ensure the safety of children with mediastinal masses. If sedation is necessary because of the age of the child, formal risk assessment should be undertaken prior to the CT scan. This pre-anesthetic evaluation is likely the most important step in the treatment of these lesions.

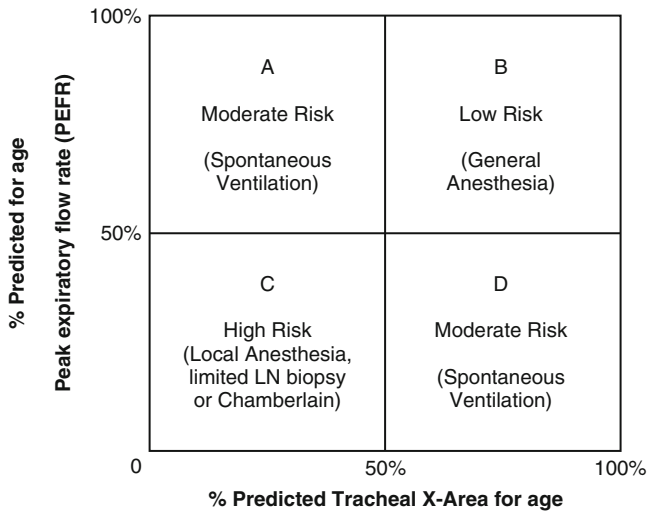

Fig. 42.3 "Shamberger Risk Assessment Box" for mediastinal masses

While clinical symptoms are helpful in evaluating the risk for anesthesia and surgery, formal pulmonary function testing and CT cross-sectional tracheal scanning used together can be very helpful in determining anesthetic risk in difficult patients. In almost all cases, if the patient is able to lie supine without orthopnea, they can undergo a rapid CT scan with IV contrast without sedation and the tracheal cross-sectional area can then be calculated. CT should be done following scanning protocols looking at this cross-sectional area of the trachea to compare with age-matched norms. The measurements of peak expiratory flow rate (PEFR) and the cross-sectional tracheal area can be combined to form a "Shamberger risk assessment box" for mediastinal masses (Fig. 42.3).

Once these measurements are obtained, patients can be risk stratified. In general, patients with both a cross-sectional tracheal area and PEFR greater than 50 % of predicted for age can safely undergo general anesthesia for a surgical procedure (Fig. 42.3). Patients with an indeterminate risk, wherein one of the measurement is lower and the other predictor is higher than age-predicted values, should be approached with caution and should be allowed to breathe spontaneously during the procedure. In these patients, biopsy under minimal sedation with local anesthetic and spontaneous ventilation is ideal. Patients in the high-risk category, specifically those with both cross-sectional tracheal area and PEFR less than 50 % predicted, are generally unfit for sedation or general anesthesia. These patients should be biopsied under local anesthesia with spontaneous ventilation and an upright position, sometimes with a Chamberlain approach.

The Chamberlain procedure is used for the evaluation of anterior mediastinal masses. In many cases the tumor tissue is easily accessible via this approach. One major advantage is that it can be done under local anesthesia. An anterior transverse parasternal incision is made after infiltration with local anesthetic, and the third or fourth rib cartilage is removed from within the perichondrium. The perichondrium is then incised, exposing the tumor. The internal mammary vessels sometimes need to be ligated and divided. This provides excellent extrapleural exposure of the anterior mediastinum with the patient breathing spontaneously. Operative planning should include the use of adjunctive topical thrombotic agents because the utility of cautery in the mediastinum is somewhat limited due to nearby vascular structures.

Alternative biopsy techniques can also be considered and must be considered in high-risk cases. These include US-guided core needle biopsy, a directed peripheral lymph node biopsy, and thoracentesis. Pleural fluid is often overlooked as a diagnostic alternative, but with appropriate cytological evaluation, the diagnostic accuracy is quite high. Moreover, pleural fluid can be obtained under local anesthesia while the patient breaths spontaneously in a sitting position. If these biopsy conditions are deemed excessively risky by the anesthesia and surgical teams, last resort adjuncts include preemptive extracorporeal membrane oxygenation (EMO) with full or partial access under local anesthesia or treating the patient presumptively.

There are distinct disadvantages to presumptive treatment (chemotherapy or radiation therapy directed toward the most likely type of tumor given the limited facts about the etiology of the lesion) of mediastinal lesions. A subset of presumptively treated patients receive inadequate staging and, thus, incomplete therapy. In other cases, the therapy may be completely misguided without an adequate diagnostic biopsy. Thus, in most cases when working with treatment teams composed of specialists from various disciplines, a compromise can be reached between the desire for diagnosis and the risk of biopsy. Most of the time, a safe diagnostic test can be arrived upon without having to treat presumptively.

Specific Considerations

In general, lymphomas, both Hodgkin and non-Hodgkin alike, will require surgical biopsy. Lymphomas are systemic diseases that result from T- and B-cell proliferation. Non-Hodgkin B-cell tumors account for approximately 85 % of all lymphomas. In children, B-cell lymphomas produce undifferentiated Burkitt's and non-Burkitt's subtypes, and both have abdominal and mediastinal presentations. Primary mediastinal B-cell lymphomas arise from the thymus and present in adolescents. Other pure mediastinal B-cell lymphomas are less common. T-cell lymphomas also arise from the thymus and make up about 15 % of non-Hodgkin lymphomas; the lymphoblastic subtype is thought to arise from the thymus or nodes of the anterior mediastinum.

While any lymphoma subtype can present as a pure mediastinal tumor, patients with matted peripheral lymphadenop-

athy as a presenting symptom can also harbor an occult mediastinal mass. Thus when a patient is suspected of lymphoma with a presumed isolated cervical lymph node enlargement, a preoperative chest radiograph should be obtained.

Generally speaking, definitive therapy for lymphoma is provided with chemotherapy with or without radiation therapy. The role of surgery in most cases of lymphoma is limited to providing a diagnostic biopsy and establishing long-term central venous access.

Thymic Lesions

Apart from lymphomas arising from the thymus, thymic lesions of the mediastinum are relatively rare and are generally straightforward to manage in children. Thymic cysts arise in the anterior mediastinum, and in addition to thymic elements, they can be lined by secretory pharyngeal epithelium. Thymic cysts can be asymptomatic but commonly present with symptoms typical of any anterior mediastinal mass. They can also rarely present as palpable masses in the neck that extends into the mediastinum. In children, malignant lesions of the thymus are extremely rare.

Thymic lesions can be approached through a suprasternal or transternal incision or a limited superior sternotomy. That said, in many cases thoracoscopic resection of these lesions is quite straightforward and should be strongly considered. If the patient is positioned in a modified thoracotomy position at a 45–60° angle, anterior thymic lesions can be excised thoracoscopically with a combination of cautery and blunt dissection.

Teratoma

Teratomas account for 10–15 % of mediastinal lesions and tend to present in older children and adolescents. Though they are more common in males in the adult population, in children, they occur equally frequently in males and females. Mediastinal teratomas arise around the pericardium or thymus and as such are generally anterior (Fig. 42.4). They tend to cause slow, progressive respiratory distress or vague symptoms such as thoracic or cervical pain. Most mediastinal teratomas in children are benign. Yolk sac tumors such as seminoma, germinoma, or embryonal carcinoma also occur with a similar location and presentation; these tumors generally have less favorable histology than teratomas.

Surgical excision is the treatment of choice for both teratomas and yolk sac tumors. Smaller lesions can be approached thoracoscopically with care taken to follow oncologic principles (avoid spillage). Even when a small thoracotomy is required for specimen removal, the access and visualization

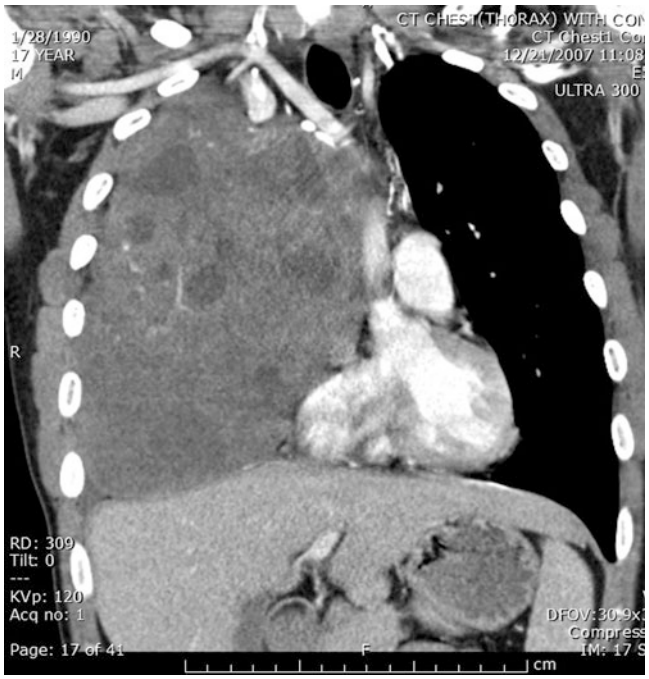

Fig. 42.4 Mediastinal teratoma

offered by thoracoscopy is often favorable and should be strongly considered in smaller lesions. Larger lesions require thoughtful operative planning as they can be quite difficult to manage. Some will be best removed with thoracotomy, while others may benefit from median sternotomy or even a clamshell or trap-door approach. For extremely large lesions, an extended lateral clamshell provides excellent exposure to an otherwise daunting (and otherwise blind) tumor resection.

Cysts

Duplication or foregut cysts can arise from the esophagus or tracheobronchial tree. They are generally classified from the organ of origin—bronchogenic cyst, esophageal duplication cyst, pericardial cyst, etc. As a rule, these lesions are benign.

In practice, cystic mediastinal lesions can often be approached with minimally invasive techniques as resection is generally straightforward. When using thoracoscopy, a modified thoracotomy position with the patient slightly overrotated beyond 90° is ideal for posterior lesions. This overrotation helps expose the posterior mediastinum near the esophagus and posterior bronchi. For more anterior or middle (pericardial) lesions, under-rotation to 45–60° is ideal.

Vascular Anomalies

Anomalous vascular tumors such as lymphatic malformations can occupy the anterior, middle, or posterior mediasti-

num. These are relatively rare but they can pose difficult management problems. These tumors tend to not respect anatomic boundaries and many are vaguely positioned in the anterior and middle compartments. Hemangiomas and various capillary, venous, arterial, and lymphatic malformations behave differently and carry some risk of bleeding, thrombosis, chylothorax, and invasion of interstitial pulmonary lymphatics. Because of the diversity of these tumors and the range of associated complications, referral to a dedicated vascular malformation center should be considered in complex cases. Consideration should be made to treat macrocystic lesions with sclerotherapy. Partial debulking to minimize both symptoms and morbidity is a reasonable option to avoid disability and complications in select cases. Asymptomatic lesions can be observed.

Smaller and less complicated lesions can be relatively straightforward. Simple or minimally lobulated lymphatic lesions can be resected with thoracoscopy. Other more complex vascular or lymphatic tumors can invade both the neck and anterior mediastinum. In these cases an open approach might include a cervical incision plus a thoracotomy, partial sternotomy, trap-door sternotomy, or formal sternotomy. More complex lesions that invade both neck and chest do not lend themselves as readily to a minimally invasive approach because the delicate nerve and vascular anatomy can be complex in the transition zone between the thoracic outlet and neck.

Neurogenic Tumors

Neurogenic mediastinal tumors are located in the posterior mediastinum and originate from the sympathetic chain ganglia. These tumors can be malignant as in the case of neuroblastoma or benign as in ganglioneuroma. Ganglioneuromas tend to present in older children and early adolescent patients, tend to be more discrete, and are less likely to invade the spinal canal or cause paralysis or neurogenic symptoms (Fig. 42.5). Neuroblastomas are malignant and are more likely to invade the spinal canal and cause weakness or paralysis. Apical neural tumors may present with Horner syndrome or heterochromia. In rare cases, these tumors can present with paraneoplastic symptoms such as hypertension, diarrhea, or opsoclonus-myoclonus-ataxia syndrome.

MRI is recommended for the evaluation of neurogenic mediastinal tumors as it is the best modality to evaluate intraspinal extension. When intraspinal extension of the tumor is detected, a multidisciplinary decision to prioritize therapy with input from the pediatric surgery, neurosurgery, and oncology is necessary. The goal is to consider the need for and the timing of laminotomy, resection, and chemotherapy. The ideal treatment modality varies from patient to patient according to symptoms, tumor type, and presentation. While laminectomy with resection of the intraspinal component was often preferred in the past, a recent broad experience from several groups including that of the Children's Oncology Group argues that treatment with chemotherapy results in less neurologic morbidity. Overall, the survival from mediastinal neurogenic tumors is generally better than for those that arise in the abdomen.

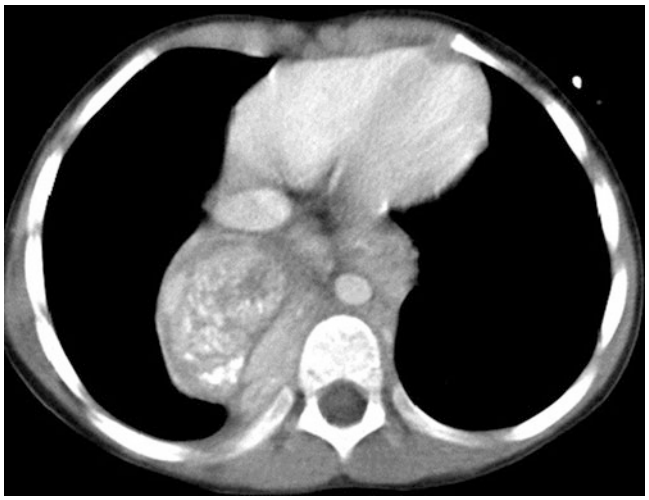

Fig. 42.5 Ganglioneuroma, posterior mediastinum

Surgically, the approach to resection varies according to the location, type, and severity of the tumor. Large lower posterior mediastinal tumors may benefit from a thoracotomy or a thoracoabdominal approach. Those higher in the chest or near the thoracic inlet can be approached by thoracotomy, sternotomy, or trap-door sternotomy. That said, there are many small neurogenic tumors of the posterior-lateral mediastinum that can be resected with thoracoscopy. When the tumor is limited to the sympathetic chain and without invasion of vessels, nerves, or spinal cord, thoracoscopy is the preferred modality.

ECMO

In mediastinal lesions that are considered high risk, when symptoms are severe or the evaluation is incomplete or no alternative therapy is available but cardiovascular collapse is a real possibility, preemptive cannulation for ECMO can be considered prior to resection. The advantage of ECMO is that cannulas (VV or VA depending on the nature of the tumor) can be positioned under local anesthetic—or smaller lines can be placed with the intent to rewire them to ECMO should the need urgently arise.

That said, if approaching a tumor resection under the specter of ECMO, it is often preferable to wire or formally cannulate but not actually initiate ECMO unless absolutely necessary because bleeding complications and the difficulty and morbidity of tumor resection increases dramatically once ECMO is initiated.

Summary

Mediastinal tumors arise from diverse but predictable pathologies. The clinical presentation often correlates with anatomic location within the mediastinum. Nearly all tumors of the mediastinum will require some type of surgical intervention; malignant tumors will require biopsy for identification and staging, and benign lesions will require definitive resection. Mediastinal tumors require intense, thoughtful, and complete evaluation prior to attempted treatment or resection because respiratory collapse may occur even with mild sedation. Surgical input should be sought early as the varied nature of mediastinal disease demands their experience and clinical expertise. In turn, pediatric surgeons should work with broader teams of oncologists, anesthesiologists, radiologists, and neurosurgeons in order to provide optimum care for these challenging patients.

Editor's Comment

Mediastinal tumors must be approached with some trepidation. Anterior mediastinal masses remain very dangerous in terms of risk of irreversible airway compromise. Fortunately there are a number of options that enable the surgeon to prevent this from happening. Like most aspects of pediatric surgery, less is more. An alternate means of obtaining diagnostic material should be sought: cervical lymph node biopsy, drainage of pleural fluid for cytology, bone marrow biopsy, or US- or CT-guided percutaneous core needle biopsy under local anesthesia. If general anesthesia is truly the only option, which is rarely the case, contingencies should be made for urgent rigid bronchoscopy or even ECMO should airway collapse become a reality.

To minimize harm the surgeon operating in the mediastinum must understand the intricate anatomy of the region, including all known variations. Biopsy or removal of apical lesions puts the stellate ganglion at risk, which can result in Horner syndrome (ipsilateral enophthalmos, small pupil, ptosis, dry eye). This is sometimes unavoidable and expected (neuroblastoma resection), and parents need to be warned in advance that it is likely to be permanent. The phrenic nerve is always at risk and should be clearly identified and protected along its entire length. The recurrent laryngeal nerve can also be injured, and its variable anatomy should be anticipated. Finally, thoracic duct injury can occur unexpectedly and results in significant postoperative morbidity. After resection of a mass, the tissue bed should be examined carefully for lymphatic fluid leakage, which will be clear in the patient who has fasted. If the source of the leak cannot be found, infusing a small amount of dairy cream through the gastric tube can be helpful.

Thoracoscopy should be the standard approach for resection of foregut duplications, thymic masses, and small paraspinal ganglioneuromas. Likewise, biopsy of almost any mediastinal lesion, including paratracheal and subcarinal lymph nodes, can be performed safely using a minimal-access approach. Mostly because the resultant scar is often cosmetically unappealing, the Chamberlain operation should only be used if there is truly no other approach available. For large or malignant lesions, thoracotomy is standard, but a muscle-sparing approach should be used if at all possible. The pediatric surgeon should also be comfortable with performing a sternotomy when necessary for large midline lesions (mediastinal teratoma). It is safe, offers excellent exposure, provides for a very stable closure, and is very well-tolerated (in most cases, better than a large thoracotomy). The only real disadvantage is the scar. Finally, the axillary approach can be useful in certain cases, especially when dealing with lesions near the apex. A transverse incision is made in the lowest axillary skin crease from the posterior border of the pectoralis major to the anterior edge of the latissimus dorsi, and the chest is entered through the third intercostal space. An extrapleural approach can be used in some cases. The principle limitations of this approach are limited exposure and the inability to extend the incision.

Suggested Reading

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Part VII

Stomach and Small Intestine

Gastroesophageal Reflux Disease

43

Rebecca L. Gunter and Charles M. Leys

Several mechanisms work together to form a barrier against reflux. There are thickened muscle fibers in the distal esophagus that form the lower esophageal sphincter (LES). The diaphragmatic crura encircle the distal esophagus, providing further support for the LES. This creates a high-pressure zone that maintains a resting tone 10–30 mmHg above gastric pressure. The lower esophageal sphincter pressure (LESP) increases in response to situations where gastric pressure increases and relaxes in association with specific reflexes, such as swallowing, belching, and vomiting. The LESP is further supported by the transmission of abdominal pressure to the intra-abdominal portion of the very distal esophagus. The angle of His, an acute angle between the gastric cardia and the esophagus, creates a valve that contributes to the barrier against reflux. Lastly, esophageal motility clears refluxate from the lower esophagus with secondary peristaltic waves.

Gastroesophageal Reflux

Gastroesophageal reflux is the *effortless* passage of gastric contents up into the esophagus. It occurs when the mechanisms of esophagogastric competence malfunction or are overcome. Normal individuals experience GER without significant consequences. Gastroesophageal reflux disease (GERD) is defined as reflux that results in significant symptoms or harm to the patient. Development of GERD results from an imbalance between factors promoting reflux and the ability of the esophagus to clear and resist gastric acid exposure. The main factor leading to GERD is thought to be dysfunction of the LES complex.

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The most common mechanism of a reflux event is inappropriate transient relaxation of the LES, which is a sudden and brief decrease in pressure to near zero that is not triggered by swallowing. Transient relaxations occur in asymptomatic individuals, but they are more frequent in patients with GERD and account for the majority of reflux episodes. Less frequently, reflux episodes are associated with a reduced basal LESP.

Other factors predisposing to GERD include anatomic abnormalities such as a congenitally short esophagus, congenital diaphragmatic hernia, hiatal hernia, and esophageal atresia. Insertion of a gastrostomy tube may promote reflux by altering the angle of His, making it less acute or obtuse. In addition, esophageal dysmotility, delayed gastric emptying, elevated intra-abdominal pressure (peritoneal dialysis, gastroschisis/omphalocele, ascites, obesity), and central nervous system impairment are associated with an increased risk for symptomatic GERD.

Diagnosis

The most common symptom of GERD in children is regurgitation or vomiting of feeds. Other signs include fussiness with feedings, feeding refusal, and arching of the back during feeds (as in Sandifer syndrome). Consistent pain with feedings and feeding refusal may result in inadequate caloric intake and failure to thrive. Respiratory symptoms include reflex apnea, acute life-threatening events, and recurrent episodes of aspiration causing hoarseness, laryngitis, pneumonia, and chronic lung disease. Esophagitis may cause acute or chronic bleeding and pain and can lead to stricture formation and dysphagia.

While many children are treated medically for GERD based on history alone, without significant work-up, children who are being considered for surgery require thorough investigation to ensure that the symptoms are actually due to GER. Many of the symptoms of GERD can be due to other

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causes, such as central apnea, pharyngeal dysphagia, tracheoesophageal fistula, esophageal web, *Helicobacter pylori* infection, food allergy or intolerance, an intrinsically sensitive emetic reflex, gastric outlet obstruction (pyloric stenosis), or intestinal dysmotility.

We begin with a complete history and physical examination to determine the character, frequency, and severity of the patient's symptoms, as well as to rule out other potential etiologies. Accompanying symptoms such as pallor, salivation, sweating, or retching might indicate activation of the emetic reflex rather than passive GER. Several validated questionnaires exist for the detection and surveillance of GERD, which is often sufficient to diagnose uncomplicated GERD and initiate medical management.

When considering surgical management for GERD, our initial test of choice is a contrast upper gastrointestinal (UGI) fluoroscopic study. The sensitivity of UGI for detecting reflux is only about 30 % as compared to pH monitoring, partly due to the short duration of the examination. Specificity is also low, as the presence of reflux on UGI does not necessarily indicate pathologic GERD. Therefore, the decision to proceed with surgical treatment should not be based solely on GER found on UGI. However, this test does provide valuable information about the anatomy and can detect other abnormalities that may explain the symptoms or alter the surgical plan, such as malrotation, hiatal hernia, esophageal or duodenal web, achalasia, or pyloric stenosis. In the absence of these findings and a clinical picture of severe GERD refractory to medical treatment, UGI is often the only diagnostic test needed before proceeding to surgery in children.

If the diagnosis of GERD is uncertain, further diagnostic tests are warranted. Esophageal pH monitoring, the standard test for diagnosing GERD in adults, is used to quantify the amount of acid exposure to the lower esophagus. A drop in pH below 4.0 is considered an acid reflux episode. The number of episodes and their lengths are recorded to create a score reflecting reflux severity. The DeMeester score for adults and older children and the Boix-Ochoa revised score for infants and toddlers provide a quantitative assessment of acid exposure. Increasingly, pH monitoring is performed in conjunction with multichannel intraluminal impedance (MII), which uses multiple electrodes along the length of the esophagus and in the stomach to detect volume, velocity, and extent of fluid and solid boluses. This is particularly useful in detecting reflux of non-acidic material, which is more common in infants or patients on acid-suppressive therapy. When used in combination, pH monitoring and MII are useful to correlate documented reflux events with patient symptomatology.

Additional diagnostic tests that can be helpful include esophagogastroduodenoscopy (EGD) with biopsy, esophageal manometry, and technetium-99 radionuclide scanning to measure the rate of gastric emptying. In the setting of hematemesis, dysphagia, or a normal pH/MII study but continued suspicion of GERD, EGD can reveal esophagitis or Barrett's esophagus, confirming the diagnosis. If by EGD one finds evidence of gastritis, infection with *Helicobacter pylori*, or food intolerance such as gluten enteropathy, those conditions should be treated first and the patient reassessed before considering surgical intervention for reflux. Esophageal manometry, while considered essential in adults, is not commonly performed in the pediatric population. However, if the primary symptom is dysphagia, manometry can detect esophageal motility disorders such as achalasia. GERD can be associated with delayed gastric emptying, especially in neurologically impaired children. However, gastric emptying studies are not obtained routinely prior to surgical intervention, as gastric emptying rates have been shown to improve after fundoplication. Assessment of gastric emptying should be considered if symptoms persist after antireflux surgery or prior to undertaking a redo fundoplication for recurrent symptoms.

Medical Therapy

The majority of children with GERD respond to medical therapy, which may be attempted empirically, sparing patients from invasive diagnostic testing. The majority of infants respond to medical treatment and experience resolution of GERD symptoms by 12–18 months of age. Feeding behavioral modifications include smaller volume feeds in an upright position. In children receiving tube feedings, continuous drip rather than bolus feedings might help reduce the likelihood of reflux. Since milk-protein allergy may manifest with GERD-like symptoms, elimination of milk protein may be a helpful initial step. Additionally, food thickeners reduce the ease with which liquids reflux. In older children, dietary changes may include a low-fat diet and avoidance of caffeine and carbonated drinks.

If these maneuvers are unsuccessful, pharmacologic therapy may be attempted. The acidity of refluxed material is reduced using antacids, histamine receptor antagonists, or proton pump inhibitors (PPIs). These may dramatically decrease acid exposure, but will not address the effects of nonacid reflux. Additionally, though the efficacy of PPIs is well established in adults and older children, their use is somewhat more controversial in infants. Promotility agents, such as metoclopramide or erythromycin, are thought to ameliorate GERD, though their success has been mixed, and they are not without significant side effects, which limit their long-term utility.

Surgical Therapy

Surgical treatment of GERD is typically indicated if an adequate trial of medical treatment fails to control symptoms. Operative management without a trial of medical management may be acceptable in the presence of complications such as severe esophageal ulceration, Barrett's esophagus or stricture, chronic pulmonary disease or recurrent aspiration pneumonia, apparent life threatening event (ALTE) spells, or persistent failure to thrive. Neurologically typical children often improve with increasing age, and if symptoms can be controlled medically, we recommend a nonoperative approach. Surgical treatment is more frequently required in neurologically impaired children. Our preferred surgical management of GERD is the laparoscopic Nissen fundoplication, with or without simultaneous gastrostomy.

Most children can be admitted from home on the day of surgery. Rarely, children with chronic lung disease such as cystic fibrosis or spinal muscular atrophy require preoperative hospitalization for pulmonary toilet and intravenous antibiotics or TPN. Perioperative blood transfusions are typically not required. Because the surgeon's initial laparoscopic view of the stomach is from the umbilicus, up, and over the transverse colon, neurologically impaired children with chronic constipation and a chronically dilated colon may present an added challenge. Several enemas, administered in the evening before surgery, can help decompress the colon. A single dose of a first-generation cephalosporin is administered intravenously just prior to incision.

Laparoscopic Nissen fundoplication is a technically challenging advanced minimally invasive procedure. In general, the technical difficulty increases as the size of the patient decreases. Selecting laparoscopic instruments appropriate to the size of the individual patient is crucial. For infants and small children, we prefer 3-mm instruments that are available in varying shaft lengths of 10, 14, and 20 cm. These are inserted through stab incisions, without the use of a port. We use a 45° 4- or 5-mm laparoscope inserted through a 5-mm camera port located at the umbilicus. In older children, 5-mm instruments may be necessary as well as additional cannulas.

After intubation, the anesthesiologist inserts an orogastric tube, and the child is moved down toward the foot of the table. Infants and small children can be placed in a frog-leg position at the very end of the table, while larger children are positioned in lithotomy with stirrups. This allows the surgeon to stand at the foot of the bed or between the patient's legs. The scrub nurse stands to the surgeon's left and the assistant is to the right. One or two monitors are positioned at the head of the table.

After preparing and draping the abdomen, a 5-mm vertical incision is made through the center of the umbilicus and the camera port is inserted with open technique using a blunt-tipped cannula with trocar. The sheath can be sutured to the umbilical skin to prevent it from inadvertently sliding out. If a gastrostomy tube is to be placed, that site is marked prior to insufflation, as insufflation tends to distort the abdominal wall and its landmarks. That site is typically in the left upper quadrant, two fingerbreadths inferior to the costal margin and to the left of midline. After insufflating and visualizing the abdomen, a stab incision is made at that location for the surgeon's working right hand instrument, which is also where needles are introduced for intracorporeal suturing. The left-hand instrument is inserted through a stab incision in the right upper quadrant, just lateral to the falciform ligament near the inferior edge of the liver. A liver retractor is inserted through the right mid-abdomen, placed under the left lateral segment of the liver to expose the hiatus, and then secured to a post attached to the bed near the patient's right shoulder. The assistant's instrument is placed in the left lateral abdomen.

The operation begins with division of the short gastric vessels. The surgeon retracts the greater curvature of the stomach to the patient's right side, while the assistant grasps the vessels and provides countertraction to the left. Starting at the level of the inferior pole of the spleen, the vessels can be ligated and divided with monopolar electrocautery connected to a Maryland dissecting instrument in infants and young children. In older children, an ultrasonic scalpel or advanced bipolar device is used. As the superior pole of the spleen is reached, the assistant pushes the spleen to the left while the surgeon pulls the greater curvature of the stomach caudally to expose the most superior vessels. Once the spleen is separated, the left side of the hiatus is visualized. At this point, the dissection of a retro-esophageal window can be started from the left side, though often the left gastric artery is not clearly visualized. Minimal dissection is performed at the hiatus, leaving the phreno-esophageal membrane largely intact, which is important to reduce the risk of postoperative herniation of the wrap into the mediastinum and subsequent recurrent GERD.

The stomach is then retracted to the patient's left and attention turned to the right side of the stomach and hiatus. The thin gastrohepatic ligament can be entered with blunt spreading and then divided with electrocautery up to the level of the diaphragm to the right of the hiatus. The right side of the esophagus is identified as well as the left gastric artery. The retro-esophageal window is then completed, using two instruments to bluntly dissect the space cephalad to the left gastric artery, while the assistant grasps the phreno-esophageal fat pad. Again, unless there is a hiatal hernia, it is not necessary to dissect the native attachments between the esophagus and the hiatus to achieve adequate intra-abdominal length of esophagus in most children.

After completing the window, the right and left crura at the posterior hiatus often appear slightly separated behind

the esophagus. The hiatus is tightened by closing this defect with a single 2-0 silk suture on a ski needle. After tying the knot, the same needle is passed through the wall of the posterior esophagus at the seven o'clock position, with care to avoid the posterior vagus nerve.

After the crural repair, the fundus of the stomach is visualized through the retro-esophageal window, aided by the assistant pushing the fundus posteriorly and cephalad on the left side of the esophagus. With the assistant pulling the phreno-esophageal fat pad anteriorly and caudally, the fundus can be grasped through the window and pulled posterior to the esophagus, bringing it over to the right side to create the wrap. After ensuring appropriate positioning of the wrap, without twisting or tension, it is pushed back through the window to the left side while maintaining control of it with the left hand grasper. This allows visualization of the hiatus while a bougie is introduced into the esophagus by the anesthesiologist and advanced into the stomach. The bougie may catch on the posterior hiatus, which can be remedied by caudally retracting the phreno-esophageal fat pad to straighten the esophagus and placing a grasper up against the posterior hiatus. The appropriate bougie size is based on the child's weight (Table 43.1). The fundus is then pulled back through the window over to the right side. The wrap is completed with three sutures of 2-0 silk on a ski needle that are then tied intracorporeally. The superior most suture incorporates a small amount of the anterior esophagus and diaphragm at the 11 o'clock position, avoiding the anterior vagus nerve. The wrap is typically about 2 cm in length and should sit slightly to the right, with the sutures at the 11 o'clock position. The bougie is removed, local anesthetic instilled in the incisions, and the umbilical fascia and skin closed. The stab incisions can be closed with steri-strips alone.

If a gastrostomy button is to be inserted, it is placed though the left epigastric stab incision. With a single grasper through that incision, the greater curve of the stomach, across from the incisura, is grasped and pulled up to the anterior abdominal wall. Two transabdominal sutures of 0 or 2-0 polypropylene or polydioxanone suture (PDS) on a large curved needle are used to fix the stomach against the abdominal wall. These sutures are passed down through the abdominal wall, through the stomach medial and lateral to the grasper, then back up through the abdominal wall. A Seldinger technique is then performed using a vascular dilator set, which typically contains a needle, wire, and several dilators. The needle and wire are inserted into the stomach lumen and then the tract dilated up to 16 Fr. The wire and dilators can be gently swirled in a circular fashion to confirm intraluminal placement. To help select an appropriate size button, the tract length can be measured with a balloon-measuring device or estimated with the length of a grasper from the skin to the peritoneum. The smallest dilator can then be inserted through the button lumen and slid over the guide wire into the stomach and the balloon inflated under visualization. The site should be inspected to ensure the balloon did not inflate between the stomach and the abdominal wall. Placement within the lumen can be confirmed by insufflating air through the button into the stomach while visualizing distension of the stomach followed by decompression out through the button. The transabdominal sutures are then tied over the wings of the button to secure it in place. These sutures remain in place for 5 days postoperatively.

Table 43.1 Recommended bougie size for esophageal calibration in patients weighing less than 15 kg

Weight (kg)	Bougie size (Fr)
2.5–4.0	20–24
4.0–5.5	24–28
5.5–7.0	28–32
7.0–8.5	32–34
8.5–10.0	34–36
10.0–15.0	36–40

Source: From Ostlie DJ, Miller KA, Holcomb GW III. Effective Nissen fundoplication length and bougie diameter size in young children undergoing laparoscopic Nissen fundoplication. *J Pediatr Surg* 2002;37:1664–6, with permission from Elsevier

Postoperative Care

Feedings are typically started several hours postoperatively, whether by mouth or by gastrostomy. We advance tube feedings over the first night and first postoperative day, attempting to reach the goal rate by 24 h following the operation. Most children are able to be discharged home on the first or second postoperative day. Children who can eat orally are instructed to follow a liquid diet for at least 2 weeks to avoid food impaction above the Nissen. Edema of the Nissen wrap typically subsides over a period of 3–4 weeks. Occasionally, children with preexisting esophagitis require continuation of acid-suppressive medications for 6–8 weeks postoperatively to allow the esophagus to heal.

Neurologically impaired children and those with other complex medical illnesses often experience dysmotility of multiple sections of the GI tract and therefore are prone to postoperative digestive disturbances, including gas bloat syndrome, retching, high gastric residuals, and constipation. Retching and gas bloat symptoms can be reduced by slowing the rate of bolus feed administration and frequent venting of the gastrostomy tube between feeds. Some patients require a period of continuous drip feedings via the G-tube to minimize gastric distension. These symptoms typically improve with time.

Dysphagia can be a problem in the immediate postoperative period for children taking solid food orally. This is usually the result of edema of the wrap or possibly a wrap that is

too tight. If symptoms persist for more than 6 weeks, dilation will usually provide significant improvement, though this risks disruption of the wrap.

Results

The short- and long-term outcomes of laparoscopic Nissen fundoplication are excellent. Compared to open fundoplication, it is associated with shortened hospital stay, less pain, shorter time to goal feedings, and fewer postoperative pulmonary complications. While the rate of failure requiring reoperation historically has been reported at approximately 6–12 %, recent studies suggest that minimal dissection of the phreno-esophageal membrane lowers the reoperation rate to around 3 %. The risk of failure is increased if patients are younger and have retching or hiatal hernia and if the esophageal hiatus is extensively dissected at the first fundoplication.

Summary

Gastroesophageal reflux disease is primarily due to dysfunction of the LES-crus complex. Patients resistant to maximal medical therapy or with severe, life-threatening complications are candidates for antireflux surgery. Laparoscopic Nissen fundoplication is a safe, durable surgical option and has become the operation of choice for pediatric gastroesophageal reflux disease in most major children's hospitals.

Editor's Comment

GERD is one of the most frequent indications for referral to a pediatric surgeon. GE reflux is quite common in all humans, but there are certain children for whom reflux is severe and intractable or associated with complications such as pain, failure to thrive, aspiration, or reactive airways disease. It is important to distinguish reflux, which is effortless, from emesis, which is forceful. Fundoplications in patients with forceful vomiting always fail. The decision to operate should be based on clinical grounds. Ideally, there should be a consensus among the primary care physician, gastroenterologist, surgeon, and parents. It is unfortunate that in some centers there is a culture of distrust between gastroenterologists and surgeons, to the clear detriment of those patients who might benefit from an operation.

Objective testing is useful in some clinically borderline cases, but available tests are insensitive and nonspecific, and therefore cannot be used as the sole factor in making the decision. The only preoperative test considered mandatory by most pediatric surgeons is an UGI contrast study, which is useful not to confirm or exclude GERD but to rule out achalasia, esophageal stricture, and gastric anomalies and malrotation.

Neurologically impaired children often need enteral access for nutrition or medications but are also often unable to protect their airway, traditionally considered an indication for fundoplication, at the time of gastrostomy. Some families choose to forego fundoplication, especially if the child has been tolerating nasogastric feedings. This might be reasonable considering that these children also have the highest incidence of postoperative complications, retching, feeding intolerance, hiatal hernia, wrap failure, and recurrent reflux.

There are several time-tested principles that are critical to performing a successful fundoplication in children: (1) Perform a 360° wrap whenever feasible. Partial wraps are not as effective or as durable, though they might be preferable when esophageal motility is poor. (2) Close the hiatus by approximating the crura posterior to the esophagus. Anterior repair of the hiatus is ineffective as the stitches are doomed to cut through. The use of pledgets or mesh is associated with a risk of esophageal erosion and perforation and so should only be used if there is truly no alternative. (3) Make the wrap as loose as possible and be careful to avoid twisting the stomach around the lower esophagus, which causes severe dysphagia. Always use a bougie to prevent overtightening of the hiatus or the wrap. There are published weight-based guidelines for the appropriate bougie to use, but one should use the largest bougie that the esophagus will accommodate comfortably. (4) Mobilize at least 3 cm of esophagus into the abdomen to make a wrap 2–2.5 cm in length. Avoid dissection of the phreno-esophageal ligament as this results in trans-hiatal migration of the wrap in up to a third of patients. Use at least three braided permanent stitches and include a bite of the esophagus with each stitch. Identify and protect both vagus nerves throughout the procedure to minimize gastroparesis. (5) Avoid unnecessary stitches—collar stitches between the esophagus and hiatus, "rip-stop" stitches (fundus to fundus below the lowest wrap stitch), or stitches between the fundus and diaphragm—which are only useful in unusual situations. (6) Always divide at least some of the upper short gastric vessels. This allows more of the fundus to be wrapped and the creation of a tension-free wrap. (7) Use a minimally invasive approach whenever possible, except maybe in small infants and some redo operations, as for many reasons it is clearly superior to the open procedure. The standard position is for the surgeon to stand at the foot of the table between the legs in stirrups, but experienced laparoscopists can easily perform the procedure standing next to a patient who is supine.

Intraoperative complications are rare but can be serious. One should be wary of an accessory or replaced left hepatic artery. If a particularly large vessel is "in the way," it makes sense to test-clamp it to be sure the liver does not demarcate. Passing a bougie can perforate the esophagus and should be considered the most dangerous part of the operation. The surgeon and anesthesiologist must agree that the bougie should be advanced slowly and only when both parties are

aware. Most perforations are low and small and best repaired primarily and covered with the wrap. Perforations of the thoracic esophagus are best managed by aborting the fundoplasty, establishing adequate drainage, restricting PO intake, and obtaining an esophagram at 5–7 days.

Redo fundoplication can be extremely tedious, mostly due to dense adhesions. This is considered by some surgeons to be an added advantage to the laparoscopic approach: revising the wrap is somewhat easier and can often be done again laparoscopically. The vagus nerves are at high risk for injury during revision fundoplasty, but performing an empiric pyloroplasty is no longer recommended due to the risk of dumping syndrome. Finally, when revising a fundoplication, it is important to take it down completely first, rather than simply reinforcing the part that has loosened. This allows proper closure of the hiatus, identification of the reason for failure, and creation of a tension-free and hopefully more durable wrap.

Postoperative dysphagia occurs in approximately 10 % of patients after fundoplication, but only about 10 % of these persist for more than 6 weeks. Those that persist should be considered for dilatation of the fundoplication, best done using a balloon dilator under fluoroscopic guidance. Refractory dysphagia is rare but will usually require revision, conversion to a partial wrap, or undoing the wrap.

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Hypertrophic Pyloric Stenosis

44

Pablo Aguayo

Hypertrophic pyloric stenosis (HPS) is one of the most common surgical conditions in newborns and is a condition well known to pediatricians and pediatric surgeons. It is characterized by thickening of the circular smooth muscle layer of the pylorus, which eventually leads to a gastric outlet obstruction. More than 90 % are diagnosed before the 10th week of life. HPS occurs with an incidence of approximately two cases per 1000 live births in white, non-Hispanic infants while occurring less frequently in African-American and Asian populations. While the reason for a gender bias is unknown, HPS has been found to be more common in males than in females with some studies reporting a ratio of up to 5:1.

Infants with HPS present with an abnormally thickened pylorus resulting in a narrowed and elongated pyloric channel, which eventually leads to a gastric outlet obstruction. The pathogenesis of HPS is related to a tonically and phasically contracting pyloric sphincter. In infants with HPS, the enteric nervous system, gastrointestinal hormones, and interstitial cells of Cajal are all affected. Abnormalities in each of these systems lead to a failure of relaxation of the pyloric muscle, increased synthesis of growth factor, and subsequently muscle hypertrophy.

The etiology remains largely unknown. Although there is no known definitive factor for its cause, a multifactorial etiology with a strong but not definitive hereditary component has been suggested. Multiple prenatal and postnatal environmental factors have also been implicated. These factors include prenatal exposure to thalidomide, hydantoins, and trimethadione and postnatally to erythromycin. Some studies also suggest an association with maternal smoking, low maternal age, infants delivered by cesarean section, and preterm birth. Bottle-feeding has also been shown to be associated with an increased risk of HPS particularly in older, multiparous mothers.

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Presentation and Diagnosis

The most common presentation of HPS is that of a term, otherwise healthy, infant with non-bloody, non-bilious emesis. Bilious emesis is unlikely in these patients as the hypertrophied pylorus prevents bile reflux. Most infants present with a several-day-to-week history of increasingly frequent and more forceful emesis, which is often described as projectile. Prior to the projectile emesis, many of these infants will be diagnosed with gastroesophageal reflux or a milk protein allergy, and it is not unusual for the infant to have been started on multiple different formulas, an H2 blocker or proton pump inhibitor. Infants with HPS do not usually appear ill and often remain hungry after the emesis.

As the gastric outlet obstruction worsens, a delay in diagnosis will often lead to severe dehydration. These infants will present clinically with lethargy, depressed fontanelles, dry mucous membranes, and poor skin turgor. Parents will describe a history of dry diapers or the absence of tears when the baby cries. More than 90 % of all infants with HPS present before the 10th week of life with a peak occurrence at 3–6 weeks. Premature infants are diagnosed on average 2 weeks later than term infants.

Non-bilious, projectile emesis associated with a hypochloremic, hypokalemic metabolic alkalosis and a palpable "olive" in the epigastric area are classically described hallmark features of HPS. Loss of large amounts of gastric fluid leads to volume depletion and loss of sodium, chloride, hydrogen ions, and potassium. The kidneys then attempt to maintain normal pH by excreting excess bicarbonate. The kidneys also attempt to conserve sodium at the expense of hydrogen ions, which can lead to a paradoxical aciduria. Careful physical examination with palpation of the hypertrophied pyloric muscle has been shown to have a positive predictive value of 99 %. A good physical exam usually requires a 5–20 min time commitment in order to calm the baby enough to adequately palpate the olive in the midepigastrium.

P. Mattei et al. (eds.), *Fundamentals of Pediatric Surgery*, DOI 10.1007/978-3-319-27443-0_44

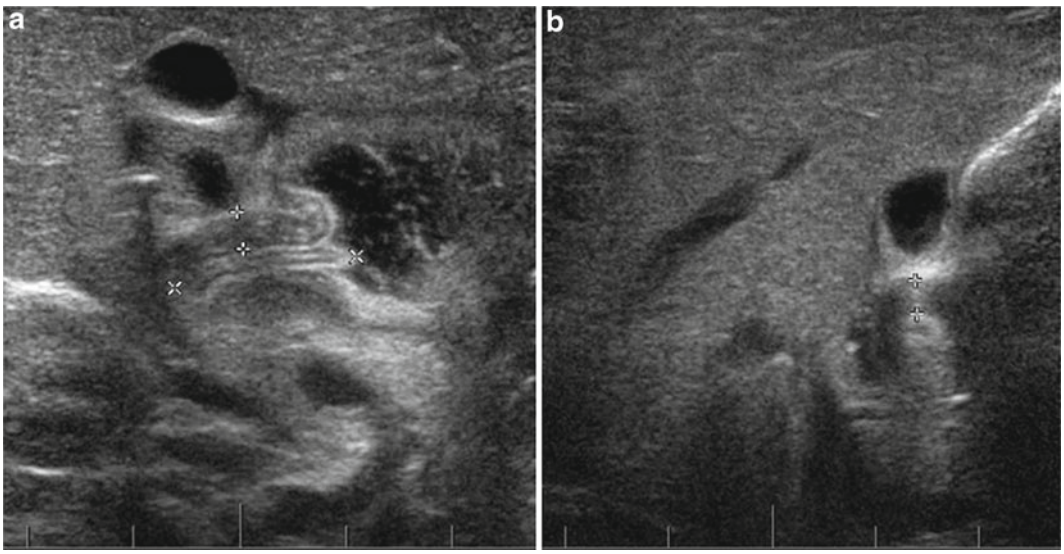

Fig. 44.1 Ultrasound images of a 3-week-old infant with HPS. (**a**) A longitudinal view with a pyloric length of 18 mm and a pyloric muscle thickness of 3.9 mm. (**b**) Transverse view demonstrating the pyloric muscle thickness

Although less cost-effective, an abdominal ultrasound (US) has been associated with an accuracy approaching 100 % and has become the most common initial imaging technique and the diagnostic modality of choice for HPS. Pyloric muscle thickness greater than 3–4 mm and a muscle length of greater than 15–18 mm are the accepted criteria for US evidence of HPS (Fig. 44.1).

If US is not available, a fluoroscopic upper gastrointestinal (UGI) contrast study may be considered. In order to avoid a chemical pneumonitis in the case of aspiration, barium is generally preferred. In HPS, the UGI will demonstrate an elongated pyloric channel outlined by a "string" of contrast material in addition to protruding "shoulders" of the muscle into the antrum (Fig. 44.2). In the absence of both a "string sign" and shouldering of the pyloric muscle, the diagnosis of HPS cannot be made with certainty. This is because pylorospasm can produce a transient complete gastric outlet obstruction. Another useful sign is a double-string sign or "railroad" or "double-track" sign due to the pyloric channel being compressed by a flattening of its lumen. Fluoroscopy is time consuming and involves radiation exposure both of which make US a more attractive and practical diagnostic approach.

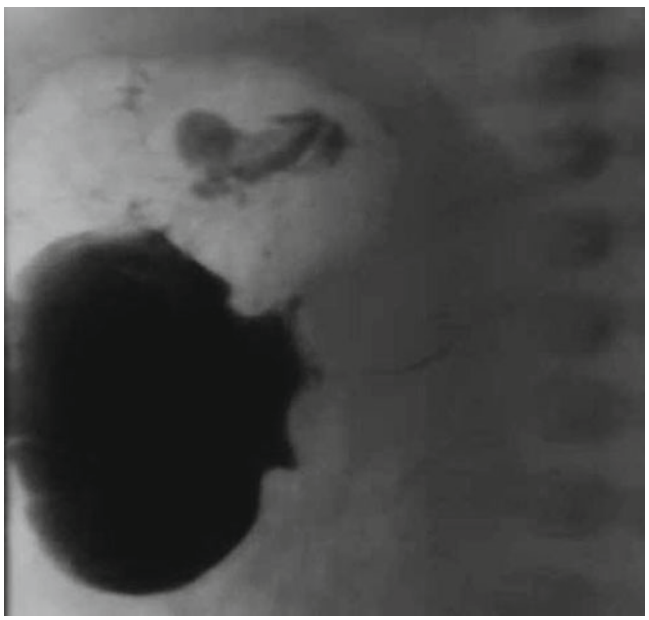

Fig. 44.2 Upper gastrointestinal study illustrating a "string sign" through the hypertrophied pyloric muscle

Preoperative Preparation

HPS is not considered a surgical emergency, and it is therefore imperative that all infants be adequately resuscitated in preparation for general anesthesia and surgical correction. Admission blood chemistries are analyzed for sodium, chloride, bicarbonate, and potassium. The majority of infants with HPS will present with a chloride-responsive, hypochloremic, hypokalemic metabolic alkalosis of varying severity depending on the duration of symptoms.

Oral feedings should be discontinued upon diagnosis and prompt intravenous access established. Nasogastric decompression should not be performed, as this worsens the electrolyte abnormalities. End points of resuscitation include adequate urine output of greater than 1.5 mL/kg/h and correction of the chloride level to greater than 100 mEq/L and bicarbonate level to less than 30 mEq/L. Our algorithm for

patients with HPS is to administer an initial IV rate of 1.5 times maintenance fluids of D_5 0.45 normal saline (NS) with 20 mEq/L until time of surgery. Additionally, we administer boluses of 10–20 mL/kg of 0.9 NS until the chloride and bicarbonate levels have normalized. While all but the most severely dehydrated patients at our institution reach their resuscitation goals well within the first 24 h, our practice is to allow at least one overnight stay prior to performing a pyloromyotomy. Adequate correction of the alkalosis prior to undergoing general anesthesia mitigates the possibility of alkalosis-induced apnea in the postoperative period.

Surgical Technique

After adequate resuscitation, the patient can be safely taken to the operating room for surgical correction of the pyloric stenosis. Prior to administration of general anesthesia, an orogastric (OG) tube is used to aspirate the stomach contents. This is particularly important if the patient received an UGI as part of the diagnostic workup. The OG tube will also be useful for instilling air into the stomach after completion of the pyloromyotomy to confirm the absence of a leak due to submucosal perforation.

There are currently two approaches to the same operative procedure: open and laparoscopic. The most successful procedure continues to be the Ramstedt extramucosal longitudinal pyloromyotomy, which can be safely performed with either approach. The muscle is split longitudinally allowing the submucosa to bulge out. This procedure is associated with excellent short-term and long-term outcomes. Muscle thickness returns to normal within 4 weeks and is associated with healing of the muscle and return of appropriate function.

Regardless of the approach, an appropriate myotomy extends from the pylorus to the circular muscles of the stomach proximally. Carrying the incision too far toward the duodenal side of the pylorus carries with it a higher risk of mucosal perforation. The adequacy of the myotomy can be confirmed once the two halves of the pylorus can be moved independently of each other. A silk suture cut to the approximate length of the hypertrophic pyloric muscle as determined by the preoperative US can also guide the surgeon in confirming an adequate myotomy length.

The open approach was historically performed through a transverse right upper quadrant (RUQ) incision but can be performed adequately through a periumbilical incision. The RUQ incision is made over the rectus abdominis muscle about two fingerbreadths above the umbilicus. The rectus abdominis muscle can be split or cut. The omentum can then be grasped and the greater curvature of the stomach pulled up until the pylorus is delivered through the wound. The hypertrophied pylorus should then be held between the thumb and the index finger of the nondominant hand. A longitudinal incision is made through the pylorus no deeper than the bevel on the scalpel blade. The muscle is then "cracked" by inserting the blunt end of the scalpel handle through the incision. A pyloric spreader is then used to gently spread the wound open from the distal pylorus to the antrum proximally. The wound length should be approximately 2 cm. At this point, one can usually easily see the bulging submucosa. The two edges of the muscle are then grasped and are moved independently in opposite directions to ensure an adequate myotomy. The anesthesiologist is then instructed to inflate the stomach with 60 mL of air through the OG tube, and the submucosa is checked for leaks.

The periumbilical pyloromyotomy is performed by first creating a semicircular incision in the supraumbilical crease. A skin flap is raised toward the xiphoid. The linea alba is then incised longitudinally and the abdominal cavity is entered. The omentum is then grasped and the greater curvature followed to the pylorus. The pylorus is gently exteriorized through the incision. The pyloromyotomy is carried out in similar fashion, as is the leak test. The pylorus is then returned to the abdomen and the fascia and skin reapproximated.

The laparoscopic approach has become increasingly popular since its description in 1991. After general anesthesia has been administered, the baby is rotated 90° on the bed so that the legs come off the edge of the bed and the laparoscopic equipment and monitors are at the head of the infant. The legs are taped in a frog-leg position to the edge of the bed, and a bump is placed at the level of the xiphoid to help retract the liver anteriorly and cephalad (Fig. 44.3). At our institution we simply press a hemostat into the center of the everted umbilicus allowing for blunt access through the center of the ring, which has not yet sealed in babies. A sheath is placed through the defect without a Veress needle and a 5-mm trocar placed through the sheath. We usually place the telescope through the sheath prior to insufflating with CO_2 in

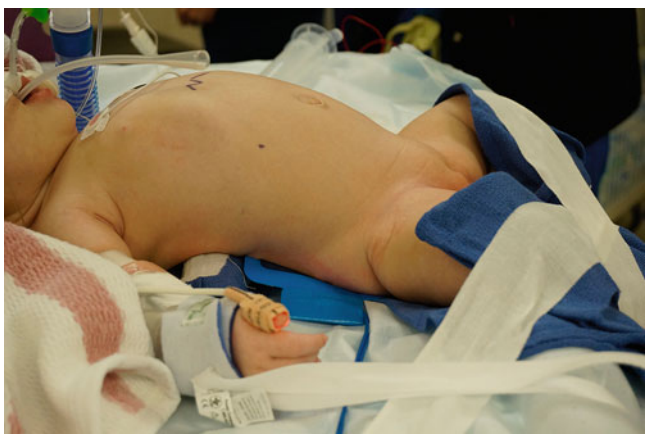

Fig. 44.3 Patient positioning for laparoscopic pyloromyotomy

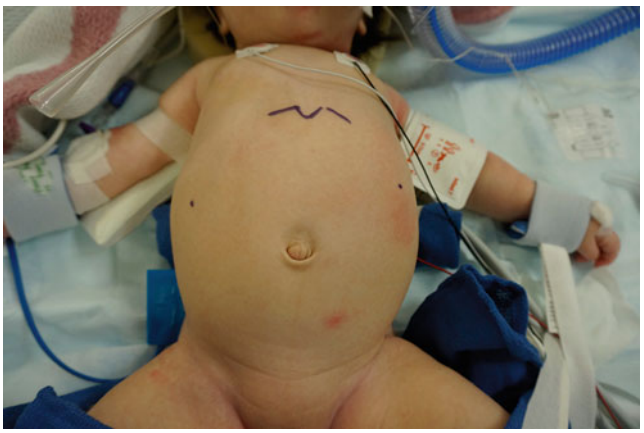

Fig. 44.4 The *marks* on the abdomen denote the stab incision sites

order to confirm placement into the abdomen and not into one of the umbilical vessels, which can lead to gas embolism. Pneumoperitoneum is then achieved to a pressure of 5–8 mmHg at a flow rate of 3–5 L/min. A 30° or 45° telescope is inserted through the umbilical port and two stab incisions are made, one in the right upper quadrant and one in the left upper quadrant (Fig. 44.4). A single-action laparoscopic grasping forceps is inserted through the patient's right side, and the duodenum is grasped just distal to the hypertrophied pylorus. A retractable arthrotomy blade inserted through the left upper quadrant incision was previously used to start the pyloromyotomy, but this instrument is no longer available. An extended cautery blade with an insulated tip inserted through the left side is now used instead (Fig. 44.5). The pylorus can be scored with or without the use of electrocautery. Once scored, the cautery blade can be used to bluntly create a space for the pyloric spreader. The pyloromyotomy is then completed with a laparoscopic pyloric spreader (Fig. 44.6). Each side of the divided muscle is then grasped and should move independently. A leak test is then performed. The omentum is then placed over the myotomy, the instruments removed under direct visualization, and pneumoperitoneum relieved (Fig. 44.7). The two stab incisions are dressed with Steri-Strips, and a single 3-0 absorbable suture is used to close the umbilical fascial ring (Fig. 44.8).

The documented benefits of the laparoscopic approach over the open approach include less frequent postoperative emesis, shorter time to achieve full feeds, less pain, shorter postoperative hospital length of stay, improved cosmetic results, fewer wound complications, and decreased overall costs. The overall incidence of perioperative complications related to either approach is approximately 5 %. With the exception of a slight (less than 1 %) increase in the incidence of incomplete pyloromyotomy in the laparoscopic approach, the risk of most perioperative complications including mucosal perforation is indistinguishable between the two approaches. Some have promoted the use of a 2-cm length of suture to measure the length of the myotomy intracorporeally to achieve a zero incidence of incomplete pyloromyotomy by the laparoscopic approach.

The overall incidence of mucosal perforation, the most feared complication associated with this operation, ranges from 0.4 to 3.6 % with either approach. Traditional surgical dogma dictated that in cases of mucosal perforation, the appropriate course of action was to close the myotomy, rotate the pylorus 90°, and redo the myotomy. Secondary to limited rotation of the pylorus, a more practical and easier approach is to repair the mucosa primarily with an absorbable suture followed by placement of an omental patch. This can be done open or laparoscopically. Postoperative care is similar with the exception of delaying feeds for at least one day. In these patients at our institution, we employ nasogastric decompression for 24 h and obtain a limited UGI prior to starting feeds after 24 h.

Postoperative Care

Historically, the practice of delayed feeding has been presumably fostered by the need to avoid postoperative emesis, the purpose of which is unclear since these infants have already clearly demonstrated the ability to safely vomit. A recent randomized controlled trial from our group compared an ad libitum feeding regimen to a delayed, regimented feeding schedule consisting of two rounds of clear liquids followed by two rounds of half strength formula or breast milk and finally ad lib feeds. The primary outcome variable in this study was duration of postoperative hospital stay which was not statistically different between the two groups. Of note, there were more episodes of emesis in the ad lib group after goal feeding was reached, but there was no difference in readmission rates between the two groups. Average postoperative time to discharge for both groups was 25 h.

Our feeding protocol consists of initiation of feeds as soon as the baby is awake enough to drink. We generally feed 60 mL of formula or breast milk every 2–3 h for at least two feeds and then transition to ad lib feeds with a minimum of 60 mL per feed on most babies. Emesis does not delay or preclude the subsequent feeding 2 h later. Babies are then discharged to home once they can tolerate three consecutive feeds without emesis.

Editor's Comment

Considered by some as yet another example of a lost art, palpating the olive has become impractical for several reasons—to be successful it requires the use of a nasogastric tube, which is painful, distressing, and no longer routine in infants with HPS; it is time-consuming and uncomfortable;

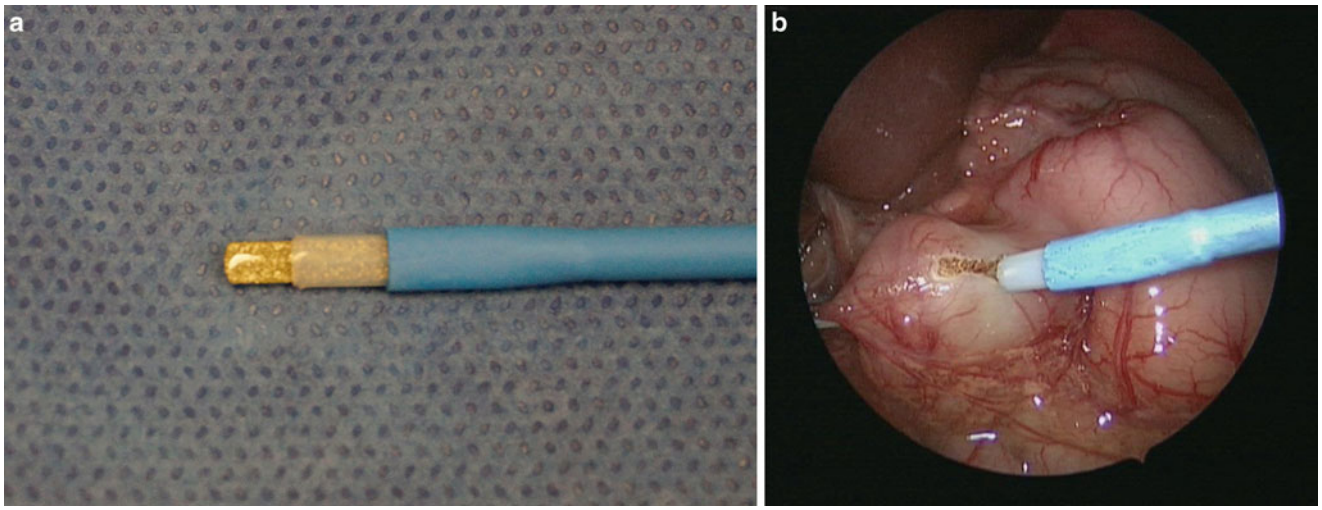

Fig. 44.5 (**a**) Cautery blade with insulated tip (**b**) Cautery blade with an insulated tip scoring the serosa over the hypertrophied pylorus

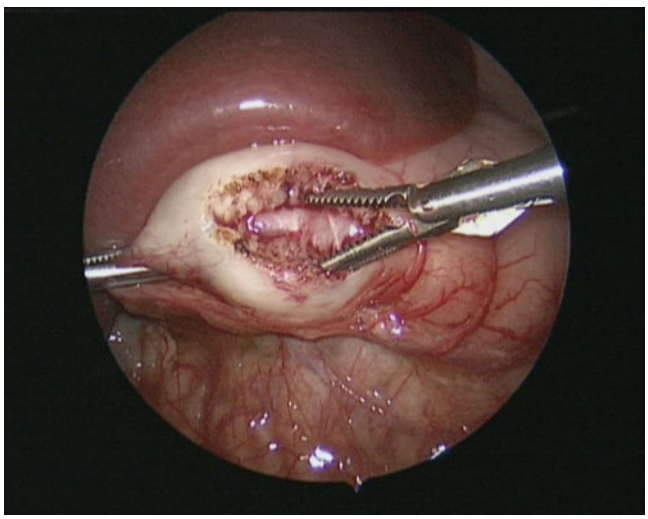

Fig. 44.6 Hypertrophied pyloric muscle after being split with the spreader

it is not especially accurate; US is a quick, painless, accurate, and relatively inexpensive alternative; and, perhaps most importantly, the surgeon is rarely called upon to make the diagnosis of HPS anymore, but rather is usually called after the diagnosis has been established by US. Nevertheless, surgeons should examine every infant after induction of anesthesia to confirm the diagnosis and gain experience with the technique. An upper GI is performed if the diagnosis is in question (bilious emesis, atypical presentation) or if the US is equivocal. Idiopathic hyperbilirubinemia was considered commonplace in infants with HPS but is now rarely seen, perhaps because patients present much earlier now. Prior to induction of general anesthesia, gastric contents must be aspirated thoroughly to prevent massive aspiration, which still carries a significant risk of morbidity (hypoxic brain injury) and even mortality in these vulnerable infants.

Given the availability of US, the diagnosis is being made earlier, with some 2-week-olds presenting having had one emesis. In these younger infants,US can be equivocal as the normal ranges were developed long ago using older controls and can be repeated in 2–3 days if the diagnosis is still in doubt. The operation can also be much more difficult because these pylori, though thicker and longer than normal, are still pliable and do not "crack" like they used to. This could lead to more recurrences and perforations. Preoperative hydration seems to be less of an issue partly because of the earlier presentation but also because anesthesiologists have liberalized their criteria, with most now accepting a bicarb of 29–30 rather than 25–26. The concern about apnea is somewhat theoretical, and the safe CO_2 level has never actually been rigorously studied.

The right upper quadrant incision was commonly employed in the past, perhaps because infants presented very late and their hugely dilated stomachs displaced the pylorus into the RUQ. But because the pylorus is actually a midline structure and the RUQ scar becomes large and unsightly in adulthood, one should *never* use a RUQ incision for pyloromyotomy. The laparoscopic and periumbilical approaches are both excellent, but the laparoscopic approach is clearly superior for a number of well-established reasons. Insufflation with a Veress needle can cause a gas embolism and is not necessary anyway, as every infant has an umbilical ring that can be dilated with a hemostat to allow easy passage of a small trocar. Many feel that grasping the stomach with the right-hand instrument and incising the pylorus with the left hand is safer than grasping the more delicate duodenum with one's nondominant hand, but either is acceptable.

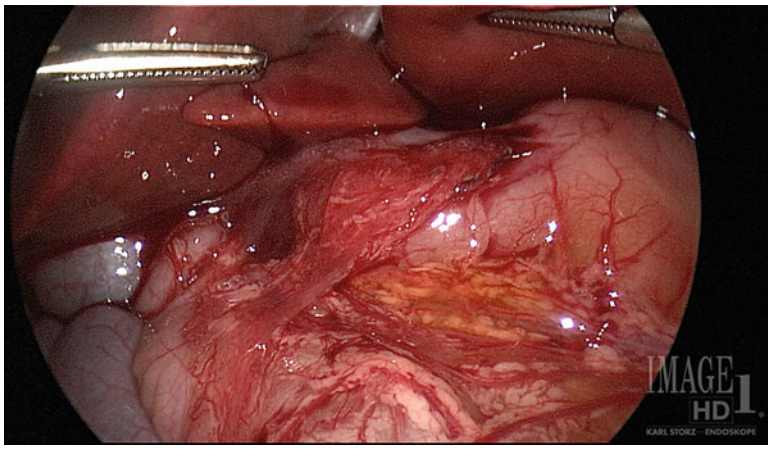

Fig. 44.7 Omental patch placed over myotomy

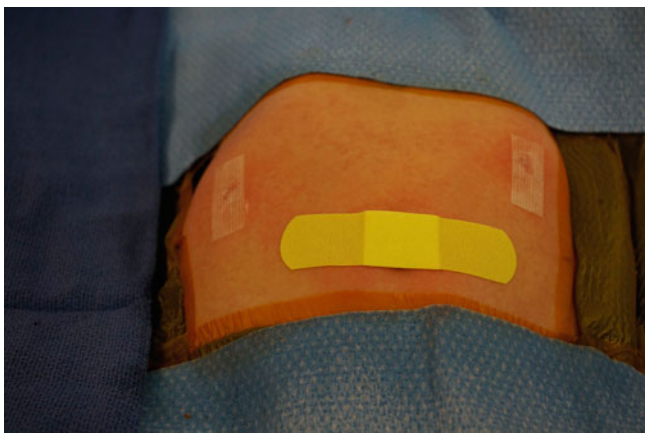

Fig. 44.8 Postoperative dressings, Steri-Strips over the stab incision, and a non-occlusive umbilical dressing

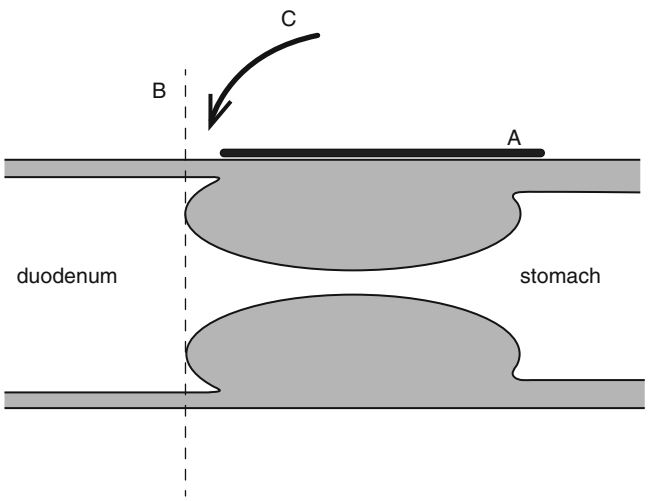

Fig. 44.9 Schematic diagram of the hypertrophic pylorus in longitudinal cross-section. **A** represents the correct length of the pyloromyotomy. **B** is the apparent end of the pylorus based on where the bulge of the muscle is perceived when viewed externally. **C** is the point where the mucosa can be injured if the pyloromyotomy is extended too far onto the duodenum. There is less of a risk of perforation on the gastric side because the gastric wall is thicker and the angle between the mucosa and the intraluminal portion of the pylorus is less acute

The most common serious technical error is overly aggressive splitting of the pyloric muscle fibers on the duodenal side, where the bowel wall is thin and the bulging of the muscle into the lumen creates an angle that is prone to perforation (Fig. 44.9). A wise adage suggests that recurrence is more likely on the gastric side (incomplete myotomy), perforation on the duodenal side (aggressive myotomy). Perforations identified at the time of the operation are a minor complication; if not recognized until the next day, they can be quite serious. Usually a small pinhole in the corner of the myotomy, these can usually be repaired with an absorbable mattress stitch that begins and ends on the serosa of the bowel. Reinforcing it with an omental patch probably adds little but is harmless. Closure of the myotomy and rotating it 90° to make another myotomy is excessive and unnecessary except in the very rare situation of a long rent in the submucosa that cannot be repaired with one or two mattress stitches.

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Surgical Enteral Access

45

Tim Weiner and Melissa K. Dedmond

Surgical access to the GI tract for the direct administration of food and medications is a common procedure familiar to most surgeons. While the technical aspects are straightforward, careful selection of patients and attention to surgical details will reward the patient, the family, and the surgeon with greater satisfaction and fewer postoperative complications. Indications for placement of a gastrostomy tube are varied and increasing: (1) inability to take sufficient oral nutrition or failure to thrive, (2) presence of pharyngeal or esophageal pathology, (3) the need to carefully titrate enteral feeds, (4) excessive metabolic demands or risks of oral feeding, (5) the need to administer unpalatable diets or medications over a long period, and (6) the need to decompress a portion of the GI tract.

Often, the decision has been more or less finalized by a primary care or referring physician, but it is appropriate for the surgeon to carefully review the indications, frankly discuss contraindications, and extensively prepare the patient and family for the operation and postoperative care. To this end, we ask the family to review a short video that discusses the G-tube from their perspective and provides them with a resource to review when they encounter questions or problems at home. In addition, our nurses provide extensive one-on-one teaching. We find that this intensive preoperative preparation has made families much more independent in the care of their child's G-tube and significantly decreased the number of phone calls and visits to the surgical clinic.

The decision to place a G-tube immediately raises questions of anatomy and pathology, and a limited but focused investigation is recommended. Some still routinely obtain an upper GI contrast study to characterize the foregut anatomy, as esophageal lesions, microgastria, gastric outlet obstruction, or malrotation might necessitate changes in the operative plan. Most surgeons also prefer to assess whether the child has clinically significant GERD. Although a thorough history and UGI is usually sufficient to resolve this issue, in some cases a pH probe or impedance study is felt to be necessary. Assuming the work-up is unremarkable, the patient is prepared in a routine manner for either open, laparoscopic, or percutaneous endoscopic gastrostomy (PEG). If there are concerns about GERD, an antireflux procedure or a more distal feeding access, such as a surgical jejunal tube, should be discussed. While some surgeons feel that placement of a gastrostomy can alter the gastric anatomy in ways that create or worsen GERD, there are no data to support the need for an antireflux operation with every gastrostomy. Should the GERD become more significant after gastrostomy, a subsequent fundoplication can still be performed, though the gastrostomy might have to be resited to allow for a full fundoplication.

In our practice, we prefer an open or laparoscopic technique and usually attempt to place a low-profile balloon-tipped button as the initial access. Unless the tube is being replaced through an established tract, we do not routinely use the PEG technique in order to avoid the rare but significant misadventures that can occur, such as liver injury, gastrocolic fistula, tube misplacement, or dislodgement into the peritoneal cavity. In children who need more distal enteral access, we generally use a Roux-en-Y feeding jejunostomy for ease of care and durability. A Witzel-type jejunostomy is a functional option but presents more challenges for long-term use: balloon obstruction, malposition, kinking within the bowel lumen, and loss of the access tract.

Open Gastrostomy

First described in the late 1800s, the Stamm gastrostomy remains a technically simple and safe operation for uncomplicated enteral access in children. A 2-cm upper midline or

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left subcostal incision is made and the anterior aspect of the stomach is identified. Our preference is to site the gastrostomy to the left of the incisura and near the greater curvature. This position limits tension on the gastric outlet and GE junction, reduces the likelihood of inadvertent placement of the tube across the pylorus into the duodenum, allows for a better trajectory if a postpyloric feeding tube is required, and does not fix the stomach at a difficult angle should a fundoplication be needed later.

We find that a single 3-0 purse-string suture at the gastrotomy site is sufficient in most cases and does not compromise a small gastric lumen. A 5–8-mm stab incision is made in the left upper abdomen being careful not to raise flaps. The exit site is chosen to avoid apposition of the tube on the coastal cartilages; in infants, one finger breadth from the lowest rib and one finger breadth from the midline incision work well. A 10–14 Fr low-profile device with a stem length estimated to account for abdominal and stomach wall thickness (usually 1.2 or 1.5 cm in infants) is carefully brought through the incision. A Malecot or Pezzer tube is used if a low-profile device cannot be placed at the initial surgery.

A small gastrotomy is made with electrocautery within the purse string, entry into the gastric lumen is confirmed, and the tube is maneuvered into the stomach, taking care to avoid a submucosal dissection. The balloon is filled (or the tube flange is snugged against the inner stomach wall) and the purse string is secured. Two to four 3-0 seromuscular stitches are placed close to the gastrostomy, being careful to avoid puncturing the balloon and then to the tube exit site within the abdomen in order to bring the anterior stomach and peritoneal surfaces into secure apposition. One or two nylon sutures are used to secure the tube to the skin and removed in 4–7 days. We typically test the tube for proper function in the operating room under direct observation before closing the incision. Use of the tube begins the following morning. Malecot or Pezzer tubes are replaced with a low-profile device after the tract has matured for 3–4 weeks.

Laparoscopic Gastrostomy

Laparoscopy can be used to guide the placement of a gastrostomy tube as a stand-alone procedure or as an adjunct to an endoscopic approach. It is also performed as part of a laparoscopic fundoplication. The anticipated exit site is determined and marked prior to insufflation, which distorts the surface anatomy. A 3- or 5-mm port and 30° laparoscope are introduced through a small umbilical incision. A second incision is made at the predetermined tube exit site, and a 3- or 5-mm atraumatic grasper is passed directly through the abdominal wall.

As in the open technique, the gastrotomy site is selected near the greater curvature on the stomach body, and the mobility of this area to the abdominal wall is tested. While preloaded, single-use T-stabilizers may be used, we prefer the placement of two heavy polypropylene U-stitches through the abdominal wall to capture the anterior stomach. This maneuver requires some degree of finesse in order to properly position the sutures lateral to the anticipated gastrotomy while traversing the seromuscular of the anterior stomach wall with enough purchase to hold it under tension. A pronounced supination-pronation as the needle is driven in a cephalad to caudad direction helps considerably. Using the stomach grasper to position the stomach as a target helps place the sutures (Fig. 45.1).

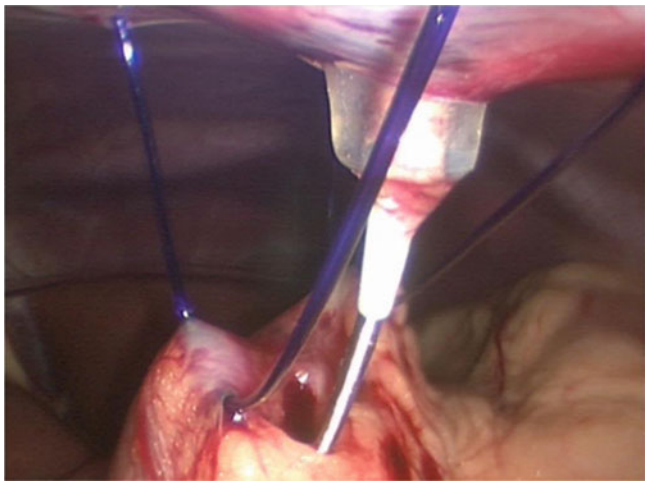

Fig. 45.1 Laparoscopic placement of a gastrostomy button device. Notice the transabdominal monofilament tacking sutures and the Seldinger technique using the small dilator to guide the button into the gastrotomy

These sutures are then tagged with a clamp, and a needle Seldinger technique is used to cannulate the stomach lumen between the U-stitches. The tract is then enlarged sequentially with dilators up to 16 or 20 Fr. An appropriately sized button is then loaded over the smallest dilator or within the peel-away device and passed into the stomach lumen. Successful placement is often registered with a distinct pop when the balloon enters the stomach. The balloon is inflated, the sutures are tied over the external flanges of the button, and the tube is tested with air under laparoscopic visualization to confirm intraluminal position. The tube can be used within 24 h, and the sutures can be removed in 4–7 days, before foreign body irritation occurs. If a peel-away system was used, some surgeons suggest confirmation of stomach cannulation by passage of the scope through the peel-away sheath. Endoscopy can also be used to confirm proper GT positioning.

Surgical Jejunostomy

In situations where postpyloric enteral access is indicated, a surgically placed tube can be created either as a side-entry (Witzel) tube, as a Roux-en-Y, or by a laparoscopic technique.

Our group feels that the Roux-en-Y is the best option in terms of ease of care, replacement, and durability. The Witzel technique is familiar to most surgeons and simply involves placing a small caliber tube, such as a 10 or 12 Fr Malecot catheter through a proximal jejunal enterotomy on the antimesenteric side of the bowel. A 3-0 purse string is used to hold the tube in place, and advancing the tube into the lumen for an additional 4–10 cm helps to secure it and prevent dislodgment. Some surgeons recommend creating a short serosal tunnel with imbricating sutures over the tube and along the long axis of the bowel. The tube then exits the abdominal wall at a selected site, and the bowel serosa adjacent to the tube is tacked to the peritoneum of the exit site.

The Roux-en-Y is typically done through a midline epigastric incision. The orientation of the small bowel is determined, and a jejunal loop 10–20 cm from the duodenal-jejunal junction is located. The small bowel is divided at this point and an end-to-side anastomosis is created distally. We find that a 5–10-cm Roux limb is usually sufficient. A 3-0 purse-string suture is then placed adjacent to the staple line at the blind end of the Roux limb. A Malecot tube or button device is then brought through the abdominal wall, an enterotomy is made within the purse string, and the tube is passed into the bowel lumen as the purse string is secured. Tacking sutures are placed and the tube is secured externally with a nylon suture.

The Roux-en-Y has the advantages of creating a straight trajectory for tube replacement and poses little risk of bowel occlusion with a balloon device. Overfilling a balloon, however, can precipitate pressure necrosis of the bowel wall, and caregivers should be carefully advised to avoid this hazard. There is also a risk of volvulus around the Roux limb, which can present as a bowel obstruction, or in the neurologically impaired child with bowel necrosis and profound sepsis.

Laparoscopic Witzel and Roux-en-Y using a combination of the Seldinger technique and extracorporeal anastomoses have been described. These are technically feasible and follow the same principles of an open technique but may entail the usual laparoscopic learning curve.

Percutaneous Endoscopic Gastrostomy

In our practice, we rarely use the endoscopic-assisted approach. The endoscopist views the anterior aspect of the stomach and places the camera light against the anticipated entry site. This is confirmed externally with the operating room lights dimmed. Insufflation of the stomach also facilitates the exclusion of colon and liver from the intended cannulation trajectory. A needle is passed through the intended gastrostomy site and visualized by the endoscopist. Premade kits include a wire which is passed through the needle and a snare used by the endoscopist to capture the wire. The wire is then drawn out through the patient's mouth by the scope, and a mushroom-flanged PEG tube is passed over the wire in a "push" technique through the patient's mouth, captured at the tube exit site and pulled through the abdominal wall. The tube is secured by placing an outer flange against the skin while the endoscopist confirms the tube's position. The tube can be replaced with a low-profile button device when the tract is mature, usually at 4–6 weeks later.

Postoperative Care

Optimal management of surgical gastrostomies is achieved through a coordinated approach involving the surgical team, nursing staff, and patient caregivers. Routine maintenance includes ensuring the child has a properly fitted, functioning gastrostomy device and careful peristomal skin care. Approximately, 85 % of children will eventually have a low-profile or skin-level balloon device placed after surgery. Gastrostomy tubes come in a variety of diameters and stem lengths, depending on the manufacturer. The tube should be able to rotate freely within its tract, with at least a few millimeters between the patient's abdomen and the outer flange. Tube size and stem length are adjusted according to the thickness of the abdominal wall and depends on weight gain and activity level, typically requiring frequent adjustments in the first year.

Low-profile balloon devices typically last 4–6 months with replacement being necessary due to the patient outgrowing the tube, a slowly leaking balloon, or rupture of the balloon, all of which can cause leakage, a loose tube, or dislodgement. Patients with balloon devices benefit from periodic assessment of the amount of water in the balloon. A small infant might need less water in the balloon depending on their size. Balloon devices can be replaced easily in the office setting; caregivers can also learn how to perform replacements at home. Alternatively, the non-balloon devices with soft silicone domes (Bard buttons) are advantageous because they can last a year or more and are much more difficult to dislodge accidentally and their flatter external appearance is more appealing to some adolescent patients. However, they are more difficult and painful to replace and malfunction more often, and the one-way valve tends to leak more.

Minor gastrostomy complications are common but usually respond to interventions that can be safely performed at home: gastrostomy leakage, accidental dislodgement, granulation tissue, and skin erosion. Educating caregivers on preventive strategies can result in fewer clinic visits and improved quality of life for patients with long-term enteral access.

Leakage from the gastrostomy site can occur for a variety of reasons including improper tube fit, inadequate volume of water in the balloon, enlargement of stomal site due to poor

wound healing, or excessive tension on the site. If the cause of the leakage is due to an enlarged stoma, the tube should be replaced with a *smaller* Foley catheter (two French sizes smaller) into the site for 24–48 h, which allows the hole to contract creating a more secure fit of the gastrostomy tube. Another option is removal of the tube for several hours to allow downsizing of the tract. Some caregivers are comfortable doing this at home, although this is most safely performed in the office or inpatient setting.

Infants and children with poor gastric motility or small stomach size can experience gastric distension with high volume enteral feeds or bolus feeds; formula may take the path of least resistance and seep out around the gastrostomy site. This problem can be alleviated with low-volume continuous feeds, which is better tolerated by many patients. Additionally, leakage coming from the opening of the gastrostomy device indicates malfunction of the one-way valve and warrants replacement of the device. Regardless of the cause of the leakage, the surrounding skin should be protected with a good barrier cream along with a gauze dressing that is changed frequently to keep the skin dry.

Accidental tube dislodgement can occur if there is little or no water in the balloon or if the tube is forcefully jerked or accidentally caught on another object. Proper education on what to do if the tube comes out can be extremely helpful in preventing frantic caregivers facing this situation. Sending patients home with an emergency kit can lessen caregiver anxiety and, moreover, prevent partial or complete closure of the gastrostomy tract, which can occur within several hours. The emergency kit should include Foley catheters that are smaller in diameter than the gastrostomy device. If the tube becomes dislodged in the initial postoperative period, the tube should be gently reinserted as soon as possible, and because a mature tract may not have been established yet, surgical consultation should be obtained prior to resuming enteral feeds. After the tube is replaced, a radiologic tube study should be performed to verify correct positioning within the stomach. Replacement of a tube in a mature tract does not require radiologic confirmation, as long as the tube is replaced into the gastrostomy site without resistance, enteral feeds flow into the stomach by gravity, and gastric contents can be aspirated to confirm correct positioning. Tubes that have been dislodged for a long time often require serial dilation of the tract with smaller diameter tubes, until the previous gastrostomy tube can be reinserted easily.

Granulation tissue is at the insertion site is a common problem. Although the exact etiology is not entirely clear and likely multifactorial, it is likely to be a foreign body reaction to the tube itself. Granulation tissue is commonly seen with new gastrostomies, in patients with poor wound healing, and in patients who have excessive tension or moisture at their gastrostomy site. Chemical cautery with silver nitrate applicator sticks is the traditional treatment for granulation tissue; this can be performed once daily or every other day with the use of topical anesthetic prior to treatment if necessary. Triamcinolone steroid cream is a less traumatic alternative, although more tedious as the cream is applied three times a day until the granulation tissue resolves. Severe overgrowth of granulation tissue unresponsive to the above measures might need to be debrided in the operating room using electrocautery for more definitive therapy. Decreasing tension at the gastrostomy site by securing extension tubing with tape over the rib area prevents trauma to peristomal region when the tubing is accidentally tugged or pulled. Moreover, keeping the site clean and dry and ensuring proper tube fit are important techniques to aid in prevention of granulation tissue.

Skin erosion is often due to excessive tension or leakage from the gastrostomy, as gastric secretions can excoriate the surrounding skin. Skin barrier creams with zinc oxide provide a good barrier to protect against constant moisture and acidic drainage. Over-the-counter zinc oxide cream works well; we prefer Critic-Aid barrier cream. Calmoseptine cream, a zinc oxide and menthol mixture that promotes skin healing, can be particularly helpful on chapped, excoriated skin. Antifungal creams and powders (Nystatin) are useful when patients develop an erythematous, yeast-like rash with multiple satellite lesions extending outward from the G-tube site.

Many caregivers are inclined to apply antibiotic ointments to the gastrostomy site; however, gastrostomies rarely become infected. Tender erythema surrounding the gastrostomy site suggests the possibility of G-tube cellulitis, which is most commonly seen in the initial postoperative period, particularly when the nylon sutures are still in place. This can be effectively treated with short-term oral or IV antibiotics and suture removal as early as possible.

An additional problem, although rare, is gastric mucosal prolapse at the gastrostomy site. Gastric mucosa is sometimes difficult to distinguish from granulation tissue and often requires operative management. A reddened G-tube site is often a reminder that a child has an ill-fitting device or that proper site care needs to be reinforced with the caregiver.

Tube Removal

When an enteral feeding tube is no longer needed, it can usually be removed safely in the office and the site allowed to close spontaneously. Tubes that have been in place for more than about a year sometimes fail to close on their own, in which case they might need to be closed surgically. Techniques vary, but the gastrocutaneous fistula is usually excised and the wound closed in layers, essentially the same approach used for any enterostomy. Tracts that are allowed

to close prematurely need to be replaced. Though this might need to be done surgically, the tract can usually be cannulated or a wire can be passed under fluoroscopic guidance and the tract dilated sequentially until a tube can fit through the tract. If the hole is big enough, a very small Foley catheter can be placed in the office or the Emergency Department, and then the tract can be dilated with a series of gradually larger catheters until a gastrostomy tube can be placed safely. Naturally, if there is *any* question as to the proper placement of the tip of the catheter, a tube contrast study must be performed prior to starting feeds.

The key to achieving exceptional gastrostomy care and function is comprehensive caregiver education, which begins in the preoperative phase. We use a 30-min teaching video to help caregivers gain a better understanding of what to expect during their child's hospital admission and postoperative management and to demonstrate core skills related to site care and the best way to trouble-shoot complications. This video has played an integral role in reducing the number of clinic and emergency room visits, as it empowers caregivers and gives them the knowledge to handle many of the low-acuity complications at home.

Editor's Comment

Given the huge emotional and psychological implications inherent in the decision, agreeing to proceed with gastrostomy or jejunostomy is often very difficult for parents. Though technically a relatively minor procedure for most surgeons, caregivers should be treated with empathy and patience as they struggle with what for them might be a life-changing event.

The laparoscopic approach has been refined and is probably the safest and most comfortable approach. Most surgeons use some modification of Georgeson's technique. Using absorbable U-stitches that are buried under the skin tacks the stomach securely to the fascia and obviates the need for external stitches around the flange of the button. There is no reason in this day and age to use an old-fashioned Malecot or Pezzer catheter. They are usually made of latex, they need to be secured to the skin with sutures and complex contraptions involving adhesives and a large wafer, and they are not user friendly. There is no reason to avoid placement of a primary button, and if, usually for some technical reason, a button cannot be placed, a Silastic gastrostomy tube with a balloon and proper valves and connectors should be used instead.

A cleanly placed gastrostomy requires, at most, a simple 2×2 split-gauze dressing; tape and bulky dressings are not necessary. Contrary to conventional teaching, G-tube cellulitis does occur on occasion, but the signs and symptoms are easily dismissed as being due to skin irritation or local trauma, and the diagnosis is nearly impossible to confirm objectively. A G-tube site that is erythematous, indurated, and tender should usually be assumed to be infected and treated empirically with antibiotics. Some surgeons are uncomfortable with this admission of a possible complication without hard evidence, but appropriate patient care obviously supersedes these concerns.

Leakage is also a common and frustrating problem that is rarely due to the tube itself. It can be due to poor positioning of the gastrostomy (too close to the pylorus) but is more often due to poor gastric emptying or distal obstruction. Placing a smaller tube will sometimes allow the hole to contract down, but a larger tube almost always makes the hole bigger and the leakage worse. When the site becomes enlarged and leaks heavily, closure and re-siting the tube is necessary.

Closure of a gastrocutaneous fistula should be a simple outpatient procedure without having to resort to a laparotomy or even laparoscopy. The fistula can be excised using a transverse elliptical incision, dissected down to just below the fascia, and ligated at its base (on the stomach). The fascia is then closed over it and the wound closed in layers. It is important not to place the gastrostomy too close to the costal margin, as the costal margin advances inferiorly as kids grow. Tubes that are right up against the lowest rib cause pain and often need to be re-sited. Usually at or inferior to a point midway between the umbilicus and the costal margin and just lateral to the rectus, sheath works well.

Surgical jejunostomies are fraught with complications and should be avoided unless all other options have been exhausted. The Roux-en-Y is more practical than the Wetzel, but there is a significant risk of volvulus around the Roux limb, which has been lethal for patients who are impaired and unable to alert others about abdominal pain. The new 12 Fr buttons work well and do not obstruct the lumen in teenagers, allowing J-tubes to be placed laparoscopically using the same technique as for gastrostomy.

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Duodenal Atresia

46

Andrew R. Hong

The duodenum is the most common location for neonatal intestinal obstruction to occur, and duodenal atresia (DA) and duodenal stenosis (DS) are by far the most common cause of obstruction at this site. The condition is frequently suspected prenatally, since the characteristic sonographic findings are easily interpreted and polyhydramnios is almost always present. Thus, this condition will frequently lead to prenatal consultation with a pediatric surgeon. Fortunately, it is a condition for which the therapeutic options are relatively straightforward and associated with a high rate of long-term success.

The overall incidence of duodenal atresia and stenosis has been estimated to be 1 in 6000–10,000 live births. The obstruction occurs between the second and third portions of the duodenum, in the region of the ampulla of Vater. In most cases, the obstruction is complete and the condition is called duodenal atresia. The two blind ends are usually close together, sometimes with a small bud of pancreas interposed between them (Fig. 46.1). There is often a significant size differential between the proximal and distal ends. Rarely, the ends are separated by a significant gap. If the obstruction is incomplete, it is termed a stenosis. In these cases, there is usually a web across the lumen at the level of the ampulla, with a central perforation that allows transit of air and some enteric contents. There is not always a significant size differential across the web, which can make it difficult to identify the exact location of the web at surgery. If the opening in the web is not very restrictive, the infant might be asymptomatic at first and diagnosis delayed.

The generally accepted hypothesis for the etiology of this condition is a failure of recanalization of the primitive foregut after the normal phase of epithelial proliferation that leads to a temporary obliteration of the lumen. This obliteration and recanalization process is unique to the foregut and indeed different than the ischemic process purported to cause jejunal or ileal atresia. Nevertheless, the true cause is unknown.

Prenatal Consultation

The vast majority of cases of duodenal atresia will be suspected by antenatal ultrasound. The obstruction occurs early in fetal life and is located proximally in the GI tract. Lack of normal absorption of swallowed amniotic fluid leads to polyhydramnios, and the stomach and proximal duodenum become dilated, a condition that is easily recognized on fetal US. Parents of a fetus with suspected DA should be referred to a pediatric surgeon for consultation, during which a number of topics should be covered. An explanation of the problem is obviously in order. The need for surgical repair shortly after birth must be made clear. The details of the operation can be reviewed to a certain extent. Sophisticated parents may want to know if the procedure can be done laparoscopically and whether the surgeon has experience with this method. The expectations for length of stay in the NICU must be managed, as it can take an infant days or weeks to reach full enteral feeds after surgery.

The association with other anomalies should be reviewed. Many mothers will have already undergone an amniocentesis, so the chromosomal status of the child will be known. However, occasionally it is not known, and the association with trisomy 21, seen in nearly a third of cases, needs to be discussed. Congenital heart defects are seen in approximately a quarter of DA patients and intestinal malrotation in a fifth. This information, when presented to young parents, can be overwhelming. Their child has a condition that is going to require major abdominal surgery within the first few days of life and potentially a prolonged NICU stay. Above all, it is the pediatric surgeon's task to convince them that this is very correctable problem and that the outlook for an excellent long-term outcome is very high.

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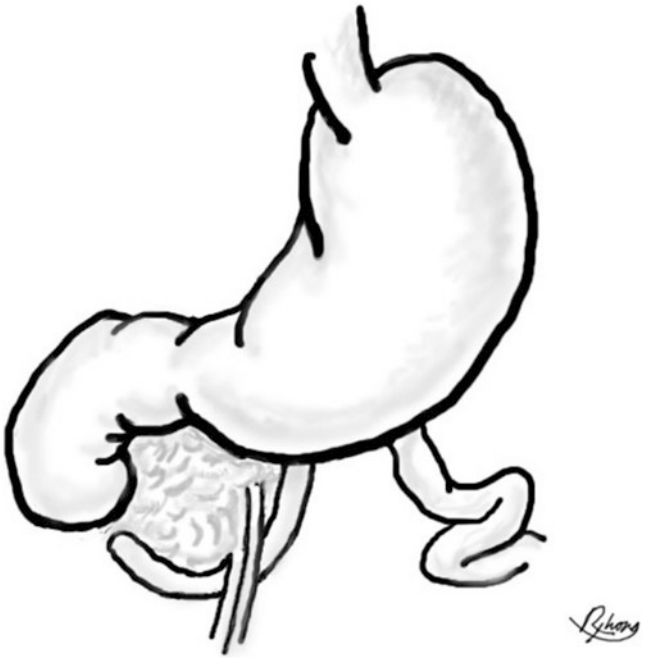

Fig. 46.1 Artist's depiction of type 3 duodenal atresia. There are three forms: type 1, in which the duodenal wall is intact; type 2, in which there is a fine cord connecting the two ends; and type 3, in which the ends are completely separated (Courtesy of Richard Hong, MD)

Diagnosis

A suspicious prenatal US will alert the surgical and neonatal team to take steps to confirm the diagnosis shortly after birth. In cases where the diagnosis is not suspected, the infant will develop symptoms of a high-grade proximal small bowel obstruction, usually within hours of birth. Feeding intolerance and emesis are the hallmarks. The emesis is usually bilious, but not always. In about 20 % of patients, the ampulla is located beyond the obstruction. Since the obstruction is so proximal, the abdomen is not distended, especially after placement of the gastric tube to suction. A plain film of the abdomen will show gas in the stomach and dilated duodenal bulb, but gas will not progress distally. Upright films are not usually done in newborns, but a lateral view will show two upper abdominal dilated loops with air-fluid levels, the classic "double bubble" of duodenal atresia.

The presence of a dilated stomach and duodenum on plain film coupled with an absence of distal gas is pathognomonic for a high-grade intestinal obstruction, and further imaging studies are not necessary. If the baby appears well, surgical repair can be planned within the next several days. Placement of a gastric tube is mandatory, as it rules out concomitant esophageal atresia and minimizes the chance of vomiting and aspiration. If the plain film does not show the characteristic findings of DA, a second film after injection of 30 mL of air into the stomach may be helpful. If the diagnosis is still in question, a contrast study, preferably in the fluoroscopy suite, should be diagnostic.

If air has progressed beyond the duodenum on the plain film, atresia is not present. If the diagnosis was suspected prenatally, it is likely that the baby has duodenal stenosis and an upper GI contrast study needs to be done (Figs. 46.2 and 46.3). If not suspected prenatally, duodenal stenosis in which the obstruction is not severe may present well after birth. Occasionally, a plain film of a neonate done immediately after birth can mimic the findings of duodenal atresia, simply

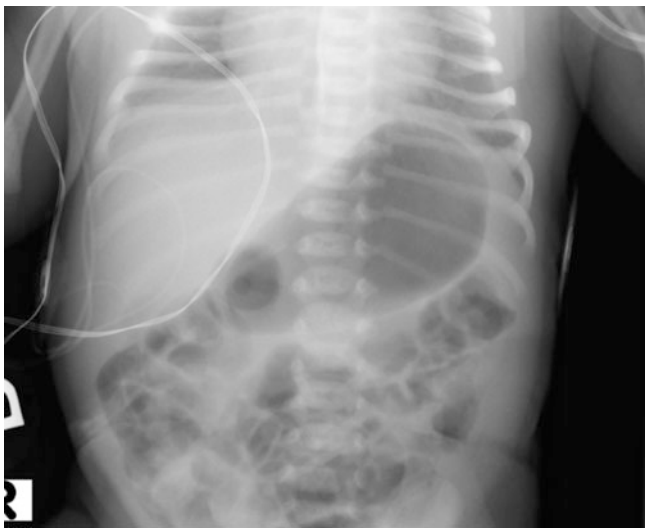

Fig. 46.2 Plain film of the abdomen of a newborn with suspected duodenal obstruction based on prenatal imaging studies. The stomach is moderately dilated, but the distal gas eliminates the possibility of duodenal atresia

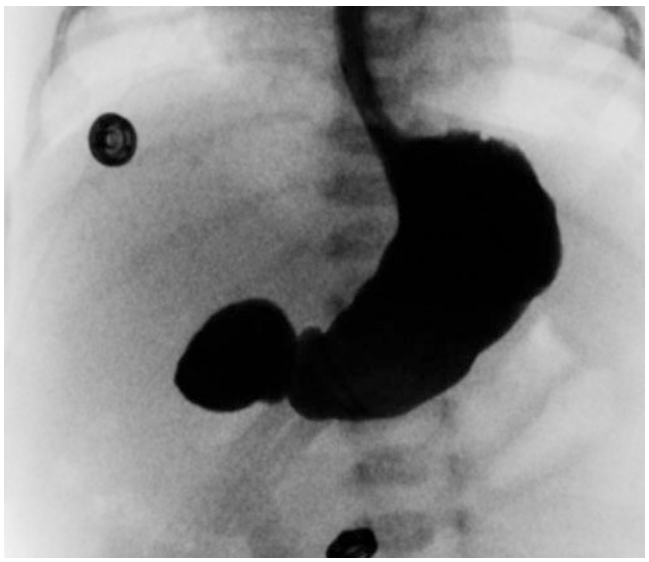

Fig. 46.3 Contrast study demonstrating dilated stomach and proximal duodenum consistent with duodenal stenosis, most likely with a perforated web

because not enough time had passed to allow the swallowed air to go distally. If there is a low index of suspicion for DA and the child is not symptomatic, a second film done several hours later might demonstrate a normal gas pattern in which case the condition is ruled out.

Other causes for high-grade proximal small bowel obstruction must be considered. Malrotation, with or without a midgut volvulus, should always be at the top of the list. Malrotation alone can lead to obstruction at the level of the duodenum from Ladd bands, but it would be highly unusual for there to be a complete absence of distal gas from this abnormality alone. A midgut volvulus can certainly cause a high-grade obstruction at this level, frequently accompanied by a paucity of distal gas or even a gasless abdomen. Usually, with this severe obstruction, there is an element of vascular compromise, leading to intestinal venous hypertension and edema, hypersecretion into the intestinal lumen, and outward signs of abdominal distension and tenderness.

Any newborn with bilious vomiting and a distended, tender abdomen deserves urgent laparotomy after a rapid resuscitation. Time should not be wasted on attempting to elucidate the cause of the obstruction, since the cause will become clear in the OR. Other less common causes for congenital obstruction at this level should be considered. Pyloric atresia, gastric antral web, and extrinsic causes such as a preduodenal portal vein might present with signs of obstruction. In the first two conditions, the emesis will always be nonbilious and the plain films would not show a double bubble. A preduodenal portal vein may be difficult to differentiate from duodenal stenosis and may not become clear until laparotomy.

Preoperative Care

Most of the time, babies with isolated duodenal atresia or stenosis are not particularly sick at birth. An assessment of the baby's fluid and electrolyte status is indicated. A naso- or orogastric tube should be placed. Central venous access, usually in the form of a PICC, should be established. Umbilical lines are not satisfactory for this condition and need to be changed to some other form prior to definitive surgical repair. Physical examination will help establish whether or not concomitant anomalies such as imperforate anus are present. A cardiology evaluation to rule out structural cardiac defects should be done prior to general anesthesia. Usually, renal sonography and chromosomal evaluation are done, but these studies should not conflict with operative timing.

While the preoperative studies are being obtained, attention should be paid to correcting fluid and electrolyte abnormalities. Since the infant is completely obstructed and will have increased losses because of the gastric tube on suction, close monitoring of the baby's fluid status is mandatory, and it should be anticipated that the needs will be greater than those of a typical newborn. The goal is to optimize the infant for surgery within the first 48–72 h of life.

Operative Approach

Standard endotracheal anesthesia is utilized. A caudal epidural catheter is a useful adjunct for postoperative pain control. Perioperative antibiotics, usually a second-generation cephalosporin, are given. A Foley catheter should be considered. If central venous access has not already been established, a percutaneous or tunneled central venous catheter should be placed at this time. Attention is then turned to the abdomen.

The standard incision for duodenal atresia is a right upper quadrant transverse incision 1.5–2 cm above the level of the umbilicus. The length of the incision should include the rectus muscle and the complete linea alba, with extension laterally as necessary. A thorough exploration of the right upper quadrant should ensue. The stomach and pylorus should be identified and the gastric tube palpated. The liver is inspected and a normal gallbladder identified. The filmy adhesions between the hepatic flexure and the duodenum and liver and gallbladder are taken down. This allows a complete examination of the anatomy and identification of anatomic abnormalities. If malrotation is present, a Ladd procedure should be performed. Confirmation of the duodenal anatomy should occur, and if duodenal atresia is confirmed, a duodenoduodenostomy is the preferred repair. We find that a table-mounted mechanical retractor allows stable exposure of the proximal and distal ends of the duodenum at the level of the obstruction. An assessment of the proximal duodenum is made, and if it is markedly dilated, tapering the dilated portion should be considered. This is accomplished by resecting the antimesenteric segment of the dilated duodenal bulb and closing it longitudinally. This can also be done with a linear GI stapler. Then, a transverse incision in the dependent portion of the proximal duodenum, close to the atresia, and a longitudinal incision in the distal duodenum are made (Fig. 46.4). To evaluate for any additional sites of obstruction, a red rubber catheter is passed distally into the duodenum until beyond the ligament of Treitz.

The anastomosis is made with 5-0 monofilament absorbable suture such as PDS. The initial stitch approximates the proximal apex of the distal incision to the midpoint of the posterior wall of the transverse incision. The apices of the transverse incision are then sutured to the edges of the longitudinal distal duodenotomy at their midpoint. Additional sutures are placed to complete the posterior wall, all with the knots inside the lumen of the bowel (Figs. 46.5 and 46.6). The distal apex of the longitudinal incision is then approximated

Fig. 46.4 Transverse proximal and longitudinal distal duodenotomies in preparation for the diamond-shaped duodenoduodenostomy described by Kimura (Courtesy of Richard Hong, MD)

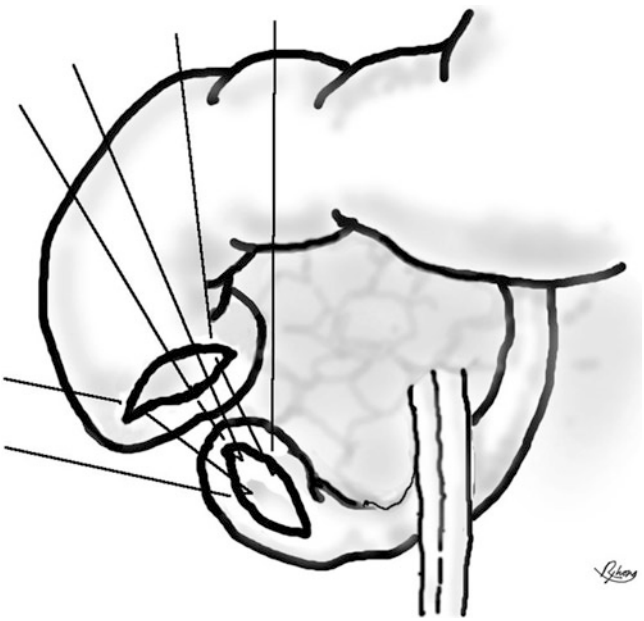

Fig. 46.5 Initial suture placement. The first stitch approximates the proximal apex of the distal incision to the midpoint of the posterior wall of the transverse incision. The apices of the transverse incision are then sutured to the edges of the longitudinal distal duodenotomy at their midpoint (Courtesy of Richard Hong, MD)

to the midpoint of the anterior lip of the transverse incision, and the anastomosis is completed with the knots on the outside (Fig. 46.7). In the past, placement of a *trans*-anastomotic feeding tube was frequently done, but that approach is used less commonly now. The wound is closed in a standard fashion and the patient is transferred back to the NICU.

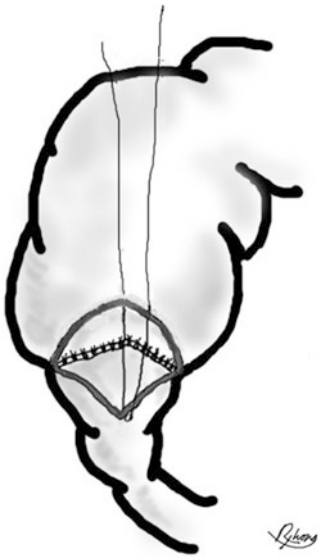

Fig. 46.6 Posterior wall of anastomosis is completed. The midpoint of the anterior wall of the transverse incision is sutured to the distal apex of the longitudinal incision (Courtesy of Richard Hong, MD)

Fig. 46.7 Completed duodenoduodenostomy (Courtesy of Richard Hong, MD)

If duodenal stenosis is present, there may not be a significant size differential in the two segments of duodenum above and below the web, and the exact location of the web may not be readily apparent upon external inspection. With the assistance of the anesthesiologist, passage of the gastric tube beyond the pylorus and up against the obstruction will usually make the location of the web apparent since the wall of the duodenum will indent where the web is attached. It is almost always close to the ampulla of Vater. Once the location of the web is determined, a decision has to be made on

how to repair the lesion. Many surgeons prefer a longitudinal incision beginning above the web and extending into the duodenum distal to it. Once the duodenotomy is made, the ampulla of Vater must be identified. The ampulla may be above, below, or in the web itself. If necessary, mild compression of the gallbladder will cause bile flow and allow identification of the orifice. Actually cannulating the duct should be avoided. A small balloon-tipped catheter such as a Fogarty or 6-Fr Foley is passed through the central opening in the web and the balloon inflated. Traction applied to the catheter will draw the web out through the duodenotomy and help define the margins of the web. A majority of the web is resected, taking care to avoid injuring the ampulla and bile and pancreatic ducts. The web can be resected with electrocautery. The edge does not need to be oversewn; the mucosa will heal. The longitudinal incision can be closed in a transverse fashion to avoid stenosis. Above all, close attention must be paid to avoid injury to the ampulla and the bile and pancreatic ducts.

Another option for DS is to perform a standard diamond-shaped duodenoduodenostomy. This approach minimizes the chance of an injury to the ampulla but may not be suitable if the web is very redundant. Occasionally, the opening in the web is very small, and chronic obstruction leads to stretching and elongation of the web into a windsock deformity (Fig. 46.8). It is important to understand this form of the abnormality, since the surgeon can be confused as to where the web inserts on the duodenal wall. The obstruction may appear to be much more distal than it really is, and the risk is that one may mistakenly open the duodenum in the wrong location or, worse, perform an anastomosis in the wrong location. In the case of a windsock, it is better to resect the web, since the redundant tissue in the lumen of the distal duodenum can lead to intermittent obstruction if left in place.

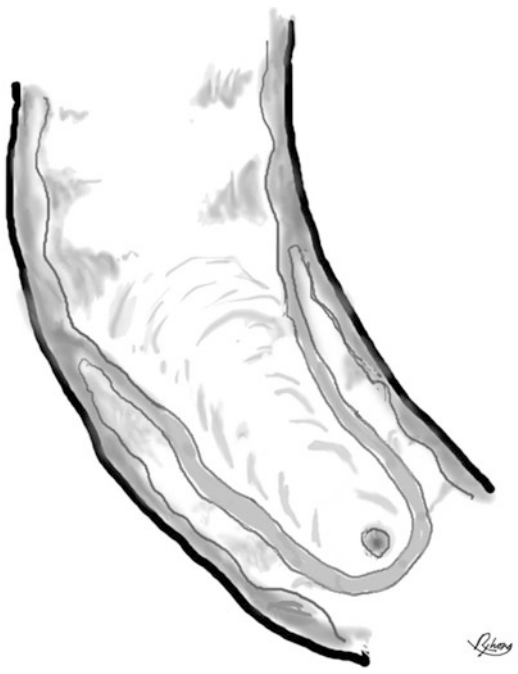

Fig. 46.8 Cross-sectional view of duodenal stenosis. Note elongated "windsock" web extending distally into lumen of duodenum below the junction with the duodenal wall (Courtesy of Richard Hong, MD)

In those rare cases of atresia where the two ends are widely separated and a duodenoduodenostomy cannot be performed, it is acceptable to perform a duodenojejunostomy with a loop of proximal jejunum brought up through the transverse mesocolon. A Roux-en-Y construct is not necessary. A gastrojejunostomy should be avoided, since this will not adequately drain the obstructed duodenum and there is a high risk of blind loop syndrome and bile reflux into the stomach.

Laparoscopic Technique

The initial experience was reported by Bax in 2001 and the first series by Rothenberg in 2002. Duodenal atresia provides an opportunity for a skilled laparoscopic surgeon to perform one of the most challenging minimally invasive procedures, a sutured bowel anastomosis in a newborn. In most cases, the anatomy is relatively straightforward, the visualization is very good, and there is a reasonable amount of space within the newborn abdomen so that the anastomosis is not difficult to set up and complete. However, the procedure demands a significant amount of skill and patience, and experience in the first decade of the twenty-first century has identified certain key steps that will improve the overall chances of success. The surgeon should be comfortable with performing laparoscopic surgery in newborns and should be facile with advanced laparoscopic techniques such as suturing and the dissection and manipulation of newborn intestine.

The preoperative preparation for the laparoscopic approach is the same. General endotracheal anesthesia is utilized and the anesthesiologist should be familiar with the effects of CO_2 insufflation on the newborn cardiovascular system. A gastric tube should be in position and on suction. Central access, either by PICC or by tunneled silastic catheter, if not already present, is established, and perioperative antibiotics are given. A Foley catheter is always placed, so that the chance of a bladder injury from cannula placement is minimized. The table is shortened as much as possible, and the infant is positioned on a warmer at the foot of the table, opposite the anesthesiologist. This allows the operating surgeon to stand at the end of the bed and to suture and dissect comfortably. The camera holder stands to the surgeon's left and the scrub nurse to the surgeon's right. Two monitors are used, one on each side of the head of the table. A table-mounted malleable anesthesia screen positioned at the head of the patient permits maintenance of the sterile field while still giving anesthesia access to the airway.

A 4-mm 30° telescope, 20-cm-long 2.7-mm-diameter laparoscopic instruments, and HD camera are used. Access to the peritoneum is established by an incision directly through the base of the umbilicus, which is usually not epithelialized. The use of a disposable cannula with an outer expandable sleeve may have some advantages here. Intraperitoneal position is confirmed with the scope. The cannula is positioned so that a minimum length is in the peritoneum and the sleeve fixed to the skin with a stitch. Pneumoperitoneum to 8 mmHg is utilized, with a flow of 2–3 L/min. After an inspection of the abdomen, two working ports are placed, the position of which is critical to maximize ease of suture placement and knot tying. The cannula for the surgeon's right hand should be placed in the left lateral abdomen at or just below the level of the umbilicus. It should be a 5 mm cannula, to allow for the passage of sutures and needles into the abdomen. The cannula for the surgeon's left hand should be located in the right lower quadrant, so that when two instruments are inserted through the cannulas and the tips are located at the site of the atresia, they meet as close to 90° as possible. If the two ports are positioned too closely together, the instruments meet at an acute angle, and suturing and knot tying become difficult. An inspection of the RUQ should be carried out at this point and the anatomy defined. If malrotation is present, a decision needs to be made whether or not to proceed with the laparoscopic approach, which is feasible but more complex.

Exposure of the RUQ is improved by placing a transabdominal suture through the falciform ligament and lifting it cephalad. Other options include (1) placing a cannula at the tip of the 11th rib on the patient's right for insertion of a malleable liver retractor positioned with an adjustable mechanical arm and (2) using a grasper passed through a sub-xyphoid stab incision and under the right lobe of the liver that is then locked onto the lateral abdominal wall lifting the liver with it.

There are usually filmy adhesions in the RUQ that can be easily taken down with careful blunt dissection. The dilated proximal duodenum is easily identified. The hepatic flexure is mobilized as necessary and the pancreas and distal duodenum are identified. Extensive mobilization of the duodenum may be necessary to permit a tension-free anastomosis. The two ends of the duodenum are assessed and the anastomosis planned. The decision-making is similar to that of the open approach. If the proximal duodenum is quite floppy, it can be suspended with tacking sutures of 5-0 PDS. A longitudinal incision is made at the end of the distal duodenum, and a transverse incision is made in the dependent aspect of the proximal duodenum. It is very difficult to pass a tube distally to assess for a second obstruction, so most surgeons do not attempt this at this time.

A diamond-shaped anastomosis is then fashioned in the standard fashion, with a few modifications. First, 5-0 PDS on a TF needle is used. The first suture is kept about 14 cm long. The apex of the transverse duodenotomy is sutured to the midpoint of the dorsal edge of the longitudinal incision, and the needle is then passed through the abdominal wall as a traction stitch. The opposite apex is sutured to the midpoint of the ventral edge of the distal duodenotomy and also brought out through the abdominal wall. The anastomosis is suspended and the back wall more easily completed. The apex of the distal longitudinal incision is sutured to the midpoint of the posterior edge of the transverse incision. The back wall is completed with interrupted sutures, knots on the inside. The anterior wall is then completed in the standard fashion. If desired, the anterior wall can be accomplished with a running suture, which makes the anastomosis easier and quicker. A quantity of air can be injected into the gastric tube by the anesthesiologist to assess the anastomosis, and the air can be milked distally to help determine if a second obstruction is present.

The management of duodenal stenosis with a minimally invasive approach can be challenging, especially if the location of the obstruction is not readily apparent upon external inspection. An attempt should be made, with the aid of the anesthesiologist, to pass a gastric tube distally until the web is reached and the location of the insertion of the web is identified by the indentation in the external duodenal wall. However, this is quite challenging in a small baby. If the location of the web is identified, a longitudinal duodenotomy is made, starting proximal to the indentation and ending distal to it. The ampulla is identified, and the web resected with electrocautery. The duodenotomy is closed in a transverse fashion with either a running or interrupted suture line. The distal duodenum is inspected for evidence of a secondary obstruction. If the location of the web cannot be identified with an intraluminal tube, it is probably more prudent to convert to an open procedure than to open the proximal duodenum randomly in search for the web.

Postoperative Care

If epidural anesthesia was utilized, the infant may be extubated in the operating room. Otherwise, the child should return to the NICU intubated and weaned from the ventilator as appropriate. The nasogastric tube and Foley catheter are left in place. Parenteral nutrition is started on the first postoperative day. Careful management of fluids and electrolytes is mandatory. Antibiotics are continued for 24–48 h. The Foley catheter is removed with the epidural catheter or on the first postoperative day. The nasogastric tube is maintained on suction until the drainage decreases and the color begins to lighten.

The return of gastric motility can be difficult to ascertain. Because the stomach and duodenum have been chronically obstructed, the onset of gastric motility is usually delayed, and the time it takes before enteral feeds can be started is often 7–10 days or more. The pylorus is incompetent, so the

gastric drainage usually remains somewhat bile tinged, and gastric residuals higher than normal may persist. However, if, after an appropriate interval, the infant tolerates interval clamping of the nasogastric tube and the residual drops to less than 20 mL per day, it is reasonable to begin enteral feeds. Time to full feeds is variable, and parental expectations should be managed during this portion of the hospitalization.

Complications

All of the potential complications associated with abdominal surgery in a newborn can occur, and continued assessment for signs of sepsis from an intra-abdominal infection or anastomotic leak is necessary. A picture of gradually increasing obstructive jaundice should raise the concern that the ampulla or bile duct was injured. Perhaps the most serious problem that the surgeon can do his best to avoid is the anastomosis that never functions. Several possibilities need to be considered. Is the proximal duodenum redundant and floppy, leading to a functional obstruction? Is the anastomosis stenotic? Is an unresected web leading to intraluminal obstruction? Is there a missed second obstruction? An upper GI contrast study will be the initial test of choice to investigate this problem. Careful attention to detail at the first operation is the best method for avoiding this unsatisfactory situation.

Outcomes

The overall outlook for patients with duodenal atresia is excellent. Most problems are associated with concurrent health problems such as trisomy 21 or congenital heart disease. Although approximately one fifth will have feedings issues during the initial 6 months of life, the vast majority improve with time and further surgical intervention is not necessary. With the common use of the diamond-shaped anastomosis, late stenosis is less common than when parallel incisions were used. Rarely, an older child with a history of duodenal atresia will present with symptoms of recurrent vomiting and feeding intolerance. A contrast study might show a dilated duodenal bulb, but the anastomosis is sometimes hard to delineate because it is obscured by contrast. In these cases, flexible endoscopy might be needed to adequately assess the anastomosis.

Editor's Comment

Repair of duodenal atresia demands awareness and technical prowess whether it is performed in an open fashion or laparoscopically. Not every case is straightforward: Should I resect or bypass a duodenal web? How do I recognize and manage a windsock deformity? How do I rule out a distal atresia? Should I taper a dilated proximal duodenum? Finally, when if ever do I consider doing a formal duodenojejunostomy?

The pediatric surgeon needs to be prepared for every variation and even unique anatomic variants that have not been described. As for a simple duodenal atresia, the treatment of annular pancreas is duodenoduodenostomy; the pancreas should not be divided or otherwise manipulated for fear of causing a pancreatic fistula. There is some disagreement regarding the proper management of the duodenal web, resection or bypass, because of the risk of injury to the ampulla. Though either approach is acceptable, in most cases it is better to excise the web, being careful to identify and preserve the ampulla, which always enters the medial (mesenteric) aspect of the web. The ampulla is identified by compressing the gallbladder and looking for the flow of bile.

The windsock deformity is essentially just a web that is stretched out distally for a variable distance. The circumferential origin of the web is always way back at the level of the ampulla even though the central portion can be several centimeters downstream, where the obstruction appears to be. These can be extremely difficult to recognize and are easily missed. It is important to remember that congenital duodenal obstruction almost always occurs at the junction of the first and second portion of the duodenum, the level of the ampulla, so that an obstruction that appears to be in the third portion should be investigated further to rule out a windsock.

It is important to rule out the presence of a second more distal obstruction by passing a catheter distally and injecting saline or air to ensure flow through the lumen. This is a problem for the proponents of the laparoscopic repair, who need to develop a creative solution. A significant number of infants with duodenal atresia also have malrotation, which needs to be addressed with a proper Ladd procedure. The anatomy can be confusing and the unused distal small bowel is often very delicate and of small caliber, demanding patience and a gentle technique.

The duodenum can be quite dilated, which creates the potential for dysmotility and stasis. It is usually best to taper the duodenum, which appears to be effective and very safe. The technique is well described, but it is a good idea to use a 20 Fr catheter within the lumen as a guide, a series of Babcock clamps on the antimesenteric border, and a GI stapling device fired sequentially along the line of resection.

If a duodenoduodenostomy cannot be performed with minimal tension and in such a way that flow of intestinal contents can be ensured (preduodenal portal vein, long gap between duodenal ends, bulky annular pancreas), there should be a low threshold to perform a loop or Roux-en-Y duodenojejunostomy, which is generally straightforward and well tolerated. Given the small caliber of the jejunum, it is important to make a long and precise anastomosis. Gastrojejunostomy is rarely a good idea.

Finally, the postoperative care of these infants can be long and difficult, mostly due to duodenal stasis and prolonged ileus. All infants should be given parenteral nutrition through a PICC line, and most with trisomy 21 or significant associated anomalies benefit from gastrostomy. The usual indication of normal bowel function, namely, a transition to nonbilious gastric aspirates, might never occur in these infants even when their ileus has resolved, presumably due to the fact that their pylorus is incompetent and they tend to reflux bile into their stomachs for a very long time. If the patient is extubated and stable on day 6–7, it makes sense to clamp the NG tube and start a slowly advancing trial of water or glucose-electrolyte solution. Most infants are ready to feed at this point, but some will need another 3–4 days before starting another trial. Infants who cannot feed beyond 2–3 weeks should have a contrast study.

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Intestinal Atresia

47

Daniel L. Lodwick and Peter C. Minneci

Intestinal atresia is a common cause of congenital intestinal obstruction and encompasses a spectrum of luminal defects that are categorized into stenosis and four different types of atresia. Stenosis is a narrowing of the bowel lumen without disruption. Type I atresia is occlusion of the lumen with a continuous outer wall, also referred to as a web. Although less common than in duodenal atresia, a type I jejunal atresia can manifest as a windsock deformity where there is a membrane that is stretched and telescopes inside the lumen. Type II atresia has discontinuity of the lumen with a persistent fibrous cord connecting the dilated proximal bowel with the decompressed distal bowel. Type III atresia is the most common type and has complete separation of the proximal and distal ends. In jejunoileal atresias, this represents two distinct subtypes. Type IIIa is characterized by a separation of the bowel and a V-shaped mesenteric deformity. Type IIIb results from loss of the entire superior mesenteric artery except for the middle and right colic arteries; this leaves only retrograde flow from the colonic arcades to supply the distal small bowel resulting in a short length of small bowel wrapped helically around its single arterial supply (Fig. 47.1). Type IIIb atresias are often referred to as a "Christmas tree" deformity, Maypole deformity, or apple-peel atresia. Type IV atresia is a combination of multiple type I–III atresias.

Jejunoileal atresia occurs in roughly 1 in 3000 live births and is most commonly sporadic. There are also familial forms that present with multiple atresias or apple-peel atresia; both of which are believed to be autosomal recessive. Jejunoileal atresia is associated with cystic fibrosis, malrotation, volvulus, and intrauterine intussusception.

Colonic atresia is a rare condition occurring in 1 in 20,000 live births and represents fewer than 10 % of all intestinal atresias. Colonic atresia is also believed to be primarily due to a vascular insult after organogenesis and is usually an isolated anomaly, but it can be associated with a number of other conditions including Hirschsprung's disease (HD), other gastrointestinal abnormalities, gastroschisis, abdominal wall defects, musculoskeletal abnormalities, and genitourinary abnormalities.

Diagnosis

Prenatal diagnosis can be suggested by dilated loops of bowel on ultrasonography or polyhydramnios. Polyhydramnios is less common than with duodenal atresia and becomes less frequent as the atresia becomes more distal due to the increased length of the fetal intestine to absorb fluid.

Clinically, jejunoileal and colonic atresias will present with emesis in the first 48 h of life. Jejunal atresias are classically associated with passage of a gray and mucoid meconium, but passage of normal meconium is possible as well. Patients with colonic atresia often do not pass meconium at all. Patients with more distal atresias are more likely to present later with a distended abdomen. Patients with colonic atresia may develop severe abdominal distension requiring mechanical ventilation. Delay in diagnosis of distal atresias can result in overdistension of the proximal end of the atresia, necrosis, perforation, septic peritonitis, and death. This is especially important in colonic atresia as the ileocecal valve can create high-pressure distension similar to a closed loop obstruction.

The initial diagnostic test for intestinal atresia is the abdominal radiograph. These patients exhibit multiple distended loops of bowel with air-fluid levels indicating intestinal obstruction (Fig. 47.2). The extent and number of distended loops will suggest the level of the atresia. A radiograph with only a few distended loops in the epigastrum is usually indicative of a proximal jejunal atresia, whereas diffuse distended loops are suggestive of a distal ileal or even

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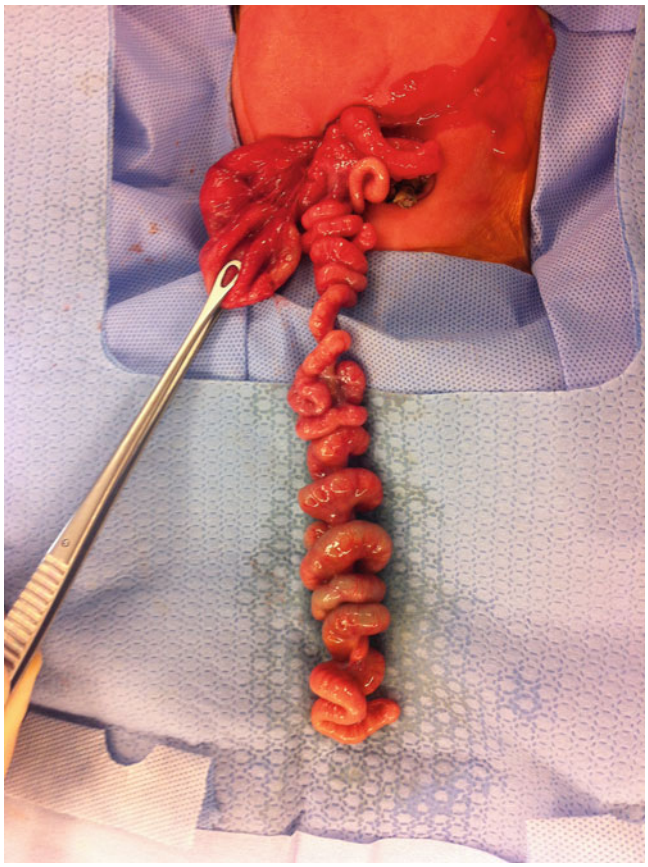

Fig. 47.1 Intraoperative image of newborn with a type IIIB atresia

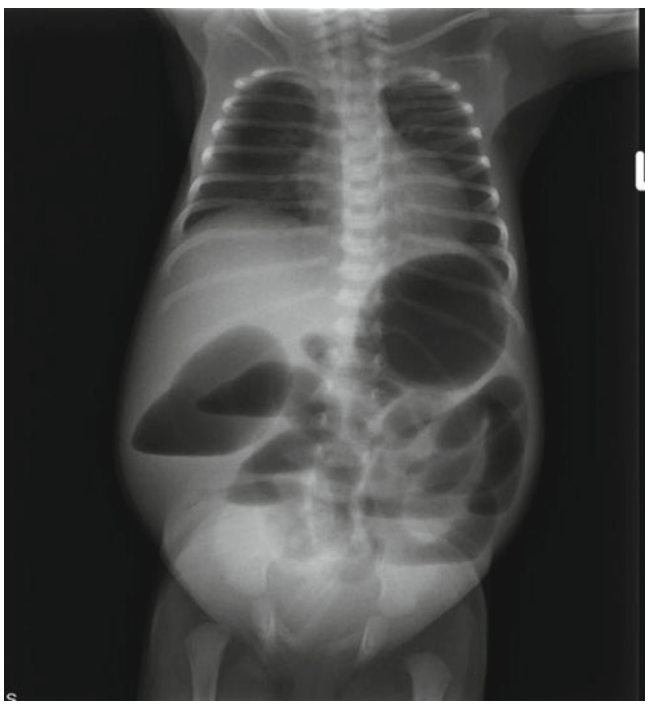

Fig. 47.2 Abdominal radiograph in a patient with ileal atresia (Courtesy of Dr. Paresh K. Desai, Radiopaedia.org)

colonic atresia. In general, colonic atresia will exhibit more severe dilation, which can be misread as pneumoperitoneum. However, it is important to remember that the neonatal colon does not reliably exhibit haustra as it does in older children or adults; therefore, it can be difficult to distinguish a distal ileal atresia and colonic atresia on a plain radiograph.

Contrast radiography can also be useful to define the anatomy of the atresia and associated anomalies. An upper GI contrast study is usually not necessary but might be needed to distinguish a proximal jejunal atresia from malrotation with volvulus in a neonate with bilious emesis. They may also be helpful for distinguishing a stenosis from a complete obstruction when the plain radiographs are equivocal or for diagnosing a windsock deformity. In cases of distal obstruction, contrast enemas are extremely useful because of the difficulty discerning distal small bowel from colon on plain radiograph. The contrast enema will show the passage of retrograde contrast to the level of the atresia. It can also aid in evaluating for total colonic aganglionosis or concomitant HD. Whenever possible, we would recommend obtaining a contrast enema to assess for additional distal atresias prior to entering the operating room; this then allows the intraoperative evaluation for distal atresia to be limited to flushing the distal small bowel into the cecum. In HD, the enema study will show contrast passing retrograde through a narrowed area of distal colon and into the dilated proximal colon usually with a reversal of the rectosigmoid ratio. In colonic atresia, the contrast enema will often show a microcolon of the distal segment from disuse, and contrast will fail to reach proximal dilated bowel.

Preoperative Management

Prior to operative correction of these anomalies, these patients should have an NG or OG tube placed for gastric decompression and IV fluid resuscitation to correct underlying dehydration and electrolyte abnormalities. Any patient with suspicion of intestinal perforation (free air or significant free fluid on radiograph, peritonitis, sepsis) should receive broad-spectrum antibiotics and undergo emergent abdominal exploration. All patients not receiving empiric antibiotics receive appropriate perioperative antibiotics beginning with a preoperative dose and continuing for 24 h.

Jejunoileal Atresia

Operative management of intestinal atresias should be based on the type and location of the lesion, the appearance of the bowel in the OR, and the presence of other anomalies or comorbidities. We prefer a supraumbilical transverse laparotomy. First, we eviscerate and examine the entire

small bowel, measure the small bowel length, assess intestinal rotation status, and examine for multiple atresias. Before performing the anastomosis, we ensure that there are no distal atresias by placing a rubber catheter into the cut open end of the distal bowel and flushing fluid into the cecum. If we did not obtain a contrast enema preoperatively, we will place a rubber catheter with a syringe of fluid attached in the rectum prior to prepping and draping; subsequently, we will flush fluid retrograde and be sure it reaches the cecum during the procedure. Alternatively, the antegrade fluid flushed into the cecum can be followed around the colon until it exits the anus.

The next step is to evaluate the size discrepancy between the ends prior to performing the anastomosis. A dilated proximal segment will have poor motility and can contribute to delayed bowel function or functional obstruction. If the dilated proximal segment is short (up to 10 cm) and the patient has a normal length of small bowel (a healthy full-term infant has an average bowel length of 250 cm, a preterm infant around 150 cm), then the dilated segment can be resected to decrease the size mismatch between the two ends. However, resection of the dilated segment may not be appropriate for patients with a long dilated segment or significantly foreshortened bowel (<100 cm). These patients should receive a tapering or plication enteroplasty. We prefer the tapering enteroplasty, which is performed by decompressing the proximal limb, placing a large rubber catheter in the lumen (20–30 Fr), and then performing a stapled resection on the antimesenteric border. We do not oversew the staple line, but others might do so usually with interrupted sutures.

After resection or enteroplasty, if there is still a size discrepancy, the distal end can be better matched to the proximal end by trimming its antimesenteric border obliquely to provide an elliptical opening. If the circumference of the edge of the distal bowel is still too small, a longitudinal incision can be made on the antimesenteric border to effectively lengthen the edge.

A special management challenge can arise with type IV atresia. While this can represent any combination of the other three types, it commonly presents with short segments of bowel separated by atretic segments. With this defect, the two available options are to resect atretic segments with the intervening bowel or to perform multiple anastomoses. This decision is made by evaluating the total small bowel length. If the patient's total bowel length is significantly less than average, then each island of bowel should be preserved to maximize length, and multiple anastomoses should be performed.

After the two ends are appropriately sized, we then perform the hand-sewn end-to-oblique anastomosis using interrupted 5-0 or 6-0 absorbable sutures in a single layer. We close the mesenteric defect with interrupted absorbable sutures taking care not to damage the vascular supply. The remaining length of small bowel is then measured and documented in the operative report; this is an important step for all atresia patients as they are at risk for short bowel syndrome and intestinal failure.

Some surgeons utilize less invasive techniques such as a periumbilical or laparoscopic approach to improve cosmesis and potentially speed postoperative recovery. With the circumumbilical approach, an incision is made either three-quarters of the way around the umbilicus or vertically through the umbilicus, and the abdomen is entered through the midline fascia. With the laparoscopic approach, an initial trocar is placed at the umbilicus and the abdomen is insufflated to 8–10 mmHg. Two additional trocars are then inserted, usually to the left and right of the umbilicus. Graspers are used to run the bowel, identify the proximal and distal ends, and evaluate for malrotation and additional atresias. Once the anatomy has been defined, the proximal and distal ends are exteriorized through the umbilicus, the proximal end is trimmed, and a standard anastomosis is performed.

These less invasive approaches may not be appropriate for certain patients. Laparoscopic visualization can be limited in patients with a large amount of bowel distension. In addition, we prefer to manage type IIIb atresias with an open procedure as the distal bowel is coiled around its sole blood supply and must be carefully uncoiled to maintain correct orientation of the vasculature.

A primary anastomosis is not always the best option. If the bowel ends show signs of vascular compromise or if the abdomen is grossly contaminated from a perforation, then an enterostomy and mucous fistula should be performed. We usually place these at opposite ends of the incision, but they can also be located next to each other in double-barrel fashion in one corner of the incision or performed at a different location from the incision.

Postoperatively, these patients should be managed with the expectation of delayed bowel function. The NG or OG tube should be confirmed intraoperatively and maintained on suction. When the tube output is decreased and no longer bilious and the patient is passing flatus or stool, the tube can be removed and the child slowly advanced on feedings. Parenteral nutrition should be started early and maintained until the patient is tolerating full feeds.

The most common postoperative complications are anastomotic leak, obstruction, and stricture. Long-term outcomes for these patients are good with survival >90 %. Some patients suffer from chronic gastrointestinal dysmotility. Others are at risk for developing short bowel syndrome including patients who underwent a large resection or who were born with foreshortened bowel or a type IIIb atresia.

Colonic Atresia

The two surgical options for colonic atresia are primary anastomosis or colostomy with delayed anastomosis. The chosen approach should take into consideration the patient's condition, the presence of perforation or peritonitis, the condition of remaining colon, and the presence of associated anomalies such as gastroschisis or HD.

In patients without comorbid conditions, a primary anastomosis is the preferred option if a distal atresia has been excluded. Because HD is not uncommon in patients with colonic atresia, an intraoperative rectal biopsy should be sent for frozen section prior to performing the anastomosis. Failure to adequately rule out HD could result in anastomotic leak or persistent bowel obstruction. The operation is performed through a supraumbilical transverse laparotomy. When planning the incision, always think ahead for potential enterostomy sites in the event that the anastomosis cannot be completed. Once the abdomen is open, the dilated proximal colon is exteriorized and then the distal colon. There can be a large size discrepancy between the two ends. The bulbous portion of the proximal end should be resected back to an area of more normal caliber to better approximate the diameter of the distal colon. Once the distal end is trimmed obliquely to more closely match the circumference of the resected proximal end, the anastomosis is completed in an end-to-oblique single-layer fashion using absorbable suture.

If the caliber of the proximal colon cannot approximate the distal segment without a long segment resection, then a primary anastomosis should not be attempted. In this instance, we will use a two-stage approach. During the initial stage, the proximal end is brought out as an end colostomy and the distal end as a mucous fistula. The resected ends of the bowel and a rectal biopsy should be sent to pathology to evaluate for ganglion cells. Subsequently, the child is brought back electively for anastomosis in 2–3 months. Some institutions have adopted the practice of feeding the colostomy output through the mucous fistula to stimulate dilation of the distal colon for better size approximation.

Postoperatively, colonic atresia patients should retain their gastric tube, and parenteral nutrition should be provided until return of bowel function. Once the NG output is both clearing and decreasing and the patient is passing flatus or stool, the tube can be removed and the diet can be slowly advanced. Survival for colonic atresia is >90 %; however, surgical repair is not without complication. The most common complications are anastomotic leak, stricture, postoperative bowel obstruction, and, rarely, short bowel syndrome.

Summary

Intestinal atresia commonly presents as a stable neonate with emesis and gray mucoid meconium. Type I atresia is occlusion of the lumen with a continuous outer wall, type II atresia has discontinuity of the lumen with a persistent fibrous cord, type III atresia has complete separation of the proximal and distal ends with a mesenteric defect, and type IV atresia is a combination of multiple type I–III atresias. The abdominal radiograph will show multiple distended loops of bowel with air-fluid levels indicating intestinal obstruction. Primary anastomosis should only be considered when there is no abdominal contamination and distal obstruction has been ruled out. Evaluation for malrotation must be performed intraoperatively.

The dilated proximal segment should be resected in most cases, and tapering enteroplasty should be used for long dilated jejunal segments to improve the size mismatch of the two ends.

Feedings should be started once bowel function has returned, and TPN should be used to support patients until bowel function returns. Long-term outcomes for these patients are good with survival >90 %. The most common postoperative complications are anastomotic leak, obstruction, and stricture.

Editor's Comment

In general, the stable newborn with bilious emesis, abdominal distension, and dilated loops of bowel on plain radiograph has one of the four diagnoses – meconium plug syndrome, meconium ileus, Hirschsprung's disease, or intestinal atresia – and should therefore have a contrast enema rather than an UGI. This is one of the few exceptions to the "every child with bilious emesis needs either an urgent upper GI or a laparotomy" rule. Proximal obstruction due to duodenal or pyloric atresia does not present with abdominal distension or distal dilated loops, and although malrotation with volvulus can present with a comparable clinical picture, it quite rarely does so, and an experienced examiner can recognize the differences. A contrast enema is therapeutic for meconium plug syndrome and some cases of meconium ileus, allows identification of a transition zone in patients with HD, and confirms the diagnosis of intestinal atresia by demonstrating an unused "microcolon." With the confidence that comes with experience, one might eventually be able to recommend surgery for intestinal atresia based simply on the plain radiographic findings that clearly shows a single absurdly dilated loop of bowel, but there is no shame in requesting a contrast enema to be more certain.

Except with colonic atresia, one should consider a laparoscopic approach in most patients with intestinal atresia. The setup is the same as for a laparoscopic pyloromyotomy with the only port being through the umbilicus; 3-mm stab incisions can be used for the instruments. The ends of the atresia can usually be delivered through the widened umbilical incision and an extracorporeal anastomosis performed. For most type II and IIIa atresias, this approach works nicely. One of the challenges with intestinal atresias is the size mismatch between the two ends and then performing a hand-sewn anastomosis on the diminutive bowel. This is a particular problem with colonic atresias. Until recently a stapled anastomosis was not an option as the diameter of the distal limb was too small to admit the anvil of a 10-mm stapler. With the introduction of the 5-mm linear stapler, many of these atresias can now be repaired with a side-to-side stapled anastomosis. This could reduce the incidence of anastomotic stricture and shorten OR times.

Whether to resect or taper the bowel is a decision best made after assessing the length of viable intestine and how much bowel would be lost if the dilated portion were resected. In most cases, it is best to resect the most severely dilated bowel (often dysmotile anyway) and taper of the bowel just proximal to this segment. Imbrication is more difficult and tends to undo itself over time. Even after tapering, some infants will develop pseudo-obstruction and require resection of a dysmotile segment at a later date.

Management of the apple-peel lesion (type IIIb) can be tricky. One finds a proximal atresia, a large mesenteric defect with loss of the primary trunk of the SMA, and the entire ileum and distal jejunum remaining precariously viable on the basis of a tiny remnant of the distal SMA and the marginal artery. Some of these patients do quite well after simple primary repair, but many have long-term motility or absorption problems and need parenteral nutrition for a long time. It is important to untwist the bowel carefully, close the mesenteric defect without compromising the remaining blood supply, and inject saline through the distal bowel to rule out another stricture.

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Abdominal Cysts and Duplications

48

Patricia A. Lange

Some intra-abdominal cystic masses are now being detected by prenatal imaging. They are often asymptomatic, but those that cause symptoms usually do so in the first year or two of life. Symptoms are usually the result of compression or obstruction due to enlargement of the cyst as it gradually fills with fluid, or bleeding and ulceration due to gastric or pancreatic lining of the cyst. Cysts can arise from solid or hollow organs, and various imaging modalities can help to distinguish the specific site of origin. Enteric duplication cysts are sometimes associated with intestinal atresias, whereas tubular colonic or rectal duplications are commonly associated with genitourinary malformations. Optimal treatment usually involves complete resection of the cyst; but in some situations, asymptomatic cysts detected prenatally can be observed clinically and monitored radiographically.

Enteric duplications are rare and represent only about one in 4500 autopsies. About two thirds of alimentary tract duplications are in the abdominal cavity, and more than half are in the jejunoileal segments. Three quarters of duplications are cystic with no communication with the adjacent alimentary tract, while the remaining are tubular, sometimes communicating with the intestinal lumen. By definition, duplications share a blood supply with the intestine and lie in close proximity to the alimentary tract. Typical histopathologic features include distinct muscle wall layers and an epithelial lining, which is often gastric or pancreatic epithelium. Several theories attempt to explain the formation of enteric duplications and intra-abdominal cysts, but the exact etiology is poorly understood. Embryologic signaling errors might lead to abnormal diverticularization of the intestinal endoderm. Other theories suggest failure of regression of the diverticular process resulting in cyst formation. No single theory works to explain all of the variety of cysts and duplications found in the thorax or abdomen.

The differential diagnosis for intra-abdominal cystic masses is broad and includes duplication cysts, ovarian cysts, lymphangiomas, liver cysts, pancreatic cysts, omental cysts, extralobar pulmonary sequestration, genitourinary abnormalities, tumors, traumatic cysts, and pseudocysts.

Adnexal Cysts

Neonatal ovarian cysts are being detected with increasing frequency given the widespread use of perinatal ultrasonography. In general, simple ovarian cysts less than 4 cm in diameter can be observed and followed with serial US, as most of these will resolve spontaneously. Those that have complex features on US or are larger than 4 cm should be electively excised to prevent torsion and to rule out neoplasm.

Older children with a simple ovarian cyst can also be observed unless the cyst is larger than 5 cm, enlarging on serial US, or causing symptoms. A complex cyst that contains calcifications usually represents a mature teratoma, but any complex cyst should be considered to potentially harbor a malignancy. Ovarian cysts can also bleed or rupture. Fallopian (para-ovarian) cysts are usually asymptomatic, but they can cause torsion.

Lymphangioma

Abdominal lymphangiomas are rare as most cystic lymphatic malformations occur in the head and axilla. They usually arise within the retroperitoneum and are sometimes extensive. Those in the abdomen occur presumably due to lack of lymphatic connection of the intestine or retroperitoneum to the normal lymphatic channels. US is a good initial study, but CT or MRI is usually necessary to confirm the diagnosis and assess the extent of the cyst, which can be

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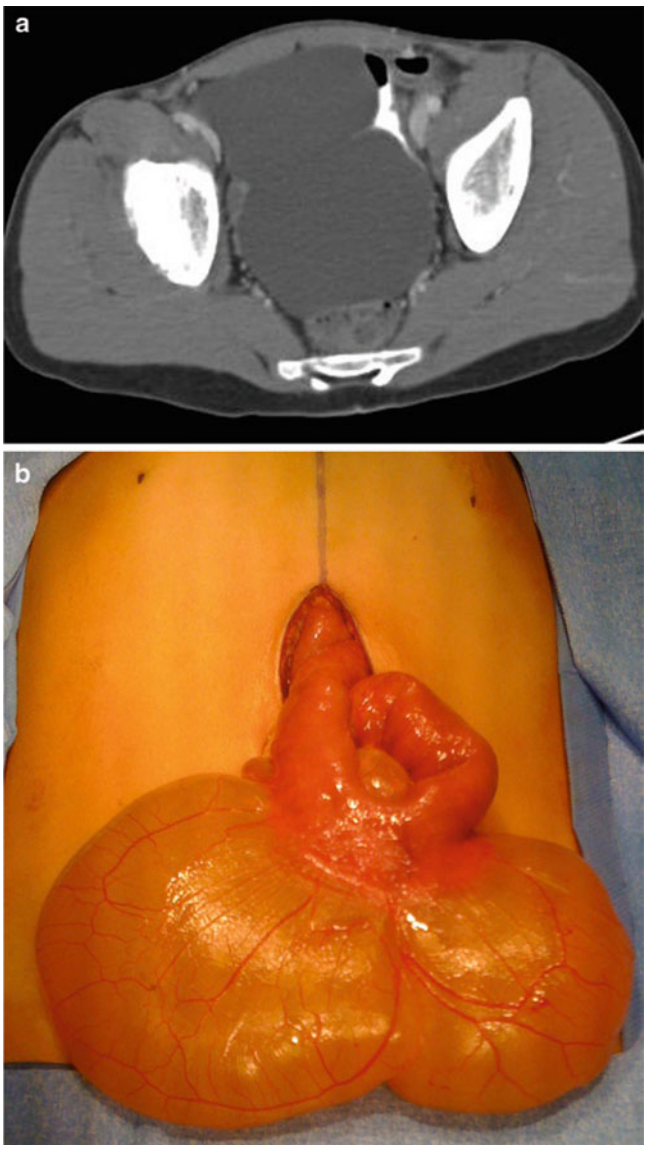

Fig. 48.1 (**a**) CT scan of a 7-year-old girl who presented with a several-month history of intermittent abdominal pain. (**b**) Intraoperative photograph of small bowel lymphangioma. A segmental resection of the ileum to include the entire cyst was performed

extensive. It usually appears as a thin-walled, multicystic mass with homogenous fluid. Treatment is complete resection, which sometimes involves resection of the adjacent intestine (Fig. 48.1). These lesions are benign but frequently recur and can be locally infiltrative.

Mesenteric and Omental Cysts

Mesenteric and omental cysts probably represent a form of lymphangioma. Mesenteric cysts are more common and can occur anywhere in the small bowel or colonic mesentery; they are most common in the ileal or distal sigmoid region. Both omental and mesenteric cysts can be simple or complex and contain a variety of fluid including serum, blood, chyle, or infected fluid. Often these cysts are found incidentally but can cause symptoms due to obstruction, segmental volvulus, or intussusception. CT and US are the preferred imaging modalities to investigate the masses or symptoms. Ideal treatment is complete surgical excision, but for large cysts or those at the base of the mesentery, drainage and marsupialization can be performed.

Liver Cysts

Liver cysts are usually asymptomatic. They include simple cysts, abscesses, hydatid cysts, and neoplastic cysts or are associated with the biliary system, such as choledochal cysts or Caroli's disease. The workup generally includes imaging such at CT or MRI to better define the cyst characteristics. Symptoms and laboratory values sometimes aid in the diagnosis. Patients with fever, elevated white blood cell count, and pain are more likely to have an abscess rather than a simple cyst.

Management depends on the etiology of the cyst. Simple cysts that are asymptomatic need no further treatment. Abscesses often respond well to percutaneous drainage and intravenous antibiotics. Cystic neoplastic lesions need to be excised with clear margins. Echinococcal (hydatid) cysts should be surgically excised or percutaneously drained and treated with anti-hydatid agents (albendazole, mebendazole).

Pancreatic Cysts

Congenital foregut duplication cysts of the pancreas are extremely rare but are also sometimes detected by prenatal imaging. True cysts have an epithelial lining. Other pancreatic cysts found in children include papillary cystic neoplasm, primitive neuroectodermal tumors, pancreatic blastomas, serous cystadenomas, and pancreatic pseudocysts. These can be treated with cyst aspiration, partial pancreatectomy, or enucleation.

Splenic Cysts

Splenic cysts can be due to trauma, in which case they are probably pseudocysts and usually resolve spontaneously. True cysts are presumably congenital in origin and usually grow slowly over time. If smaller than 5 cm and asymptomatic, they can be observed, but serial US (every 6 months to a year) should be performed. Cysts that are larger than about 5 cm or are causing symptoms (they can also rupture, but this

is exceedingly rare) should be excised. Complete excision of the cyst usually requires a partial or, in some cases, total splenectomy.

Genitourinary Abnormalities

Obstruction of the lower genitourinary structures can lead to cystic changes in more proximal structures and present as a cystic abdominal mass. Often these are discovered on prenatal ultrasound during routine screening or for workup of oligohydramnios or fetal growth retardation. Abnormalities include polycystic kidneys, isolated renal cysts, hydronephrosis, ovarian cysts, ureterocele, urachal cysts, abdominoscrotal hydroceles, and duplications of the vagina/uterus. Most of these abnormalities can be treated postnatally, and specific treatment is aimed at relieving obstructions or removing cysts.

The urachus is a duct that connects the allantois and the bladder through the umbilical cord that can persist as a urachal remnant if either the umbilical or the bladder portion remains patent. If both ends close but the central component of the urachus persists, the result is a urachal cyst, located in the properitoneal space between the umbilicus and the dome of the bladder. These slowly enlarge after birth and typically present in toddlers in the form of an abscess in the midline below inferior to the umbilicus. Rarely, they are identified as a palpable mass in the absence of infection. Complete excision is the treatment of choice though this should be attempted only after the abscess has been drained and all signs of infection have completely resolved.

Tumors

Complex cystic abdominal masses should be considered neoplasms until proven otherwise (Fig. 48.2). US, CT, and MRI are used to evaluate for cystic neoplasms and possible metastases or synchronous lesions. Tumor types include intra-abdominal sacrococcygeal teratoma, ovarian germ cell tumors, pancreatic neoplasms, mucinous cystic neoplasms, and renal or genitourinary tumors. Teratomas can arise in the retroperitoneum or root of the mesentery and not uncommonly from the stomach, in which case they are usually misdiagnosed as a gastric duplication cyst.

Trauma/Pseudocysts

Blunt force injury to the abdomen most commonly involves solid organs. Trauma to the abdomen can also cause rupture of preexisting cysts (hydatid, renal, choledochal, splenic) or the formation of pseudocysts. Hematomas around the liver and spleen, the two most common organs injured in blunt abdominal trauma, can also mimic intra-abdominal cysts. Acute and chronic inflammation of the pancreas sometimes leads to leakage of pancreatic enzymes that ultimately develops into a pseudocyst. Ventriculoperitoneal shunts sometimes result in the formation of a cerebrospinal fluid pseudocyst, which can become infected, cause a small bowel obstruction, or result in shunt malfunction. Cyst and pseudocyst formation due to abdominal trauma can be completely asymptomatic or they can cause pain, distension, and obstruction. In some cases, the workup for blunt trauma leads to the discovery of a preexisting intra-abdominal cyst.

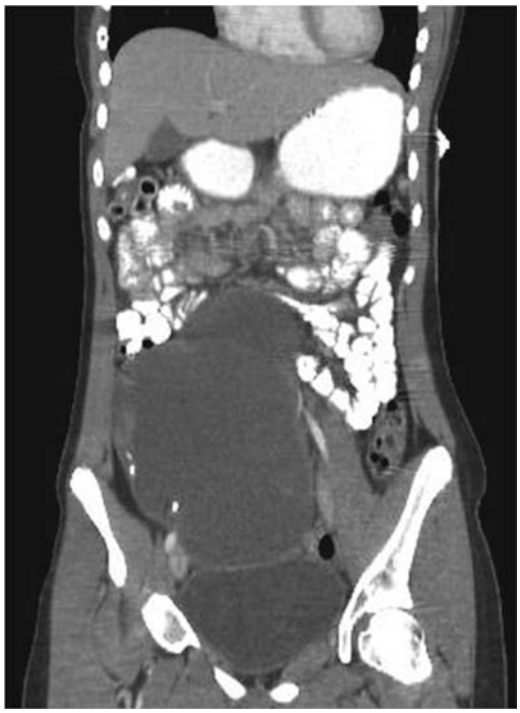

Fig. 48.2 CT scan to evaluate a palpable abdominal mass in a 14-year-old girl. Note the calcifications in the RLQ. The mass was resected and revealed a mature teratoma of the left ovary

Diagnosis

Though enteric duplications are sometimes found unexpectedly at laparotomy, many are identified preoperatively by medical imaging. Ultrasonography can often detect alimentary tract duplications by their signature appearance—a hyperechoic mucosa and hypoechoic outer smooth muscle layer (Fig. 48.3). Peristalsis within the abnormal structure further supports the diagnosis. Cystic structures in the abdomen detected by prenatal US should be followed up by a postnatal study. If asymptomatic, these structures can usually be followed with serial US until the child is older and elective surgery is deemed safer.

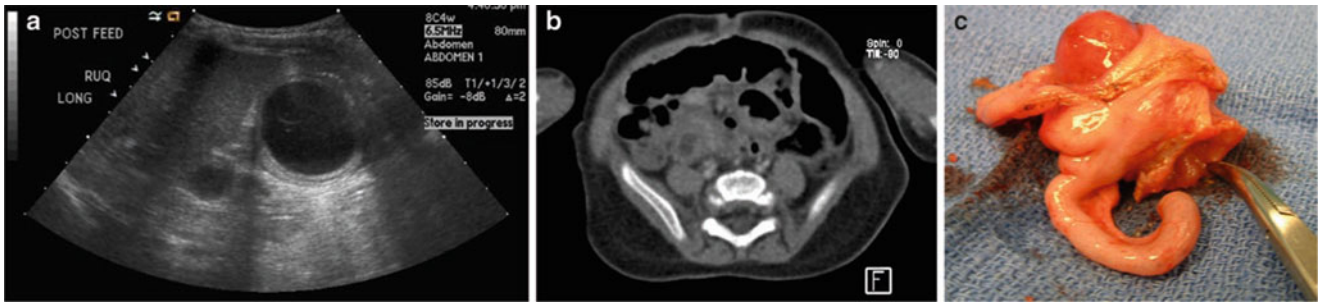

Fig. 48.3 (**a**) Abdominal US showing cystic structure in upper abdomen. (**b**) CT scan showing cystic structure in right lower quadrant. This is in a different location than the cyst seen on abdominal US indicating mobility either outside or within the intestine. (**c**) Resection of terminal ileum and cecum for cecal duplication cyst that had caused intermittent intussusception

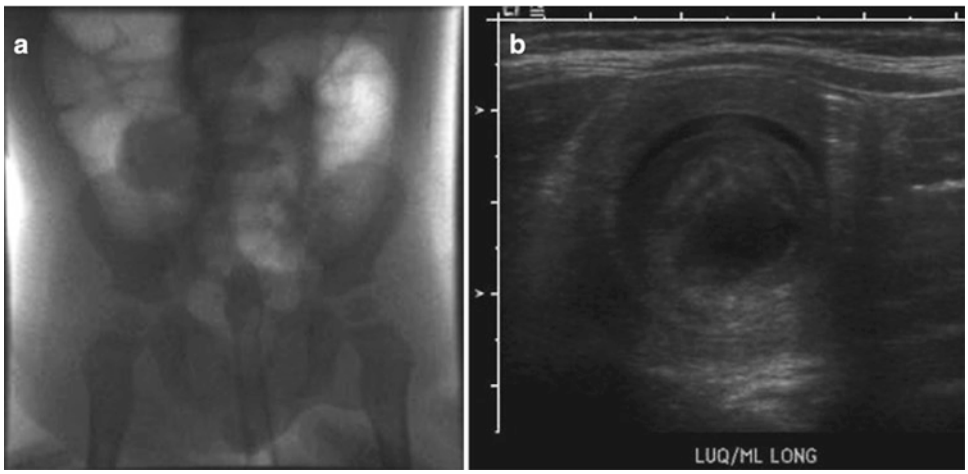

Fig. 48.4 (**a**) Air-contrast enema to evaluate for intussusception. A persistent mass is seen in the ileocecal valve area with no air refluxing into the terminal ileum. (**b**) Abdominal US showing intussusception of ileal duplication cyst

Additional imaging is sometimes necessary to determine the origin of the cystic structure as this can alter management. CT provides more detail and information about the relationship to nearby structures. Spiral CT is useful for identifying feeding vessels, especially when an extralobar pulmonary sequestration is thought to be present. CT scans are also better able to detect synchronous lesions in the chest or abdomen.

MRI is being performed more frequently in the prenatal period and can often detect asymptomatic intra-abdominal cystic structures. This modality is also useful in delineating biliopancreatic abnormalities and can help to distinguish intestinal duplication cysts, choledochal cysts, and pancreatic cysts. MRI has the additional advantage of avoiding radiation in children but often requires the use of general anesthesia in young children.

Contrast studies (upper GI with small bowel follow-through, contrast enema) are sometimes used to investigate particular symptoms. A child with bilious emesis undergoing an UGI to rule out malrotation might instead be found to have a duodenal duplication. Barium or air enemas to diagnose and treat intussusception might reveal a persistent cystic structure in the cecum or terminal ileum that on exploration is confirmed to be an enteric duplication cyst (Fig. 48.4).

ERCP and MRCP are useful diagnostic adjuncts when cysts are located in close proximity to the biliary or pancreatic systems. They should also be used when patients present with jaundice or have symptoms of pancreatitis. Although advancements in radiographic technology are rapidly improving, the final diagnosis is often not determined until surgical resection and histopathologic examination.

Treatment

When treating a patient with a symptomatic enteric duplication or intra-abdominal cyst, the primary goal should be complete resection. For the simple cysts, excision can be relatively straightforward. Tubular duplications are often intimately associated with the normal bowel, making simple excision impossible. Segmental intestinal resection can be performed for cysts confined to a short segment. Because most upper abdominal cysts have gastric or pancreatic ectopic mucosa, bleeding and ulceration can occur if the cyst is

not removed or if the mucosa is left intact. For this reason, long small bowel duplications require mucosal stripping and marsupialization of the cyst wall.

For certain locations, different techniques are employed. Gastric duplications are commonly found on the greater curve of the stomach and usually do not communicate with the gastric lumen. Children with gastric duplications might be completely asymptomatic or they can present with non-bilious vomiting, failure to thrive, or hematemesis. Removal of these cysts is recommended to prevent bleeding, ulceration, and, although extremely rare, malignant degeneration. The cyst can usually be removed without having to remove any of the stomach. Simply excising the cyst and the common wall and closing the serosal defect should be adequate. If there is communication with the gastric lumen and the cyst is small, a segmental resection can be performed. For larger cysts, resection of the common wall followed by repair of the gastrotomy is necessary.

Duodenal duplications are less common than gastric or small bowel duplications. These are typically found on the mesenteric side of the first or second portion of the duodenum. Presenting symptoms include vomiting, abdominal mass, failure to thrive, pancreatitis, jaundice, or bleeding. Diagnosis can be made with abdominal US, UGI, or CT. ERCP can also be used to confirm the diagnosis and is sometimes be therapeutic, if a window can be created between the cyst and duodenal lumen. Most duodenal cysts contain duodenal mucosa but up to 20 % have gastric mucosa and therefore can cause ulceration and bleeding. Removal of the cyst or stripping the mucosa will prevent these complications. Care must be taken not to injure the common bile duct or pancreatic duct during cyst resection.

Small bowel duplication cysts are the most common variety and can be either cystic or tubular. Tubular duplications share all or part of their wall with the intestine and can have a shared or separate blood supply. They are usually on the mesenteric side and present with bleeding, obstruction, intussusception, perforation, or a palpable mass. The diagnosis is rarely made preoperatively. Treatment involves removal of small cysts by enucleation, larger cysts by segmental resection, and long tubular duplications by mucosal stripping.

Colonic duplications present in a similar fashion to small bowel duplications: vomiting, obstruction, volvulus, or perforation. Making the diagnosis preoperatively is challenging, and often these cysts are not discovered until laparotomy or laparoscopy. Like their small bowel counterparts, these can be cystic or tubular. They can be found on the mesenteric or the antimesenteric side of the normal colon and can end blindly or as a separate anus or as a fistula to the genitourinary tract. The proximal end of the duplication usually connects to the normal colon and can thus become filled with stool. If the distal end has no fistula or colonic connection, the duplicated tube can fill with stool and compress the normal rectum.

Colonic duplications have a high association with other intestinal and genitourinary anomalies. Children with double penis, bifid scrotum, double vagina, or didelphic uterus should be evaluated for possible colonic duplication. Since the mucosa of the duplication is usually colonic and not at risk for bleeding, complete resection is not usually required. The distal portion of the duplication can be connected to the normal colon to relieve buildup of stool within the duplicated segment.

Rectal duplications are very rare and are more common in females. They are typically located posterior to the normal rectum. Many have a fistulous connection to the rectum or skin and are confused with perirectal abscess or fistula in ano. Rectal duplications present with pain, constipation, bleeding, fistula, or prolapse. Workup typically includes contrast enema, CT, or MRI. These studies will also help to rule out spinal cord anomalies such as myelomeningocele. Complete resection of a rectal duplication can be achieved by a transanal or posterior sagittal approach. Occasionally, an unresectable duplication will need to be addressed by mucosectomy.

Many intra-abdominal cysts and duplications are amenable to minimal access surgery. The same principles are applied: complete resection or partial resection with mucosectomy. Any cystic structure suspected of being a malignancy should be left intact with avoidance of spillage of cyst contents. As with an open approach, laparoscopic exploration should be thorough enough to evaluate for synchronous intra-abdominal cysts and associated anomalies.

Percutaneous drainage and sclerosis of lymphocytic cysts can often be a good alternative to surgical resection, especially for cysts that reside at the base of the intestinal mesentary. Repeat procedures are often necessary to completely obliterate the cystic structure but can often be done with ultrasound guidance and light sedation. This technique depends on the accessibility of the mass for a safe percutaneous approach.

Children with intussusception who require surgical exploration should be examined intraoperatively for intraluminal masses. A duplication or mesenteric cyst can cause intussusception and will need to be excised, usually with a segmental resection of the involved intestine (Fig. 48.3).

Postoperative Care

The postoperative care of children undergoing resection of duplication cysts is no different that used after other intestinal procedures. The timing of initiation of enteral feeds is determined by the surgical procedure. If a simple cyst is entirely removed and the intestinal lumen remains intact, feeds can start in the immediate postoperative period. Those children undergoing intestinal resection with primary anas-

tomosis or marsupialization of a cyst might need to wait until adequate return of bowel function. Following resection of upper abdominal cysts such as those found in the stomach and duodenum, patients usually require nasogastric tube decompression for 1–2 days. Antibiotics are generally not needed in the postoperative period and need only be given prior to the surgical incision.

Children should be monitored for recurrent bleeding following excision or mucosectomy of duplication cysts, especially if any mucosa was left behind. Resection of cysts lying in close proximity to the pancreas can induce postoperative pancreatitis that will usually resolve with bowel rest. Patients who undergo resection of rectal duplication cysts and develop fecal incontinence should undergo anal manometry and should be considered for biofeedback therapy. Duplication cysts that are found in adulthood need to be removed due to the risk of malignant degeneration. Nevertheless, routine follow-up imaging is usually not necessary in the asymptomatic patient.

The overall prognosis for children with duplication cysts is generally excellent. As many of these are now being discovered prenatally, earlier detection and treatment can often be carried out before symptoms or complications occur.

Editor's Comment

Ovarian cysts identified antenatally or at birth are often the result of antenatal torsion. They are usually asymptomatic and can be safely observed, but many will fail to resolve by serial US and should be removed. The contralateral ovary should be inspected; however, oophoropexy is probably unnecessary. Simple ovarian cysts in older girls should be excised if they are large, growing, or symptomatic. The inner lining can usually be stripped cleanly, preserving the ovary proper. Simple unroofing or marsupialization results in a high recurrence rate and should only be done if stripping is impossible due to hemorrhage or inflammation.

A true cyst can theoretically be treated by removing its epithelial lining, though complete excision is often easier and less morbid. By definition, enteric duplication cysts have a mucosal lining, but removal of just the lining is a challenge. It is usually safer to excise it. Since they almost always arise from the mesenteric side of the bowel wall, this often entails bowel resection in older children; however, duplications identified in utero and excised in newborns can often be excised completely without disturbing the blood supply of the adjoining bowel. This approach is not used for long tubular duplications or duodenal duplications, which should be stripped, if possible, or the common wall between the cyst and the adjacent bowel lumen can be obliterated to create a single lumen. This is not ideal in that it essentially creates a diverticulum, but it might be the only alternative to an extensive and dangerous bowel resection (Whipple procedure, esophagectomy).

A simple liver cyst should be observed and will usually remain stable, unless it represents an echinococcal cyst or abscess. Splenic cysts must always be completely excised by partial or total splenectomy, as the characteristically trabeculated inner lining can never be stripped or obliterated. Some have tried using sclerotherapy, the argon beam coagulator, or marsupialization, but each of these techniques is associated with an unacceptable recurrence rate.

Omental cysts can torse, bleed, or rupture, in some cases mimicking appendicitis. They can be simply excised by laparoscopic partial omentectomy. Mesenteric cysts (lymphangiomas) are more difficult to deal with as they can insinuate extensively within the mesentery and retroperitoneum. Ideally, they should be excised, but this might not be feasible, in which case the only option is partial excision and marsupialization.

Most abdominal cysts and duplications can and should be approached laparoscopically, at least at first. Preoperative planning must include high-resolution three-dimensional imaging such as a CT or MRI. The goal should be to effectively eradicate the cyst, either by excision, epithelial stripping, or marsupialization, in that order of preference, but to minimize postoperative discomfort and scarring.

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Anomalies of Intestinal Rotation

49

E. Marty Knott and Sohail R. Shah

Anomalies of intestinal rotation are estimated to occur in 1 in 500 live births. There are numerous variants of these anomalies, with the most common being *malrotation* and *nonrotation*. Intestinal *malrotation* describes specific anatomy that is usually asymptomatic; however, the associated narrow mesenteric pedicle places patients at risk of life-threatening *midgut volvulus*, which is estimated to occur in 1 in 2500 live births. *Nonrotation* has a similar intestinal configuration; however, the mesentery is sufficiently broad to minimize the risk of midgut volvulus. Another intestinal rotational anomaly is *incomplete rotation*, which occurs when the normal rotational process of the midgut has been interrupted. Understanding the embryology that results in these various degrees of intestinal rotation is the first step in the appropriate diagnosis and treatment of these patients. Once an intestinal rotational anomaly is suspected, the management is dependent on the anatomy and associated symptoms.

Embryology

Normal intestinal rotation is a complex event that begins in the 4th week of gestation when the straight intestinal tube begins to rapidly elongate. During this elongation, the alimentary tract herniates through a widened umbilical defect completing a 90° counterclockwise rotation. By the 10th week, the alimentary tract returns to the abdomen, making another 180° counterclockwise turn for a total of a 270° turn. From the 11th week on, fixation of the bowel in the abdomen occurs. This normal rotation results in the classic "C-loop" duodenum with the concavity to the patient's left and the 4th portion of the duodenum ending at the ligament of Treitz, which should be located to the left of the spine approximately at the level of the pylorus. This ligament provides a tether point for the proximal jejunum. As a result of normal rotation, the superior mesenteric artery (SMA) passes anterior to the third portion of the duodenum, which is fixed in the retroperitoneum, and the superior mesenteric vein (SMV) lies to the right of the artery. The cecum is similarly fixed in the retroperitoneum, and this provides the small bowel mesentery a broad base that runs from the left upper quadrant to the right lower quadrant. This wide mesenteric root helps to prevent torsion around the vascular pedicle.

The exact etiology of intestinal rotational anomalies is unknown. A variety of factors are likely involved including a wide array of genetic mutations. In fact, malrotation often occurs as part of a syndrome that includes multiple anomalies. Mutations in *FOXF1* result in intestinal malrotation, urinary tract abnormalities, and alveolar capillary dysplasia, which is fatal. Syndromes such as Martinez-Frias syndrome, those associated with intestinal atresia and short bowel, and megacystitis, microcolon, and intestinal hypoperistalsis have been described. There are several disorders of left–right differentiation such as heterotaxia that are also associated with some form of an intestinal rotation anomaly. The importance of this is not any single association, but rather an understanding of the complex genetic factors that are involved with normal gut rotation.

Any process that interferes with the normal elongation, herniation, rotation, and return of the bowel into the abdomen will result in some degree of incomplete intestinal rotation. For this reason, congenital diaphragmatic hernia and abdominal wall defects are universally associated with abnormal rotation.

Understanding the embryology allows for differentiation of the terminology and specific anatomy associated with variants of intestinal rotation anomalies. *Malrotation* describes a failure of the intestine to complete the full 270° rotation, resulting in the 4th portion of the duodenum remaining to the right of the spine as it fails to cross the midline. The SMA runs alongside the duodenum, rather than crossing

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anterior to it, and is within a narrow mesenteric pedicle that connects the duodenojejunal junction with the cecum. Although the majority of patients with *malrotation* are asymptomatic, the narrow mesenteric pedicle puts them at risk for *midgut volvulus*. A complete volvulus can result in vascular cutoff at the base of the SMA, leading to ischemia from the duodenum to the proximal transverse colon.

Nonrotation has a similar intestinal configuration to malrotation and also indicates that the SMA does not cross anterior to the duodenum; however, it also suggests that the mesentery is broad enough to minimize the risk of volvulus. Nonrotation is the anatomy that is usually found in patients with congenital diaphragmatic hernia and those who have undergone a correctly performed Ladd procedure.

Other features of incomplete rotation may also be of clinical significance. The abnormal position of the cecum can lead to a delayed diagnosis of acute appendicitis in patients who present with left-sided abdominal pain. Additionally, the cecum may have peritoneal attachments to the right lateral abdominal wall that cross over the duodenum, known as Ladd's bands. These peritoneal bands may cause intermittent obstruction of the duodenum or proximal jejunum, leading to chronic abdominal pain and poor oral intake.

Rare forms of intestinal rotational anomalies also exist. These include *reverse rotation*, in which the duodenum lies anterior to the transverse colon, and other anomalies where the left and right colon are not fixed to the posterolateral abdominal walls. When the latter occurs, the small bowel can herniate through the mesocolic defects, causing intestinal obstruction. These unusual anomalies are rarely identified until abdominal exploration.

Diagnosis

Although the majority of patients with malrotation are asymptomatic, the most common presentation of symptomatic malrotation is during infancy. Any infant that presents with bilious emesis must be suspected of having malrotation and possibly midgut volvulus. A prompt diagnosis of malrotation with midgut volvulus is critical to prevent intestinal loss secondary to ischemia. Approximately half of patients with midgut volvulus present with bilious emesis. The bilious nature of the emesis allows for differentiation from pyloric stenosis, which typically presents with non-bilious emesis in a well baby; however, the differential diagnosis still includes other intestinal obstructions including intestinal atresia, meconium ileus, and Hirschsprung disease. Other physical findings might include a scaphoid abdomen if the intestinal obstruction is very proximal. However, as gastric distention increases and intestinal ischemia progresses leading to bowel edema, abdominal distention becomes more common. Additionally, as intestinal ischemia leads to mucosal sloughing, bloody stools may be present. At any time during the evaluation, if the infant develops signs of peritonitis or sepsis, including tachycardia, hypotension, or oliguria, then plans should be made for immediate surgical exploration.

Laboratory evaluation of a patient with suspected midgut volvulus should include a CBC, basic chemistry panel, lactic acid, PT/PTT, and determination of base deficit. In a stable patient, imaging has a critical role in the diagnosis. Plain abdominal radiographs most often reveal a nonspecific bowel gas pattern. However, occasionally findings suggest the diagnosis. Due to the proximal obstruction in midgut volvulus, a "double bubble" may be evident, similar to what is seen with duodenal atresia. The differentiating finding is usually the presence of some distal intestinal gas with midgut volvulus, as opposed to the complete lack of distal gas in duodenal atresia. Additionally, if the process has advanced to intestinal ischemia, the abdominal radiograph may also demonstrate bowel wall thickening, pneumatosis intestinalis, or portal venous gas.

The upper gastrointestinal contrast study (UGI) remains the standard to evaluate for malrotation in the stable patient. Contrast is administered into the stomach, and fluoroscopy is used to follow its course through the duodenum and into the proximal jejunum. A normal UGI demonstrates the classic "C-loop" of the duodenum that crosses the midline and the duodenojejunal junction (ligament of Treitz) to the left of the spine at the level of the pylorus (Fig. 49.1). An UGI with evidence of malrotation will demonstrate the failure of the duodenum to cross the midline (Fig. 49.2) and also often have evidence of the majority of the small bowel on the right side of the abdomen. If the malrotation is associated with

Fig. 49.1 A normal UGI with the duodenum crossing the midline and the duodenojejunal junction at the level of the pylorus

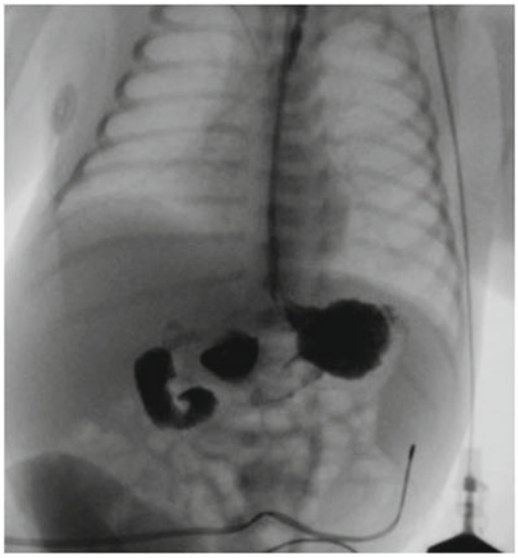

Fig. 49.2 An UGI demonstrating malrotation with the duodenum failing to cross the midline

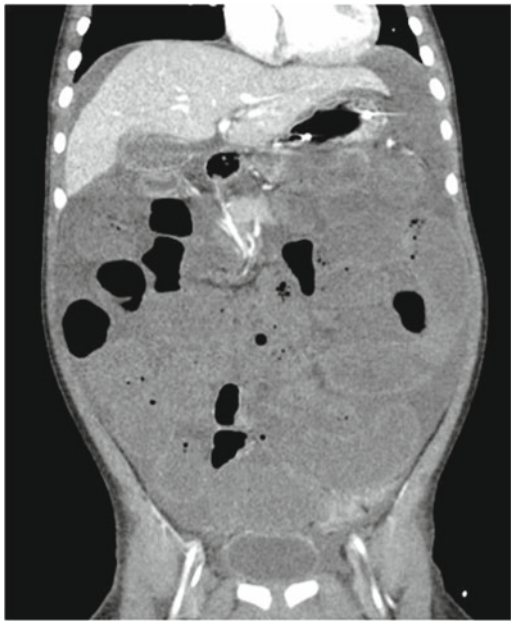

Fig. 49.3 A CT scan demonstrating intestinal volvulus with swirling of the mesenteric vessels, ascites, and pneumatosis intestinalis

midgut volvulus, the UGI will demonstrate an abrupt cutoff due to the proximal obstruction. Additionally, a corkscrew pattern of the jejunum without passage of contrast is sometimes evident on lateral views. A contrast enema may also be used to assess the colon and the position of the cecum, which should be found in the right lower quadrant with normal rotation; however, this is not always a reliable test since 15–20 % of patients with malrotation have a normally positioned cecum, and this study will not assess for proximal obstruction associated with midgut volvulus.

CT with contrast has a high sensitivity and specificity for malrotation and volvulus but is rarely needed in suspected volvulus (Fig. 49.3). Intravenous contrast may allow one to see perfusion defects to the bowel. MRI can also be used to diagnose malrotation, but it is more expensive and time consuming.

Ultrasound can assess the relationship of the superior mesenteric vessels to the duodenum. Normal anatomic position would be to find the SMA to the left of the SMV. While reversal of this arrangement suggests malrotation, normal anatomy is variable. A swirling or whirlpool pattern around reversed superior mesenteric vessels is indicative of volvulus and in the appropriate clinical scenario should prompt surgical intervention. Additionally, US might show free fluid, bowel wall edema, pneumatosis intestinalis, or portal venous gas.

If at any point bowel ischemia is suspected, emergent operation should be performed without imaging. The classic patient with volvulus presents with bilious emesis, a scaphoid abdomen, and shock. Delay in intervention can lead to bowel loss, short bowel syndrome, and even death. Even in a stable patient with suspected volvulus, imaging should be done promptly.

Treatment

Midgut volvulus requires emergent surgical exploration. While proceeding to operative intervention, the child should receive aggressive fluid resuscitation and preoperative prophylactic antibiotics; however, these should not delay the operation. The operative approach begins with a laparotomy incision, evisceration of the bowel, and gentle detorsion of the bowel mesentery in a counterclockwise direction. This maneuver should relieve the vascular obstruction and allow for reperfusion. The intestinal loops should be maintained in warm saline-soaked laparotomy pads while viability is assessed. Intestinal viability may be determined by visual inspection, and a Doppler probe or fluorescein may be used to assess flow through the mesenteric vessels. Only frankly necrotic bowel should be resected. Aggressive resection during this initial evaluation can unnecessarily result in short bowel syndrome. A second-look operation within the next 24–48 h is sometimes warranted to reassess the viability of the intestine that appears borderline. After correction of the volvulus, the underlying malrotation is addressed through a Ladd procedure.

In the absence of midgut volvulus, emergent surgical intervention is not necessary. In these cases the patient with malrotation may be scheduled for an elective Ladd procedure. The goal of the Ladd procedure is to relieve partial proximal bowel obstruction by abnormally formed peritoneal bands (Ladd's bands) and to widen the base of the mesentery to prevent midgut volvulus. This is accomplished by

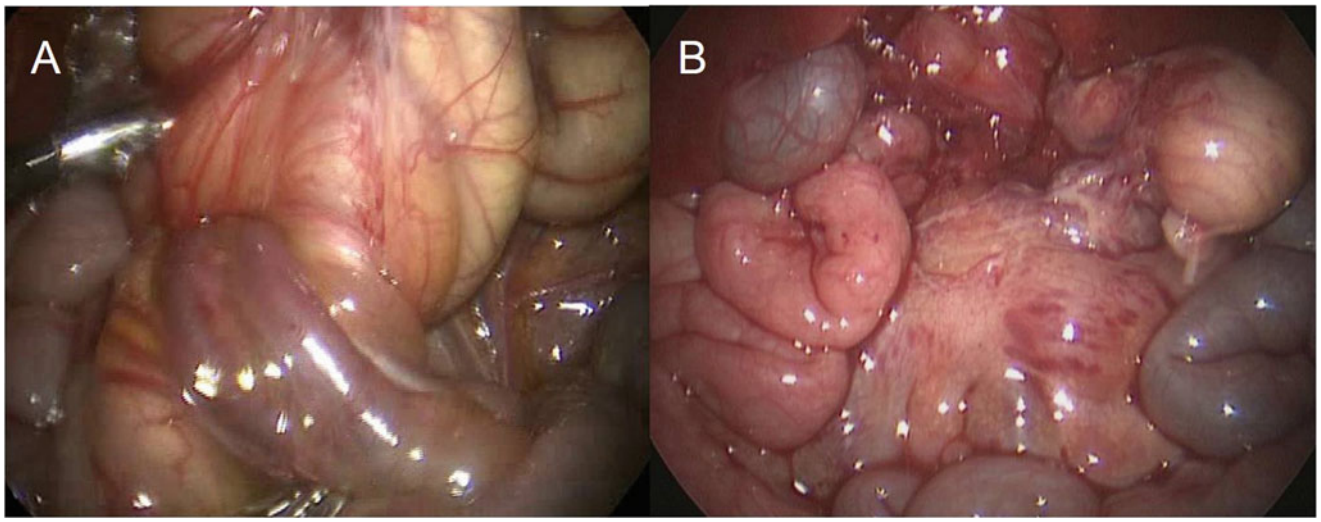

Fig. 49.4 (**a**) A patient with intestinal torsion, without bowel compromise, secondary to malrotation. (**b**) The same patient with widened mesentery after a laparoscopic Ladd procedure, including detorsion of the bowel

dividing the bands that cross anterior to the duodenum and widening the base of the mesentery by separating any anterior mesenteric connections between the duodenum and the colon. Ladd's bands and mesenteric connections are typically avascular and can be divided without electrocautery, thereby decreasing the risk of mesenteric injury. The Ladd procedure is then completed by performing an appendectomy, due to the resulting abnormal position of the cecum, and finally by replacing the bowel with the duodenum and small intestine on the right side of the abdomen and the colon on the left.

The use of laparoscopy for treatment of malrotation is safe and seems to be effective. Laparoscopy is becoming more popular especially in older children undergoing an elective Ladd procedure. Ladd's bands can be divided and the mesentery can be widened laparoscopically using the same principles as with the open technique (Fig. 49.4). The appendectomy can then be performed in the standard laparoscopic manner or can be exteriorized and removed extracorporeally through the umbilicus.

Postoperative Course

The postoperative course is dependent upon the indications for the operation and the intraoperative findings. Patients with midgut volvulus who undergo bowel resection often require continued intensive care monitoring for fluid resuscitation and respiratory support. Those who are to undergo a planned second-look operation are usually left intubated between the two operations. Patients with intestinal ischemia can be expected to have a prolonged postoperative ileus, and parenteral nutrition should be instituted early.

Meanwhile, patients who undergo an elective Ladd procedure usually have a short postoperative course consisting of routine pain management while awaiting return of bowel function. A nasogastric tube is not usually required in these patients.

Long-term follow-up demonstrates that small bowel obstruction occurs in up to 10 % of patients after a Ladd procedure; however, the rate of recurrent volvulus is typically less than 2 %. Current early evidence supports laparoscopic correction of malrotation as being equally safe and effective as the open approach.

Editor's Comment

Many people confuse the terms *malrotation* and *volvulus*, but they are not interchangeable. *Malrotation* describes a specific anatomy that is essentially harmless and usually asymptomatic; however, malrotation puts people at risk of midgut *volvulus*, which is potentially catastrophic. In addition to signifying that the duodenum does not pass behind the SMA, *malrotation* also implies that the cecum and duodenum are adjacent to each other and that the entire midgut is based on a narrow mesenteric pedicle. *Nonrotation* also indicates that the duodenum does not pass behind the SMA, but it suggests that the mesentery is sufficiently broad that the risk of volvulus is minimal—it is the anatomic configuration that remains after a properly performed Ladd procedure and occurs naturally in most patients with congenital diaphragmatic hernia and other anomalies that associated with rotational abnormalities.

Infants and children with bilious emesis and no reason to have adhesions should be presumed to have malrotation with

volvulus until proven otherwise. (One important exception is the well appearing newborn with a neonatal bowel obstruction and dilated loops of bowel who is better served with a contrast enema to rule out meconium ileus, meconium plug, intestinal atresia, or Hirschsprung disease.) If the child is septic or has peritonitis, he or she should be prepared for immediate laparotomy. Time is of the essence. If the patient is stable, an upper GI contrast study should be performed urgently—it cannot wait until morning. If the findings are consistent with volvulus, the patient goes to the OR immediately. If there is malrotation without volvulus, most pediatric surgeons make plans to operate within 24 h. It is important to note that the picture of a well appearing child and a totally benign abdomen (even if laboratory values and radiographs are within normal limits) does not rule out the possibility of volvulus with ischemic bowel.

The Ladd procedure can be performed laparoscopically or open. Most useful when the procedure is being performed nonemergently, the laparoscopic approach is often quite difficult and it is relatively common even for experienced laparoscopists to convert to open. Regardless of the approach, the steps are the same:

1. Detorse the bowel in a counterclockwise direction ("turn back the hands of time"): if bowel is frankly necrotic, it should be excised, which places the child at risk for short gut syndrome and intestinal failure. If the bowel is of questionable viability, a second-look operation should be planned for 48–72 h.
2. Divide Ladd's bands.
3. Straighten the duodenum (lyse all adhesions and undo its typical accordion configuration).
4. Broaden the mesentery—separate the colon and duodenum, open the anterior mesenteric peritoneum, and fan out the vessels of the mesentery.
5. Remove the appendix.
6. Establish a nonrotation configuration: place the small bowel on the right side of the abdomen with the duodenum along the right lateral side wall, and place the colon on the left side with the cecum in the left lower quadrant.

Cecopexy and duodenal fixation sutures are unnecessary and create sites around which a volvulus could occur. Regarding the Ladd procedure, trainees always place undue importance on the lysis of Ladd's bands. But the most important steps are the broadening of the mesentery, which is what prevents volvulus, and the straightening of the duodenum, which relieves the GI symptoms these patients often have (emesis, reflux, failure to thrive). Turbid fluid at operation is almost always chylous ascites due to lymphatic congestion from partial volvulus and not evidence of bowel perforation. Postoperatively, many patients have a prolonged ileus. Some will have protracted symptoms of duodenal dysmotility or pseudo-obstruction.

There are many variants of malrotation, including partial rotation and right and left paraduodenal hernia. All are treated by trying to establish the nonrotation configuration—the steps of the Ladd procedure are modified as needed but the final anatomy should be the same. The exception is reverse rotation, which often requires that a portion of the bowel be divided and reconnected to relieve entrapment. The rotational anomalies displayed by patients with heterotaxy are also often quite challenging to deal with. The goal in these cases is to do whatever it takes to leave the patient with a mesentery that is as broad as possible and therefore unlikely to volvulize.

The upper GI is the standard for the diagnosis of malrotation, but in clinical practice is frustratingly imprecise. To avoid missing a single case of malrotation, pediatric radiologists adhere to very strict criteria to define what is normal. Any variation, no matter how clinically insignificant, will be read out as the dreaded "cannot rule out malrotation." Exploratory surgery has historically been the only way to decide if the intestine was truly malrotated; however, newer imaging modalities (US, MR) are becoming increasingly useful to confirm the retroperitoneal sweep of the duodenum and the absence of a narrow root of the mesentery. The ligament of Treitz can also be displaced by gastric or colonic distension, and simply repeating the upper GI after a few days or weeks might yield a different result. Because 15 % of patients with duodenal malrotation have normal colonic anatomy, contrast enema is not an accurate test for malrotation. Finally, there are some children who have an abnormally low ligament of Treitz. If the duodenum passes behind the SMA and the mesentery is sufficiently broad, these children are at minimal risk of volvulus and can be safely observed.

Suggested Reading

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Necrotizing Enterocolitis

50

Michael J. Morowitz

Necrotizing enterocolitis (NEC) is a disorder of intestinal inflammation in newborn infants that commonly progresses to tissue necrosis and systemic illness. Although the condition had been described earlier under different names, NEC became recognized as a distinct entity largely as a result of reports in the 1960s and 1970s detailing clinical experience with the disease at the Babies' Hospital in New York. Today NEC remains a major source of morbidity and mortality in neonatal ICUs. Whereas early reports described NEC in late preterm or term infants, NEC is most commonly observed today in very low birth weight (VLBW) (birth weight <1.5 kg) infants born prematurely at a gestational age of 32 weeks or less.

Population-based studies have consistently demonstrated the incidence of NEC among VLBW infants to be in the range of 5–12 %. The absolute number of infants with NEC is probably rising, as improvements in neonatal intensive care have made it possible for an increasing number of premature infants to survive beyond the first few days of life—in effect these improvements create a larger pool of infants at risk for NEC. A third of patients with NEC will require emergency surgery, and recently published data suggest that the mortality rate in this group approaches 35 %. It is humbling to consider that there are few other surgical emergencies, even among adults, with mortality rates this high. Among those that survive NEC, the disease is also clearly an independent risk factor for compromised functional outcomes.

A fundamental challenge in caring for infants at risk for NEC is the lack of currently available knowledge regarding the pathophysiology of the disease. We simply lack the robust mechanistic details required to explain how specific risk factors somehow converge to create an often-disastrous phenotype. One unsolved question is why the disease is seen predominantly in premature infants. The explanation for this remarkable epidemiologic finding seems to be their gut immaturity and exaggerated immune response. A functional consequence of gut immaturity, as manifested by decreased motility, reduced concentration of proteolytic enzymes, increased permeability, and immaturity of both cellular and humoral immune responses, is an impaired gut barrier and predisposition to bacterial translocation. Similarly, experimental evidence (e.g. increased expression of Toll-like receptor 4) and clinical findings both suggest that intestinal inflammation is excessive in premature infants. Taken together, these observations have led to the hypothesis that the underdeveloped gut of VLBW infants is not equipped to deal with the stimuli encountered upon transitioning from the protected intrauterine environment to life in the neonatal ICU, especially enteral feeding.

Still, if these predisposing features of gut immaturity apply to all VLBW babies, it remains puzzling why only a subset of infants develops NEC. A possible explanation is that infants with NEC harbor particularly abnormal or virulent populations of intestinal bacteria. Numerous older studies failed to prove this to be the case, but these studies suffered from methodological limitations. Recently, technical and conceptual advances in studying the human microbiome have generated renewed efforts to profile gut bacteria in preterm infants. Relative to term infants, it does appear that preterm infants harbor aberrant populations of gut bacteria characterized by reduced biodiversity, decreased abundance of anaerobes such as *Bacteroides* and *Bifidobacterium* species, and increased abundance of facultative anaerobes such as *Enterococcus* and *Staphylococcus* and common gram-negative enteric organisms from the family *Enterobacteriaceae* (Fig. 50.1). Thus, an important lesson appears to be that nearly all preterm infants possess microbiome profiles dominated by potential pathogens. Attempts to distinguish the microbiota of infants with and without NEC have been less definitive. While some studies have indicated that babies with NEC possess even larger populations of

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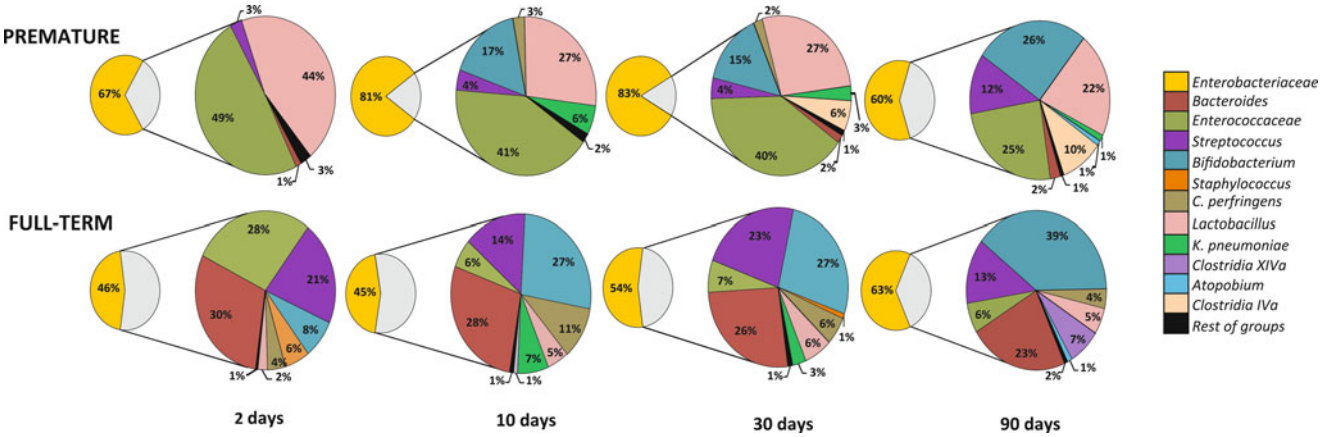

Fig. 50.1 Relative abundance of bacterial taxa in fecal samples collected from premature and full-term infants during the first 3 months of life. Samples from premature infants are enriched with facultative anaerobes such *Enterococcus* and common gram-negative pathogens from the family *Enterobacteriaceae*. Samples from full-term infants are enriched with obligate anaerobes including species of *Bacteroides* and *Bifidobacterium* (Reprinted from Arboleya S, Solís G, Fernández N, et al. Facultative to strict anaerobes ratio in the preterm infant microbiota: a target for intervention? Gut Microbes 2012; 3:6, 583–588, by permission of Taylor & Francis Ltd)

Enterobacteriaceae, results across studies have been inconsistent. Like other complex disease phenotypes, NEC likely represents a convergence of a predisposing genetic background with specific environmental exposures (formula feeding and disturbances of the microbiota), with the risk of disease being highest in the presence of an underdeveloped gut. Novel approaches are needed to tease apart these factors.

Diagnosis and Medical Management

The classic presentation of NEC is a preterm infant who develops feeding intolerance, abdominal distension, and bloody stools in the first month of life. Interestingly, age of onset is inversely proportional to gestational age; whereas most premature infants with NEC are affected at 2–4 weeks of age, late preterm and term infants with NEC tend to develop disease in the first few days of life. Early aggressive enteral feeding and indomethacin for the treatment of patent ductus arteriosus were previously considered risk factors for NEC, but recent well-controlled studies have not validated these associations. Recently, prolonged empiric antibiotic therapy in the newborn period for "rule-out sepsis" has been identified as a possible independent risk factor for NEC.

Reliable radiographic findings in NEC include pneumatosis intestinalis, portal venous gas (Fig. 50.2), and pneumoperitoneum (Fig. 50.3). Laboratory findings often include thrombocytopenia and metabolic acidosis. On physical examination, infants with NEC may exhibit abdominal tenderness, erythema of the abdominal wall, palpable bowel loops, or a fixed abdominal mass. The presence of abdominal wall erythema in newborns indicates perforation or necrosis causing inflammation that extends through to the skin due to a lack of subcutaneous fat. Occasionally, infants with advanced disease will develop abdominal compartment syndrome, and their lower extremities will appear blue and congested due to obstructed venous return. When these classic findings are present, the diagnosis of NEC is straightforward.

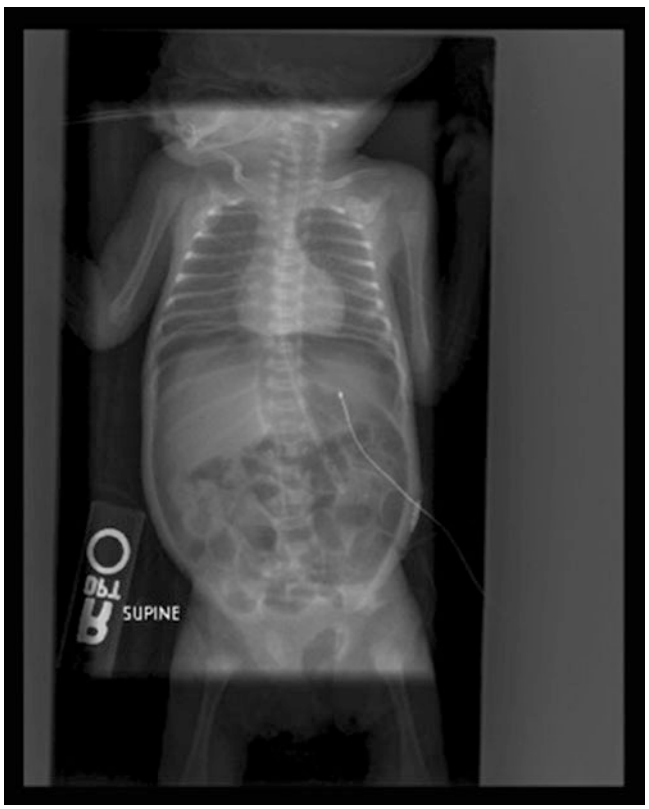

Fig. 50.2 Supine plain radiograph demonstrating extensive pneumoperitoneum outlining the liver in an infant with NEC

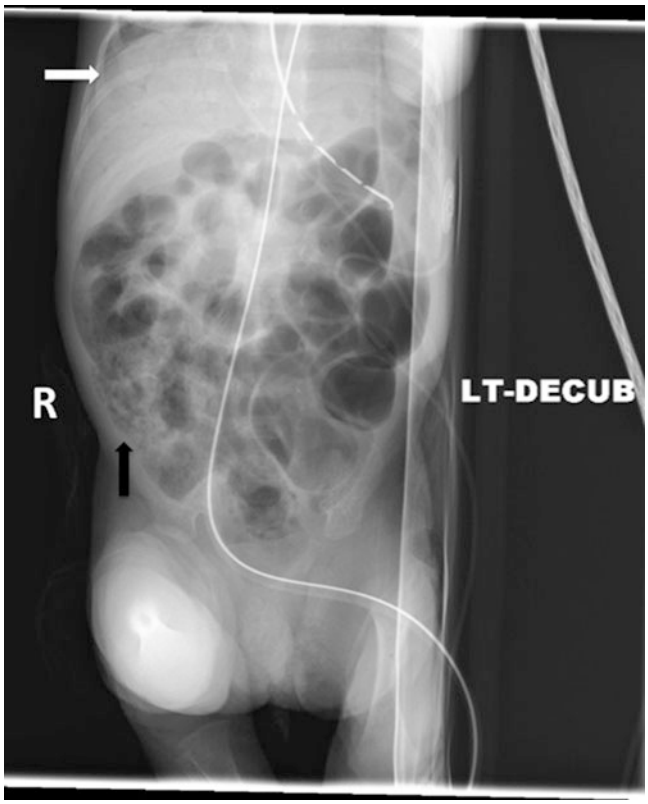

Fig. 50.3 Left lateral decubitus radiograph demonstrating both portal venous gas (*white arrow*) and extensive pneumatosis intestinalis (*black arrow*) in an infant with NEC

Infants presenting with fulminant disease and systemic illness will be referred early for surgical evaluation. However, particularly in stable patients, many presenting signs of NEC are nonspecific features of instability in newborns—lethargy, temperature instability, apnea, bradycardia, and hypoglycemia or hyperglycemia. In these cases, it can be challenging to distinguish NEC from ileus secondary to neonatal sepsis. Depending upon the center, infants with mild symptoms may not be referred early for surgical evaluation.

Babies with NEC require varying levels of supportive care and resuscitation. Some require endotracheal intubation and vasopressor support, while many others do not. Initial management of NEC consists of antibiotics, bowel rest with decompression of the stomach, and parenteral nutrition. Interestingly, the efficacy of antibiotics and bowel rest has never been tested or proven in NEC. Both are likely to further disturb the microbiota, but they seem like reasonable interventions nonetheless. For unclear reasons, it has long been said that anaerobic coverage is unnecessary in NEC. However, recent microbiome-profiling studies have clearly demonstrated the presence of anaerobes such as *Clostridiaceae* in fecal and tissue samples from VLBW infants. Thus, a regimen of broad-spectrum antibiotics that includes some anaerobic coverage is recommended. At our institution, we use cefotaxime in combination with either ampicillin or vancomycin for 10–14 days. Clindamycin is added in cases of perforation and portal venous gas, but there is no evidence to support this particular practice. Enteral feedings are generally held for 7–14 days; many groups advocate restarting feeds as soon as infants look clinically well.

Roughly one third of patients with NEC will require surgery despite optimal medical management. Traditionally it has been recommended to defer surgery for NEC until "gangrene is present but a perforation has not yet occurred." In reality, no test or biomarker has been identified to reliably aid in making this distinction, and clinical experience is therefore required. Much has been written about indications for surgery in NEC, and little has changed in this regard in recent years. The only absolute indications are pneumoperitoneum on plain films and the presence of bile or meconium upon paracentesis, which is used less frequently today. Abdominal wall erythema, worsening clinical status, and fixed loops on plain films are also strong relative indications. Portal venous gas itself is not an indication for surgery, but many babies with portal gas will ultimately meet criteria for surgical exploration. By contrast, many babies with pneumatosis without portal venous gas improve with medical management. Because the disease can progress rapidly, babies with NEC that do not initially meet criteria for surgery should receive surveillance plain films of the abdomen 2–3 times daily for 1–2 days to identify signs of bowel perforation. Several groups have tried to mathematically model the pathogenesis of NEC in silico such that an infant's initial laboratory values upon presentation with NEC can be leveraged to predict the eventual need for surgery, but this has generally failed.

Until recently, spontaneous intestinal perforation (SIP) of the newborn was not clearly distinguished from NEC in clinical practice or in research studies, but SIP is currently considered a distinct clinical diagnosis. SIP is typically seen during the first week of life, but can be observed as late as the second week of life. It presents with distension, hypotension, and pneumoperitoneum although babies are typically not as acutely ill as babies with NEC. At laparotomy, a single well-defined intestinal perforation is observed without the diffuse necrosis or bowel inflammation seen in NEC; the site of perforation is generally the terminal ileum. The mechanism of disease of SIP is not known but likely differs from NEC. Regardless of the pathophysiology, the presence of an intestinal perforation mandates surgical treatment. In choosing a surgical approach, we do not distinguish between SIP and NEC for the simple reason that it is impossible to know the diagnosis with certainty in the absence of a laparotomy. However, others advocate for treating the conditions separately, with a bias toward peritoneal drainage in SIP rather

than a laparotomy. Identification of biomarkers that can distinguish NEC and SIP would be extremely valuable in this common clinical scenario.

Surgical Management

Regardless of the surgical approach, the most urgent procedures for NEC can be safely performed in the neonatal ICU (NICU). This practice mitigates the potential risks, notably hypothermia, inherent in transporting a critically ill neonate to and from the operating room. When a laparotomy is planned, we generally bring a complete OR team with anesthesiologists to the NICU to participate in the operation. Preparation for surgery is similar to other urgent neonatal procedures. Depending upon the condition of the infant, resuscitation prior to surgery may include treatment of shock with vasopressors and volume replacement, ventilator support, correction of coagulopathy and thrombocytopenia, blood transfusion, and antibiotic administration. Generally, we utilize adhesive surgical drapes to prevent fluid from accumulating around the infant. We also routinely establish central venous access at time of surgery if not already present.

Historically, bowel perforation from NEC mandated a laparotomy and bowel resection. In 1977, Ein and colleagues in Toronto described a technique for placing peritoneal drainage (PD) catheters for babies with NEC. This was originally proposed as a temporizing maneuver prior to a subsequent laparotomy for definitive management. Over time, it became apparent that a subset of babies improved after drain placement and did not require a laparotomy and its attendant morbidity. However, since some infants will decompensate after drain placement, the obvious challenge lies in selecting babies that will respond favorably. Treatment failure of some infants should not be surprising when an uncontained perforation from gangrenous bowel is managed with nothing more than a drainage catheter; there is no other analogous situation in all of general surgery in which such an approach would be tolerated.

Our approach at the Children's Hospital of Pittsburgh of UPMC to NEC with bowel perforation has evolved with time. Previously PD was used liberally for infants less than 1 kg, but a seemingly large number of infants required a subsequent laparotomy days, weeks, or months after drain placement. These laparotomies can be quite difficult, and for this subset of babies, it seems that it would have been preferable to perform a definitive laparotomy at the time of bowel perforation. With all of this in mind, we currently reserve the use of PD for initial therapy of infants with fulminant disease who may not tolerate a laparotomy. If babies respond favorably to resuscitation and PD placement, we schedule a laparotomy within the next 1–2 days for definitive management.

Peritoneal Drainage

Primary peritoneal drainage is performed at the bedside after administration of pain medication and muscle relaxant. The infant's abdomen is prepared with iodine solution, and local anesthetic is administered. A small transverse incision, roughly 1 cm, is made at McBurney's point. A curved hemostat is used to gently spread through the layers of the abdominal wall, creating a path of entry into the peritoneal cavity. Often, meconium or air is encountered. Many surgeons irrigate the abdomen with warm saline through this incision, although we have abandoned this maneuver because of concern for spreading bacteria throughout the abdomen. A quarter-inch Penrose drain is gently advanced through the wound and secured with a fine nonabsorbable suture. Care should be taken to avoid trauma to the liver or the bladder, both of which are prominent in VLBW infants and are therefore at risk during this procedure. Some surgeons pass the drain through a counter incision in the left lower quadrant. This approach probably increases the risk of bladder injury slightly, but is attractive because the two ends of the drain can be sutured together rather than suturing the drain to the impossibly thin skin of the VLBW neonate. After 1–2 weeks, when there is no evidence of ongoing wound drainage, the drain can be backed out daily until it is completely removed.

Laparotomy

The primary goals when performing a laparotomy for NEC are to remove gangrenous bowel and to preserve intestinal length. The abdomen is entered via a transverse supraumbilical incision. In many cases, a right-sided incision will provide adequate exposure, but often the incision is extended to the left of midline to enable better visualization of the ligament of Treitz or the distal colon and rectum. Care must be taken to avoid inadvertent injury to the liver; the liver in premature infant is uniquely susceptible to major traumatic injury due to a very thin capsule and unusually fragile hepatic parenchyma. Such injuries during a laparotomy for NEC are rare but can be fatal.

The entire GI tract is explored systematically and the burden of disease is assessed. Typically, NEC is classified as focal, multifocal, or diffuse. The terminal ileum is most commonly involved, but roughly half of all cases will involve both the small and large bowel. The red, thickened, and inflamed bowel represents segments of intestine that are diseased but should be expected to survive. By contrast, gangrenous bowel appears gray or black and cannot be salvaged. In advanced cases, one may encounter paper-thin segments of pale white intestine, representing the complete loss of bowel wall integrity and necrosis of all layers of the bowel wall except the serosa. All gangrenous segments should be

resected. The length of bowel remaining at the conclusion of the procedure and the presence or absence of the ileocecal valve should be recorded.

With focal disease, after resecting gangrenous bowel, we typically create a diverting enterostomy and a mucus fistula and place them both within the wound. The stomas should be secured to the fascia of the abdominal wall, but there is no need to formally mature them because their edges will roll back over time to adhere to the skin. Many surgeons prefer not to place stomas within laparotomy incisions, but we have encountered few major complications related to this practice. Several groups have reported good success with resection and primary anastomosis in hemodynamically stable NEC patients with focal disease. Such an approach potentially avoids the risks of common ostomy-related complications.

The presence of multifocal gangrenous disease requiring concomitant bowel resections presents unique considerations, and no single operative approach can be recommended to account for all clinical scenarios. Traditionally, multifocal disease was treated with multiple stomas or mucus fistulae. A drawback of this approach is that, at the time of ostomy reversal, mobilizing each stoma from its position in the skin may result in loss of several more centimeters of the bowel. A nice approach is to create a temporary diverting proximal ostomy and to "splice" the distal segments together by performing multiple primary anastomoses. These can be done in an expedited fashion because they will be protected by the proximal ostomy. Both of these approaches suffer from the difficulties inherent in managing proximal stomas, including problems with skin care and fluid and electrolyte losses. Some adventurous surgeons complete multiple primary anastomoses without a protective enterostomy in multifocal disease, although in our opinion the risks of this approach outweigh the benefits.

In cases of multifocal disease in which bowel viability is uncertain or borderline, a reasonable approach is to plan a second-look procedure 1–3 days after the initial laparotomy. At the initial operation, obviously necrotic bowel is removed, and viable ends of remaining bowel segments are ligated with sutures or clips. These principles formed the basis of the "clip and drop back" technique popularized by Grosfeld and colleagues in Indiana. In the original description of this approach, the abdomen was re-explored after 1–2 days of further resuscitation, nonviable segments of intestine were removed, and intestinal continuity was restored. It is equally reasonable to create stomas at the time of the second laparotomy if the infant's condition has not yet stabilized. At the first operation, the abdomen can be closed temporarily in any number of ways, but we prefer a Silastic silo because they are easy to use, they allow for direct visualization of the bowel, and they effectively eliminate the possibility of a compartment syndrome.

Diffuse intestinal involvement, also referred to as pan-NEC or NEC totalis, is observed in up to 20 % of surgical cases and represents a formidable challenge for surgeons. One can find different definitions of NEC totalis in the literature, but a commonly used definition is necrosis of >75 % of the length of the small intestine. In such cases of diffuse bowel necrosis, particularly when the colon is also involved, the likelihood of perioperative mortality is high regardless of the surgical intervention due to the profound systemic inflammatory process accompanying the intestinal disease process. However, it is quite reasonable to expect that a certain percentage of VLBW infants will survive despite diffuse disease. The obvious problem in this scenario is that the surviving infant will almost certainly suffer from intestinal failure and its expected complications, which include neurodevelopmental delay and central line infections. Although outcomes after intestinal rehabilitation and intestinal transplantation are significantly improving, these treatment plans require months or years of specialized care and a high incidence of complications. For these reasons, intraoperative discussions with the neonatologist and the patient's family are recommended to place operative findings within the larger context of family wishes and an infant's overall condition, such as the presence of comorbidities or intraventricular hemorrhage. Historically, surgeons have commonly closed the abdomen without bowel resection in anticipation of impending death. Alternatively, depending upon family wishes, a massive bowel resection can be performed. Finally, some surgeons have reported success simply by creating a proximal diverting ostomy for NEC totalis, leaving a substantial burden of necrotic bowel in situ. This technique has not been prospectively evaluated and has not gained widespread acceptance.

Postoperative Care

Just as the initial presentation of NEC can vary widely, so too can the postoperative course. Some infants respond very favorably to removal of gangrenous bowel and demonstrate a rapid improvement in hemodynamic parameters. By contrast, others will remain gravely ill or even decompensate further after surgery for NEC. A particularly difficult problem is distinguishing whether a postoperative decompensation represents the presence of residual gangrenous bowel that must be resected or whether it represents a fulminant systemic inflammatory response that would only be exacerbated by another laparotomy. Postoperative care therefore must be individualized and often entails ongoing ventilator support, vasopressors, and blood product transfusion. As noted, antibiotic administration and bowel rest should continue for 7–14 days, postoperatively. Quality data are not available to guide length of these therapies, but there is a

trend toward earlier resumption of enteral feeds in the presence of clinical improvement.

The complications and clinical problems related to ostomies in VLBW infants are well recognized. In the first week after surgery, it is common to observe necrosis at the distal aspect of a stoma created for an infant with NEC. Generally, this necrotic segment will slough off, and the stoma will mature itself as the infant improves clinically. In rare cases, possibly due to technical considerations, necrosis of the ostomy extends down to the level of the abdominal wall, and in these cases an early stoma revision is warranted. After several weeks, commonly encountered subacute problems include stricture, prolapse, and parastomal hernias. Most of these problems can be definitively managed at the time of ostomy reversal. Strictures at the level of the abdominal wall fascia can be vexing because they can interfere with ventilation by generating abdominal distension and because they can interfere with a transition from parenteral to enteral nutrition. I often dilate these stomas with a soft catheter, but this must be done gingerly given the fragile nature of the recovering intestine. If stoma function does not recover with dilation, a contrast study should be obtained to search for a more proximal obstruction.

Because of the relatively high incidence of stoma-related complications, much has been written about the optimal timing for ostomy reversal in infants that recover from surgical NEC. Some authors advocate waiting until infants reach a post-conceptual age of 40 weeks in order to reduce the risk of anastomotic leak or stricture due to gut immaturity. Many others advocate much earlier reversal as soon as 2–4 weeks after the initial surgery. Ultimately, this decision should be tailored to the infant's clinical course. If an infant can be transitioned to full enteral feeds despite the presence of an enterostomy, the second surgery can be postponed until a post-conceptual age of 38–40 weeks. However, if the infant demonstrates signs of intestinal insufficiency, then the stoma reversal should be performed earlier. Prior to ostomy reversal, a contrast study should be obtained either via a mucus fistula or via the rectum to exclude the presence of an ischemic stricture that must be resected at the time of the stoma reversal. Strictures of the colon and terminal ileum frequently occur in babies with medical NEC 4–6 weeks after the initial diagnosis of NEC, but they can also occur in surgical patients at the site of a prior primary anastomosis or in defunctionalized distal segments of intestine.

Outcomes

Numerous recent publications have documented that short-term and long-term outcomes after surgery for NEC remain poor, with an overall mortality of approximately one third. It is also well established that NEC is the most common primary diagnosis among children with intestinal failure/short bowel syndrome. Important recent reports suggest that over 40 % of patients surviving after surgery for NEC will suffer from intestinal failure (defined as >90 days of parenteral nutrition). Intestinal failure (IF) in NEC patients may result simply from an inadequate amount of remaining bowel after massive bowel resection, or it may reflect the presence of intestinal segments that were healthy enough to survive surgery, but not healthy enough to function properly. Infants and children with intestinal failure are at risk for numerous complications, including cholestasis, catheter-related sepsis, and death. Fortunately, advances in intestinal rehabilitation are now enabling IF patients to achieve enteral autonomy with lower rates of total parenteral nutrition (TPN)-induced liver failure, but it must be recognized that this process requires years of rehabilitation even at experienced centers.

Finally, several important studies have confirmed that surgical NEC is an independent risk factor for major neurodevelopmental delay. At 1 or 2 years after discharge, children that require surgery for NEC have a significantly increased rate of developmental delay requiring special education. Moreover, the incidence of cerebral palsy, deafness, and blindness is higher in babies requiring surgery for NEC than in matched controls. These grave statistics further underscore the acute challenges in caring for infants with NEC.

Prevention

Given the poor outcomes after onset of NEC, there is a clear need for disease prevention, and it is important for pediatric surgeons to be aware of ongoing efforts among newborn medicine practitioners to prevent NEC. The most effective means of preventing disease has long been recognized to be the use of human breast milk, although in practice this can be challenging due to inadequate milk supply among women that deliver prematurely. Selective gut decontamination with prophylactic administration of enteral antibiotics has proven effective in some small trials, but has been associated with increased microbial drug resistance. Two approaches that appear efficacious are administration of live bacterial probiotic supplements and administration of lactoferrin, a whey protein nutritional supplement. Probiotic administration has become relatively popular in Asia and Europe, but has not yet gained acceptance in the United States due to a confusion about which probiotic preparations are superior and due to scattered reports of infections secondary to probiotic usage. Lactoferrin is a naturally abundant component of breast milk that is available in bovine and recombinant forms and appears to have an excellent safety profile. More widespread administration of such agents is anticipated in the future.

Summary

NEC remains an important cause of morbidity and mortality among newborn VLBW infants. Despite decades of research, our understanding of the pathophysiology of NEC is limited. The classic presentation of NEC is a preterm infant in the first month of life that develops feeding intolerance, abdominal distension, and bloody stools. Pneumoperitoneum remains an absolute indication for surgery; abdominal wall erythema, worsening clinical status, and fixed loops on plain films are reliable relative indications. Laparotomy with bowel resection and ostomy formation is the most accepted surgical option for advanced NEC, although many surgeons perform a primary anastomosis in babies with NEC. The primary goals during surgery for NEC include removal of gangrenous bowel and preservation of intestinal length. Mortality rates remain as high as 34 % among infants requiring emergent surgery for NEC. Among NEC survivors, important long-term complications include intestinal failure and neurodevelopmental delay.

Spontaneous intestinal perforation is a clinical entity that is distinct from NEC, but making this distinction is currently difficult without a laparotomy. The role of peritoneal drainage after bowel perforation remains unclear, but PD is clearly an acceptable temporizing treatment option for infants not stable enough for laparotomy. Recent randomized trials have failed to clearly demonstrate a survival benefit of primary peritoneal drainage or laparotomy for NEC patients with bowel perforation.

Editor's Comment

NEC is a disease we should be able to prevent, and the current use of maternal or banked breast milk as the first choice for feeding premature infants has reduced its incidence dramatically. Therapy for NEC is primarily medical. Surgery is indicated only for complications—perforation, bowel necrosis, or overwhelming sepsis. As ultrasound is used more frequently, perforations should be detected earlier than by plain radiograph. But deciding whether and when to operate can still be difficult and is ultimately based on good judgment and experience. In general, it is probably better to risk operating "too soon" than waiting until it is too late to make a difference.

Peritoneal drainage has fallen somewhat out of favor but is still useful, specifically for the extremely critically ill micropreemie with an obvious perforation who cannot be transported safely, needs more time for resuscitation, or has other anomalies that need to be sorted out. In these cases, drainage can temporize. If the patient is too unstable for transport it could be due to tension pneumoperitoneum, in which case decompression with a 14-gauge IV catheter may stabilize the patient for transport. Most infants should be able to tolerate a trip to the OR, and it is easier to maintain a high ambient temperature in the OR than in the NICU. And in case of trouble such as liver rupture, it is better to be in the OR with access to instruments and good lighting.

Though drainage alone is occasionally definitive, one can justify a laparotomy 2–3 days later whether the patient has improved (safe for laparotomy) or deteriorated (needs something more definitive). Drainage can be performed through two tiny lower quadrant incisions. The abdomen is irrigated with warm saline and three quarter-inch Penrose drains are used—one passed between the two incisions, one placed into the pelvis from the right side, and one placed into the left upper quadrant from the left side—so that the abdomen is widely drained, the liver is avoided, and the drains can be tied to themselves rather than to the patient.

Some children operated upon for NEC as infants sport a huge, misshapen, and cross-hatched scar across their upper abdomen. There is rarely a need to make such a monstrous incision. Unless there is the bowel to be dealt with near the ligament of Treitz, a small right lower quadrant incision is all that is necessary. The entire abdomen in a small premature is available through this incision and the ultimate appearance is far superior. The stoma and mucous fistula can be brought out in the corners of the wound, and the incision can be closed with sutures in Scarpa's fascia and Steri-Strips or glue on the skin. The ostomies do not need to be matured. They should be secured to the fascia and the ends simply left to hang out. This will prevent ischemia and ostomy stenosis.

There is a tendency to wait a long time to close the stoma in these infants, which puts them at risk for parenteral nutrition-associated liver failure. Closing the stoma usually allows them to tolerate enteral nutrition sooner. If the patient is stable, one should consider closing the stoma within two weeks. There is even a trend toward performing a primary anastomosis at the original operation and avoiding a stoma altogether. At any rate, continuity should be reestablished no more than 6–8 weeks after resection.

The most difficult situations arise when there is loss of nearly the entire small intestine. Despite recent advances in the field of intestinal transplantation, it is still very unlikely that an infant with essentially no intestine can be made to survive long enough to undergo a successful transplant. Nevertheless, it will likely soon be a viable option, and every case should be assessed individually and with intimate involvement of the parents. It is also important to remember that the remaining intestine was likely ischemic and though now viable might be dysmotile or otherwise dysfunctional. On the other hand, the potential for bowel growth in the preemie is sometimes astonishing—we have seen 10–15 cm of jejunum become 60–90 cm of the healthy appearing bowel at re-exploration weeks later.

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Short Bowel Syndrome

51

David F. Mercer

Short bowel syndrome is associated with significant life burden for both affected children and their caregivers. The most severe form is termed intestinal failure, which also encompasses profound functional disorders of the intestine. The diagnosis of IF was often considered tantamount to death, and in many cases caregivers were encouraged to withdraw life support after the diagnosis was made; indeed, this practice continues today. There have been substantial advances in the field, however, especially over the past 10 years, which have rendered this approach largely obsolete.

Intestinal failure includes diseases characterized by a loss of absorptive surface and disorders with intact surface but impaired absorption, either from direct functional problems or poor motility. In the former category, the most common diagnoses are necrotizing enterocolitis, gastroschisis, intestinal atresia, malrotation, and iatrogenic short bowel. The latter category encompasses diagnoses such as microvillus inclusion disorder, tufting enteropathy, autoimmune enteropathy, syndromic diarrhea, and complex motility disorders often grouped under the term pseudo-obstruction, which can include both myopathic and neuropathic variants as well as disorders of function associated with mitochondrial disease.

Intestinal Length

Much has been written about what length of intestine is required for freedom from parenteral nutrition, and attempts have been made to define short bowel syndrome based on length criteria. Over time, as management has improved, historic guidelines are no longer reliable, and the length of intestine at which children are able to achieve enteral autonomy seemingly reduces with every passing year. What is known intuitively is that as small intestinal length declines, it is more difficult to achieve enteral autonomy.

With diminishing small intestine, there is increasing importance in the length of the large intestine, which contributes significantly to both fluid and calorie absorption. As a starting point, children with more than 50 cm of small intestine and 65–75 % of the colon who are managed in a specialized program will be highly likely to achieve enteral autonomy over time. As colonic length reduces, the amount of small intestine that is required increases. Where there is no colon available at all, there is no absolute length of the small intestine that is universally required, but in general children will need in excess of 100 cm. Children with the very shortest length of the remaining intestine, termed "ultrashort bowel," can pose the most difficulty in management. This too is variably defined, but is generally accepted to be less than 30 cm of the small intestine. With an adequate length of the large intestine however, even this category of children will have a very high likelihood of achieving successful enteral autonomy, given sufficient time for adaptation.

Hence, there is truly no absolute length of small bowel below which at least some attempt at intestinal rehabilitation is not desirable; the only exception to this statement would be children with complete loss of the small intestine and large intestine, where continuity cannot be reestablished between the proximal small bowel and distal small bowel because of anatomic constraints.

The determination of length in a child with short bowel syndrome can itself be prone to error. The only truly reliable method for measuring length is direct evaluation at the time of laparotomy. Beginning at a fixed anatomic point, a silk tie is laid along the antimesenteric surface of the unstretched bowel and then cut at the terminal point of the small intestine. The tie can then be measured with a ruler. This value is then recorded in the operative note along with a description of the intestine and its motility and measurements of typical diameters along the length of the intestine. Having full anatomic information described in an operative report is of paramount importance in subsequent management, especially

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where reconstructions are required. Wherever it is possible, at any subsequent laparotomies, it is worth taking the extra time to divide all adhesions, expose the entire length of the small intestine, and repeat measurements for comparison with earlier operations. Attempting to measure intestinal length from imaging studies is prone to significant variation and error.

There will often be significant increase in the intestinal length from what is recorded at the earliest laparotomies, as there is a doubling of intestinal length in the third trimester and continual growth of the intestine in proportion to growth of the body overall in subsequent years. What appears to be a very small length of jejunum in a highly premature infant can turn out to be significantly longer when the child is 6–12 months of age. Again, this argues strongly against withdrawing support in premature infants with short bowel syndrome based on the measurement of intestinal length alone.

At our center we have established a general management algorithm for children with SBS (Fig. 51.1). When the diagnosis is made, early transfer of the child to a specialized IF management center should be considered, as they offer a dedicated multidisciplinary approach to IF treatment including specialized TPN management, feeding therapy programs, experience with enteroplasty, and access to novel clinical agents and trials. A truly comprehensive program will also be able to offer access to intestinal transplantation in the event all rehabilitation efforts fail. If it is not clear whether a child has SBS and local expertise is available, a trial of advancing enteral feeds and progressively reducing TPN while maintaining growth curves may be warranted. It is important that these patients be closely monitored because if they fail to wean off TPN even while maintaining adequate growth, transfer to a specialty center should be made. Considerable irreversible harm in the form of progressive liver disease, loss of central venous access sites, and recurrence of severe central line infections can result if proper referrals are not made in a timely fashion.

Parenteral Nutrition

The mainstay of initial management of the child with short bowel syndrome is provision of parenteral calories. This requires central venous access, which may involve peripherally inserted catheters (PICC) or a permanent tunneled central venous. The latter are preferred, as they are amenable to the use of ethanol locks, which have been shown to reduce rates of central line infection by 80 %. An ethanol lock involves instilling a fixed volume (often 0.5–2 mL depending on the size of the line) of 70 % ethanol into the central line and allowing it to dwell for some period, typically no less than 2 h and in some cases as long as 24 h. An attempt

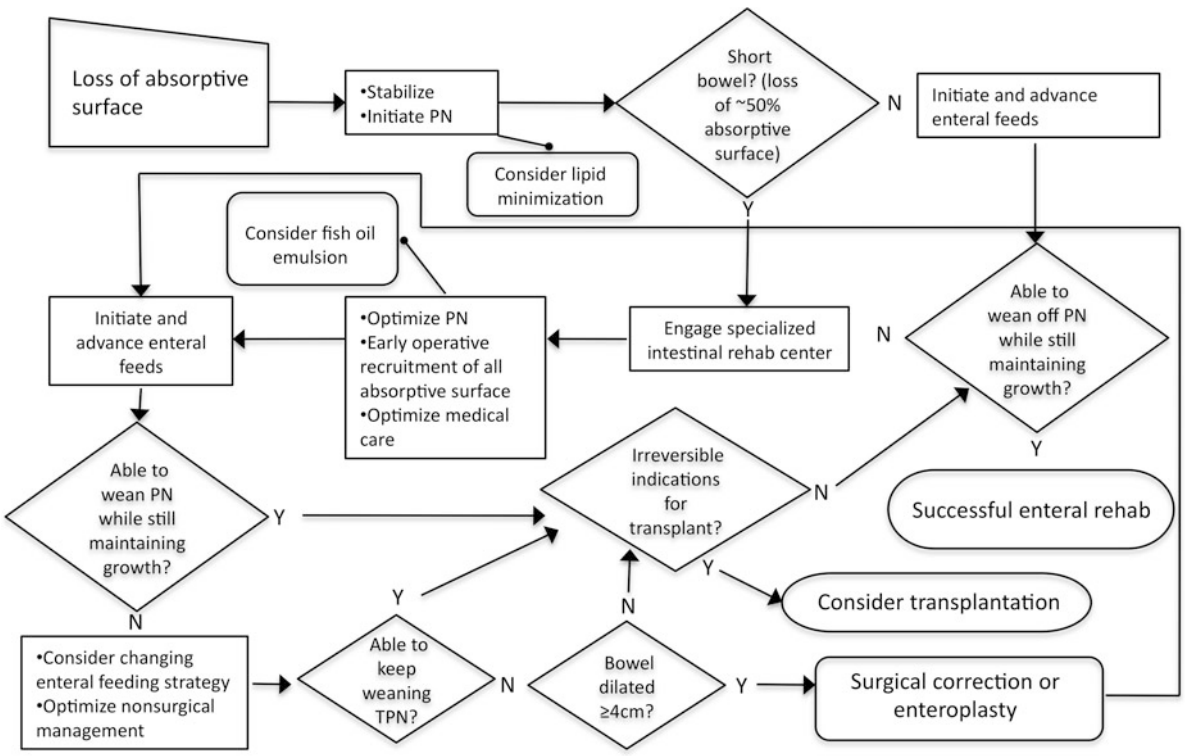

Fig. 51.1 General management algorithm for the management of a child with short bowel syndrome. Progress around the algorithm is recursive until the end points of successful intestinal rehabilitation or progression to transplant are reached

can be made to withdraw the ethanol and flush the line with saline prior to hooking it up for infusion; however, this is associated with higher rates of line occlusion from clots. As a result many centers are simply flushing the dwelling ethanol through the line. A program to insure proper aseptic technique is used when accessing central lines is equally important in limiting central line infections. Children who have the fewest central line complications are generally those with the most fastidious caregivers. Whenever there is a central line complication and as long as the child is stable, every attempt is made to leave the line in place and treat through the complication. Constantly replacing lines or going to new access sites will lead to progressive loss of venous access sites over time.

Ongoing TPN management is critically important in ensuring adequate growth of the child while minimizing complications associated with TPN. Vitamin and micronutrient requirements need to be met, which poses challenges in an era where there are often shortages of commercially available additive preparations. Children are monitored with weekly or twice weekly labs to be sure that electrolytes are balanced and hydration status is appropriate. Progress on growth curves must be followed, and the child crossing growth curves in a downward fashion needs to have enhanced provision of calories. In general, we provide approximately 85 kcal/kg/day as a full TPN requirement for infants and small children. This can be modified as the child gets older based on individual growth characteristics

One specific area of parenteral nutrition to address is the provision of lipid calories. In North America, most intravenous lipid emulsions are derived from soybeans. Classically, neonates were managed with higher doses of intravenous lipids to ensure adequate calories, up to as much as 3 g/kg/day. At these levels, intravenous lipid emulsions in this population can be rapidly hepatotoxic. The exact etiology of this hepatotoxicity is not well defined, but is in part due to plant phytosterols in the soy emulsions, which paralyze bilirubin transporters within hepatocytes, especially in the developing infant liver. Signs of cholestasis are usually noted within 1–2 weeks of initiation of TPN at this level, and development of histologic changes is apparent a few weeks after that. If no intervention is made, frank cirrhosis will occur within 6 months. There is now a general trend toward minimization of soy-based lipids, limiting them to 1 g/kg/day or less if possible when jaundice occurs. This necessitates an increase in glucose infusion rate and protein calories, which can be difficult in some children. Alternative lipid emulsions have been developed, permitting clinicians to add additional calories without the side effects associated with soy-based lipid emulsions. Intravenous fish oil emulsions are proving to be beneficial in these children, leading to life-changing alterations in their management. These emulsions are given in doses up to as much as 1.5 g/kg/day, to supplement the caloric intake of an infant with intestinal failure. Fish oil emulsions, however, are deficient in some key essential fatty acids, so if they are to be used as the sole lipid calorie source, essential fatty acid profiles must be monitored closely. Supplementation with soy lipid emulsions may be required. Often, a regimen that is based on fish oil can be supplemented with lower amounts of soy-based lipid each week to prevent essential fatty acid deficiency. There are other products being developed which combine different blends of lipids to maximize the benefits of each while minimizing toxicity.

Enteral Nutrition

After establishing a regimen of parenteral nutrition and showing positive growth on a weekly basis, the next step in management of a child with short bowel syndrome is to attempt to restore intestinal continuity, recruiting all areas of functional intestine back into the enteric stream. This should involve early consideration of operations to close enterocutaneous fistulas and reverse ostomies and mucous fistulas created during the neonatal period. This is contrary to the traditional teaching of waiting for 3–6 months or longer before restoring intestinal continuity. Likewise, except in the most extreme cases, clinicians should not fear the creation of severe diaper rash from intractable diarrhea after restoring continuity—this can almost always be managed with topical therapy. In our practice, we will restore intestinal continuity at the earliest possible opportunity, as early as 3–6 weeks after the most recent surgical intervention. This must be tempered by the individual clinical situation, but when there has not been extensive contamination of the abdomen, restoration of continuity is almost universally possible sooner than traditionally thought possible. Getting all segments of bowel back "online" allows for optimal use of all absorptive surface area and for stimulation of adaptation through enteral feeding.

Enteral feeds are initiated at the earliest possible time if the patient has a proximal segment of the intestine that is accessible. When it is impossible to restore intestinal continuity for a prolonged period of time, distal re-feeding of proximal ostomy output into downstream bowel through the mucous fistula should be attempted. This is a logistical challenge for nursing staff and caregivers, but it provides as many of the benefits of functional intestinal continuity. There are myriad ways to provide enteral feeds, which suggests that no one method to be better than the rest. We have found success using different approaches and tailoring them to the individual child's needs.

Children with SBS require enteral access for provision of feeds, as enteral demand feeding is inadequate for the provision of volume and calories necessary to fully rehabilitate them. Furthermore, drip feeds stimulate endogenous production of glucagon-like peptide-2 (GLP-2), which is

critical for driving the adaptive response during rehabilitation. This access can initially be in the form of a nasogastric or nasojejunal tube, although a permanent gastrostomy tube is preferred, as it simplifies care and minimizes disruptions in feedings due to tube dislodgement. In many cases, a gastrostomy tube can be placed laparoscopically or percutaneously with endoscopic guidance, although open gastrostomy is an acceptable alternative.

In most infants and young children, tube-feeding strategies are based on the use of either breast milk or a commercially available formula. In children with the more extreme versions of short bowel syndrome, calories may be optimally provided in the form of an elemental formula, where there is little or no digestion of the nutrient components required. Other options include semi-elemental formula, containing a protein hydrolysate rather than individual amino acids. This requires more digestion on the part of the child, but also provides a denser caloric formula with less osmotic load. In some cases, especially where intestinal length is longer, more standard infant formulas may be acceptable. Care must be taken to avoid formulas with significant sugar content. Formula may often not be very palatable to children when they have been exposed to breast milk initially. When children are initiated on specialized formulas from infancy, however, we have often found that they will tolerate them orally very well.

There should be continual progress in advancing on tube feeds, with constant reevaluation of tolerability. Children who are not tolerating feeds well will often manifest this by excessive vomiting or diarrhea. In general, we will tolerate a child having 6–7 bowel movements per day, as long as they are not all massive in size ("blowouts"), which are not contained by a standard diaper. If a child is not able to have progressive reduction in parenteral calorie intake with sustained adequate growth, then the conclusion must be made that the enteral calories are not being absorbed. In contrast to parenteral calories, energy is required for tube feeds to be absorbed; thus, we will typically strive to provide 120–130 % of the estimated TPN calorie requirement as enteral calories to wean off of parenteral nutrition. In some cases, this could be as high as 200 %.

It is also very important to continue oral stimulation through provision of oral feeds from the earliest possible time. The use of the oral route contributes to improved intestinal adaptation through growth factors in the saliva and also facilitates learning of oral skills, which will be critically important later in life. When possible, some oral calories should be provided in addition to any other enteral calories sources, to ensure that oral skills are not lost. Oral stimulation and feeding may occur using either specialized formulas or age-appropriate foods. Early engagement with a feeding therapy program will be of significant benefit in later years and avoid an outcome in which the patient has achieved enteral autonomy but still has significant oral aversions.

Medical Therapy

Medical therapy has some role in the management of children with short bowel syndrome. This can take the form of drugs that can enhance motility, such as erythromycin, amoxicillin–clavulanic acid, metoclopramide, or domperidone, or agents that reduce motility, such as codeine or tincture of opium, soluble fiber, or pectin. When the intestinal length is quite short and the terminal ileum has been lost, the bile salt-binding resin cholestyramine reduces irritation of the residual colon, rectum, and perianal skin that can occur from unabsorbed bile salts. When inflammation is seen on biopsies from either the upper or lower endoscopy, there is sometimes a role for anti-inflammatory therapy in the form of either topical or systemic corticosteroids or even inflammatory bowel disease therapies such as azathioprine or monoclonal anti-TNF antibodies.

Finally, antibiotics are often used in the treatment of children with short bowel syndrome. This is usually in response to the somewhat poorly defined syndrome of bacterial overgrowth, typically manifested by gassy distention, excessive flatulence, vomiting, change in stool pattern, and enteral feeding intolerance. This may be more properly termed as dysbiosis, as it is not necessarily caused by specific overgrowth of any one type of bacteria or by the presence of bacteria in atypical locations. Classical hydrogen breath testing for bacterial overgrowth is unreliable in the short bowel population because of the proximity of the colon to the upper aerodigestive tract. Quantitative bacterial cultures can be taken from aspirates of the duodenum or small bowel at the time of endoscopy, although at this time culture methods yield relatively nonspecific information regarding species and sensitivities. The use of 16S ribosomal RNA sequencing methods to elucidate the full complement of bacteria in the microbiome is still in its infancy, but is likely to prove useful in the future. Oral antibiotic selection is often empirical and includes gentamicin, sulfamethoxazole/trimethoprim, ciprofloxacin, metronidazole, or fluconazole. We tend to take care in initiating regular long-term antibiotic therapy and rotate drugs to prevent antimicrobial resistance.

One final area of potential future advancement is in the provision of teduglutide, an analog of GLP-2, an intestinotrophic growth factor that leads to elongation of the intestinal villi and enhanced overall absorption. It has been approved for use as a daily subcutaneous injection in the management of SBS in adults. Data suggest it leads to at least a 20 % reduction in overall TPN and fluid volume required and that this might continue to improve with duration of treatment. It does appear that the treatment effect is reversible in most cases however and patients can revert to their pre-existing phenotype within a few weeks after cessation of the drug.

Surgical Intervention

A critical decision point is when there is a lack of progress in weaning TPN and advancement of enteral feeds. This plateau may manifest as an inability to reduce parenteral nutrition while still maintaining a normal growth curve or failure to progress along a normal growth curve on volumes of parenteral and enteral nutrition that previously were sufficient for adequate growth. The timely recognition of this situation is one of the most important things a treating team can do to improve overall outcome. In general, a plateau invokes the need for repeating many baseline tests including a contrast study of the small intestine, upper and lower endoscopy with biopsies, and quantitative bacterial cultures, stool viral cultures, and repeat biochemical nutritional assessments. These are times when all facets of medical care need to be reconsidered, including the type and method of enteral feeding, medications, and antimicrobial therapy. Careful but persistent attempts at improving function and breaking through the plateau are critical, but a team also needs to recognize when attempts push through medically are futile, for therein lies the potential role for surgery.

Surgical intervention is best employed when a child is at a plateau and all attempts at optimizing medical therapy have failed. At this point, the radiographic assessment of the GI tract is of critical importance. Assuming that at this point the intestine is back in continuity, contrast studies are performed to determine if there are areas of abnormal dilation or narrowing, areas of poor antegrade peristaltic function, or other anatomic abnormalities amenable to surgical correction. While failure of antegrade progression of contrast is almost always of concern, rapid transit is of lesser clinical significance, as the overall transit time of radiographic contrast does not seem to correlate with transit of enteral feeds. In general, an area of dilation of more than 3.5 cm, especially when associated with loss of intestinal markings or visible to-and-fro motion of contrast, is considered significant and is often an indication for surgical intervention. The overall length of the dilated segment is not necessarily of critical importance, as there are instances in which a very short segment of dilated intestine leads to complete impairment of overall bowel function that then rapidly improves upon surgical correction.

We consider surgical intervention when there are both a plateau in the inability to wean parenteral nutrition with exhaustion of all medical management options and the presence of significant radiographic dilation, and we would consider either of these findings alone is insufficient indication for surgical intervention. Overall nutrition should be optimized prior to surgical intervention, with the use of enhanced parenteral calories if necessary.

Other than ensuring adequate nutrition, there is relatively little additional preoperative preparation that is required before intervening in a child with SBS who is at a plateau. No bowel preparation is required and an existing laparotomy scar is used, keeping the incision as small as possible. Due to the typical complexity of dissection and intervention for enteroplasty, a laparoscopic approach is not advised. The procedure begins with complete mobilization of the small intestine from the duodenum down to and including the junction with the large intestine. All adhesions should be carefully taken down, with care to preserve the mesentery to all loops of the intestine. At this point the anatomy should be fully defined, taking careful measurements and ensuring they are recorded for inclusion in the operative note. Specific attention should be paid to areas of dilation and associated strictures and whether there is peristalsis throughout the bowel both spontaneously and in reaction to mechanical stimulation.

A Foley catheter is next passed through the entire small intestine, typically gaining access via a gastrostomy tube site. Once in the large intestine, the balloon is inflated to a diameter appropriate for the size of the intestine of the child, typically 1–2 cm, and then carefully withdrawn through the entire length of the small intestine looking for occult strictures. The bowel is also completely decompressed at this time. After the catheter has been removed, strictures are repaired by stricturoplasty or by limited resection if needed. Where there is dilation of the small intestine upstream of a stricture, especially when the dilation is not massive, it has been in our practice not to perform enteroplasty on these segments as they are felt to be reactive to the obstruction rather than the result of bowel adaptation.

Dilation of the intestine without an obvious obstruction is when we should consider enteroplasty. This dilation has been termed "adaptive" although the exact mechanism is not known. In actuality, it does not serve an adaptive function, as it ultimately impairs enteral tolerance and leads to plateaus. With enteroplasty, we can take advantage of this maladaptive process to help get past a plateau. The goal is to achieve a uniform luminal diameter that is age and size appropriate. When there is a good length of small intestine with only a short segment of dilation, the best surgical option might be to resect the short dilated segment with primary anastomosis. The dilated segment can also be managed by tapering enteroplasty (Fig. 51.2). The antimesenteric border is controlled with Babcock clamps and trimmed with multiple firings of a GI stapler down to an age-appropriate diameter, typically 1.5–2 cm.

In the majority of cases, the surgeon will be performing an enteroplasty that restores the normal volume–surface area ratio of the intestine but does not reduce overall absorptive surface. The overriding principle is to create uniformity of the intestinal lumen without areas of narrowing. The two most common procedures used today are the longitudinal intestinal lengthening and tapering (LILT or Bianchi procedure) and the serial transverse enteroplasty or STEP procedure.

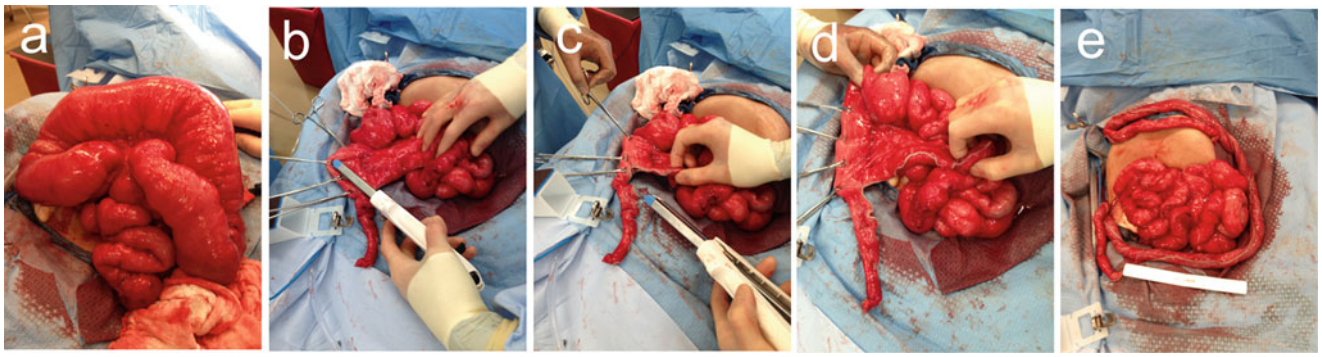

Fig. 51.2 Performance of long segment tapering enteroplasty. (**a**) Significantly dilated bowel segment is seen in the context of reasonable overall bowel length; (**b–d**) Babcock clamps are placed along the antimesenteric edge of the dilated bowel, and serial linear staple firings are used to excise excess intestine; (**e**) completed enteroplasty, with centrally located small bowel loops reduced back to a 2 cm luminal diameter

Performance of LILT is predicated on the fact that the mesenteric blood supply to the intestine approaches at the 6 o'clock position and decussates around the bowel in both directions to join at the 12 o'clock antimesenteric position. The two leaves of blood supply are gently separated on the mesenteric surface of the bowel, taking care to keep all vessels intact. The plane between the divided blood vessels is typically maintained by placement of a Penrose drain. Beginning at the proximal end of the dilated segment and progressing distally, the bowel is then divided in longitudinal fashion, either with hand sewing or more commonly using a GI stapling device. The stapling device is used to taper into and out of the dilated segment at either end, and then the two newly created "dead ends" of bowel are brought together in a lazy "S" conformation and are anastomosed together. This effectively doubles the length of the dilated segment and maintains antegrade peristalsis. It is technically challenging however, and if any of the delicate vessels are damaged to either limb of the LILT, segmental intestinal loss can occur, which could abrogate any potential gains. While in experienced hands it can be performed with minimal operative morbidity or loss of intestine, its performance has largely fallen out of favor in most centers, having been supplanted by the STEP procedure as technically easier to perform with equivalent overall results.

The STEP procedure uses a series of alternating staple firings to create a zigzag pattern along a dilated segment of intestine, effectively reducing the luminal diameter, while still maintaining an intact blood supply to the bowel with minimal dissection of the mesentery. In the original description of the procedure, it was performed in a side-to-side fashion, with a small opening made in the mesentery through which a stapler was placed. But we have found it better to orient the staple lines in the mesenteric–antimesenteric direction, which makes it easier to maintain orientation of the intestine and ensure that the staple lines adequately cross the midline (Fig. 51.3). The side-to-side approach can lead to a helical conformation of the bowel, which is very difficult to correct surgically later should further dilation occur.

Segments of intestine that are >3.5 cm are identified, and a series of Babcock clamps are placed gently along the antimesenteric border, making sure that it is stretched out flat and not torsed at all. A small hole is made through the mesentery near the beginning of the dilated segment just at the undersurface of the bowel, and a stapling device is fired across the bowel, choosing a 30 or 60 mm load depending on the size of the intestine. It is critically important that the staple line goes across the longitudinal midline of the intestine, as failure to cross this midline will ultimately be ineffective, with persistent dilation along the segments over time. We gauge the overall lumen of the STEP bowel to be approximately 2–2.5 cm from the outside edge of one staple line to the outside edge of the next staple line, which leaves an internal luminal diameter that is typically 1.5–2 cm. This is conveniently roughly the width of a thumb, which facilitates visual placement of the stapling device. The next staple line is placed in antimesenteric fashion, and this alternating pattern is used back and forth along the dilated segment of the bowel, again taking care that each staple line goes across the longitudinal midline. Where the bowel is very dilated, sometimes an additional staple line needs to be made to lengthen one that has already been placed. At the beginning and at the end of a STEPed segment of the bowel, the stapling device is gently angled so that there is a smooth transition. This will sometimes create a small triangular dog ear of the intestine on one side of the staple line, which we typically excise to eliminate the blind end.

All staple lines are checked twice with gentle compression or insufflation with saline or air. The crotches of the staple lines may be reinforced with horizontal mattress 4-0 absorbable sutures, though we have not found this necessary with modern staplers. We do not oversew the staple lines. Upon completion, all the STEPed segments are rechecked to make sure the bowel is well perfused and there is reactive peristalsis with gentle mechanical stimulation. Repeat length measurements are taken using a silk tie, and this value is recorded in the operative note.

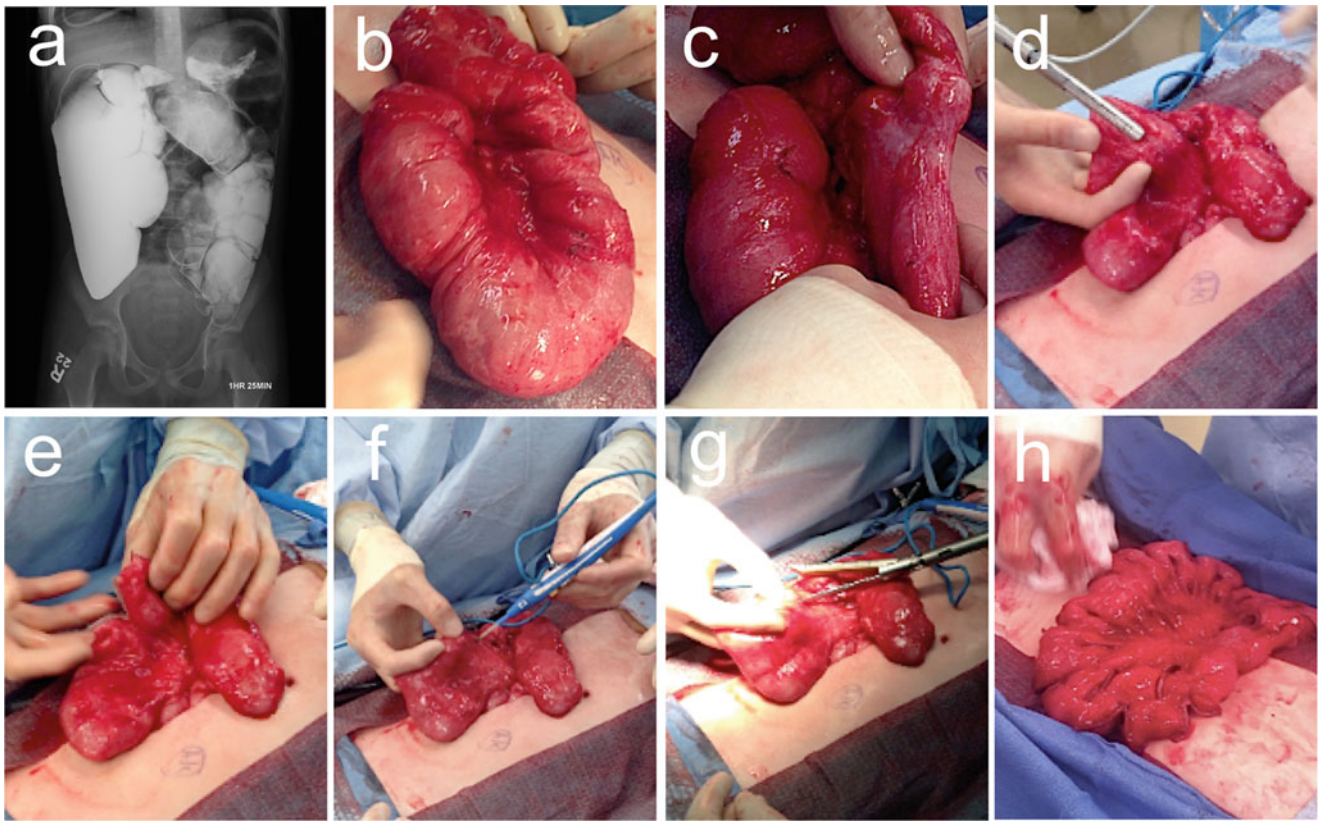

Fig. 51.3 Performance of a STEP procedure. (**a**) Small bowel series showing significant dilation in an 8-year-old child postmidgut volvulus; (**b**) dilated small intestine correlating with radiographic appearance, dilated to 8 cm in places; (**c**) passing a 2 cm Foley balloon to ensure no intrinsic stricture and suction out luminal contents; (**d**, **e**) firing linear stapler along antimesenteric surface of bowel and subsequent appearance of first STEP staple line; (**f**, **g**) making a small opening in mesentery at the base of the intestine and firing mesenteric-side STEP line; (**h**) completed STEP procedure with 28 firings of stapler to maintain a 1.5–2 cm lumen throughout

The STEP procedure is much more straightforward when the intestine has not been operated on before. When a child has undergone a prior enteroplasty, either a LILT or a STEP, a repeat STEP is still possible often with excellent results. Greater care must be taken in the initial dissection and all prior staple lines need to be dissected out fully. Again, the chief goal for the surgeon is to achieve uniformity of the lumen (Fig. 51.4), which might involve creating new STEP staple lines, although it can be somewhat challenging to maintain the normal zigzag confirmation. Two new staple lines need to be placed between the existing staple lines in alternating fashion and there are often space constraints. More often, existing staple lines can be elongated, or short areas of tapering can be performed to reduce the luminal diameter in dilated areas. There might also be areas that were previously insufficiently dilated for enteroplasty that have now become large enough.

The STEP procedure can be performed with very minimal postoperative morbidity. Leakage from staple lines is virtually unheard of if all lines are checked carefully and reinforcing sutures are placed where required. Bowel function typically resumes in 4–7 days. The gastrostomy tube is progressively clamped over a few days and when tolerated for 24 h feeds are restarted and advanced as tolerated. It usually takes 10–12 weeks for the full benefit of the STEP procedure to be realized. With long-term follow-up, most patients have normal motility and very few sequelae. When chosen with the right selection criteria, there is usually rapid reversal of a plateau following a STEP procedure, with progressive reduction of parenteral nutrition requirements over the subsequent year.

When patients have gone on to have long-term morbidity in association with a STEP procedure, it typically has fallen into one of three patterns. There are some who develop recurrent dilation, both in areas where the bowel has undergone enteroplasty and occasionally in areas outside of the STEP, where the bowel was not considered adequately dilated for intervention. While not truly a complication of the procedure itself, this "underSTEPing" should be approached as per any other dilation. In contrast, when children have been "overSTEPed" and the luminal diameter has been reduced too much, there are strictured areas that prevent proper antegrade passage of the enteric stream. This presents in a more profound fashion with inability to tolerate

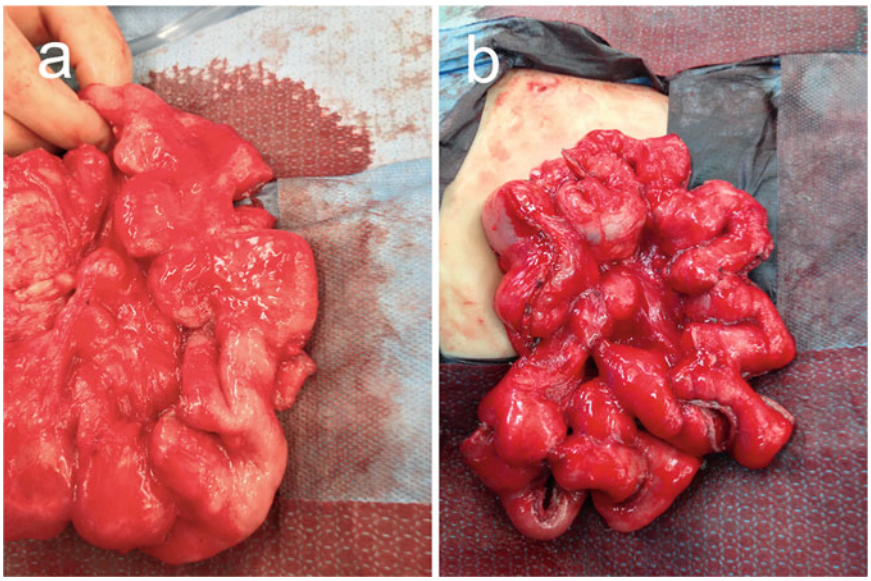

Fig. 51.4 Typical appearance of a redo STEP following prior failed STEP procedure. (**a**) Small intestine showing ineffective prior STEP, with dilation, segmentation, and blind loops (in surgeon's fingers). Prior STEPs had been performed in a challenging helical pattern, and the child had poor antegrade peristalsis. (**b**) Appearance of the bowel following corrective surgery, using a series of excisions, extension of staple lines, and new STEPs to achieve uniformity of the intestinal lumen

feeds even at levels that were previously easily handled, in association with upper GI evidence of obstruction. This requires operative repair, and in the limited number of cases we have seen, a short segmental resection is usually needed. Finally, there have been a small number of patients who have presented with an inflammatory bowel disease-type picture in an isolated segment of the intestine, typically very distal and close to the junction with the colon. This does not appear to be associated with ischemia and poor motility does not appear to be the issue. The proximity to the colon suggests that this could be a microbial phenomenon, although there is no direct proof of this. In some cases we have had to perform resections of the segment, and in at least one case, we saw progression of the inflammatory phenotype in a new more distal segment. We have seen some response with both anti-inflammatory therapy and antimicrobial therapy, but the overall etiology of the process still remains obscure.

Successful management of SBS results in the ability to wean from parenteral nutrition and to have the central venous catheter removed, which significantly reduces morbidity. Once the patient is on full enteral feeds, modifications are made to get the feeding regimen to be exclusively nocturnal and to increase oral or bolus intake during the day, with a goal of trying to get off of any continuous drip feeds. There must be careful ongoing monitoring of both growth and biochemical nutritional parameters.

Intestinal Transplantation

There are times when despite the best efforts and intentions, there is progressive development of indications for transplantation. Recommending a child for intestinal transplantation should not be viewed as a failure, but rather as another path to achieve the goal of full enteral autonomy. In children, the commonly accepted indications for considering transplantation include: (1) signs of end-stage liver disease; (2) loss of central venous access sites or recurrent severe catheter infections, especially fungal infections and those requiring admission to the ICU; and (3) an unreconstructable GI tract, when there is truly no absorptive surface remaining for attempts at rehabilitation. While formerly it was believed that cholestasis was an indication for transplantation, this is definitely no longer true. Likewise, even hepatomegaly and signs of portal hypertension (mild to moderate splenomegaly with thrombocytopenia) are not necessarily indications for transplant. If these findings are thought to reflect inadequate prior management, an attempt should be made at rehabilitation. In select patients most of these findings will resolve over time. Even fibrosis or frank cirrhosis on a biopsy is not an absolute indication for transplantation. Rather, the decision should be made when the manifestations of the disease are so life-threatening that further attempts at rehabilitation are considered more risky than transplantation.

When considering intestinal transplantation, the exact procedure to be performed is dictated by the clinical circumstances. In a child with SBS, a well-preserved and functional foregut and minimal liver disease with little or no portal hypertension, transplantation of an isolated intestinal graft is likely adequate. This graft is typically comprised of the full length of the intestine from just beyond the duodenum and is fed by arterial blood supply through the SMA. For isolated intestinal transplants in children, in order to obtain adequate length of blood vessels for implantation, the pancreas is included with the graft and then is carefully excised on the back table prior to implantation. This way the full length of the SMA and portal vein in its intrapancreatic portion are preserved. The SMA of the graft is anastomosed

directly to the anterior surface of the infrarenal aorta. Graft outflow is established by anastomosing the portal vein of the graft either to the cut end of the recipient superior mesenteric vein just below the pancreas or directly to the IVC. The proximal graft is anastomosed to the proximal jejunum and the distal end to the native colon. In some cases, a segment of the right colon is included with the intestinal graft to provide some additional water absorption. Typically a loop ileostomy is created proximal to the colonic anastomosis for easy monitoring of graft output and for easy access for endoscopic biopsies.

When there is significant liver disease, an inadequate native foregut or a significantly allosensitized patient, a combined liver small bowel transplant is an option. This graft is procured taking a long segment of the thoracic aorta and leaving celiac and SMA access intact. This graft will typically be comprised of the liver, duodenum, pancreas, and full length of the small bowel. The graft might also include a portion of the stomach or colon as indicated. The caval outflow of the graft is anastomosed to the native IVC either using a standard bicaval technique or in piggyback fashion. Arterial inflow is created by an anastomosis between the donor aortic conduit and the aorta. All of the graft portal structures are maintained intact—no portal or biliary anastomosis is required. The native foregut can be removed or preserved, which would necessitate the creation of a portacaval shunt between the native portal vein and IVC to allow for venous outflow. The new graft is anastomosed to the recipient's stomach, either directly or with a Roux-en-Y. The distal graft and loop ileostomy are formed in typical fashion.

In both cases, induction immunotherapy is used initially to reduce the recipient alloimmune response, and then immunosuppression is typically maintained using a calcineurin-based regimen. Additional immunosuppressant agents are added as needed. Currently grafts are monitored by following ileostomy output and with serial endoscopic biopsies of the graft. There is no accepted noninvasive marker for rejection. Isolated small intestine graft and liver–intestine grafts have equivalent perioperative morbidity and mortality. In the long-term, it appears there might be an immunological advantage and hence graft survival advantage when the liver is included in the graft. The 1-year survival rate for children following intestinal transplant is approximately 80 %, with graft survival slightly lower. The 5-year survival rate for patients is approximately 65 %, with graft survival of 60 %. Some element of rejection will typically be detected in 30–40 % of grafts, which can usually be treated medically with complete resolution. There are some instances when a severe exfoliative rejection occurs which cannot be reversed and necessitates the removal of all or most of the graft. Re-transplantation has satisfactory long-term results, although the survival at 1 and 5 years are certainly lower. Overall, intestinal transplantation is an excellent solution for achieving enteral autonomy when the child has developed significant complications.

In summary, the care of patients with intestinal failure has changed dramatically over the past decade, and survival results have rapidly improved. Historically, the attitude has been that SBS is a uniformly fatal diagnosis, and many infants have had their life support withdrawn needlessly based solely on the changes in their GI tract. When there are multisystem problems contributing to the consideration for withdrawal of support, the decision may be merited; but if the sole reason for consideration of withdrawal is SBS, parents should be fully informed about the potential for intestinal rehabilitation and even intestinal transplantation prior to making a final decision. Excellent results have been achieved in many centers around the world in all types of patients, including children with ultrashort bowel $\leq$10 cm in length. Children are optimally treated by a multidisciplinary team with experience in intestinal rehabilitation. For many treating surgeons, this should prompt contacting an established IF team for input on management and possibly a transfer of care. This initial contact should be made as soon as possible after the loss of intestine has occurred so that children can start suitable treatment as early as possible and avoiding irreversible complications. This has already led to significantly improved survival in this very challenging population of children and should continue to do so in the future.

Editor's Comment

Short bowel syndrome and intestinal failure are rare and extremely costly diseases. The life burden of this disease is extreme, and it is unremitting even in patients who can be rehabilitated. Intestinal transplant outcomes have improved significantly over the last decade and although it can restore enteral autonomy, it does not reduce life burden. The likelihood of successful rehabilitation is reduced if the patient has an underlying motility disorder due to gastroschisis, type IIIb intestinal atresia, or necrotizing enterocolitis. There is hope in the form of a recently developed glucagon-like peptide-2 analog, which might be able to improve the absorptive capacity of the remaining intestine. It will not, however, be able to replace the absorptive function of intestinal segments lost to disease. Thus, our efforts are best spent trying to reduce the incidence of diseases leading to short bowel syndrome.

Teams that care for patients with short bowel syndrome need experience, creativity, and patience, as the first several months of life for these infants are often marked by frustrating trial and error, frequent complications, unexpected downturns, and extremely slow progress, with the added time pressure of avoiding TPN-induced liver failure. It is important to have a unifying philosophy, as abrupt and premature changes in course only increase frustration and harm.

In general, newborns with >60 cm of intestine are likely to wean from parenteral nutrition, those with <40 cm are unlikely to become independent enteral feeders without intervention, and those between 40 and 60 cm have an intermediate prognosis. Premature infants have a remarkable ability to grow their bowel, so it is best to avoid grandiose predictions based on any initial length measurement. Contrary to traditional dogma, stomas should be closed early, as most infants tolerate enteral feedings better and have fewer complications when bowel continuity has been reestablished.

While diffuse bowel dilatation is a welcome sign of bowel adaptation and makes the patient a candidate for bowel lengthening, segmental dilatation can be due to strictures, adhesions, or segmental dysmotility. Since contrast and motility studies do not reliably distinguish between a true obstruction and pseudo-obstruction, one should have a low threshold to explore the abdomen and perform a lysis of adhesions in these children.

Pediatric surgeons of a certain era have experience with the Bianchi procedure, and in the right patient it can certainly work extremely well. The STEP operation, on the other hand, also has excellent results. It is also easier to perform and can be repeated later if necessary to gain even more length, which is why in children with SBS it is currently the bowel-lengthening procedure of choice.

Suggested Reading

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Meconium Ileus

52

Peter Mattei

Meconium ileus is a small bowel obstruction in newborns caused by inspissated meconium. It is associated with cystic fibrosis in nearly all cases and up to 20 % of newborns with cystic fibrosis present with meconium ileus. Thick mucus and pancreatic enzyme insufficiency lead to extremely viscous meconium that cannot pass through the ileum, although why some infants with cystic fibrosis develop meconium ileus and others do not remain unclear. While often treatable by nonoperative means, many of these infants require laparotomy and can have a lifelong difficulty with bowel function related to their cystic fibrosis.

As with other causes of bowel obstruction, meconium ileus also can give rise to volvulus, ischemia, and perforation. This form of complicated meconium ileus sometimes occurs in utero and can result in intestinal atresia, short bowel syndrome, or meconium peritonitis, which itself can cause ascites, intraperitoneal calcifications, or meconium pseudocysts. Antenatal ultrasound scan (US) may detect echogenic or dilated loops of bowel or ascites, but except for the occasional case of polyhydramnios related to a more proximal volvulus or atresia, many are not detected before birth. While each seen in isolation is considered nonspecific, fetuses with the combination of *both* echogenic *and* dilated bowel on antenatal US are more likely to require laparotomy for meconium ileus or neonatal bowel obstruction in the newborn period.

Diagnosis

Meconium ileus must be considered in the differential diagnosis of any newborn infant with a bowel obstruction or failure to pass meconium in the first few days of life. Most are otherwise well-appearing newborns who present with feeding intolerance or bilious emesis and progressive abdominal distension. The remainder of the physical examination is often unremarkable, and the family history is positive for cystic fibrosis in less than one third of cases. The differential diagnosis of newborn bowel obstruction includes intestinal atresia, volvulus, meconium plug syndrome, and Hirschsprung disease.

The next step in the diagnostic workup is plain radiography of the abdomen. This usually demonstrates dilated air-filled loops of bowel consistent with a distal obstruction. A large amount of retained meconium with a ground-glass or soap bubble appearance (Neuhauser's sign) is highly suggestive of meconium ileus (Fig. 52.1). On the other hand, the presence of air-fluid levels makes the diagnosis less likely, given that the highly viscous meconium does not layer out very easily. The presence of peritoneal calcifications suggests the diagnosis of complicated meconium ileus as a result of in utero perforation and subsequent meconium peritonitis.

Patients who are clinically well with no evidence of perforation or ischemic bowel should have a contrast enema. Prophylactic antibiotics are given before the study is undertaken. A contrast study will confirm and treat meconium plug syndrome and might suggest the diagnosis of Hirschsprung disease or small left colon syndrome. If the findings include a microcolon, then a diagnosis of intestinal atresia or meconium ileus is most likely. It is in this situation that the pediatric radiologist will usually attempt to reflux the contrast material into the ileum. If there are filling defects in the terminal ileum consistent with pellets of meconium, then the diagnosis of meconium ileus is confirmed. Further retrograde progress of the contrast column will reveal a dilated segment of the ileum filled with meconium (Fig. 52.2). The contrast itself may help to evacuate the meconium and thus alleviate the obstruction.

The choice of contrast material probably matters very little, although the traditional recommendation is diatrizoate meglumine (Gastrografin, Schering Diagnostics, Berlin, Germany). Gastrografin formulations in the past included a wetting agent, polysorbate 80 (Tween-80, Unigema, New

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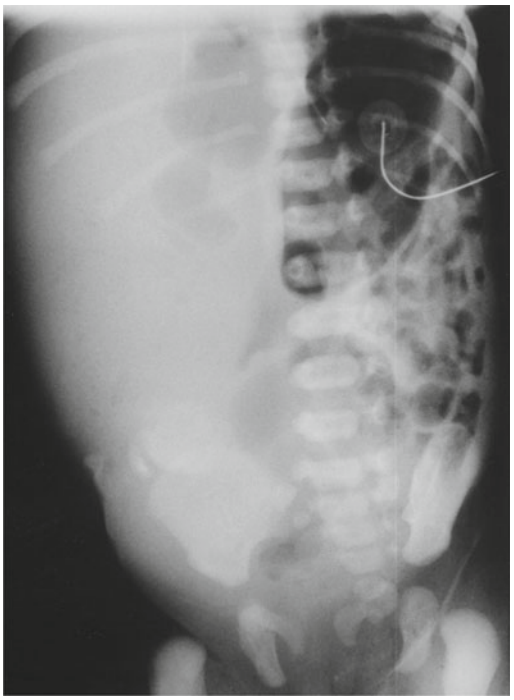

Fig. 52.1 Plain radiograph of a newborn infant with meconium ileus. Note the dilated loops suggestive of obstruction, the paucity of gas, and ground-glass appearance of meconium in the *right lower quadrant* (Neuhauser's sign)

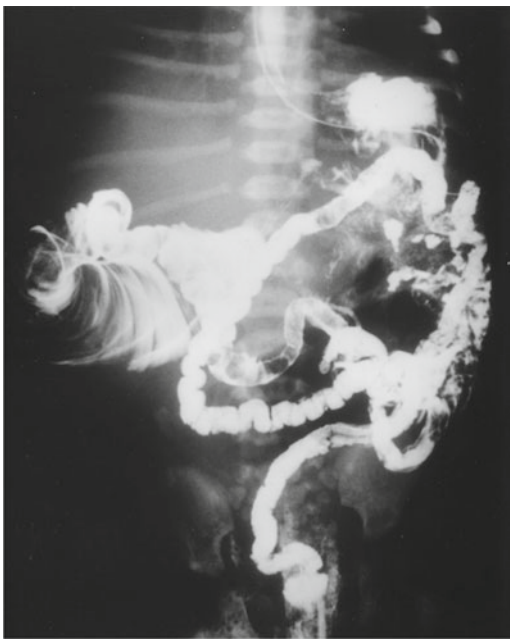

Fig. 52.2 Contrast enema in an infant with meconium ileus. Note the small caliber of the unused microcolon, the filling defects in the ileum (meconium pellets), and the hugely dilated bowel proximal to the obstruction

Castle, Delaware), which perhaps made it a superior solvent for evacuation of inspissated meconium. Current formulations do not contain Tween-80, and although its high osmolarity (1900 mOsm/L) might give it a theoretic advantage, many experienced pediatric radiologists feel that other agents are just as effective. Others have added Tween-80 or acetylcysteine to the contrast material and feel that this improves their results. Nevertheless, most of us are bounded by the preferences and experiences of the radiologists at our respective institutions, which are likely the most important factor.

Some radiologists are comfortable with the technique and are therefore more aggressive, whereas others are less likely to keep trying due to a concern about the potential for a bowel perforation. In the past, some reports suggested that the success rate with contrast enema was in the range of 65–80 %. Current success rates are generally much lower for reasons that are not entirely clear. Possibilities include the prior high success rates were somehow erroneous or inflated, less experience among current pediatric radiologists, a change in the formulation or osmolarity of modern contrast agents, or, perhaps most likely, a trend among radiologists to be less aggressive in their attempts to clear the obstruction for fear of a bowel perforation. The fact that current perforation rates are much lower than previously reported would support this theory.

Total colonic aganglionosis (long-segment Hirschsprung disease) sometimes presents a clinical and radiographic picture indistinguishable from meconium ileus. If the obstruction is alleviated by contrast enema, aganglionosis should be ruled out by suction rectal biopsy. If a laparotomy is performed, colonic biopsies and the appendix should be evaluated for the presence of ganglion cells. Not every infant with meconium ileus has cystic fibrosis, though the true number is unknown and varies among diverse populations. It is especially in these infants that aganglionosis coli needs to be ruled out with certainty.

The diagnosis of cystic fibrosis is still best made by measurement of sweat chloride after the collection of sweat using pilocarpine iontophoresis, but the test is not always useful in the first few weeks of life. Genetic testing can be performed on a buccal smear or blood sample, but genetic testing only detects approximately 99 % of all mutations. Some state newborn screens include measurement of immunoreactive trypsinogen using standard blood collection blots; however, the results often take weeks to process and need to be confirmed with more definitive tests because of a high false-positive rate. Nonetheless, all infants with meconium ileus should be treated as though they have cystic fibrosis until the diagnosis can be ruled out with sweat chloride testing. General support and genetic counseling should be available for the families while the diagnosis is being confirmed.

Treatment

Nonoperative therapy is possible if the contrast enema is successful in clearing a significant amount of meconium, though sometimes the enema needs to be repeated. These patients are maintained on bowel rest initially. Adequate intravenous hydration is provided and is especially important if high-osmolarity enema solutions have been used. A typical management regimen is 10 % acetylcysteine (Mucomyst) administered by orogastric tube at a dose of 10 mL every 6 h for 7–10 days. Acetylcysteine is a mucolytic that is very effective in loosening the viscous meconium in infants with meconium ileus. The contrast enema should be repeated if signs of obstruction recur. These infants also need to be assessed frequently for evidence of bowel perforation related to the obstruction or the enemas. When all signs of obstruction have resolved, enteral feedings can be started and advanced carefully. Pancreatic enzyme supplements are provided after feedings have started.

Some babies with meconium ileus complicated by in utero perforation can be treated nonoperatively, though most require laparotomy. An operation can be avoided in infants with peritoneal (or scrotal) calcifications on radiography who are presumed to have had meconium peritonitis but who show no signs of obstruction and are passing meconium without difficulty. A cautious feeding trial may be started while the cystic fibrosis workup continues. More often the calcifications are identified in an infant being evaluated for obstruction, in which case laparotomy is indicated without further studies.

Patients who fail nonoperative therapy should undergo laparotomy. The parents are informed that the goal is to remove the inspissated meconium but that a bowel resection, stoma, or tube ileostomy may be necessary depending on the operative findings. We prefer to make a transverse right lower abdominal incision, through which the ileum can be easily delivered and an ileostomy and mucous fistula can be brought out if necessary (Fig. 52.3). The cecum might need to be gently mobilized, and the peritoneum should be protected from contamination with saline-moistened gauze packs.

Simple meconium ileus, with no evidence of perforation, volvulus, or atresia, is best treated by irrigation. An enterotomy is made on the antimesenteric border of the dilated ileum for instillation of irrigation solution and evacuation of the meconium. Although saline solution is used by some surgeons with good results, many prefer to use acetylcysteine. Acetylcysteine comes in 10 and 20 % solutions and can be diluted with saline or water to a final concentration of 4 %. A 10- or 12-Fr catheter is used to instill the irrigation solution, which usually allows the tar-like meconium to be removed easily from the bowel lumen through the enterotomy (Fig. 52.4). The acetylcysteine also should be instilled distally to allow further evacuation of meconium from the colon. After removal of the inspissated meconium, the enterotomy is closed *transversely* and an appendectomy is performed. The pathologist should be made aware that the appendix needs to be evaluated specifically for the presence of ganglion cells. Histologic examination of the appendix might also reveal mucous plugging of the crypts and exuberant intraluminal mucinous material, which are suggestive of cystic fibrosis. At the conclusion of the procedure, especially if a large amount of meconium was seen to pass into the colon, a gentle anal dilatation and rectal irrigation should be performed.

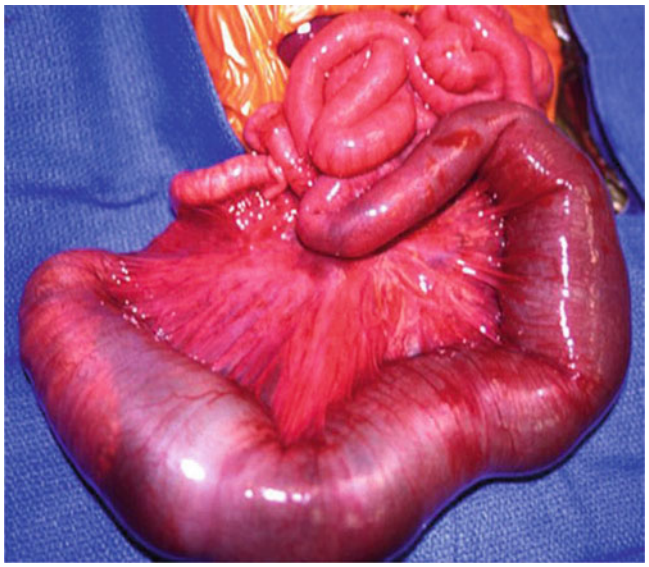

Fig. 52.3 Operative findings in a patient with meconium ileus. There is gradual tapering of the ileum, which is filled with inspissated meconium

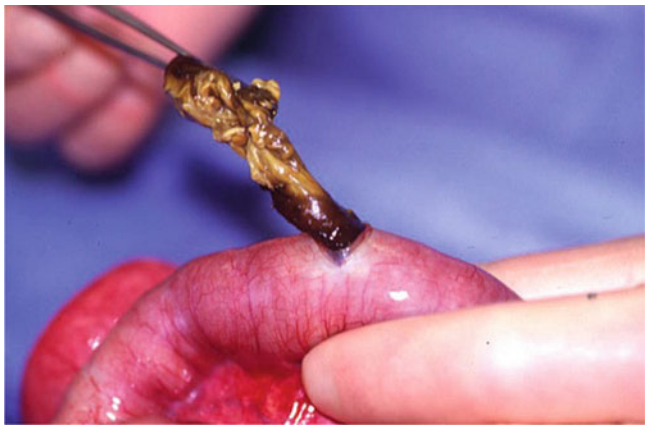

Fig. 52.4 The meconium has the consistency of tar and can be pulled out through the enterostomy in large pieces

Although enterotomy and bowel irrigation are useful approaches in most cases of simple meconium ileus, a modified technique is occasionally necessitated by the operative findings. In the past, it was a common practice to treat all

infants with meconium ileus with an ileostomy. This was felt to be necessary to facilitate postoperative irrigation and evacuation of meconium. Although no longer used routinely, the various stoma operations that have been described should be part of the armamentarium of the pediatric surgeon (Fig. 52.5). The Bishop-Koop ileostomy is a Roux-en-Y construct in which the distal limb is brought out as an end stoma and the proximal bowel is anastomosed end to side. This procedure is still commonly used by many pediatric surgeons and generally produces excellent results. The Santulli-Blanc operation creates a proximal stoma and the distal bowel is sewn to it end to side. The Mikulicz operation was widely used in the past for various indications and consists of a double-barrel stoma in which the two ends are sutured together side to side for some length proximal to the end of the stoma. It was designed for bedside stoma closure in which the common wall was crushed and obliterated with a specially designed clamp (Mikulicz clamp) and the bowel ends were closed over the top. This operation is rarely used today.

Another useful option is a tube ileostomy. A small-caliber rubber tube, usually a Malecot or T-tube, is placed through a small enterotomy and secured with a purse-string suture. The bowel is tacked to the fascia in standard fashion with the tube exiting through a small stab incision. This allows instillation of irrigant solution directly into the ileum without the creation of an ileostomy. Of course, a conventional end or loop ileostomy may be necessary if peritonitis or obstruction precludes a safe anastomosis after bowel resection or volvulus.

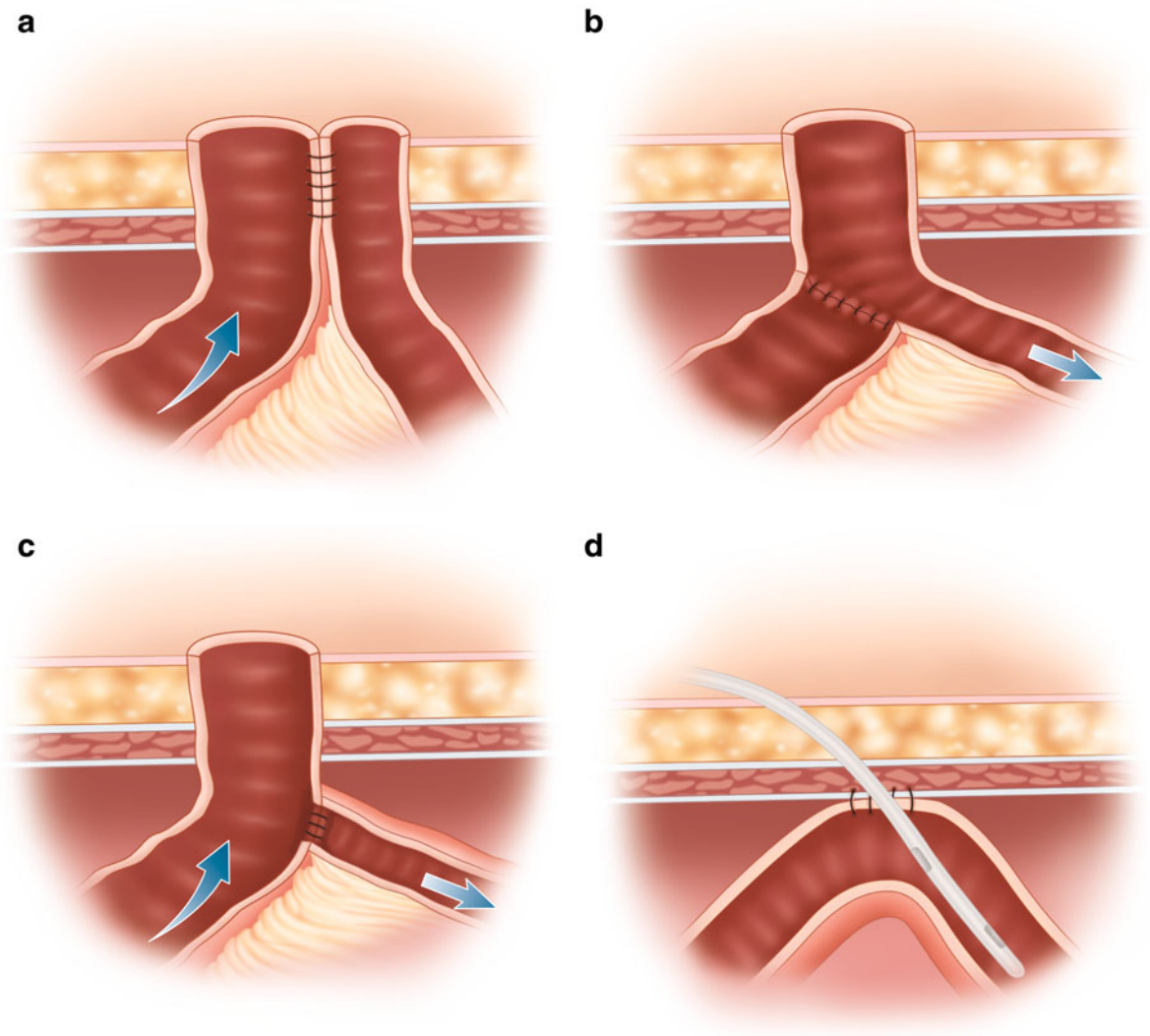

Fig. 52.5 The operations described in the past for meconium ileus are mostly of historical importance but are still occasionally useful in selected patients. (**a**) The Mikulicz operation after resection of the dilated ileum. (**b**) The Bishop-Koop operation. (**c**) The Santulli-Blanc operation. (**d**) Tube enterostomy for postoperative irrigation (Reprinted with permission from Rescorla FJ, Grosfeld JL. Contemporary management of meconium ileus. World J Surg. 1993;117(3):318)

The approach to complicated meconium ileus is the same as for any complicated intestinal process and includes an extensive lysis of adhesions, careful inspection of the bowel, bowel resection when necessary, and evacuation of inspissated meconium. Perforations are sometimes amenable to primary repair if a distal obstruction can be safely excluded. If a bowel resection is felt to be necessary, a judgment is made whether primary anastomosis is feasible or a stoma is necessary, based on the condition of the bowel, the likelihood of a distal obstruction and the overall condition of the patient. The fibrous wall of a meconium pseudocyst is debrided without sacrificing viable intestine. Meconium peritonitis can cause obstruction due to adhesions, requiring extensive adhesiolysis. The adhesions are typically dense and vascular. It is not necessary to perform a radical debridement of all meconium or calcified plaque that is encountered, as long as the obstruction is relieved. Appendectomy should be performed to rule out long-segment Hirschsprung disease and to avoid diagnostic confusion in the future. A gastrostomy should be considered in infants with complicated meconium ileus, especially if extensive bowel resection is necessary. Most infants will also need central venous access for parenteral nutrition during the postoperative period.

Postoperative Care

Patients are initially on bowel rest and are given acetylcysteine by gastric tube. Rectal irrigations are also useful. Most infants eventually establish a normal stooling pattern and can be advanced on feedings within 1–2 weeks but should be maintained on parenteral nutrition in the meantime. Recurrence is uncommon and treatment can be attempted using contrast enema, if necessary. Reoperation may suggest the need for ileostomy and a more definitive workup for Hirschsprung disease.

Infants with meconium ileus require an extensive workup involving multiple pediatric subspecialists including gastroenterologists, geneticists, pulmonologists, and pediatric surgeons. Family support should include access to counseling services and social work assistance. Patients are initially followed in the surgery office as after any major abdominal procedure, and the surgeon may need to become involved again later for issues related to feeding access, central venous access, and stoma care. Stomas can be taken down after the customary 4–6 weeks, according to the usual criteria of adequate weight gain and resolution of symptoms. A distal contrast study should be performed to rule out obstruction prior to reanastomosis.

Short-term complications are relatively common in infants with simple meconium ileus. Peritonitis and unplanned return to the OR are apparently higher in infants who undergo primary closure, while infants who were given an ileostomy have longer lengths of stay, have more operations overall, and take longer to reach goal feedings, perhaps due to high stoma output. There are advantages and disadvantages to either approach and there is as yet no consensus as to which approach—enterostomy with primary repair, tube ileostomy, or temporary formal ileostomy—is superior. The decision is based on judgment, experience, and the details of the individual case at hand.

Long-term complications are generally those common to patients with cystic fibrosis. Patients also can present years later with bowel obstruction. Those with a history of meconium peritonitis or laparotomy may have obstruction due to adhesions or segmental volvulus, but other diagnoses need to be considered. Patients with cystic fibrosis are more susceptible to intussusception. The intussusception can be of the conventional ileocolic variety seen in patients under the age of 3 years, but are sometimes ileoileal and can occur in older children. Appendicitis appears to be more common in patients with cystic fibrosis and when associated with perforation and phlegmon can be a cause of bowel obstruction or severe ileus. Inguinal hernias are also more common in this population and can of course be a cause of obstruction due to incarceration. Pancreatic enzyme supplementation has been implicated in the development of colonic strictures (*fibrosing colonopathy*) that generally occurs in adolescents and young adults with cystic fibrosis. These are diagnosed by contrast enema and are treated with resection and primary anastomosis. Finally, older patients are also at risk for *meconium ileus equivalent*, an obstruction caused by inspissated stool in the ileum and colon. Many of these patients can be treated initially with decompression and enemas, although some will require laparotomy. The cause is unknown but is presumably related to the high viscosity of intestinal mucus.

Summary

Meconium ileus is a cause of bowel obstruction in the newborn that mainly affects infants with cystic fibrosis. The diagnosis is confirmed with contrast enema, which can sometimes also be therapeutic. Patients with complications related to the obstruction, including volvulus, perforation, or atresia, and those who fail nonoperative management require operative intervention. At laparotomy, the conventional approach for simple meconium ileus is to irrigate the bowel lumen with acetylcysteine through a small enterotomy, which facilitates evacuation of the highly viscous meconium. Patients with complicated disease may require bowel resection, tube enterostomy, or creation of a stoma, several varieties of which have been described over the years for management of the disease. Most patients respond well to therapy in the short-term but need to be followed closely for complications related to their underlying disease. This includes bowel obstruction, which has many potential causes in these patients.

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Intussusception

53

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Intussusception is the invagination of one portion of the intestine, known as the intussusceptum, into the lumen of the adjacent intestine, referred to as the intussuscipiens. It is one of the most common causes of small bowel obstruction in infants and children. Although described in children of all ages, this disease is most commonly seen in children between 6 and 10 months of age. The majority of cases that affect children between 3 months and 3 years of age are idiopathic, meaning a specific pathologic lead point cannot be identified. While the true cause of idiopathic intussusception is not known, it is generally believed that a viral illness results in hypertrophied Peyer patches within the ileum. These thickened areas serve as the lead point of the intussusception. Other lead points causing an intussusception include Meckel's diverticulum, polyps, intestinal duplications, lymphoma, tumors, and in rare cases, the appendix. The incidence of a pathologic lead point ranges between 1.5 and 12 %, and the incidence increases in proportion to age, especially after 2 years of age. Ileocolic is the most common form of intussusception found in children, although enteroenteric intussusceptions are more common when a pathologic lead point is present.

Ultrasound has become the preferred first imaging modality for the diagnosis of intussusception. Air-contrast enema reduction is the initial treatment of choice for reduction given its high success rate. Multiple attempts at reduction can be made safely. For patients who fail reduction, the next step in management is surgery. The overall recurrence rate is roughly 5 % after reduction, with approximately one-third occurring within the first 24 h and the majority occurring within 6 months of initial presentation.

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Diagnosis

Obtaining an adequate history and physical examination is critical to the diagnosis of intussusception in children. Patients typically present with sudden episodes of transient and severe abdominal pain during which the child may draw his or her legs up toward their abdomen. These episodes are sometimes associated with nausea and vomiting. Following these episodes, patients are often pain-free. Parents might note bloody or "currant jelly" appearing stool, which is reflective of blood clots and sloughing of the mucosa. This is usually a later finding and a harbinger of bowel ischemia. Abdominal physical findings include a "sausage-shaped" mass in the right upper quadrant (RUQ) or the "Dance sign," in which in addition to a sausage-shaped mass in the upper abdomen, the right lower quadrant (RLQ) feels empty on palpation.

With a history and physical examination concerning for intussusception, several imaging modalities are available for diagnosis including X-ray, ultrasound (US), contrast enema, CT, or MRI. US is currently the easiest and most accurate tool used to diagnose intussusception. While potentially useful, CT exposes children to unnecessary radiation while MRI takes longer, costs more, and often requires sedation in this age group. Three-dimensional imaging can be a powerful tool for the diagnosis of pathologic lead points, which is why they are often used in older children, in whom a pathologic lead point such as a tumor is more common and could be identified.

Abdominal US has replaced the contrast enema as the initial study of choice for diagnosis of intussusception. Findings on ultrasound suggestive of intussusception include a "target sign" or "donut lesion" which is reflective of the bowel wall

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and mesenteric fat telescoping within the intussusceptum (Fig. 53.1a). Another finding suggestive of intussusception is the "pseudokidney" sign in which the edematous walls of the bowel are observed within the intussuscipiens (Fig. 53.1b). If US findings are equivocal but the history and physical findings are suggestive of intussusception, additional imaging, usually a contrast enema, should be considered. Further, US can be used to evaluate for recurrence in patients with renewed symptoms after reduction.

Treatment

Initially, children with a suspected diagnosis of intussusception should be treated with intravenous fluid resuscitation and bowel rest. The diagnosis should be confirmed by US. Once confirmed, children without evidence of peritonitis should undergo an attempt at reduction using an air-contrast enema (Fig. 53.2). Historically, a dose of antibiotics would be administered prior to the enema for the treatment of "bacterial translocation." However, this is not necessary, as no clear benefit has been demonstrated. Furthermore, administration of antibiotics can delay the air-contrast enema and has been associated with complications. Some children referred for an air enema will ultimately be diagnosed with infectious colitis, not intussusception. The administration of antibiotics to these patients can have significant consequences. A single dose of antibiotics given to a child with *E. coli* O157:H7 can result in the development of hemolytic uremic syndrome. It is not our practice to administer antibiotics prior to this procedure.

During an air-contrast enema, a maximum pressure of 120 mmHg is delivered three separate times in an attempt to reduce the intussusception. Reduction is confirmed by fluoroscopy with free reflux of air into the small bowel. Perforation during an air-contrast enema is rare, observed in less than 1 % of patients, but can result in tension pneumoperitoneum and subsequent hemodynamic collapse. Thus, a member of our surgical team is made aware when these procedures are being performed so that they may be readily available for needle decompression. The American College of Radiology recommends that fluoroscopic guided intussusception reduction be performed with a surgeon readily available; however, surgical attendance is not required during the procedure.

If the initial air enema is successful, the child should be kept NPO for a period of 6–12 h, after which a diet may be started. The child may be discharged if tolerating a diet and is otherwise clinically well with resolution of abdominal pain. If the initial air-contrast enema is not completely successful in reducing the intussusception but some air is demonstrated refluxing into the small bowel, then the child should be kept NPO with intravenous fluids for 2–4 h, and the study is repeated. If the intussusception persists, the radiologist may perform repeated attempts at reduction. If enema reduction is ultimately successful, the child should be observed and kept NPO for 6–12 h before reintroducing a diet. Often the repeat air-contrast enema will demonstrate resolution of the intussusception. In our experience, these children either spontaneously reduce or we fail to capture the reduction on imaging. If the child does not experience a recurrence of symptoms over a 24 h observation period, has a benign abdominal examination, and tolerates a diet, the child may be discharged home (Fig. 53.3).

If the child demonstrates signs of peritonitis or repeated enemas fail to reduce the intussusception, the next step in management is operative exploration. We initially approach these cases laparoscopically. The trocars are positioned in a similar location to that of an appendectomy. Once laparoscopic access has been gained through an umbilical port, the intussusception is usually identified in the right lower quadrant. Following this, two additional trocars are placed, one in

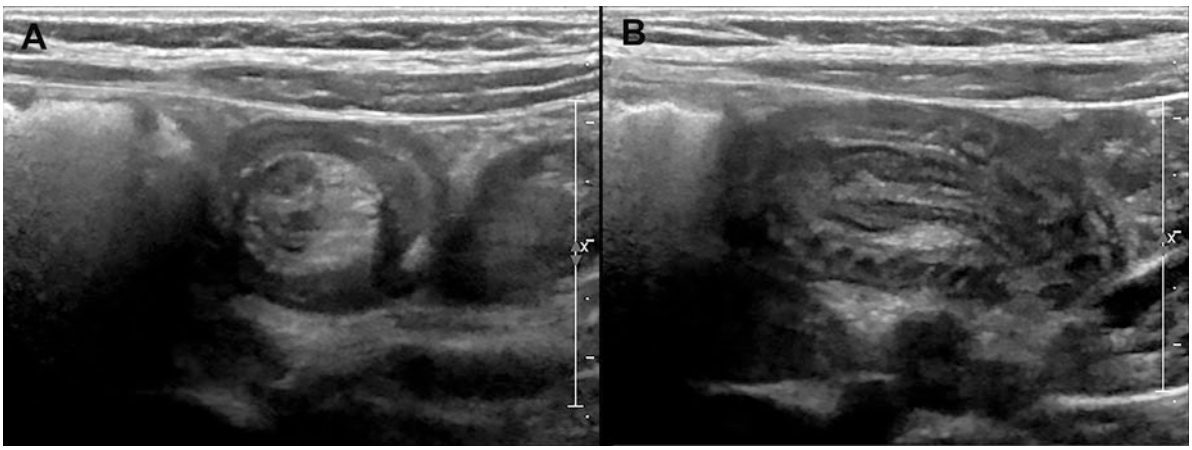


Fig. 53.1 Images from an abdominal ultrasound depicting (**a**) classic target sign and (**b**) a pseudokidney sign seen in intussusception

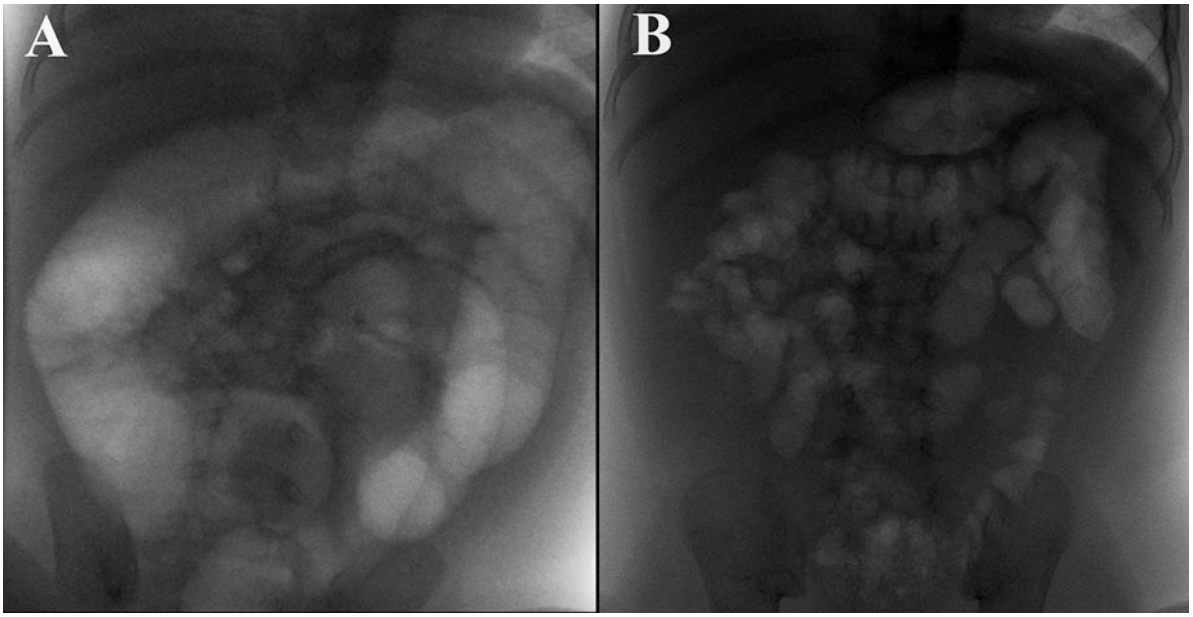
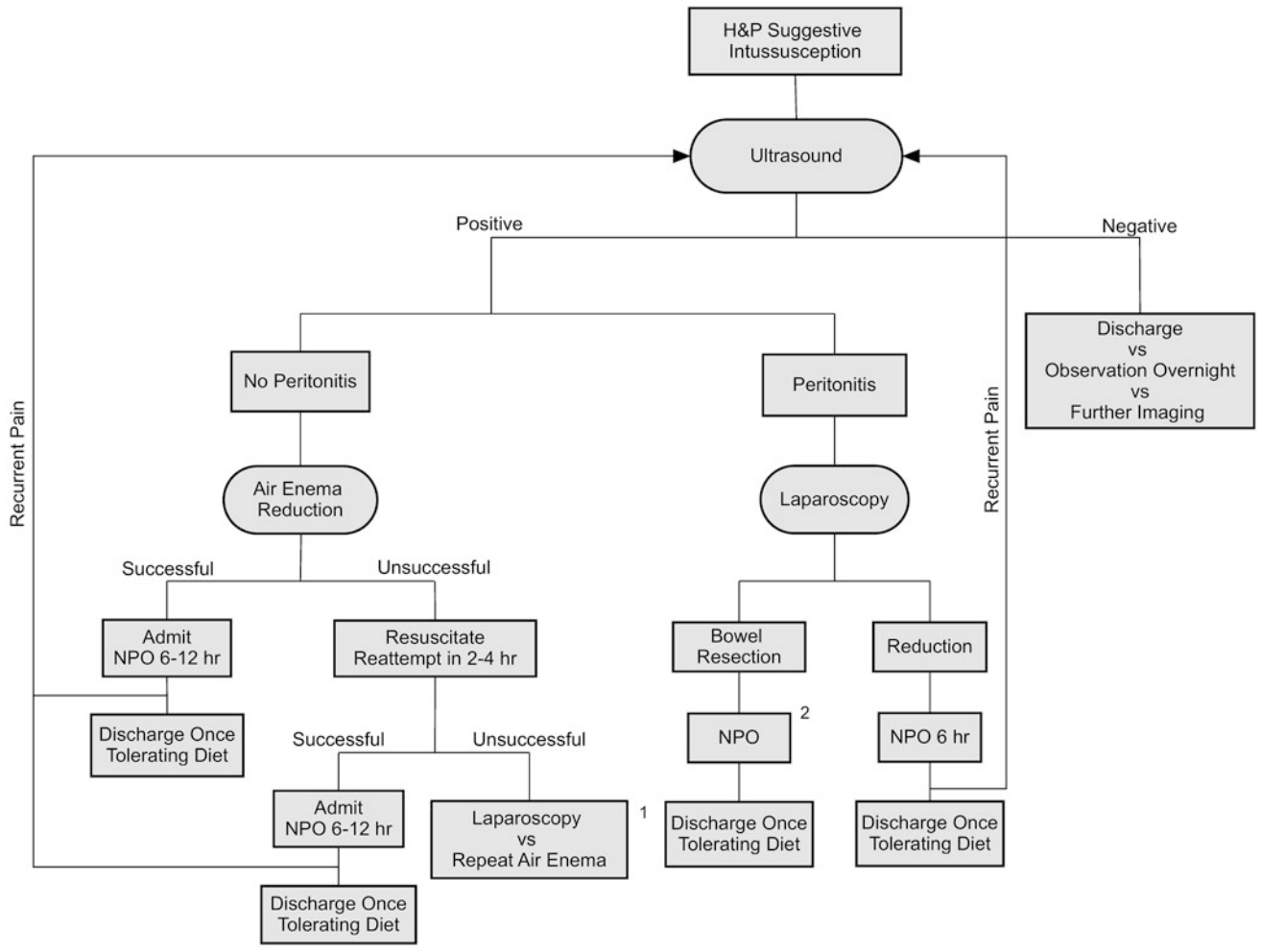


Fig. 53.2 Air-contrast enema for intussusception reduction (**a**) incomplete reduction. The intussusception is almost completely reduced to the end point at the cecum, (**b**) successful reduction. Air filling the small bowel at the end of the enema



1
Based on clinical picture and radiology resources repeat air enema may be attempted.
2
Advance diet per surgeon preference.

Fig. 53.3 Algorithm for the treatment of intussusception

the left lower quadrant and one in the suprapubic region. In patients for whom air-contrast enema was not successful at complete reduction, the intussusception is typically partially reduced and found in the ascending colon. In order to reduce the intussusception, gentle tension should be used to carefully pull apart the affected area of the bowel. Using two graspers, one stabilizes the intussuscipiens while the other is used to reduce the intussusceptum with gentle continuous pulling. The bowel may appear congested and edematous, but resection is not performed unless necrosis or frank perforation is present.

If the intussusception is unable to be reduced laparoscopically, then an accessory incision can be created. Depending on the location of the intussusception, either the umbilical incision can be extended or a separate right lower quadrant incision can be created. Once the intussusception has been delivered, manual reduction is attempted by squeezing the intussusceptum out of the intussuscipiens, similar to squeezing a tube of toothpaste. If the intussusception cannot be reduced after conversion to an open procedure, a limited bowel resection encompassing the area of intussusception is performed with a primary anastomosis.

We do not routinely perform an appendectomy with surgical reduction. Following any operation for intussusception, the child should initially be kept NPO until return of bowel function. Diet may be advanced as tolerated. If the child presents with recurrent symptoms of intussusception after surgical reduction, an US should be performed. If recurrent intussusception is identified, an air-contrast enema should be repeated.

Future Directions

Air-contrast enemas are the treatment of choice for intussusception, since they have a high success rate and are less invasive compared to surgical reduction. However, they expose the child to ionizing radiation. Ultrasound-guided hydrostatic reduction with normal saline is a relatively new method described for reduction of intussusception. Success rate of reduction has been reported to be greater than 80 % and does not expose the patient to radiation. With qualified operators and appropriate technology, it is conceivable that US-guided hydrostatic reduction could become the initial treatment of choice, especially in the current climate of concern regarding the long-term effects of radiation exposure in children.

While recurrence following enema reduction is a known risk for intussusception, there is lack of data to support the need for admission and observation following nonoperative reduction. Further studies are under way to answer the question as to whether children could be safely discharged from the ED (Emergency Department) following successful reduction of intussusception.

Editor's Comment

The "less is more" approach has clearly improved the management of intussusception. We are using less radiation to diagnose this problem, and US-guided reduction will almost certainly replace fluoroscopic reduction someday. We are less inclined to use antibiotics prior to hydrostatic reduction and more likely to discharge patients early after successful reduction, limiting their exposure to hospital-associated infections and limiting treatment costs. Finally, the new generation of pediatric surgeons has a laparoscopy-first mind-set, resulting in smaller scars and earlier discharge (besides nicely disproving yet another formerly sacrosanct surgical dictum: "never ever pull the bowel apart to reduce an intussusception").

The classic presentation of intermittent colicky pain is very well known, but a sizable minority of patients present with lethargy or obtundation, sometimes severe enough to suggest CNS injury or disease. Regardless of the presentation, it is not possible to exclude the diagnosis with certainty by any combination of history, physical examination, laboratory studies, or plain X-rays. In fact some teach that if intussusception is mentioned in any correspondence and no alternate diagnosis can be confirmed, one is duty-bound to obtain an US.

If the diagnosis is confirmed by US, the next step is contrast enema, the type of which (air or liquid) should be determined by the radiologist, not the surgeon. Some radiologists insist that a surgeon be present in case of a perforation, perhaps so that we might percutaneously evacuate air in the very rare case of a tension pneumoperitoneum, but in practice the typical child with a perforation needs to be resuscitated and properly prepared before going to the OR anyway. The most important role of the surgeon in these situations is to maintain a calm and commanding presence while the patient and parents are being prepared for a trip to the OR.

One might be tempted to perform a biopsy (or, worse, a resection) of the edematous or hemorrhagic "mass" that is often found in the wall of the cecum or ileum after successful operative reduction, but this should be avoided. Some still routinely perform an appendectomy, which, though probably unnecessary, is safe and, some believe, might prevent a recurrence. If resection is required, ileostomy should almost never be necessary, even after a perforation, as a primary anastomosis can almost always be done quickly and safely.

Children over the age of five and those of any age who develop multiple recurrences pose a challenge—while a diligent search for a lead point with US, CT, MRI, and endoscopy is reasonable, deciding whether laparotomy or bowel resection should be performed requires a great deal of clinical experience and good judgment. Small bowel and colonic intussusception, on the other hand, are very often a pathologic lead point and should prompt at least a diagnostic laparoscopy to rule out lymphoma, Meckel's diverticulum, polyp, tumor,

or vascular malformation. In stable patients with Henoch-Schonlein purpura (HSP) or postoperative intussusception, a 12–24 h period of close observation (assuming no signs of sepsis or peritonitis) is reasonable, as the intussusception often resolves spontaneously in these patients.

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Meckel's Diverticulum

54

Joshua D. Rouch and Steven L. Lee

Meckel's diverticulum is the congenital persistence of all or part of the omphalomesenteric duct, also referred to as the vitelline duct or yolk stalk. The omphalomesenteric duct is the primitive connection between the fetal yolk sac and developing midgut. At approximately week 5–7 of fetal gestation, this connection regresses as the placenta grows to become the main source of nutrition for the developing embryo. Incomplete regression leads to malformations such as a fibrous band, persistent sinus, cysts, omphaloenteric fistula, or most commonly a Meckel's diverticulum. It is a true diverticulum, consisting of all intestinal layers. Paired right and left vitelline arteries are branches of the primitive aorta and accompany the omphalomesenteric duct. The right vitelline artery eventually becomes the superior mesenteric artery and will provide a terminal branch to the diverticulum. The left vitelline artery involutes, but any vitelline arterial remnant that fails to obliterate completely will form fibrous bands connecting the gut to the abdominal wall. Ectopic tissue can be found in the diverticulum, and its presence often is what leads to the clinical presentation. Commonly reported types of ectopic tissue are primarily gastric or pancreatic in origin. However, isolated series have documented the presence of ectopic endometrial, colonic, or duodenal tissue.

The "rule of 2s" is well known in pediatric surgery and is used to describe a Meckel's diverticulum: The incidence is roughly 2 % of the population. If symptomatic, it is generally recognized by 2 years of age. It is 2 in. in maximal dimension and is located within 2 ft of the ileocecal valve, but these measurements vary significantly in the reported literature. One of two types of heterotopic tissue is commonly found within the diverticulum, including the gastric and pancreatic tissue.

Meckel's diverticulum can be symptomatic or asymptomatic. There are critical differences in terms of the age of presentation, acuity, associated abnormalities, and treatment depending on the presentation. Most often it will have been encountered at celiotomy for another cause and is merely an incidental finding. Symptomatic Meckel's diverticula, however, are occasionally difficult to diagnose, are higher acuity, and involve a more complex treatment strategy. Symptomatic Meckel's diverticula are usually present in the form of bleeding, inflammation, or obstruction. The different presentation, diagnosis, and eventual treatment for each of these presentation styles are varied, but most often involve surgical treatment.

Gastrointestinal Hemorrhage

The most common manifestation of a Meckel's diverticulum is bleeding. This is typically due to the ectopic gastric tissue within the diverticulum, which causes ulceration in the adjacent normal ileal mucosa. The ulcer is generally located just distal to the diverticulum. These patients classically present with painless, episodic bright red blood per rectum, which can be massive and associated with profound blood loss and low hematocrit. The majority of patients with a bleeding Meckel's diverticulum will present within the first 3 years of age. Among all children with gastrointestinal hemorrhage, roughly half are attributable to a Meckel's diverticulum.

Initially, these patients need to be resuscitated and are often given blood products. In order to confirm the diagnosis, the patient should be administered a technetium-99m pertechnetate nuclear medicine scan. In most cases this will visualize the heterotopic gastric tissue distant from the

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stomach. Occasionally, the pertechnetate scan does not perfectly visualize the heterotopic tissue. To enhance the scan and increase its sensitivity, some administer pentagastrin or an H_2 receptor blocker. These drugs enhance the uptake of the technetium-99m pertechnetate or prevent its expulsion from gastric mucosal cells. Re-scanning after a non-diagnostic study can also sometimes be useful. Other methods of detection, especially tagged-RBC scans or angiography, are generally less helpful, unless the rate of bleeding at the time of the test is sufficient to detect blood loss of at least 0.5 mL/min. If the clinical suspicion remains high despite a negative Meckel's scan, diagnostic laparoscopy is indicated.

The mainstay of treatment for a bleeding Meckel's diverticulum after appropriate resuscitation is surgical resection. Laparoscopic, single-incision laparoscopic, or open approaches are acceptable, depending on surgeon preference. Generally, a mini-laparotomy or a laparoscopic approach with eventual enlargement of a trocar site can permit easier extracorporeal segmental resection and anastomosis. It is important to visually inspect the diverticulum and palpate for any thickened or inflamed tissue. Thickened tissue within the diverticulum or at its base likely represents heterotopic tissue, while thickened distal bowel likely contains the inflamed, marginal ulcer. Especially in a patient who presented with bleeding, it is vital to resect the diverticulum along with any ulcerated tissue found adjacent to the Meckel's diverticulum, as failure to do so greatly increases morbidity and the chance for re-operation. The subsequent anastomosis should be between two healthy appearing ends of bowel and can be performed as a hand-sewn end-to-end anastomosis or a side-to-side anastomosis with a GIA stapler.

Postoperative care is routine and depending on the amount of bowel manipulation have differing rates of postoperative ileus. Need for re-operation and wound infection are uncommon complications for patients with bleeding from a Meckel's diverticulum.

Bowel Obstruction

Patients with a symptomatic Meckel's diverticulum can present with symptoms related to an obstructive process of the bowel. However, Meckel's diverticulum may not be the highest entity on a clinician's differential diagnosis in patients with nausea, vomiting, intermittent abdominal pain, or bloody stools. This is because intussusception, small bowel volvulus, internal hernia, and other obstructive processes are usually encountered outside the context of Meckel's diverticulum. Obstruction due to Meckel's diverticulum often presents within the first year of life.

Ileoileal and subsequent ileocolic intussusception, with the diverticulum serving as a lead point, is the most common cause of intestinal obstruction related to a Meckel's diverticulum. However, it is usually at operation that this is discovered. These patients present with symptoms of intussusception—vomiting, intermittent colicky abdominal pain, bloody stools, and occasionally a palpable left lower quadrant mass—and should be treated along the typical intussusception algorithm. This occurs most often during infancy or early childhood. When a Meckel's diverticulum is the lead point, routine reduction with air or contrast enemas is unlikely to be successful, and surgery is generally required. Diagnostic laparoscopy or laparotomy reveals the Meckel's diverticulum as the cause.

Small bowel volvulus and internal hernia are also possible and should be treated as surgical emergencies. Importantly these patients present with pain out of proportion to abdominal examination findings and do not have a history of prior abdominal surgery. These patients should be resuscitated, given intravenous antibiotics, and taken to the OR urgently for abdominal exploration. A Meckel's diverticulum or another malformation related to the embryonic vitelline duct may be encountered. This might be in the form of a volvulus around a fibrous band connecting the Meckel's diverticulum to the abdominal wall or an internal hernia between the diverticulum and a mesodiverticular artery with a separate loop of bowel trapped within it (Fig. 54.1).

Inflammatory Process

Perhaps the most elusive symptomatic presentation of a Meckel's diverticulum is an acute intra-abdominal inflammatory process, which is known to mimic appendicitis, Crohn's disease, ulcerative colitis, or even gastroenteritis.

This presentation is more common in older children. Generally the history is very similar to that of acute appendicitis, with vague abdominal pain progressing to localized abdominal pain accompanied by fevers, chills, anorexia, and nausea. The pathophysiology is very similar to that of appendicitis. Ultrasound (US) or computed tomography (CT) of the abdomen may also demonstrate findings felt to be consistent with acute appendicitis, with the correct diagnosis not recognized until the operation. If a patient is being taken for appendectomy and the operative findings of the appendix do not appear to match the preoperative presentation or scan, the surgeon should keep the diagnosis of an inflamed Meckel's diverticulum in mind and carefully inspect the abdomen prior to closing.

The technical details of operation are similar regardless of presentation. In the case of inflammation, if the adjacent bowel appears healthy and is palpated to be normal, a stapled diverticulectomy is reasonable. In the case of perforation of the diverticulum with peritonitis, segmental bowel resection with primary anastomosis is safe. Stoma creation is very rarely indicated.

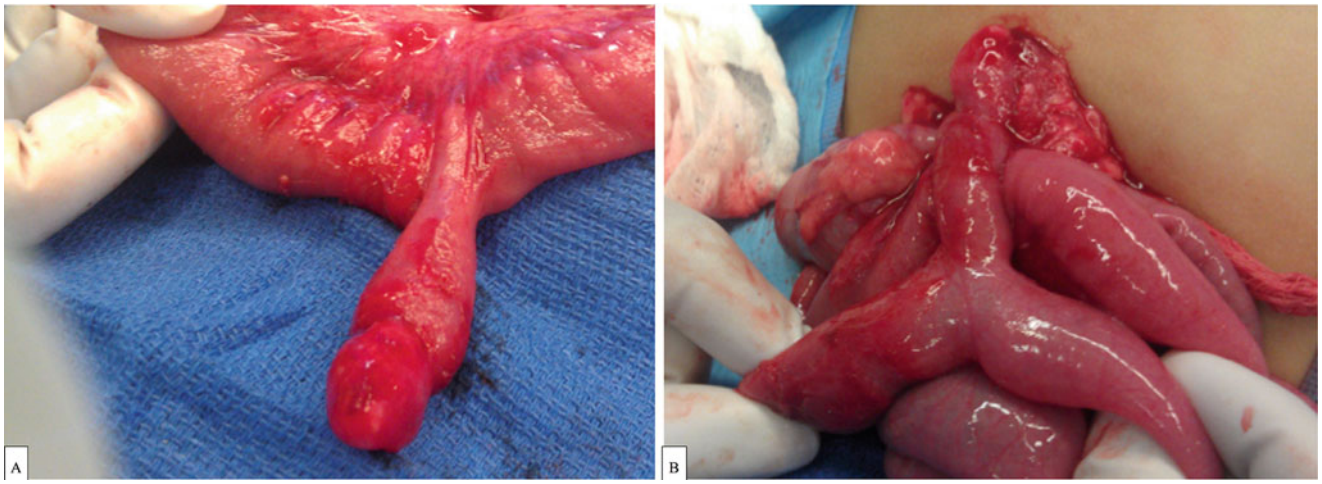

Fig. 54.1 Meckel's diverticula that arise from the antimesenteric border of the ileum. (**a**) Inflamed Meckel's diverticulum. (**b**) Meckel's diverticulum with a fibrous connection to the abdominal wall and an internal hernia causing obstruction

Incidental Meckel's Diverticulum

While there is little controversy over the surgical treatment of a symptomatic Meckel's diverticulum, there is no consensus on whether to remove incidentally found diverticula. In the case of a healthy appearing diverticulum without fibrous bands attached to the abdominal wall, we would advocate leaving them alone. However, if ectopic tissue or a mass can be palpated in the diverticulum or if it is adherent to the adjacent bowel or abdominal wall, it should be resected. Similarly, in the case of operation for suspected appendicitis, if a mildly inflamed appendix is found and a Meckel's diverticulum identified, the diverticulum should be removed (Figs. 54.2 and 54.3).

Atypical Presentation

One interesting presentation is that of a Littré hernia, occurring when a Meckel's diverticulum is found within an incarcerated hernia. First described in 1700 by Alexis Littré, this rare entity is described as a painful groin mass that is not accompanied by obstruction or peritonitis and most commonly occurs in inguinal and femoral hernias. These should be resected and the hernia repaired in the usual fashion.

Persistent sinuses and omphaloenteric fistula generally present with drainage from the umbilicus. In the case of a persistent sinus, the drainage can be serous or purulent, whereas enteric drainage represents an enterocutaneous fistula. If granulation tissue is present, some surgeons have advocated for silver nitrate application in the office. A patent urachus is also within the differential diagnosis, especially for those with straw-colored drainage. A fistulogram can confirm the course of any connection to the bowel or bladder and help with operative planning. Foreign bodies can become lodged within Meckel's diverticula, and there have been reports of toothpicks, coins, seeds, and even a fish bone found at operation. Though much less pertinent in children, Meckel's diverticula have been associated with various malignancies, including carcinoid tumors, adenocarcinomas, gastrointestinal stromal tumors (GIST), sarcomas, and lymphomas. However, the mean age at presentation is between the fourth and sixth decades of life.

Summary

Meckel's diverticulum is the most common congenital malformation of the gastrointestinal tract and is part of a spectrum of anomalies that derive from a persistent omphalomesenteric duct. It is most often an incidental finding, but most symptomatic patients present with gastrointestinal bleeding, obstruction, or inflammation, the likelihood of each varying with age: <1 year of age for umbilical pathology, 0–1 year of age for obstruction, 1–3 years of age for gastrointestinal hemorrhage, and 7–9 years of age for inflammation. Heterotopic gastric and pancreatic tissue is frequently found within the diverticulum. The secretion of acid or enzymes from this tissue is thought to be the cause of bleeding from and inflammation of the diverticulum and surrounding tissue. A Meckel's scan using technetium-99m pertechnetate scintigraphy can localize the heterotopic tissue in the diverticulum. When symptomatic, resection is indicated, and any associated ulcerated or inflamed small bowel should be resected as well. Controversy still exists regarding the resection of asymptomatic, incidentally found Meckel's diverticulum. We recommend leaving them when asymptomatic and no mass is palpable within it. Complications are rare but include ileus, wound infection, incomplete diverticulectomy, and adhesive bowel obstruction.

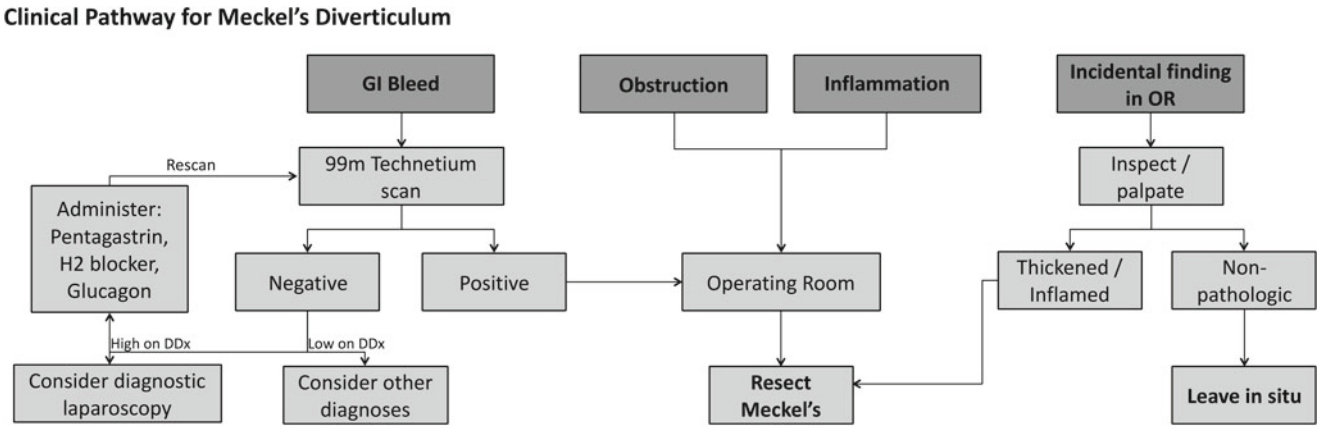

Fig. 54.2 Clinical pathway treatment strategy for patients with presentations consistent with symptoms from Meckel's diverticula

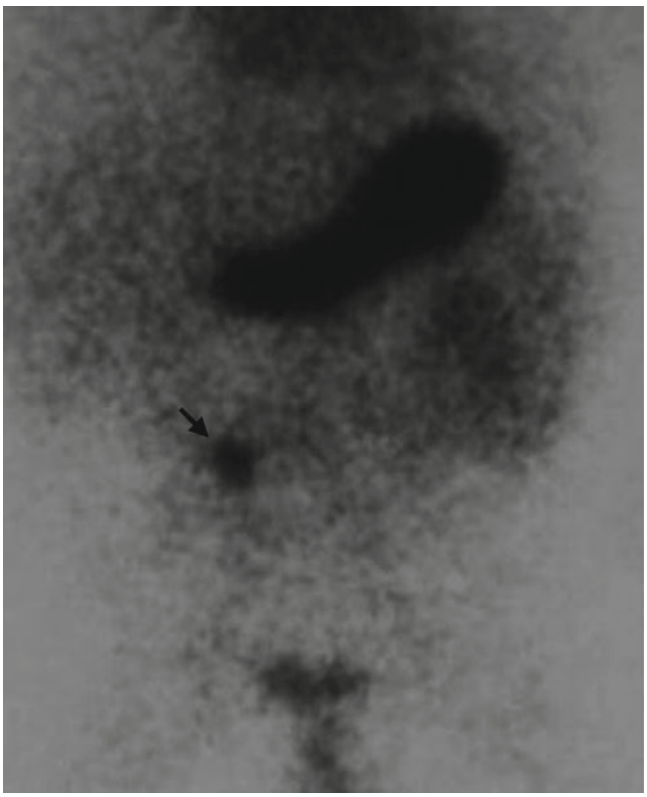

Fig. 54.3 Technetium-99m pertechnetate "Meckel's scan" showing uptake in the stomach as well as heterotopic gastric uptake in the *right lower quadrant* (Reprinted from Caro P, Ryan S. Small Bowel Normal Anatomy and Congenital Anomalies. Abdom Imaging. 2013;537–50, with kind permission from Springer Science and Business Media)

Editor's Comment

Meckel's diverticulum is a simple defect that can cause big problems. Except when it causes gastrointestinal bleeding, the diagnosis is usually made in the operating room when a child undergoes an exploration for bowel obstruction, intussusception, volvulus, or an acute inflammatory process that looks very much like acute appendicitis. In fact, the presence of a Meckel's diverticulum should be considered in any patient with an atypical presentation and should be carefully sought for when the findings at exploration are anything other than what was expected. The distal meter or so of the ileum should be inspected carefully, as it is not always easily apparent and the location is highly variable. While an asymptomatic diverticulum found incidentally should probably be left alone, unless it is tethered to the abdominal wall or there is a mass, a simple diverticulectomy performed with a GIA stapler oriented transversely across the base is quick and generally quite safe.

The "Meckel's scan" demonstrates gastric mucosa and therefore is only indicated in patients who are bleeding. It is not 100 % sensitive either, so if the clinical suspicion remains high after a negative scan, diagnostic laparoscopy should be considered. For most symptomatic diverticula, a minimal-access approach is best, as the diverticulum can usually be mobilized laparoscopically and then delivered through a small periumbilical incision. When a Meckel's diverticulum is suspected preoperatively, it is probably safer to place the first trocar away from the midline, as the diverticulum is sometimes adherent to the undersurface of the umbilicus where it can be easily injured. Bowel resection with primary anastomosis is necessary for the short diverticulum with a large mass of ectopic tissue or when an inflammatory process involves the base. Bowel resection is also recommended for bleeding to ensure that the portion of the adjacent ileum containing the ulcer is removed with the specimen. Ileostomy is almost never necessary when dealing with a complication of a Meckel's diverticulum.

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Bariatric Surgery

55

Joy L. Collins

Adolescent obesity remains a significant problem in the United States, lagging behind but following the trend of adult obesity. In some regions, nearly 40 % of adolescents are obese, and many are developing severe obesity-related comorbid conditions that result in a reduced quality of life and can be progressive and life-threatening. Although nutritional counseling and behavioral modification programs have been moderately successful for overweight and obese children in the younger age groups, medical management appears to be less effective in the adolescent and young adult populations. It is estimated that up to 80 % of obese teenagers will go on to become obese adults, with a pattern of continued weight gain as they enter adulthood. Bariatric surgery has been demonstrated to be a safe, effective, and durable weight-loss method in adults, but its widespread application in the pediatric population remains controversial. Nevertheless, data increasingly show a similar safety and efficacy in adolescents.

Defining obesity in children and adolescents is not as straightforward as it is in adults. In younger children, obesity is defined as the 95th percentile of body mass index (BMI) for age from the reference charts constructed from extensive data collected by the National Health and Nutrition Evaluation Surveys (NHANES). In 18-year-olds, the 95th percentile of BMI for age corresponds to a BMI of 30 kg/m^2. For adolescents, in the absence of a more epidemiologically accurate method to define severe obesity for age, the BMI seems to be a clinically useful correlate of adiposity.

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Patient Selection

Most surgeons have adopted a BMI-based algorithm for determining candidacy of adolescents for bariatric surgery. The National Institutes of Health (NIH) defines an adult bariatric surgery candidate as having a BMI >40 or a BMI >35 with a severe obesity-related comorbidity. In our practice, patients with a BMI >35 with one or more severe obesity-related comorbid conditions (type II diabetes, moderate-severe obstructive sleep apnea, pseudotumor cerebri, severe nonalcoholic fatty liver disease) or BMI >40 with one or more less severe obesity-related comorbidities (mild obstructive sleep apnea, insulin resistance, hypertension, dyslipidemia) are considered for evaluation. According to guidelines established by the NIH and the Metabolic and Bariatric Surgery Accreditation and Quality Improvement Program (MBSAQIP), patients being considered for bariatric surgery should be evaluated at a specialized center by a multidisciplinary bariatric team who has expertise in dealing with adolescents and can provide appropriate comprehensive long-term follow-up. This requires the collaborative efforts of a variety of specialists and should include surgeons with bariatric training and expertise, pediatric medical advisors who are physicians with education and accreditation in general pediatrics or pediatric subspecialty training, bariatric nurse specialists or other bariatric clinicians, anesthesiologists with special interest and expertise in caring for obese patients, nutritionists, exercise physiologists, and adolescent psychologists and psychiatrists.

Preoperative Work-Up and Education

Preoperative assessment consists of a comprehensive evaluation by the pediatric medical advisor, surgeon, and other specialists with discussion of the results among team members. The main components of the preoperative assessment and education include nutritional, psychological, and medical evaluations. The patients' families are included in each portion of this process.

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In our program, the medical evaluation is a process that consists of multiple visits with all members of the bariatric team. The initial evaluation consists of a complete history and physical examination plus screening for medical causes of obesity, obesity-related comorbid conditions, and vitamin deficiencies. Sexual and skeletal maturity is assessed by physical examination and by bone X-rays, and any identified medical conditions or risk factors are evaluated by specialist referrals as needed. The surgeon is involved early in this evaluation process and offers patients and families an initial extensive discussion and education regarding potential bariatric surgery.

The recommended minimal preoperative laboratory studies include a chemistry panel, hepatic function panel, lipid profile, CBC, hemoglobin A1c, fasting blood glucose and insulin levels, thyroid-stimulating hormone, thiamine, folate and iron levels, urinalysis, and a pregnancy test for girls. Because unrecognized sleep disorders are prevalent in the severely obese, a complete sleep history is obtained, with referral to pulmonology for evaluation and formal polysomnography. We have uncovered severe obstructive sleep apnea in patients who had no history of snoring, irregular breathing, or increased daytime somnolence. An upper-GI series is performed in patients with symptoms concerning for reflux to confirm normal anatomy and rule out significant hiatal hernia or GERD. A right upper quadrant ultrasound is performed to rule out cholelithiasis (patients without gallstones who undergo surgery are candidates for treatment with ursodiol for 6 months to reduce the risk of developing gallstones during the initial period of rapid weight loss). We also obtain a DEXA scan preoperatively and at 1 year postoperatively to follow bone mineral density before and after significant surgical weight loss.

The nutritional evaluation focuses on detailed weight and dietary histories, the identification of environmental cues that encourage or promote inappropriate eating behavior, screening for protein and vitamin deficiency, and education regarding the appropriate postoperative nutritional and exercise programs required for success. A nutritionist educates the patient and family extensively about necessary postoperative dietary changes and evaluates the patient's ability to cooperate with postoperative requirements. It is expected that such preoperative education will be done over 3–5 visits, but frequently requires several more.

A comprehensive psychological evaluation is crucial and is conducted by an expert in adolescent development. In order to be considered for surgery, the patient is required to demonstrate an acceptable level of emotional and cognitive development, reasonable expectations of the surgery, an understanding of risks and possible outcomes, and the motivation and ability to comply with postoperative follow-up and recommendations. Certain red flags are sought, such as active emotional, behavioral, or eating disorders and alcohol or drug use. Any substance abuse or psychiatric disorders must be adequately treated and stable before considering surgical intervention. Additional goals of the psychological evaluation session are to provide counseling and education regarding the lifestyle changes following bariatric surgery and to determine the existence of social and family supports which are essential for success. There is a particular focus on potential psychological stressors, both for the adolescent and his or her family, which would make compliance difficult. Family support and commitment are essential, and both the patient and family must agree to the necessary long-term lifestyle changes and follow-up. In addition, the adolescent must have no plans for pregnancy for 2 years after surgery, at which time weight loss will usually have stabilized.

Collaborative discussions involving all relevant specialists about each candidate are essential, with the goal of determining suitability for bariatric surgery and an individual plan for pre- and postoperative management. In the weeks before the operation, the patient has a final visit with the surgeon and nutritionist, as well as a final evaluation by an anesthesiologist. An extensive informed consent discussion is conducted with the adolescent and his or her family, and a final review of the perioperative regimens and instructions is completed.

Surgical Procedures

Bariatric procedures have historically been loosely divided into two main categories: purely restrictive and restrictive plus malabsorptive. Purely restrictive operations include (1) vertical banded gastroplasty (Fig. 55.1), (2) adjustable gastric band (Fig. 55.2), and (3) vertical sleeve gastrectomy (Fig. 55.3). Combination restrictive and malabsorptive procedures include (1) the Roux-en-Y gastric bypass (Fig. 55.4) and (2) the partial biliopancreatic bypass with duodenal switch, which is primarily malabsorptive (Fig. 55.5). Although these procedures have been given labels such as "restrictive" and "malabsorptive," it is becoming clear that the mechanism by which all of the bariatric procedures produce weight loss and improvement of obesity-related medical conditions is complex and likely involves various gut hormone signaling pathways.

The vertical banded gastroplasty has fallen out of favor in even the adult population due to a high rate of weight regain and reflux symptoms. Likewise, although the biliopancreatic bypass with duodenal switch results in excellent weight loss in super-morbidly obese adults, it has a higher rate of operative complications and severe postoperative nutritional deficiencies. For this reason, many surgeons feel that this is an inappropriate operation for adolescents.

The Roux-en-Y gastric bypass, which consists of a small gastric pouch (restrictive component) and a bypassed segment of stomach, duodenum, and proximal jejunum (malabsorptive component), is generally considered the gold standard bariatric

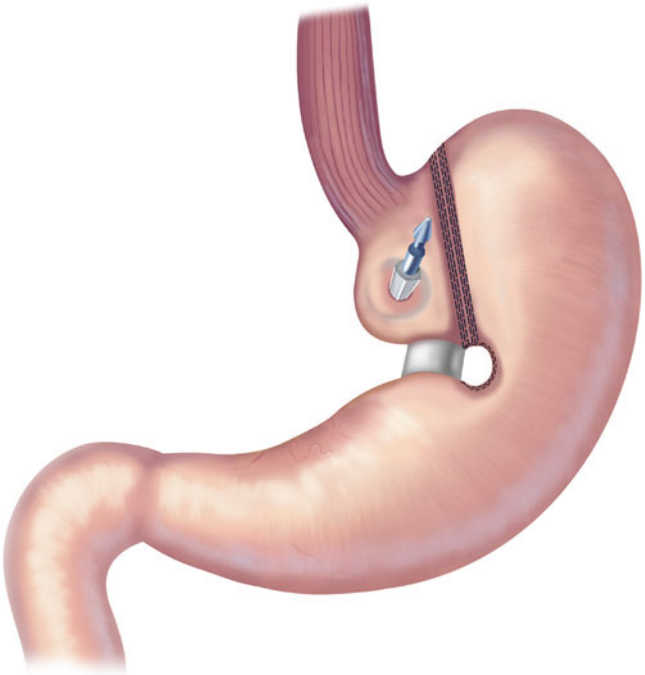

Fig. 55.1 Vertical banded gastroplasty. Adapted from Atlas of Metabolic and Weight Loss Surgery published by Cine-Med Publishing, Inc., 2010, www.cine-med.com

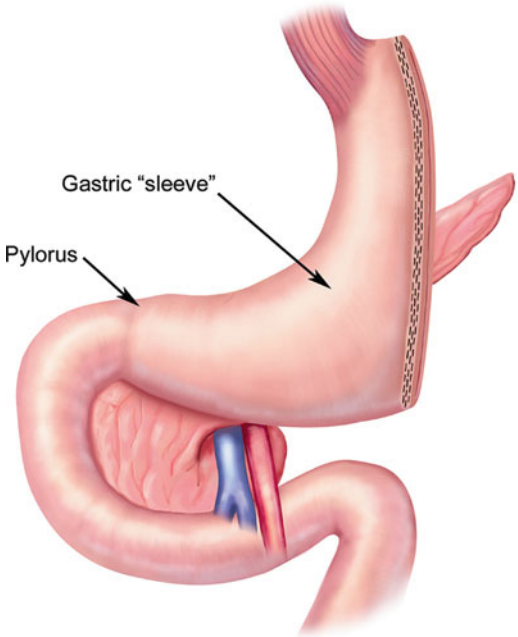

Fig. 55.3 Sleeve gastrectomy. Adapted from Atlas of Metabolic and Weight Loss Surgery published by Cine-Med Publishing, Inc., 2010, www.cine-med.com

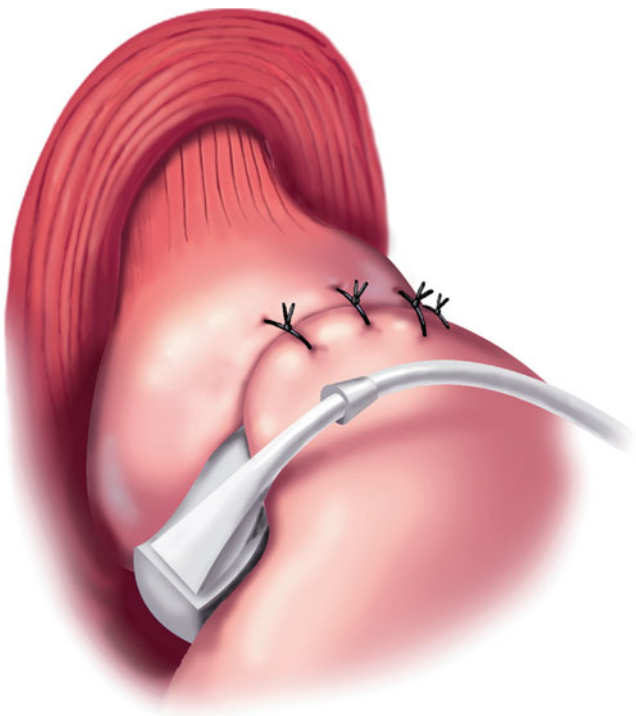

Fig. 55.2 Adjustable gastric band. Adapted from Atlas of Minimally Invasive Surgery published by Cine-Med Publishing, Inc., 2007, www.cine-med.com

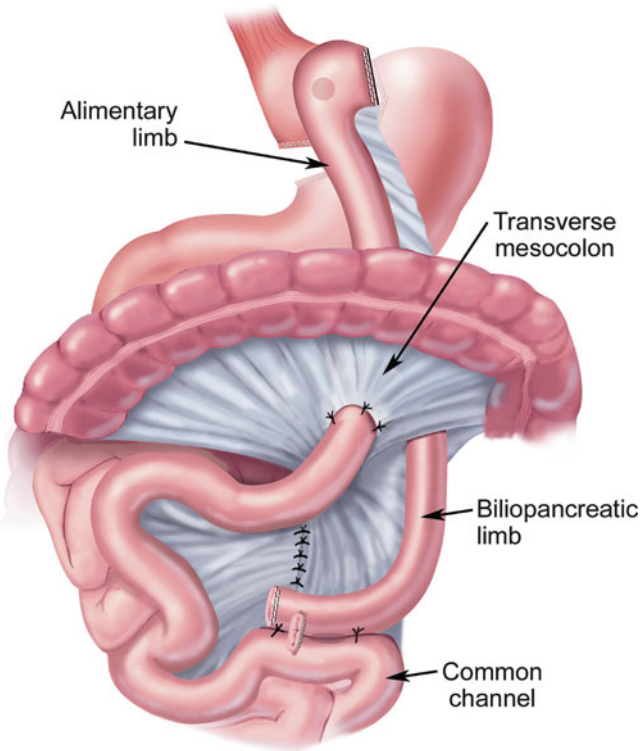

Fig. 55.4 Roux-en-Y gastric bypass. Adapted from Atlas of Minimally Invasive Surgery published by Cine-Med Publishing, Inc., 2007, www.cine-med.com

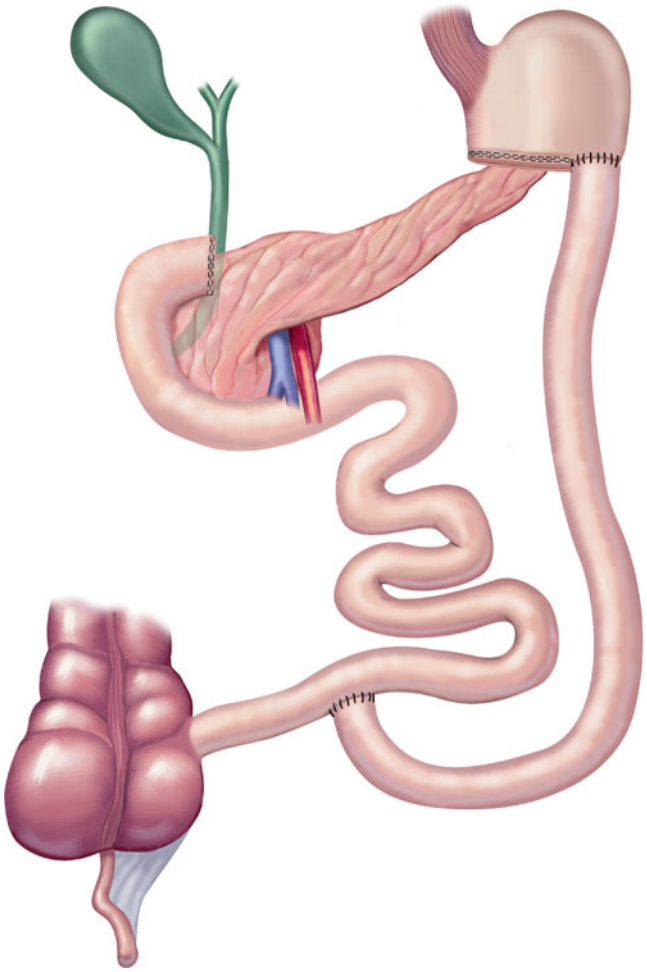

Fig. 55.5 Biliopancreatic diversion. Adapted from Atlas of Metabolic and Weight Loss Surgery published by Cine-Med Publishing, Inc., 2010, www.cine-med.com

procedure in adults. This has also been the most commonly performed procedure in adolescents, although the trend in both adult and adolescent patients over the past 3–5 years has shifted in favor of the vertical sleeve gastrectomy. Many studies with limited numbers of patients have supported its safety and efficacy in the adolescent population, with the primary concerns being sustainable efficacy and long-term safety. The 0.5–1 % mortality rate associated with the Roux-en-Y gastric bypass in adults is considered unacceptable by most who work with pediatric patients. For this reason, some clinicians feel that the adjustable gastric band and the sleeve gastrectomy are more appropriate procedures for this age group.

The adjustable gastric band was initially an attractive option because it is adjustable and theoretically "reversible," with the associated minimal disturbance of normal anatomy making nutritional deficiencies less likely (though these operations still significantly impair the intake of vitamins and nutrients). In addition, although the procedure has a unique set of complications, a number of which require reoperation, overall it is associated with less nutritional risk than the Roux-en-Y gastric bypass. However, the weight-loss profile has been less robust than for the Roux-en-Y gastric bypass and the sleeve gastrectomy. For this reason, in addition to the high incidence of multiple reoperations for technical issues, this leads to a significant loss of interest in this procedure for durable weight loss. To date, the adjustable gastric band is not FDA approved for patients under the age of 18 years and appears unlikely to gain approval in this age group for the foreseeable future.

In recent years, the vertical sleeve gastrectomy (also referred to commonly as the "sleeve gastrectomy") has become more widely utilized as a stand-alone procedure in both adult and adolescents, and this is the preferred procedure for the patients in our program. It is an especially attractive option for young patients because there is no implanted foreign body with associated maintenance and technical issues as with the adjustable gastric band and no gastrointestinal bypass. The sleeve gastrectomy involves a 75–80 % irreversible gastrectomy and has an efficacy profile similar to that of the Roux-en-Y gastric bypass. The sleeve gastrectomy also appears to have a more favorable safety profile, although there remains a risk of staple line leakage among other serious risks.

Perioperative Management

Patients are placed on a very low calorie diet for 2 weeks prior to the surgery date to decrease liver volume and mesenteric fat density, facilitating the technical aspects of the operation and reducing surgical risk. Patients arrive in hospital on the morning of their operation, and in the preoperative holding area, patients are given an injection of low-molecular-weight heparin (40 mg subcutaneously), which is continued twice daily after the operation. A dose of a second-generation cephalosporin is also administered preoperatively and continued for 24 h postoperatively. Sequential compression devices are placed preoperatively and are used for the duration of the surgical procedure and postoperative hospital stay.

Surgical Procedures

Vertical Sleeve Gastrectomy

Any of the current bariatric procedures can be completed either laparoscopically or through a standard laparotomy incision, and certain technical details may vary depending on an individual surgeon's training and preference. Initial access to the abdomen is gained through a carefully placed Veress needle, followed by insufflation to a pressure of 15 mmHg and placement of an initial 5- or 12-mm port. A total of five or six ports are typically placed, arranged in such a way to provide

access to the gastroesophageal junction and the entire greater curvature of the stomach. A liver retractor is placed to facilitate the visualization of the upper stomach and gastroesophageal junction.

Beginning approximately 5–6 cm distal to the pylorus, the gastrocolic ligament is entered and the vasculature along the greater curvature of the stomach is divided with a tissue-sealing device. The gastrosplenic and gastrocolic ligaments are divided up to the left crus, which is visualized. Posterior adhesions to the pancreas are lysed. A calibrating tube or bougie is passed trans-orally into the pylorus and placed against the lesser curvature. Bougie sizes ranging from 32 to 60 Fr have been described, and we typically use a 36-Fr bougie. Starting at a chosen distance from the pylorus, the endoscopic stapler is fired successively along the length of the intragastric bougie until the angle of His is reached. This results in a 75–80 % gastric resection with the remaining stomach forming a tubular or sleeve shape. The excised stomach can usually be easily removed through an enlarged 12-mm port site.

It is crucial to avoid stapling too close to the gastric incisura (which can create a kink or stenosis) or to the gastroesophageal junction (the most common site of a staple line leak). It is also imperative to choose staple loads that are of the correct size for the thickness of the tissue, as this reduces the risk of a postoperative leak. Some surgeons prefer to use staple line reinforcement products, which necessitate a larger staple size.

Once the staple line is created, the bougie is removed and the staple line is inspected. Any bleeding points are clipped or oversewn with absorbable suture. A nasogastric tube is carefully placed by the anesthesia staff under direct laparoscopic visualization. Air or dilute methylene blue is instilled to check for a staple line leak. A Jackson-Pratt or similar drain may be placed along the staple line and exteriorized through one of the laparoscopic port sites. We do not routinely leave a drain in place. If a drain is left in place, it is typically removed within the first few postoperative days.

Laparoscopic Roux-en-Y Gastric Bypass

Abdominal access can be similarly achieved with a Veress needle, followed by insufflation to a pressure of 15 mmHg and placement of a non-bladed 5-mm trocar. Two 12-mm trocars and three additional 5-mm trocars are placed. The left lobe of the liver is retracted with a flexible triangular or D-shaped retractor. The jejunum is divided 40 cm beyond the ligament of Treitz using a linear endoscopic gastrointestinal anastomosis stapling device, and one or two firings of the vascular-load stapler are used to divide the mesentery to provide length for creation of the gastrojejunal anastomosis. A Roux limb of either 75 cm (for patients with BMI <50) or 150 cm (for patients with BMI >50 or with diabetes mellitus) is created. The length of the Roux limb is measured visually and a stapled jejuno-jejunal anastomosis is created with the linear stapler after the two limbs of jejunum are transfixed to one another with stay sutures. The mesenteric defect is closed with a running suture.

The Roux limb can then be passed in a retrocolic or antecolic position. If passed through a retrocolic tunnel, closure of this mesenteric defect is crucial. We typically bring the limb up in an antecolic fashion after dividing the omentum, unless the Roux limb is of insufficient length to perform a tension-free gastrojejunal anastomosis. A small (10–15 mL) lesser curve gastric pouch is created with care to dissect the angle of His and exclude the gastric fundus entirely. A 35-mm endoscopic linear stapler is used to create the gastrojejunal anastomosis after a posterior layer of braided nylon suture is placed. The remaining enterotomy is then closed in two layers—an inner layer of absorbable suture and an outer layer of nonabsorbable suture. An endoscope is passed into the Roux limb from above and acts as a bougie to prevent inadvertent gastrojejunal stoma narrowing during the two-layer closure. The endoscope then allows for inspection of the completed anastomosis with intraluminal air insufflation under saline to ensure that the anastomosis is air-tight. The endoscope is then used to evacuate air from the pouch and Roux limb. A closed-suction drain is placed near the anastomosis and brought out through the right upper quadrant 5-mm port site. If an anastomotic leak is identified with air insufflation, the leak is repaired and reinforced with fibrin glue and a gastrostomy tube is placed in the bypassed gastric remnant.

There are certainly many different ways of performing these anastomoses, including entirely hand-sewn techniques or the use of an end-to-end anastomosis stapler to create the gastrojejunal anastomosis. Some surgeons prefer to use a bougie instead of an endoscope when creating this anastomosis. No controlled studies have been performed to demonstrate the superiority of any of these methods over the other, and it is reasonable for each surgeon to modify certain details based on training and experience.

Laparoscopic Adjustable Gastric Banding

Over time, the technique of adjustable gastric band placement has evolved into a method called the *pars flaccida technique*, which emphasizes minimal retroesophageal dissection and placement of the band out of the lesser sac. This has resulted in placement of the band higher on the stomach and lower rates of postoperative gastric herniation and band slippage. Patient positioning and port placement vary based on surgeon's preference, but trocar placement similar to that used to perform a laparoscopic Nissen fundoplication is recommended. Many surgeons use port placement similar to that of the laparoscopic Roux-en-Y gastric bypass. Once access is

gained and the abdomen insufflated, a liver retractor is placed through a 5-mm trocar in the right subxiphoid or upper quadrant region. Additional ports are placed, including a 12- or 15-mm port in the left paramedian region. The band is primed with saline and may be placed into the abdomen early in the procedure or after dissection is completed.

A grasper is used to retract the fat between the greater curvature and the spleen downward, placing the fundus of the stomach on stretch. A cautery device is used to carefully dissect the fat pad off of its location at the angle of His and incise the peritoneum lateral to the gastroesophageal angle. Gentle blunt dissection is used to free the fundus from its attachment to the diaphragm. The nearly transparent gastrohepatic ligament overlying the caudate lobe (pars flaccida) is then incised, with care taken to spare the hepatic branch of the vagus nerve and an accessory hepatic artery, if encountered. The right crus and vena cava should now be identified, as one can be mistaken for the other in morbidly obese patients. The peritoneum just medial to the right crus is incised just at the beginning of the lesser curve of the stomach, and the grasper is passed very gently through the scored peritoneum behind the stomach. No force should be used, and if all dissection has been correctly done, the tip of the grasper will emerge just to the left of the angle of His.

The saline-primed adjustable band is now passed through the incision of a 12- or 15-mm trocar site, if it has not already been placed within the abdomen. The end tag of the band is placed in the jaws of the retroesophageal grasper and is pulled through to encircle the stomach. The band is locked into place and should be loose enough to allow the placement of the tip of a 5-mm instrument between the band and the stomach. Gastric-to-gastric sutures of nonabsorbable material are then placed to approximate the stomach above and below the band without tension. Sutures are carried as far posterolateral as possible, but it is important not to suture the stomach over the buckle of the band, as this promotes erosion. These sutures, along with the minimal retroesophageal dissection, have been demonstrated to minimize slippage of the band.

The liver retractor is then removed and the abdomen desufflated, after the port tubing is pulled through the left abdominal 12- or 15-mm port site. This port site is extended laterally in each direction and dissection is carried down to expose the rectus sheath. The tubing is connected to the access port, and the access port is fixed in four places to the fascia using nonabsorbable suture. Once all sutures are placed, the access port is parachuted down to the fascia and the sutures tied. Any excess tubing is replaced into the abdomen, and the fascial opening is not approximated. All wounds are then closed. No fluid is placed in the balloon of the band at the time of initial placement; band adjustments ("fills") are commenced approximately 6 weeks after the operation.

Postoperative Care

Postoperatively, patients are placed in a monitored setting on a surgical ward. Maintenance intravenous fluids are administered and postoperative discomfort is managed with patient-controlled analgesia. Sequential compression devices are utilized, subcutaneous low-molecular-weight heparin is administered, incentive spirometry is emphasized, and ambulation is commenced on the evening of surgery. Early warning signs of a complication include tachycardia, tachypnea, fever, oliguria, worsening abdominal pain, or an increasing oxygen requirement.

On the first postoperative day, some surgeons obtain a water-soluble contrast upper-GI study to rule out anastomotic leak or obstruction. Patients with a normal study and who are clinically well are started on a clear liquid diet on the first postoperative day. Many patients are ready for discharge on the second postoperative day with a follow-up appointment in 1 week. If all is well at this first visit, the patient is advanced to a full liquid, high-protein, pureed diet. Advancement to a regular solid diet is achieved over the first few weeks to 1 month. Follow-up is frequent, and in our program, visits are scheduled monthly for the first 6 postoperative months, every 3 months for the next 18 months, and yearly thereafter. Laboratory evaluation is performed every 6 months and includes iron and vitamin levels.

At each follow-up visit, the diet history is reviewed with emphasis on protein, fluid, and vitamin compliance. Weight loss is assessed and laboratory results and changes in comorbid conditions reviewed. Dietary advancement after the first month is performed with the close supervision of our bariatric nutritionist and involves gradual introduction of solid food items. The goal is a well-balanced, high protein (0.5–1 g/kg of ideal body weight per day), small-portion diet. The consumption of a minimum of 64 oz of non-carbonated, noncaloric, non-caffeinated beverages is emphasized, as this prevents dehydration and facilitates weight loss. Nonsteroidal anti-inflammatory medications are avoided to reduce the risk of marginal ulcer formation. Ursodiol may be prescribed for 6 months in patients who had a normal right upper quadrant ultrasound preoperatively. The required postoperative vitamin and mineral supplementation includes (1) a multivitamin (one adult or two children's chewable tablets), (2) calcium 500 mg TID, (3) iron 150–325 mg daily, (4) vitamin B12 500 μg PO daily or 1000 μg IM monthly, and (5) vitamin C 500–1500 mg daily. Zinc 10–20 mg daily is optional and might prevent hair loss.

We also emphasize the importance of at least 30 min of exercise per day, which provides patients with a host of benefits in addition to maximizing weight loss. Any difficulties or non-compliant behaviors result in counseling by the surgeon and referral to the appropriate specialist, such as the nutritionist or exercise physiotherapist. Our office staff make

pre-visit phone calls to remind patients and their parents of the upcoming appointment and follow-up calls when patients miss their appointments.

Complications

Complications can occur during the operation or in the early or late postoperative periods. Some complications are unique to the type of procedure performed (Table 55.1). The most feared intraoperative complications during the performance of either operation include inadvertent perforation of the esophagus, stomach, or intestine, which may or may not be recognized at the time of surgery. Additional intraoperative complications include airway mishaps and anesthetic complications, as well as bleeding from the abdominal wall, spleen, mesentery, or staple line. It is important to inform patients that any of these complications could require conversion to laparotomy.

The most dreaded postoperative complication in patients who have undergone the vertical sleeve gastrectomy or the Roux-en-Y gastric bypass is a staple line leak, which can be life-threatening if not recognized and managed immediately. Mild tachycardia is sometimes the only sign of staple line or anastomotic leak, and the surgeon should have a very low threshold for returning a patient to the operating room to investigate this possibility. No study is 100 % sensitive for a leak in the early postoperative period and an extensive work-up will delay diagnosis and treatment. In the event that a leak is identified in the operating room, the area should be widely drained and a gastrostomy tube placed in the bypassed gastric remnant (in the case of a Roux-en-Y gastric bypass) to allow for enteral feeds until the leak is healed.

An intestinal obstruction can occur at any time and is usually due to an internal hernia, volvulus, or adhesions. Any patient with bilious emesis following a Roux-en-Y gastric bypass must be assumed to have an obstruction distal to the jejuno-jejunal anastomosis until proven otherwise, which requires exploration and must be dealt with expeditiously. Pulmonary embolus is a particularly devastating and life-threatening complication in this population, and prophylactic measures must be undertaken as described.

Table 55.1 Potential complications of the various bariatric procedures

Roux-en-Y gastric bypass	Vertical sleeve gastrectomy	Adjustable gastric band
Operative	Operative	Operative
Gastrointestinal perforation	Gastrointestinal perforation	Perforation of stomach or esophagus
Bleeding	Bleeding	Bleeding
Twist or kink in Roux limb	Twist or kink of gastric sleeve	Damage to band or tubing during placement
Devascularization of biliopancreatic or Roux limb	Staple line leak	
Anastomotic leak		
Early postoperative	Early postoperative	Early postoperative
Emesis/dehydration	Emesis/dehydration	Emesis/dehydration
Food impaction	Food impaction	Food impaction
Anastomotic leak	Staple line leak	Esophageal obstruction by band
Anastomotic bleed	Staple line bleeding	Trocar site/band port infection
Wound infection	Obstruction due to kink or twist of sleeve	Deep venous thrombosis
Deep venous thrombosis	Wound infection	Pulmonary embolus
Pulmonary embolus	Deep venous thrombosis	Other pulmonary complication
Other pulmonary complication	Pulmonary embolus	
Dumping syndrome	Other pulmonary complication	
Late postoperative	Late postoperative	Late postoperative
Emesis/dehydration	Emesis/dehydration	Emesis/dehydration
Food impaction	Food impaction	Food impaction
Anastomotic stricture	Gastroesophageal reflux	Gastric herniation (band “slippage”)
Marginal ulcer	Staple line leak	Gastroesophageal reflux
Bowel obstruction	Nutritional deficiency	Esophageal dilation
Internal hernia		Band erosion in to esophagus
Incisional hernia		Abdominal abscess
Gallstone formation		Port infection
Nutritional deficiency		Port displacement or malfunction
Dumping syndrome		Nutritional deficiency
Nephrolithiasis		

In individuals with clotting disorders or a prior history of pulmonary embolus, preoperative vena cava filter placement may be beneficial.

The development of de novo postoperative gastroesophageal reflux has been described following vertical sleeve gastrectomy, as has worsening of preoperative reflux symptoms. For this reason, preexisting reflux disease was initially felt to be a contraindication to sleeve gastrectomy; however emerging data is less clear and this issue has become more controversial. Many surgeons feel that patients with preoperative reflux disease are reasonable candidates for the vertical sleeve gastrectomy procedure, particularly since these symptoms can be adequately medically managed in most patients. Symptoms of reflux are not an absolute contraindication to the sleeve gastrectomy in our program, but warrant further preoperative investigation. We discuss this issue among the potential postoperative complications with our patients and families in our program.

In adults, bariatric surgery is associated with a mortality of approximately 0.5 %. Although the reported surgical mortality rate in adolescents is lower than in adults, the patient, his or her family, and all care providers must be aware of this risk and have a high suspicion for early studies or interventions when necessary.

Outcomes

Over the last decade, an increasing body of literature has emerged demonstrating the safety and efficacy of bariatric surgery in adolescents. Weight loss after gastric bypass has been similar to that seen in adults, with several series reporting durable excess weight loss of 60–80 %. If the appropriate dietary and exercise regimen is followed, this dramatic weight loss seems to occur with preservation of visceral protein and a low incidence of postoperative complications.

Similarly good outcomes have been described after vertical sleeve gastrectomy (50–70 % excess weight loss over 12–24 months) and more modest outcomes with adjustable gastric banding, although some reports describe up to 60 % excess weight loss at 2 years and excellent resolution of obesity-related comorbid conditions. The most common complications described in pediatric patients have been mild nutritional and vitamin deficiencies, which typically resolve with supplementation.

Although early data suggest that adolescents can achieve significant weight loss following bariatric procedures, it remains to be seen whether or not such weight loss and comorbidity resolution are sustainable over the adolescent's lifetime. It is also unclear what potential unforeseen negative consequences may arise. However, at this time when we are faced with an increasingly growing population of obese adolescents who are facing severe and life-threatening complications of their obesity, bariatric surgery may be the best solution that we have to offer at this time. Because of this, adolescent bariatric surgical programs are being developed to meet the needs of these patients. These programs should be comprised of a multidisciplinary team of highly trained individuals with the experience to assess and meet the unique needs of the morbidly obese adolescent. Until more long-term outcome data is available, surgical criteria should remain relatively conservative, the selection process rigorous, and centers should be committed to frequent, long-term patient follow-up and data collection for clinical research.

Editor's Comment

The application of bariatric surgical techniques in children remains somewhat controversial. This is due to the significant risks involved, the uncertain long-term effects, and the widespread misperception that obesity is largely behavioral or psychogenic in origin. Nevertheless, the risks are currently acceptable, especially when compared with the risks of morbid obesity, the long-term effects appear to be largely manageable, and it is increasingly clear that, rather than being simply a psychological or emotional disorder, morbid obesity is a genetically based metabolic disorder that happens to manifest itself in the form of a specific behavior (excessive oral intake of food). It seems reasonable, therefore, to offer these children some relief from their symptoms and the serious sequelae associated with morbid obesity. On the other hand, the operation is clearly not an immediate or permanent cure and it also does not address the underlying cause. Success depends on an extraordinary amount of work and commitment on the part of the patients and their families, friends, and healthcare workers.

The most effective operations also carry the highest risk and are therefore less commonly performed in children. The once popular and minimally invasive laparoscopic gastric banding operation has fallen into disfavor, mostly due to its poor intermediate- and long-term success rates. The laparoscopic gastric sleeve operation seems to have taken its place in most centers.

Bariatric operations differ from most other surgical procedures in that a surgeon cannot expect to see a patient in the office, make a decision regarding the indications and risk, and schedule the operation if the patient agrees to proceed. The key to the success of a bariatric program is the large number of clinicians that form part of the team including psychologists, nutritionists, gastroenterologists, endocrinologists, nurses, and surgeons. Protocols must be clearly designed and continually modified to achieve the best results with the least morbidity.

The operations are technically quite challenging, partly due to the body habitus of the patients. Special operating tables and instruments are needed to support the weight of the

patients and allow proper access to the abdominal cavity. Careful dissection and respect of natural tissue planes are difficult to achieve due to the anatomic distortion caused by excessive adipose tissue but are critical to the success of the operation. Staple lines must be secure, but visual confirmation is rarely sufficient. Intraoperative endoscopy and testing anastomoses for leaks with air insufflation are critical adjuncts that reduce the risk of dehiscence and death. Postoperative vigilance for even the slightest indication of a problem (unexplained tachycardia) and a low threshold for urgent reoperation are also vital to mitigating the effects of an anastomotic leak.

Children who undergo weight-loss surgery are patients for life, as the morbidity is significant, and in the absence of an ongoing program to monitor weight loss and overall health status, recurrence rates are very high. Eventual transfer to an adult program becomes necessary, making it important to develop good relationships between pediatric and adult programs.

Suggested Reading

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Chronic Abdominal Pain

56

Frazier W. Frantz

Historically, functional abdominal pain was utilized as a diagnosis of exclusion, invoked only after a battery of biochemical and radiographic testing and, in some cases, nontherapeutic surgical procedures had been exhausted. Thanks to the efforts of the American Academy of Pediatrics Subcommittee on Chronic Abdominal Pain, the Rome criteria have evolved as a classification system based on gastrointestinal symptomatology to allow categorization and standardization of treatment and to obviate the need for extensive diagnostic testing in children who meet inclusion criteria for one of the functional gastrointestinal disorders (Table 56.1). While the Rome criteria have not been universally adopted by pediatricians and pediatric gastroenterologists in clinical practice, they are helpful in providing understanding and reassurance to families that their child's symptoms correspond to a real, albeit nonorganic, diagnosis.

The exact etiology and pathogenesis of functional abdominal pain is not well understood, but it is believed to result from dysregulation of brain–gut communication. Specific aspects believed to contribute to this process include: (1) abnormal bowel reactivity to physiologic stimuli (meal, gut distension, hormonal changes); noxious stress stimuli (inflammatory processes) or psychological stressful stimuli (parental separation, anxiety); (2) visceral hyperalgesia, a decreased threshold for pain in response to changes in intraluminal pressure associated with infection, inflammation, intestinal trauma, or allergy; and (3) abnormal central processing of afferent signals at the level of the central nervous system.

The typical presentation of children with functional abdominal pain includes a history of recurrent, episodic abdominal pain, which is vaguely localized in the midline. The pain is characterized as aching or cramping and is usually non-radiating. It may be associated with nausea, vomiting, dizziness, or diaphoresis, but there is characteristically no temporal correlation of pain with activity, meals, or bowel habits. Interference with normal, daily activities, including school attendance, is common. In between episodes, the child feels well. On physical examination, there are usually no significant abnormal findings, specifically no localizing signs of abdominal tenderness. Laboratory studies, if obtained, are usually normal.

Treatment for patients diagnosed with functional abdominal pain is predominantly carried out by primary care providers, but, in difficult cases, may require the skills of a multidisciplinary team, including a gastroenterologist and a mental health professional. The primary goals of treatment are to reassure and educate the family, address psychological factors, and focus on the return to normal functioning rather than on complete disappearance of pain. An array of psychological treatments for pain management, including cognitive behavioral therapy, have been employed to address underlying psychosocial factors, which contribute to clinical symptoms. On an individualized basis and based upon the specific FGID, medications may be prescribed for symptom relief. Several medications with documented efficacy in appropriate situations include peppermint oil (IBS); H-2 blockers/proton pump inhibitors (dyspepsia); anticholinergics (dicyclomine [Bentyl] and hyoscyamine [Levsin] for antispasmodic properties); fiber therapy, laxatives, and stool softeners (IBS with constipation); and tricyclic antidepressants.

There are several caveats that should be appreciated by surgeons evaluating patients with presumed FGID. First, it is counterintuitive to the surgical thought process that a child with lifestyle-impairing chronic abdominal pain will not benefit from an extensive work-up and eventual therapeutic operation. The reality is that this classification system, the Rome criteria, has been evolving for nearly 10 years, and follow-up has revealed that, in children clinically diagnosed with functional abdominal pain, only 2 % have eventually been found to have an organic abnormality. Second, when evaluation of a child with chronic abdominal pain yields

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Table 56.1 Rome III child and adolescent diagnostic criteria for abdominal pain-related functional gastrointestinal disorders (FGIDs)

Functional dyspepsia
Must include all of the following, experienced at least once per week for at least 2 months:
1. Persistent or recurrent pain or discomfort centered in the upper abdomen (above the umbilicus)
2. Not relieved by defecation or associated with the onset of a change in stool frequency or stool form (i.e., not irritable bowel syndrome)
3. No evidence of an inflammatory, anatomic, metabolic, or neoplastic process that explains the subject's symptoms
Irritable bowel syndrome (IBS)
Must include all of the following, experienced at least once per week for at least 2 months:
1. Abdominal discomfort (an uncomfortable sensation not described as pain) or pain associated with two or more of the following at least 25 % of the time:
a. Improved with defecation
b. Onset associated with a change in frequency of stool
c. Onset associated with a change in form (appearance) of stool
2. No evidence of an inflammatory, anatomic, metabolic, or neoplastic process that explains the subject's symptoms
Abdominal migraine
Must include all of the following, experienced two or more times in the preceding 12 months:
1. Paroxysmal episodes of intense, acute periumbilical pain that lasts for 1 h or more
2. Intervening periods of usual health lasting weeks to months
3. The pain interferes with normal activities
4. The pain is associated with two or more of the following:
a. Anorexia
b. Nausea
c. Vomiting
d. Headache
e. Photophobia
f. Pallor
5. No evidence of an inflammatory, anatomic, metabolic, or neoplastic process that explains the subject's symptoms
Childhood functional abdominal pain
Must include all of the following, experienced at least once per week for at least 2 months:
1. Episodic or continuous abdominal pain
2. Insufficient criteria for other FGIDs
3. No evidence of an inflammatory, anatomic, metabolic, or neoplastic process that explains the subject's symptoms
Childhood functional abdominal pain syndrome
Must include childhood functional abdominal pain at least 25 % of the time and one or more of the following, experienced at least once per week for at least 2 months:
1. Some loss of daily functioning
2. Additional somatic symptoms such as headache, limb pain, or difficulty sleeping

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findings consistent with FGID, it is advisable to closely involve the child's primary care provider and necessary subspecialists as a multidisciplinary team, particularly if this diagnosis was not previously considered. One of the challenges encountered when the surgeon is the primary treating physician is that the patient and family expect that a surgical procedure will eventually lead to pain resolution. Third, it is not uncommon for patients diagnosed with FGID to present with acute abdominal pain. If nothing has changed in the history or examination, this may represent a flare of their functional abdominal pain, and reassurance is indicated. If, however, there is a change in the symptomatology or focal findings on examination, a work-up for potential underlying organic causes is warranted.

Abdominal Pain of Organic Etiology

Abdominal pain of organic etiology is characterized by an underlying inflammatory, anatomic, metabolic, or neoplastic process as the source of the pain. The differential diagnosis for causes of chronic abdominal pain of organic etiology is extensive and organized based upon the predominant organ system involved or the underlying pathophysiology (Table 56.2). It should be appreciated that many of the potential diagnoses are nonsurgical in nature and are curable with appropriate medical treatment. The challenge implicit in working through this differential when presented with a child with chronic abdominal pain is that there will be a great deal of overlap in the presentation of both surgical and nonsurgical causes.

Table 56.2 Differential diagnosis of organic causes of chronic abdominal pain

Gastrointestinal	Genitourinary
Acid peptic disease	Urinary tract infection (pyelonephritis, cystitis)[a]
Esophagitis[a]	Nephrolithiasis[a]
Gastritis (including *H. pylori*)[a]	Ureteropelvic junction obstruction/hydronephrosis[a]
Peptic ulcer disease[a]	Dysmenorrhea[a]
Gastroesophageal reflux[a]	Ovarian cyst[b]
	Pelvic inflammatory disease/tubo-ovarian abscess[c]
Infectious/inflammatory	Fitz-Hugh–Curtis syndrome (perihepatitis)[a]
Infectious colitis/gastroenteritis (parasitic, bacterial, viral)[a]	Pregnancy (intrauterine or ectopic)[c]
	Endometriosis[c]
Inflammatory bowel disease[c]	Genital tract obstruction[b]
Chronic appendicitis[b]	Sexual abuse[a]
	Mittelschmerz[a]
Anatomic/congenital	
Malrotation (Ladd's bands or intermittent volvulus)[b]	**Metabolic/genetic**
	Hypercalcemia[c]
Intestinal duplications[b]	Lead poisoning[a]
Meckel's diverticulum (obstruction, intussusception, diverticulitis)[b]	Acute intermittent porphyria[a]
	Familial Mediterranean fever[a]
Chronic/recurrent intussusception[b]	Hereditary angioedema[a]
Hernias (abdominal wall, diaphragm)[b]	
Lymphatic malformation (including mesenteric and omental cysts)[b]	**Hematologic/vasculitis**
	Sickle cell disease[a]
	Henoch–Schonlein purpura[a]
Mechanical/dysmotility	Systemic lupus erythematosus[a]
Constipation[a]	
Appendiceal colic[b]	**Neoplastic**
Bezoar or foreign body[c]	Lymphoma (obstruction, perforation)[c]
Intra-abdominal adhesions[b]	Solid tumors—neuroblastoma, kidney, ovary, liver, rhabdomyosarcoma, hepatoblastoma—compression, hemorrhage, rupture, torsion[b]
Intestinal pseudo-obstruction[a]	
Median arcuate ligament syndrome[b]	
Malabsorptive	**Musculoskeletal**
Lactose intolerance[a]	Trauma[c]
Celiac disease[a]	Rectus hematoma[c]
	Discitis[a]
Hepatobiliary/pancreatic	
Chronic hepatitis[a]	
Cholelithiasis/chronic cholecystitis[b]	
Biliary dyskinesia[c]	
Choledochal cyst[b]	
Chronic pancreatitis[a]	
Pancreatic pseudocyst[b]	

[a]*M* medical management
[b]*S* surgical management
[c]*C* combined medical and surgical management

Work-Up

The initial central focus in evaluating children with chronic abdominal pain is determining the etiology of their symptoms—functional or organic. This determination will direct the bulk of subsequent diagnostic and therapeutic considerations. Unfortunately, there are no clear-cut diagnostic markers to distinguish these. While children with chronic abdominal pain and their parents are more likely to be anxious or depressed compared to children without chronic abdominal pain, the presence of anxiety, depression, behavior problems, or recent nega-

tive life events does not appear to be useful in distinguishing between functional and organic abdominal pain. Likewise, while children with chronic abdominal pain are more likely than children without chronic abdominal pain to have headache, joint pain, nausea, vomiting, or altered bowel habits, these associated symptoms do not appear to be helpful either. What is helpful in making this distinction is the presence of alarm symptoms and signs (Table 56.3). When these are present, the likelihood of organic disease is higher, and more extensive diagnostic testing is indicated to identify a specific, underlying cause of the pain (inflammatory, anatomic, metabolic, or neoplastic).

A detailed history, including dietary, psychological, and social factors, and complete physical examination are the most important elements in the evaluation of children with chronic abdominal pain. The goals here are to investigate potential signs or symptoms that would suggest an organic cause for the pain and, if these are not present, to construct a patient profile for comparison with the defined FGID profiles. If the patient fits one of these profiles and does not demonstrate alarm symptoms or signs, extensive diagnostic testing is not necessary, and treatment for functional abdominal pain can be initiated. When possible, the history should be obtained directly from the patient. Pertinent aspects that characterize the pain, such as location, quality, timing, and frequency, as well as precipitating factors or events, should be elicited. Specific questioning should be directed to antecedent viral illness, as a considerable percentage of patients can develop IBS-type symptoms after viral gastroenteritis. Associated symptoms, such as nausea, vomiting, diaphoresis, dizziness, or pallor, should be noted. Patients presenting with an infectious picture associated with persistent diarrhea should be queried regarding recent international travel. In post-menarchal females, questioning regarding menstrual irregularity, pain associated with menstruation, or the presence of a vaginal discharge may expose underlying gynecologic pathology. Prescription and over-the-counter medications being taken by the child should be recorded. NSAIDs in particular can cause gastritis and mucosal ulcerations. It is also helpful to inquire about medications the child has taken to try to relieve the abdominal pain and how efficacious these were.

Table 56.3 Alarm symptoms and signs for organic causes of chronic abdominal pain

History
Age of onset before 5 years old
Involuntary weight loss
Deceleration of linear growth
Unexplained fever
Gastrointestinal blood loss
Protracted or bilious emesis
Chronic, severe diarrhea
Pain that awakens the child from sleep
Pain well localized away from the umbilicus (especially persistent right upper or right lower quadrant pain)
Referred pain to the back, shoulders, or extremities
Dysuria, hematuria, or flank pain
Family history of inflammatory bowel disease or peptic ulcer disease
Physical examination
Localized tenderness in the right upper or right lower quadrants
Localized fullness or mass effect
Hepatomegaly
Splenomegaly
Costovertebral angle tenderness
Tenderness over the spine
Perianal abnormalities—skin tags, fissures, fistulas, ulceration

The physical examination should be performed in a comfortable environment for the child with the parents present. All clothing should be removed, and the child placed in a patient gown. Physical findings of underlying organic diseases can be subtle and should be carefully sought out (Table 56.3). The child's growth parameters should be measured and plotted on standard charts to assess growth failure or weight loss. Potential clues on generalized examination include the presence of jaundice, rashes, clubbing, or joint tenderness and swelling. Aphthous ulcers and stomatitis suggest underlying inflammatory bowel disease. The presence of bruising or other injuries suggest the possibility of abuse or trauma. Pain that is exacerbated with movement, particularly if it is well localized and associated with superficial tenderness, suggests a musculoskeletal cause.

The abdominal examination should focus on the presence of a mass, localized tenderness, organomegaly, or hernia. The presence of localized tenderness in the right upper or lower quadrants, especially if this correlates with the site of persistent pain, has the highest correlation with underlying organic disease of surgical import. The costovertebral angles should be assessed for tenderness. The perianal area should be carefully inspected for evidence of skin tags, fissures, fistulas, ulcerations, or signs of sexual abuse. Digital rectal examination, performed in a gentle and reassuring manner, allows assessment of the volume and consistency of stool in the rectal vault and provides for sampling of stool for occult blood testing. Pelvic examination is particularly important in postpubertal females, especially those who are sexually active, to look for signs of infection or a pelvic mass. In prepubertal females, palpation for sacral or pelvic masses is probably best accomplished by a modified bimanual exam using concomitant digital rectal and abdominal wall palpation.

Rather than employing a shotgun approach to rule out all possible causes of a particular clinical presentation, the laboratory and radiographic diagnostic evaluation should be driven by an index of suspicion based on pertinent alarm symptoms and signs in the history and physical examination. There are no consensus recommendations regarding initial diagnostic testing for patients presenting with chronic

abdominal pain. A reasonable approach is to order a limited lab panel initially, consisting of a CBC, urinalysis, and stool occult blood test. Screening laboratory abnormalities that should raise suspicion for an underlying organic disease include the presence of anemia, leukocytosis, abnormal urinalysis, and occult blood in the stool.

Once the patient has reached the subspecialty level of consultation, especially if alarm symptoms and signs are present, a complete set of labs should be obtained to investigate several of the more common causes of chronic abdominal pain. This lab panel should include a CBC with differential, comprehensive metabolic panel (including liver chemistries), erythrocyte sedimentation rate, amylase, lipase, stool occult blood test, urinalysis, and urine culture. A pregnancy test should be obtained in adolescent girls. If diarrhea is present, stool samples should be analyzed for occult blood, leukocytes, ova, and parasites and sent for culture. A history of precedent antibiotic use would warrant analysis for *C. difficile* as well. Additional laboratory studies to investigate specific diagnoses should be based upon abnormalities in the history and physical findings.

Diagnostic imaging should certainly be considered when the pain is localized, when symptoms of GI obstruction are present (vomiting, constipation), or to confirm or characterize abnormalities discovered on physical examination. The decision as to which diagnostic studies to employ should be based on a risk–reward/yield assessment. In general, the least invasive studies should be used first. Abdominal or pelvic ultrasound is probably the most frequently utilized modality. US is particularly useful for imaging the hepatobiliary and genitourinary tracts and should uniformly be used when positive historical (persistent, focal pain) or focal examination findings suggest underlying disease of gallbladder, renal, or ovarian origin. It is effective for retroperitoneal tumor screening and is also sensitive, albeit somewhat operator dependent, for detecting intussusception or cystic anomalies, such as intestinal duplications. Plain films of the abdomen are appropriate for patients presenting with symptoms of GI tract obstruction. These may identify abnormalities in the bowel gas pattern, a radiopaque stone in the urinary tract or gallbladder, an appendicolith, and a potential GI foreign body or fecal retention.

Barium contrast upper GI series with small bowel follow-through is indicated for patients who present with symptoms of GI tract obstruction to rule out malrotation or other causes of mechanical obstruction. It is also useful for evaluating the ileum in patients suspected of having Crohn's disease. In children it is not helpful in identifying peptic ulcer disease. CT provides the most information regarding the intra-abdominal organs but exposes the child to ionizing radiation. Unless the study is being done specifically to detect a stone in the urinary tract, intravenous and enteral contrast should be used to optimize the diagnostic yield. Measures that minimize radiation exposure, including weight-based dose adjustment and lead shielding, should be routinely employed. For specific indications, such as MRCP to assess pancreatic ductal anatomy or MR enterography to assess potential IBD, the utilization of MRI for evaluation of suspected intra-abdominal pathology is very useful.

For patients who present with chronic abdominal pain associated with alarm symptoms and suspected organic disease of gastrointestinal origin, early gastroenterology consultation is recommended. This applies to patients with symptoms of either acid peptic disease or altered bowel patterns (possible colitis or IBD). Esophagogastroduodenoscopy is the standard for diagnosing inflammatory and infectious disorders of the upper GI tract and should be considered in untreated patients with alarm symptoms, patients who fail to respond to gastric acid reduction therapy for functional dyspepsia, and patients whose symptoms recur after attempting discontinuation of seemingly effective therapy. It allows diagnosis of *H. pylori* gastritis by confirming the presence of both *H. pylori* and mucosal injury. In patients with suspected celiac disease, EGD allows sampling of small intestinal tissue to look for evidence of villous flattening with lymphocytic infiltration to confirm the diagnosis. In addition to the high diagnostic yield of EGD, the disorders identified typically have a high response rate to appropriate medical therapy. Colonoscopy should be considered for patients with chronic abdominal pain and altered bowel patterns who manifest an alarm symptom, any extraintestinal manifestations of potential IBD, or an elevated ESR.

It certainly is not mandatory for all pediatric patients with chronic abdominal pain to undergo extensive diagnostic imaging, especially for those in whom surgical intervention is planned. Some surgeons would argue that these studies have a low diagnostic yield, lead to patient and family anxiety, and might detect abnormalities that are not causally related to the abdominal pain.

The diagnostic accuracy and effectiveness of proceeding directly to diagnostic laparoscopy without imaging, especially for patients with focal RLQ pain or tenderness, is well documented. While this is appropriate for RLQ symptomatology, some consideration should be given to using diagnostic imaging preoperatively to narrow the differential diagnosis for other clinical presentations, such as those with non-localizing pain. Our own preference in these circumstances is to obtain some study, US or CT, to exclude tumors or other pathology of the retroperitoneum prior to diagnostic laparoscopy because the retroperitoneal area is not well visualized laparoscopically. Additionally, in patients who have warning symptoms or signs of apparent GI origin, it is probably better to employ endoscopic evaluation prior to laparoscopy to exclude GI mucosal disease as the source of pain.

Surgical Approach

A thorough work-up will typically yield one of three groups of patients with chronic abdominal pain of organic etiology for treatment: (1) those with an identified, nonsurgical, organic cause; (2) those with focal abdominal pain or an identified organic cause requiring surgical intervention; and (3) those with non-localizing abdominal pain and a presumed, organic cause which remains unidentified despite diagnostic testing (with or without endoscopy). Treatment for the first group is straightforward and requires subspecialty referral if this was not obtained earlier in the work-up. It is still possible that these patients will require surgical intervention if their medical treatment fails or their disease progresses. However, the initial focus of treatment for these patients will be medical.

Surgical treatment for patients with focal pain or an identifiable organic cause can be carried out using laparoscopy in most circumstances, including surgical diseases of the gallbladder (symptomatic cholelithiasis), appendix (chronic appendicitis), or ovary (ovarian cyst). An open or laparoscopic-assisted surgical procedure will be more effective or appropriate for some diseases in this category including tumor resection, treatment for malrotation with intermittent volvulus or bowel resection.

A significant subset of this group of patients is represented by children who present with recurrent RLQ pain of unknown origin. Diagnostic laparoscopy with planned elective appendectomy has proven to be an effective intervention in this patient population. Besides gross findings of chronic appendicitis, laparoscopy has allowed detection of other significant intra-abdominal findings, such as Meckel's diverticulum, adhesions, hernias, and ovarian cysts. Histologic examination of the resected appendices has revealed abnormalities in up to 80 % of cases. Most importantly, the majority of patients treated in this fashion, including those in whom no pathologic abnormality was detected, experienced considerable short- and long-term reduction in their abdominal pain.

The third group, those with non-localizing abdominal pain, is the most challenging because the expectation is that a considerable number of these patients will have no obvious pathology and thus derive little benefit from the procedure. Performing a safe operation with minimal morbidity is of paramount importance. Reasonable expectations should be communicated to the patient and family prior to operation. These are patients who should also have preoperative imaging of the retroperitoneum (US or CT) and endoscopy based upon the presence of GI warning symptoms or signs. This clinical setting is well suited for diagnostic laparoscopy and essentially entails careful and systematic examination of the abdominal wall and all contents of the intra-abdominal cavity. Initial attention should be paid to areas of more frequent pathology, such as the RLQ and pelvis. The distal ileum should be examined carefully to detect signs of ileitis or Meckel's diverticulum. In girls, the pelvic organs should be carefully inspected. Intraperitoneal fluid, if present, should be sampled and sent for analysis and culture. Visualized pathology should be recorded and addressed. Once the diagnostic portion of the procedure is completed, empiric removal of the appendix should be undertaken. Attention should be paid to generous injection of local anesthetic for regional (transversus abdominis plane (TAP)) and local blocks because the last thing that a patient with chronic abdominal pain wants to do is wake up in pain.

Specific Disorders

In general, the medical and surgical treatment of specific organic causes of chronic abdominal pain will be very similar to the treatment exercised for these entities in the acute setting.

Anatomic/Congenital GI Disorders

Intestinal malrotation is more difficult to diagnose in older children because they do not usually present with the picture of duodenal obstruction with bilious emesis typical of infants. These patients present with chronic abdominal pain that is usually postprandial, is transient and diffuse, and may or may not be associated with emesis. Alternatively, the pain might be associated with diarrhea or evidence of malabsorption associated with mesenteric lymphatic stasis from chronic or intermittent volvulus. A high index of suspicion needs to be maintained to ensure that this diagnosis is not missed because of the risk of midgut volvulus. While screening abdominal US sometimes suggests malrotation based upon SMA/SMV vessel inversion (SMA normally to the left of the SMV), the diagnostic study of choice is contrast upper GI with small bowel follow-through. Alternatively, a CT scan with enteral contrast demonstrating all of the proximal small intestine on the right side would confirm the diagnosis. Treatment entails a Ladd's procedure with appendectomy. While more recent literature suggests that older patients who are asymptomatic and found to have incidental malrotation are candidates for observation, patients with chronic abdominal pain and malrotation require surgical intervention.

Intestinal duplications are cystic or tubular structures that are intimately attached to some segment of the alimentary tract and share a common muscular wall and vascular supply with it. The most common site of involvement is the ileum. A considerable number of these may be lined with ectopic mucosa, usually gastric or pancreatic, especially if they involve the small intestine. Presenting symptoms and signs include abdominal pain, gastrointestinal hemorrhage, and

obstruction due to mass effect or intussusception. The diagnosis is established by US or CT. Surgical treatment involves complete surgical excision, sometimes requiring resection of normal intestine with the attached duplication due to potential interruption of mesenteric blood supply. For duplications that cannot be safely resected due to the risk of injury to adjacent structures or because a long segment of intestine would have to be sacrificed (for tubular duplications), treatment options include stripping the mucosa of the cyst and leaving the seromuscular layer intact or, for colonic duplications (which do not usually contain ectopic mucosa), opening the common wall between the cyst and native intestine for internal drainage.

In the chronic setting, patients with Meckel's diverticulum present with obstruction, intussusception, or diverticulitis. While radiographic evidence of these processes is sometimes present preoperatively, it is often not possible to confirm Meckel's diverticulum as the actual pathology until operation. This entity should always be considered in patients who present with chronic RLQ pain. Treatment entails resection of the diverticulum and may require segmental enterectomy with anastomosis to avoid luminal narrowing after diverticulectomy alone.

Older children with chronic intussusception will present with colicky abdominal pain and usually have symptoms of intermittent obstruction. Unlike infants who present with idiopathic intussusception, a large percentage of these patients will have a lead point (Meckel's diverticulum, tumor, intestinal polyp, duplication cyst, among others) that will require surgical intervention. The diagnosis will usually be made on CT or contrast studies obtained to rule out obstruction, but US is also a reasonable screening study. The limitation of barium enema is that it only allows investigation of the large intestine, and many of these patients may have isolated small bowel involvement. Treatment should include reduction of the intussusception and resection of the lead point. If a polyp is discovered as the lead point, consideration should be given to screening the entire colon to exclude additional lesions. On occasion, the site of a chronic, non-obstructing intussusception will be found to have "healed" as a circumferential, fibrotic ring. Because of the subsequent risk of stricture formation at this site, consideration should be given to segmental resection or stricturoplasty.

Intra-abdominal lymphatic malformations can develop in the mesentery of the intestine, omentum, or retroperitoneum. They are congenital and progressively enlarge in size due to underlying lymphatic obstruction. Presenting symptomatology depends on location and size. Generally, those originating in the omentum or retroperitoneum present with vague abdominal pain and abdominal distension once they are large enough to compress surrounding structures. Those in the mesentery present more acutely with signs of obstruction or abdominal pain due to compression, torsion, or infection. The diagnosis is made using US or CT. Treatment consists of complete surgical resection. Those located in the mesentery are often multiloculated and wrapped around the intestine, which makes segmental intestinal resection necessary. Those originating in the retroperitoneum have the highest risk of recurrence.

Median arcuate ligament syndrome (MALS) is a vascular compression syndrome characterized by symptoms of postprandial epigastric abdominal pain, nausea, occasional diarrhea, and weight loss. Female predominance has been observed. Regarded as an unusual cause of abdominal pain, the true incidence of MALS is unclear because the symptom complex overlaps with chronic functional abdominal pain. The etiology is controversial but is generally attributed to compression on the celiac trunk by the diaphragmatic crura, leading to decreased blood flow and subsequent postprandial abdominal pain. Neurogenic compression of the celiac nerve plexus has also been postulated. Screening consists of duplex US, and the diagnosis can be confirmed with CT or MR angiography. Treatment with laparoscopic release of the median arcuate ligament, including surgical neurolysis, has resulted in significant improvement in celiac artery blood flow, symptom relief, and overall quality of life.

Inflammatory Bowel Disease

Chronic abdominal pain is common in children with IBD. For patients with Crohn's disease, classic presentation symptoms include abdominal pain, anorexia, weight loss, growth failure, and diarrhea. In some instances, symptoms are nonspecific, and this disease will have to be sorted out from all of the other causes of RLQ pain. Patients with ulcerative colitis demonstrate hematochezia, diarrhea, tenesmus, and abdominal cramping.

Laboratory findings suggestive of IBD include anemia, elevated ESR, thrombocytosis, hypoalbuminemia, and heme-positive stool. Since the pathophysiology and treatment of these diseases is very different, it is important to differentiate Crohn's disease from UC. One of the most distinguishing clues on physical exam is the presence of perianal disease, which affects 30–50 % of children with Crohn's disease. The ultimate distinction is going to depend on histologic findings from tissue obtained via endoscopy, radiographic findings of small intestinal disease (Crohn's), and pertinent serum markers for these diseases. Anti-*Saccharomyces cerevisiae* antibodies (ASCA) and perinuclear antineutrophil cytoplasmic autoantibodies (pANCA) have been found to be strongly associated with Crohn's disease and UC, respectively.

In the chronic setting, the treatment for these illnesses is predominantly medical. The most common indications for surgical intervention involve patients with Crohn's disease who have a fixed stricture or chronic abdominal pain due to localized disease that is unresponsive to medical therapy.

Strictureplasty or segmental resection (typically ileocecectomy) with primary anastomosis is appropriate for these patients. Less common indications involve treatment of complications of Crohn's disease: symptomatic fistula or bowel obstruction that fails to respond to medical therapy, abscess formation that fails antibiotic therapy and percutaneous drainage, and persistent perianal disease (abscess, fistula).

Gallbladder Disease

Biliary tract disease of surgical import in children as a source of chronic abdominal pain includes gallstone disease and biliary dyskinesia. The symptoms and signs of gallstones are similar to those in adults, and patients achieve uniformly good results with laparoscopic cholecystectomy. Many have evidence of chronic cholecystitis on histologic examination.

The diagnostic triad for patients with biliary dyskinesia includes postprandial pain, nausea, and gallbladder ejection fraction <35 % on a CCK–HIDA scan. Multiple studies have documented that 75–80 % of patients treated with laparoscopic cholecystectomy achieve good short- and long-term pain relief. However, relief after surgery does not correlate with preoperative ejection fraction values, and this same response rate has been observed in patients who did not undergo surgery, some of whom are treated simply with a bland diet. Some surgeons will now attempt a 4–6-week course of a bland diet and repeat the CCK–HIDA prior to proceeding with cholecystectomy. Others have tightened the threshold for abnormal gallbladder ejection fraction to 10 %. Prior to removing the gallbladder for biliary dyskinesia, investigations (EGD, liver chemistries, amylase, lipase) to ensure the absence of alternative pathology should be undertaken.

Pancreatic Disease

Chronic abdominal pain of pancreatic origin is uncommon in children and occurs due to chronic pancreatitis and pancreatic pseudocysts. Chronic pancreatitis is most commonly familial, in contrast to acute pancreatitis, which is more commonly attributable to trauma, gallstones, viral infections, or drugs. It is a progressive and irreversible disease that leads to both exocrine and endocrine insufficiency and produces severe, chronic pain. The disease can be broadly classified as obstructive (due to a focal, fibrotic narrowing or stenosis from previous acute pancreatitis) or calcifying (due to stone formation with "chain of lakes" strictures).

While treatment is predominantly medical with enzyme replacement therapy and analgesics, surgical intervention should be considered when these fail to relieve pain. Central to operative planning is delineation of pancreatic duct anatomy by ERCP or MRCP. Based upon this anatomy, appropriate intervention with ductal drainage (endoscopic or surgical) or pancreatic resection can be planned. Two of the most commonly utilized procedures include longitudinal pancreaticojejunostomy (modified Puestow procedure) and local resection of the pancreatic head combined with longitudinal pancreaticojejunostomy (Frey procedure). These are effective in relieving pain and reducing narcotic dependence and may also have a beneficial role in slowing progressive pancreatic insufficiency.

Most pancreatic pseudocysts in children result from trauma. Other etiologies include familial pancreatitis and the typical causative factors for acute pancreatitis in childhood. When these persist, a spectrum of symptoms and potential complications occur, including persistent abdominal pain, nausea, vomiting, and infection or rupture of the pseudocyst. The treatment options include operative and expectant management. Due to the rarity of this disease in children, there are no clear-cut treatment guidelines, and care is based on extrapolation of adult guidelines. Based on analysis of children with persistent pseudocysts, it appears that those pseudocysts arising from nontraumatic etiologies are more likely to require and benefit from surgical interventions, while pseudocysts due to trauma are more likely to resolve with expectant/conservative management. For pseudocysts associated with familial pancreatitis, surgical intervention must not only focus on drainage of the pseudocyst but also on treating underlying pancreatic ductal abnormalities.

Bezoar and Foreign Body

Bezoars may be palpated as abdominal masses in children who present with chronic abdominal pain but are usually detected in the stomach on EGD or contrast studies obtained because of the presence of obstructive symptoms. Trichobezoars, composed of hair, are the most common and typically require surgical removal by laparotomy with gastrotomy or enterotomy. If they are small, endoscopic fragmentation and removal is sometimes possible. When removing these from one segment of the proximal GI tract, it is important to exclude additional distal bezoars. Phytobezoars, composed of vegetable matter, can usually be managed with chemical dissolution and endoscopic fragmentation.

Among the risks of foreign body ingestion are intestinal obstruction and perforation. Radiopaque foreign bodies are easy to identify on plain films, but those that are radiolucent might not be appreciated until operation is performed for complications. The perforations caused by foreign bodies can occur slowly over time and result in at least partial containment and more subtle clinical signs. A high index of suspicion and thorough investigation of the entire GI tract are

often necessary to successfully identify these at the time of operation.

Intra-abdominal Adhesions

Although patients might complain of recurrent pain after abdominal surgery and, in the absence of other identified pathology, the discomfort is sometimes attributed to "adhesions," it is unclear whether adhesions can actually cause abdominal pain. More importantly, it is difficult to advise surgical intervention or adhesiolysis for pain control alone, especially considering the potential morbidity and the fact that adhesions will reform after each operative intervention. For children who present with these complaints, reassurance that the discomfort should abate as the adhesions soften over the course of 6 months or so after surgery may be helpful. Consideration for adhesiolysis is warranted in patients who complain of chronic pain associated with nausea or vomiting and evidence of at least partial or segmental intestinal obstruction on imaging.

Tumors

Intra-abdominal tumors are usually detected as asymptomatic abdominal masses or after investigation prompted by systemic signs or symptoms reveals their presence. However, when these tumors achieve a certain size, they can produce abdominal pain. For lymphoma, these symptoms are usually those of intestinal obstruction. The potential for perforation due to tumor infiltration into the bowel wall or as a result of chemotherapy is also present. Symptoms caused by the pediatric solid tumors, neuroblastoma, kidney, ovary, liver, rhabdomyosarcoma, and hepatoblastoma are usually due to compression on adjacent structures, hemorrhage into the lesion, or rupture. Ovarian tumors also carry the risk of torsion.

If not previously appreciated, physical examination after symptoms manifest will usually reveal a mass. Diagnosis should be confirmed with US, CT, or MRI. Once a tumor is detected, attention should be focused on resuscitation and then a staging work-up in accordance with standardized protocols.

Ureteropelvic Junction Obstruction

Unlike infants with UPJ obstruction who present with an abdominal mass or urinary tract infection, the majority of older children present with chronic abdominal pain that is indistinguishable from other causes. This can lead to a delay in diagnosis and jeopardize the chances of salvaging renal tissue and function. Clues include pain that is referred to the groin or flank, the presence of an abdominal mass on either side of the midline and hematuria. Unfortunately, the absence of these findings does not exclude UPJ obstruction. A high index of suspicion and liberal use of US to look for hydronephrosis are necessary to establish a timely diagnosis.

Ovarian Cysts

Girls with symptoms caused by ovarian cysts usually present with pelvic pain due to capsular stretch of the enlarging lesion or peritoneal irritation by fluid or blood within the pelvis resulting from cyst rupture. Pelvic US will confirm the diagnosis and can sometimes exclude ovarian torsion as the source of pain. Most are functional ovarian cysts of either follicular corpus luteum (hemorrhagic) or theca lutein origin.

These cysts are typically observed for spontaneous resolution, which occurs within 4–8 weeks. Indications for surgical intervention include associated significant pain, cyst size greater than 6 cm in diameter, persistence beyond 8 weeks, cyst enlargement during observation, and evidence of ovarian torsion. Cystectomy with ovarian tissue preservation is the preferred operative strategy and can usually be performed laparoscopically. Residual fluid or blood in the pelvis should be aspirated. Laparotomy should be considered for cysts larger than 8–10 cm in diameter and when malignancy is a concern based on US findings to facilitate intact removal and staging as indicated.

Pelvic Inflammatory Disease

PID is a sexually transmitted infection of the female pelvic organs caused by ascending polymicrobial infection with microorganisms from the vagina and cervix to the upper genital tract, most commonly involving *Neisseria gonorrhoeae* and *Chlamydia trachomatis*. In the chronic setting, this represents a diagnosis that has been missed due to mild symptomatology or a recurrence due to continued sexual activity or treatment noncompliance.

Affected patients present with a wide variety of nonspecific complaints, including most commonly lower abdominal pain that is bilateral and exacerbated with movement. Purulent vaginal discharge, urethritis, vaginitis, and fever may be seen. The presence of RUQ pain in this setting, referred to as Fitz-Hugh–Curtis syndrome, is due to perihepatitis from transperitoneal or vascular dissemination and signifies a considerable pathogenic inoculation. Physical findings supporting the diagnosis include cervical or vaginal mucopurulent discharge, cervical motion tenderness, adnexal tenderness, and fever. Laboratory evaluation should include a pregnancy test, CBC, ESR, an HIV

screening test, and endocervical cultures. Pelvic US is useful to confirm the diagnosis and can detect a tubo-ovarian abscess.

Empiric treatment with broad-spectrum antibiotics should be started. Patients with mild to moderate PID can receive outpatient therapy with a single dose of an intramuscular third-generation cephalosporin plus oral doxycycline (and possibly metronidazole for anaerobe coverage) for 14 days and close follow-up. Inpatient therapy is recommended for those who have severe PID, a tubo-ovarian abscess, high fevers, nausea, or vomiting and those who have failed outpatient therapy. Recommended parenteral regimens include a second-generation cephalosporin with oral or intravenous doxycycline or clindamycin combined with gentamicin. When a TOA is present, clindamycin and metronidazole are added for improved anaerobic coverage.

Surgical intervention should be considered if the TOA fails to resolve on follow-up imaging, if the clinical picture fails to improve after 48–72 h of intravenous antibiotics, or if there is a high suspicion of an alternate diagnosis. This is typically accomplished with laparoscopy and entails confirmation of diagnosis with incision and drainage of the TOA or salpingo-oophorectomy. Alternative treatment of the TOA could involve ultrasound or CT-guided drainage.

Endometriosis

Endometriosis is defined as the presence of functioning endometrial tissue (glands and stroma) outside of the uterine cavity. These ectopic implants are believed to result from retrograde menstruation and can be found throughout the pelvis and on the ovaries, parietal peritoneum, broad and uterosacral ligaments, and cul-de-sac. They can invade the serosa of the intestinal wall and have been reported at distant sites as well. In children, adolescents are affected and present with dysmenorrhea and severe perimenstrual lower abdominal and pelvic pain. Those with genital tract obstruction from imperforate hymen or vaginal septum may have a higher incidence and severity of disease.

Physical findings that support the diagnosis include retroversion of the uterus with tenderness and decreased mobility, nodularity or tenderness along the uterosacral ligaments, the presence of adnexal masses suggestive of endometriomas, and induration or nodularity of the rectovaginal septum. There are no specific laboratory tests or imaging studies to confirm the diagnosis. Pelvic ultrasound may demonstrate findings of an ovarian endometrioma or alternative pathology.

Definitive diagnosis requires laparoscopy or laparotomy with tissue biopsy and pathologic confirmation of suspected lesions. The classic description is of a dark-pigmented lesion attributed to hemosiderin deposition. Medical management with NSAIDs is the first-line therapy for mild disease, followed by oral contraceptive agents. If these are ineffective at relieving pain, laparoscopy should be undertaken to confirm the diagnosis and potentially to excise or ablate any visible lesions and adhesions. In general, surgical intervention is probably undertaken earlier in adolescents in hopes of preserving fertility. Once the diagnosis is confirmed, treatment with gonadotropin-releasing hormone analogs (Lupron) can be utilized but should be reserved for patients who have completed pubertal maturation (16 years of age) because of bone mineral density loss associated with this drug.

Sickle Cell Disease

Abdominal pain and ileus are common during acute crises in children with SCD. Surgeons are frequently called upon for the challenging task of ensuring that these symptoms are not due to a surgical cause. The absence of bone or pleuritic pain may be a clue to an underlying primary intra-abdominal source, but there are usually few other differentiating factors. Physical findings may be equivocal as well. Because of the potential morbidity associated with missing an intra-abdominal surgical source, imaging in these children should be used liberally, consisting primarily of abdominal CT to evaluate the multitude of potential causes. After initial consultation, close follow-up is necessary as symptoms associated with a sickle cell crisis usually resolve within 4 days. Persistence beyond this time should raise suspicion for another cause.

Rare Causes of Chronic Abdominal Pain

There are a number of unusual etiologies that must be considered in appropriate clinical circumstances. Most are medical conditions, but surgeons should appreciate the types and breadth of these diagnoses.

Hypercalcemia

Children with hypercalcemia can present with chronic abdominal pain as part of a symptom complex including nausea, constipation, polydipsia, polyuria, fatigue, lethargy, weakness, and cognitive difficulties. There may be a history of nephrolithiasis. Potential underlying causes include primary hyperparathyroidism (HPT), vitamin D intoxication, milk/alkali syndrome, familial hypocalciuric hypercalcemia, William's syndrome, prolonged immobilization, thyrotoxicosis, and malignancy (much rarer compared to adults).

Once the level of hypercalcemia is determined, attention should be focused on rehydration and medical treatment to correct calcium levels. A work-up to determine the underlying

cause, including measurement of intact parathyroid hormone to rule out primary HPT, should be undertaken. If primary HPT is present, consideration should be given to investigating for other findings of the multiple endocrine neoplasia (MEN) syndromes 1 (parathyroid hyperplasia, pancreatic islet cell tumors, pituitary adenoma) or 2A (parathyroid hyperplasia, pheochromocytoma, medullary thyroid cancer).

Lead Poisoning

Lead poisoning results from chronic exposure, most commonly from lead-based paint ingestion by those living in old homes in urban areas. The diagnosis should be considered in patients who present with abdominal complaints and a history of environmental exposure. Symptoms at presentation might include severe, colicky abdominal pain, anorexia, constipation, stocking-glove paresthesias, hyperactivity, or seizures. Physical examination may reveal oral ulcerations, a gingival lead line, and peripheral neuropathy. Lab analysis often demonstrates microcytic anemia with basophilic stippling of red blood cells. Bone films may exhibit lead lines of the distal femur, tibia, and fibula. The diagnosis is confirmed with findings of elevated serum lead levels (recent exposure) or elevated 72-h urine lead levels after calcium disodium edetate administration. Treatment involves oral or parenteral chelating agents.

Acute Intermittent Porphyria

The hepatic porphyries are a group of inherited metabolic disorders caused by specific enzyme deficiencies in the heme biosynthetic pathway with subsequent accumulation of excess metabolic precursors in the tissues. These are inherited in an autosomal dominant manner with low clinical penetrance. The incidence is 1–10 per 100,000 population. Presentation is rare before puberty, and many carriers develop symptoms only after exposure to precipitating factors, such as certain drugs, menstruation, or physical/emotional stress. The acute porphyries, of which acute intermittent porphyria is the most common, are characterized by attacks of severe abdominal pain with nausea, vomiting, and constipation; signs of sympathetic overactivity with tachycardia and hypertension; peripheral motor neuropathy which can progress to weakness and paralysis; and neuropsychiatric symptoms including seizures, anxiety, and mental status changes. These symptoms can last for days to months. The diagnosis may be suspected with the finding of port-wine urine and confirmed with measurement of urinary porphobilinogen and porphyrins. More specific quantitative and enzyme tests are subsequently employed. The abdominal examination in these patients typically reveals findings of underlying ileus with distension and decreased bowel sounds, but evidence of peritoneal irritation may be present. Treatment involves carbohydrate loading with intravenous glucose infusion, intravenous hemin infusion, and removal of precipitating factors.

Familial Mediterranean Fever

Familial Mediterranean fever (FMF) is an autosomal recessive disorder that manifests in childhood as self-limited and recurrent attacks of fever, peritonitis, synovitis, and pleuritis that last for 1–2 days and occur once or twice monthly. The exact cause of the disorder is unclear, but the pathophysiology appears to be related to a pyrin gene mutation affecting regulation of inflammation in neutrophils. It is common in populations of Eastern Mediterranean origin (incidence of one in 2700 in Israel). The abdominal findings can be impressive, with frank peritoneal findings, often prompting nontherapeutic laparotomy. Laboratory tests reveal leukocytosis with an acute phase reaction (elevated CRP and ESR). Plain films may demonstrate bowel wall edema and air–fluid levels. The diagnosis is suspected with the appropriate ethnic background and demonstration of the typical clinical profile. The diagnosis can be confirmed, and at-risk family members can be identified by detection of mutations of the FMF susceptibility/pyrin gene, *MEFV*. Colchicine is an effective treatment for prevention of acute febrile attacks. A positive response to colchicine therapy helps to confirm the diagnosis of FMF and differentiates this from other pediatric fever syndromes. Long-term complications from FMF include amyloidosis, degenerative arthritis, renal vein thrombosis, and narcotic addiction.

Hereditary Angioedema

Hereditary angioedema is a rare, autosomal dominant disorder that primarily affects the respiratory and GI tracts, manifesting as episodic, self-limited swelling of the face, larynx, extremities, and bowel. It is caused by inadequate activity of the protein C1 inhibitor (C1INH), which regulates intravascular activation of complement. Clinical symptoms are attributed to associated dysfunction in the kallikrein/bradykinin pathway. GI symptoms due to mucosal edema include colicky abdominal pain, nausea, vomiting, and diarrhea and can occur in the absence of swelling at other sites. The swelling can be severe enough to cause intestinal obstruction. Upper GI series may demonstrate thumb printing due to mucosal edema. Measurement of serum C4 levels can be used to screen for this disease, with assays for C1INH antigen and C1INH functional levels used to confirm it.

Medical therapy has expanded considerably over the past 5 years. The armamentarium for first-line therapy for acute attacks now includes C1INH concentrate (pooled plasma), recombinant C1INH, bradykinin B2 receptor antagonist, kallikrein inhibitor, and fresh frozen plasma. Prophylaxis to prevent recurrent attacks includes therapy with attenuated androgens (danazol), tranexamic acid, or C1INH concentrate infusion.

Abdominal Vasculitides

It is not uncommon to encounter chronic/recurrent abdominal pain as part of the presenting symptom complex for vasculitic diseases that affect pediatric patients. These are systemic illnesses that involve multiple organ systems, including the intestines and solid organs. Two prototypical diseases in this category include Henoch–Schonlein purpura (HSP) and systemic lupus erythematosus (SLE). For HSP, the abdominal pain is attributed to intramural bowel wall hemorrhage/hematoma with potential intussusception, while, in SLE, there are multiple potential intra-abdominal sources of pain.

The important point to appreciate from the surgical standpoint is that these are predominantly medical diseases that respond to appropriate medical therapy with immunosuppression and optimization of hemodynamic and hematologic parameters. While surgery does not have a central role in therapy, surgical intervention is necessary in the event of evidence of severe GI compromise/intestinal ischemia, intestinal obstruction (due to intussusception in the case of HSP), perforation, or life-threatening hemorrhage.

Summary

The work-up for chronic abdominal pain frequently involves a visit with a surgeon; however, the vast majority of causes can be considered functional or nonsurgical in nature. Utilization of the Rome criteria can help the surgeon distinguish between problems that are organic and may require surgical intervention and those that require nonsurgical management.

Editor's Comment

Chronic and recurrent abdominal pain is a common indication for referral to a pediatric surgeon, especially the experienced laparoscopist with a known willingness to consider operating on these children. Many will have suffered for months or years with debilitating pain and are desperate for relief at any cost, but it is important to remain circumspect and to consider intervention only for children who are likely to benefit. To that end, the Rome criteria are a major advance that should help us identify appropriate surgical candidates.

Until very recently, we routinely assumed that abdominal pain with no proven organic basis was psychosomatic or a harbinger of mental illness. Although the patient experiencing an acute attack of abdominal pain can occasionally appear restive or erratic, the enlightened surgeon understands that these situations are complicated and that the patient could very well be suffering from a disease process that has simply yet to be elucidated and defined. The picture is especially muddled in patients with an underlying cognitive disability like autism, who often have a high pain threshold and an inability to communicate.

Perhaps the most common cause of recurrent abdominal pain is constipation. However, one must be careful not to assume this or to casually dismiss a complaint of abdominal pain as "just constipation," which is often an insensitive oversimplification. A more tactful approach is to recommend empiric therapy for constipation while a systematic and thoughtful evaluation is being carried out.

Appendiceal colic is probably underappreciated as a cause of recurrent abdominal pain. This is partly due to the fact that the classic picture (postprandial RLQ or periumbilical pain associated with nausea and pallor) is often absent and the appendix is invariably normal by imaging studies and partly due to the fact that many surgeons do not believe it to be a genuine phenomenon. Many believe it is real and are willing to perform an empiric appendectomy whenever a diagnostic laparoscopy is performed for abdominal pain. It is surprising how often there is pathology (fibrous obliteration of the lumen, fecalith) and how often patients feel better after the operation. Remember also that endometriosis in young girls has a different appearance than the "powder burns" classically described in women. Instead, they often appear as tiny nondescript bumps or subtle translucent plaques on the peritoneal surface. Any questionable lesion should be excised and sent for analysis.

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Crohn's Disease

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Peter Mattei

Crohn's disease is one of the two commonly seen inflammatory bowel diseases. As opposed to ulcerative colitis (UC), which only directly affects the colon and rectum, Crohn's disease can affect any part of the intestinal tract. It can also involve the full thickness of the bowel wall, which accounts for many of the complications associated with the disease. Surgery is not curative but is reserved for the treatment of complications that are acutely debilitating or refractory to medical management. The etiology is unknown. It is increasingly clear that most patients have a genetic predisposition, though what purported environmental triggers are involved is less clear. Medical therapy has improved significantly, especially with the development of biological drugs, mostly variations of a monoclonal anti-TNF antibody. The prevalence of the disease is increasing, more patients are being identified at a younger age, and many still develop complications that require surgical intervention. Many complications are related to the typical delay in diagnosis that is still on the order of 1½–2 years—by the time the diagnosis is confirmed, there has often been a long period during which the untreated disease has been very active and rather destructive. Although the disease can affect any part of the GI tract "from the mouth to the anus," most patients who come to the attention of a surgeon have one of three distinct patterns of disease: ileal, colonic, or perianal.

Ileal Disease

Children with acute ileitis will sometimes present with right lower quadrant pain, fever, and GI symptoms, thus mimicking acute appendicitis. When findings consistent with ileitis are seen on an abdominal US, CT, or MRI, the patient is usually treated medically for presumed infectious ileitis by the medical service and evaluated for the possibility of Crohn's disease as an outpatient. If a patient is brought to the operating room for presumed appendicitis and found instead to have ileitis, the surgeon has a decision to make: resect, biopsy, appendectomy, or simply close. In the setting of chronic symptoms (abdominal pain, diarrhea, poor weight gain, growth failure) and severe disease in the ileum that is clearly chronic (fibrosis, chronic bowel obstruction, creeping fat, fistulae), ileocecal resection with primary anastomosis is acceptable and safe. On the other hand, if the symptoms are clearly of recent onset and the ileal disease appears to be mild, non-obstructing, and acute, then resection might be considered excessive and unnecessary, as medical therapy could be effective. Biopsy is inadvisable because of the risk of postoperative fistula formation or abscess. Appendectomy is probably safe if the base of the appendix and the cecum itself are clearly normal. Regardless, it is important to document the findings in great detail in the operative note and, whenever possible, with intraoperative photographs.

More commonly, the surgeon is consulted for the patient with known Crohn's disease who has developed severe chronic symptoms or an acute complication. The most common chronic picture is that of a partial small bowel obstruction due to a fibrotic stricture or recurring bouts of near-complete bowel obstruction that respond to high-dose steroid therapy. Other common chronic complaints include recurrent abdominal pain, failure to thrive, short stature, and delayed sexual maturation. Some patients develop adverse reactions to or intolerance of medical therapy or simply desire relief from taking so many drugs. Ileal disease will sometimes fistulize to other loops of the bowel, the colon, or the bladder. Sinus tracts that open into the peritoneum can result in free perforation or enterocutaneous fistula but more commonly produce an intra-abdominal abscess.

Except for the exceedingly rare case of free perforation and the occasional complete bowel obstruction that does not respond to bowel rest and corticosteroids, these patients can nearly always be treated on a semi-elective basis. This is preferable to having to perform an emergency operation as the risks are greater, the likelihood of needing a temporary

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diverting ileostomy is probably slightly higher, and the need to make a large laparotomy incision is greater. While awaiting operation, patients should be given nasogastric or intravenous nutrition. Abscesses should be drained percutaneously and the drain left in place (essentially a controlled enterocutaneous fistula) while the patient is treated with antibiotics: intravenous for 2 weeks and oral for 2–3 weeks until the day of surgery. Formal bowel preparation is not necessary, but having the patient take nothing but clear liquids for 24 h prior to operation seems to help decrease the amount of fecal material in the ileum and the diameter of the chronically obstructed bowel.

Diagnosis

The decision to operate is based principally on the patient's clinical picture and response to medication; however, medical imaging can help to identify the most active site of disease and over time can reveal the rate of progression of the disease. The upper GI contrast study with small bowel follow-through helps to demonstrate the location of disease and gives some information regarding its severity (Fig. 57.1). It is very sensitive for small bowel strictures but gives little information regarding the relative contributions of inflammation and fibrosis on the origin of the stricture. This is potentially important regarding prognosis—in theory inflammation is reversible while fibrosis is not. When reviewing these images, it is important to focus not only on the more vivid luminal contrast but also to the negative space in the image, which represents the thickened wall of the affected bowel segment pushing other contrast-filled loops out of the way. This study will also sometimes demonstrate a fistula or signs of chronic obstruction.

CT is also a very useful study in patients with Crohn's disease but tends to be less commonly used than UGI, perhaps because of the perception that it exposes the patient to more radiation. MR enterography is being used more frequently and has become the diagnostic study of choice in patients with Crohn's disease.

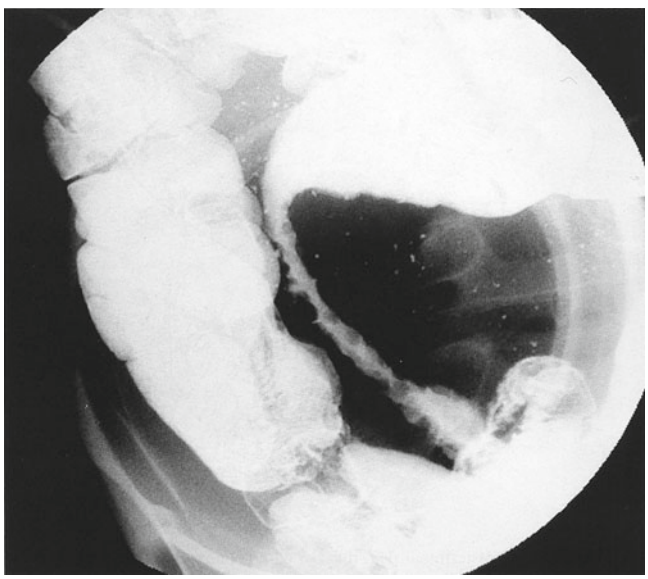

Fig. 57.1 Upper GI contrast study with small bowel follow-through in a patient with Crohn's disease of the terminal ileum. This image demonstrates a long segment of stricturing disease in the ileum. Note the "negative space" adjacent to the thin column of contrast within the strictured segment, which is the bowel wall, thickened by inflammation and fibrosis, displacing adjacent contrast-filled loops of bowel (Reprinted from von Allmen D. Surgical management of Crohn's disease. In: Mamula P, Markowitz JE, Baldassano RN, editors. Pediatric inflammatory bowel disease. New York: Springer; 2008, p. 459.)

Surgery

Bowel resection is the treatment of choice for long or strictured segments of Crohn's disease of the small intestine. In the vast majority of cases, this entails ileocecectomy (Fig. 57.2). A primary anastomosis is almost always feasible; ileostomy is almost never, if ever, indicated. The operation can and should be performed through a very small transverse right lower quadrant, lower midline, or periumbilical incision made just large enough to allow removal of the diseased bowel (typically 4–6 cm). For ileocectomy, the right colon is laparoscopically mobilized up to and including the hepatic flexure, which allows the resection and anastomosis to be performed through a very small incision created by extending one of the port sites. A small transverse right lower quadrant muscle-splitting incision is cosmetically acceptable and associated with little postoperative discomfort. A side-to-side, functional end-to-end, 75-mm stapled anastomosis is preferred: it is quick, is associated with a minimal risk of leak, and has superior long-term patency rates compared to traditional

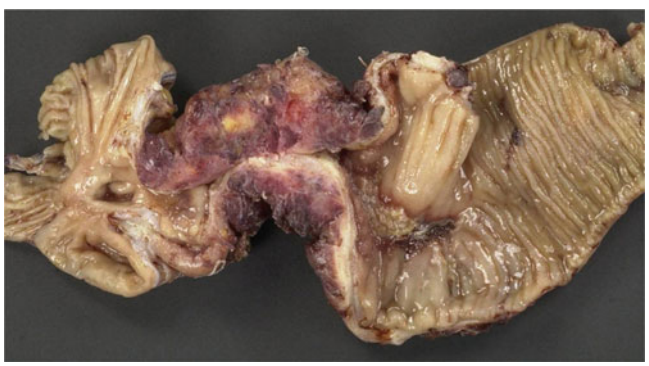

Fig. 57.2 Pathologic specimen from patient with Crohn's disease and ileal stricture. Note the thickness of the wall of the strictured segment and the large diameter of the chronically obstructed and dilated ileum proximal to the stricture (*right*)

hand-sewn anastomoses, particularly in this patient population. All incisions should be closed primarily with absorbable suture in standard fashion and the use of cyanoacrylate glue results in excellent cosmesis and a very low incidence of wound infection.

Besides complete laparoscopic mobilization of the right colon, there are several other maneuvers that can help to minimize the size of the open incision. The cecum is usually uninvolved and can be delivered into the incision first. Divide the right colon with a stapling device just above the cecum, place a stay suture at the corner of the distal colon staple line, and drop it back into the abdomen. Next try to deliver the diseased bowel, sometimes pausing to divide the mesentery between absorbable ligatures. The mesentery in Crohn's disease is often thick and very vascular, making suture ligatures the safest way to control bleeding from the mesentery. When trying to deliver the diseased bowel, a laparotomy sponge provides a good grip on the bowel, while a gentle back-and-forth rocking motion and simultaneously sliding a short one-inch Richardson retractor around the incision to push the skin and fascia down and away will often allow the phlegmonous bowel to be delivered. A small wound protector helps a great deal. The proximal bowel is divided just proximal to the diseased segment (it does not need to be histologically normal, only grossly normal) and that end is marked with a stay suture and dropped back inside. The mesentery is then divided in the usual fashion.

Prior to making an anastomosis, the small bowel should be inspected all the way back to the ligament of Treitz to be sure there are no other areas of severe disease that might require resection. Mild disease is left alone, while short strictures can be treated by resection or a standard Heineke–Mikulicz stricturoplasty. Some patients need two or more resections but usually still have excellent outcomes. Every effort should be made to preserve bowel length. It is much easier to close the mesenteric defect before performing the anastomosis. It also allows you to rule out the presence of a twist in the bowel. It cannot be overemphasized that ileostomy should almost never be indicated. In many cases, a fistula to a normal adjacent bowel or sigmoid colon can be controlled laparoscopically by application of a gastrointestinal endostapler across the fistula, cutting across a tiny bit of the normal bowel. If the involved loop is also diseased, then it should be resected. Dividing the fistula laparoscopically allows both loops to be delivered sequentially through the same small incision rather than as a large, phlegmonous mass. A fistula to the bladder usually requires suture repair of the bladder with absorbable suture and Foley catheter decompression for several days. Unexpected abscesses can be evacuated and the adhesions forming the walls of the abscess lysed. Resection of the diseased bowel is still indicated if it can be freed from all adhesions.

Colitis

Crohn's disease can create colonic strictures that are resected using a laparoscopic-assisted technique as for small bowel disease, but this is an uncommon presentation. However, when it occurs near the rectosigmoid junction or when the disease extends into the rectum, this is one of the rare indications for colostomy, as a low anterior or rectal anastomosis is perilous under these circumstances.

The diagnosis is usually confirmed by colonoscopy or contrast enema. MRE is also increasingly being used. A common clinical manifestation of Crohn's colitis is fulminant hemorrhagic colitis. It is often confused with UC and it is this difficult distinction that creates some of the uncertainty regarding the best surgical course of action. If UC is considered highly likely and the patient with hemorrhagic colitis fails to respond to maximal medical therapy, one should feel comfortable recommending a subtotal colectomy with ileostomy and delayed proctectomy with ileoanal reconstruction. On the other hand, Crohn's colitis will in some cases respond to simple ileal diversion or segmental colectomy, thus allowing preservation of at least part of the colon and rectum.

Diverting ileostomy is a reasonable option in some children with severe colitis and a high suspicion for Crohn's disease. It is offered in some centers as an alternative to the seemingly dramatic step of performing a colectomy. A Turnbull ileostomy, a loop ileostomy in which the proximal bowel is Brooked and the mucous fistula end is flush with the skin, is an excellent choice that allows for decompression of the distal bowel, provides access to the colon for studies or antegrade infusion of medication or enemas, and is easy to reverse. The decision to reverse the ileostomy is then often delayed indefinitely and is a difficult one because of persistent disease in the colon and vacillation regarding the appropriate next step. In addition, after ileostomy takedown, there is a low but disappointing incidence of disease recurrence. In most cases of fulminant hemorrhagic colitis, whether the ultimate diagnosis is UC, Crohn's colitis, or indeterminate colitis, the best course of action is usually a subtotal colectomy, preferably performed laparoscopically. This allows the patient to heal, improve nutrition, and wean medications (corticosteroids) while the diagnostic conundrum is resolved with more certainty. When the patient with UC is healthy, reconstruction can be in the form of a proctectomy and J-pouch ileoanal reconstruction. If the patient turns out to have Crohn's disease, an ileosigmoid colostomy or ileorectostomy can be performed, but only if the rectum is grossly normal and intact (no gross disease, no strictures).

Laparoscopic subtotal colectomy is a safe and straightforward operation. Three ports are placed, all 5 mm, except in the larger patient for whom a 10 mm advanced bipolar electrocautery

device is felt to be necessary, one at the umbilicus and one each in the lower quadrants. The right lower quadrant port should be placed at the site marked for the ileostomy. The lateral attachments of the colon and the omentum are mobilized using the harmonic scalpel while the mesocolon is divided close to the colon (not a cancer operation) with a bipolar electrocautery device designed to handle larger blood vessels. We start at the sigmoid colon, mobilize up to and including the splenic flexure and start taking the gastrocolic omentum of the left lateral transverse colon. We then create an opening in the proximal sigmoid mesocolon and begin to divide the left mesocolon up to and around the splenic flexure and across the middle colic vessels. We then complete the division of the gastrohepatic omentum and take down the hepatic flexure. The right colon is mobilized and the mesocolon is divided from the transverse colon to the ileocecal arcades. We then use a 60 mm endostapler to divide the distal sigmoid colon.

The colon can then be brought out through the right lower quadrant port site, which has been enlarged to accommodate an ileostomy. Hemostasis is confirmed, the abdomen is irrigated, and the port sites are closed. Finally, a Brooke ileostomy is matured in the standard fashion. Patients with UC can undergo completion proctectomy and J-pouch ileoanal anastomosis in 2–3 months assuming they are well nourished and off steroids and Crohn's disease has been ruled out. Any uncertainty regarding the possibility of Crohn's colitis should be considered a contraindication to proctectomy and ileoanal reconstruction. These patients are candidates for diverting ileostomy, partial colectomy, or subtotal colectomy with ileostomy.

Patients with isolated segments of colonic Crohn's disease that are refractory to medical therapy or strictured are candidates for colonic resection and primary anastomosis. However, the patient and their family need to understand that the outcomes are not nearly as good as for small bowel resection and the risks are much higher. These include anastomotic strictures, recurrent colitis that is sometimes very rapidly progressive and resistant to medication, and anastomotic dehiscence. Dehiscence is especially common when more than one resection and anastomosis are required and when there is active rectal disease or distal stricture. These are patients who might be best served with a temporary colostomy or diverting ileostomy. Crohn's colitis is a very challenging disease that will test the judgment and skill of even the most experienced surgeons.

Perianal Disease

Perianal Crohn's disease can range from mild and annoying to stubborn and heartbreaking. The clinical manifestations include anal fissures, skin tags, fistula-in-ano, perirectal abscess, and anorectal stricture. The pattern of disease is usually chronic with intermittent flares or rapid progression of disease. Medical therapy is improving the plight of these patients to some degree, and pelvic MRI has revolutionized the diagnostic assessment of these patients who previously would require extensive probing and instrumentation under anesthesia, which was also surprisingly inaccurate. Nevertheless, surgical intervention is still frequently required to treat symptoms, prevent worsening of disease, and avert complications.

We tend to try our best to avoid fecal diversion except in the most severe cases, mostly because of the obvious significant emotional and psychological issues related to having a stoma in adolescence, but also because although the infectious complications of the disease often resolve after diversion, the inflammatory and destructive components of the disease may persist or even progress. Nevertheless, ostomy diversion is unfortunately sometimes the only practical and safe option.

The manifestations of perianal Crohn's disease usually fall into three categories: (1) anal fissure with associated skin tag, (2) fistula-in-ano with associated perirectal abscess, and (3) anal or rectal stricture. There are currently no surgical techniques available for definitive repair of any of these conditions. In fact, with the exception of making a small incision to drain a pointing abscess, the surgeon is well advised to avoid the temptation to make an incision or place a stitch of any kind in the perianal region of a patient with active Crohn's disease. The role of the surgeon in these cases is nonetheless important and includes control and prevention of infection, relief of discomfort and symptoms, and prevention of progression of disease. This is a medical disease and the best a surgeon can hope to accomplish in these situations is to place a metaphorical Band-Aid on the problem, which is an important role, but we also need to avoid making things worse by ill-advised heroic attempts.

Fissures are longitudinal ulcers in the anoderm that are lined with granulation tissue and can be quite destructive. They are a harbinger of active Crohn's disease and are treated medically. Large, painful, confluent fissures that threaten the sphincter complex are an indication for diversion. They should never be excised or closed with sutures as these maneuvers invariably fail and usually result in even larger non-healing wounds.

Skin tags are almost always associated with fissures, representing a strange and seemingly pointless attempt by the body to heal them. Skin tags should almost never be excised as they usually either grow back or result in an open wound that heals poorly. In the rare patient whose Crohn's disease has completely resolved but who has residual skin tags and no signs of active inflammation, it might be reasonable to excise them. It is also sometimes useful as a diagnostic maneuver since skin tags can have the characteristic granulomata of Crohn's disease on histopathology.

Fistula-in-ano is treated surgically but conservatively. Fistulectomy should be avoided, as wound complications and sphincter injury are too often the result. Simple debridement, temporary drainage, and placement of a silk seton will allow simple fistulas to close, minimize the incidence of abscess formation, and possibly limit extension of the fistulizing process while the patient waits for their medical therapy to take effect. Fistulas are often complex and deep-seated. They can burrow circumferentially, and up to the labia or scrotum, and can form multiple external skin openings along a single long tract.

The mainstay to the surgical approach is examination under anesthesia (EUA); however, pelvic MRI is an excellent way to assess the true extent of disease prior to going to the OR. In the OR, the fistula should be probed gently, avoiding the creation of a false passage, but all will have an external skin opening and an internal opening in the rectum. A No. 2 silk thread is passed through the fistula and tied to itself loosely in the form of a non-cutting seton. This is well tolerated and can be left in place indefinitely, keeping the fistula open at both ends and preventing the formation of an abscess. The seton usually falls out on its own within 6–12 months or it can be removed painlessly in the office if medical therapy has allowed complete resolution of all signs of active inflammation and chronic infection. If better drainage is needed, a Silastic vessel loop tied to itself can be placed in parallel with the silk seton and removed in 2–3 weeks in the office. Complex fistulae require creative combinations of drains and setons. It is usually best to find a way to tie the drains to themselves to avoid premature dislodgement and obviate the need for stitches to the skin. An alternative is to secure the drain with a rapidly absorbing suture material to allow the drain to fall out on it own within a few weeks.

In patients with Crohn's disease, a perirectal abscess is always associated with a fistula and is therefore best managed in the operating room. This allows complete evacuation of the abscess, which is often quite large and complex, and control of the fistula with a Silastic drain (short-term) and a silk seton (long-term). Abscesses should never be packed as this is unnecessary and cruel. The cavities are usually filled mostly with granulation tissue that may be debrided. A small Penrose drain can be placed and tied to the vessel-loop drain that was placed in the fistula. These can usually be removed in the office in a few weeks. These abscess cavities are often signs of active Crohn's disease, with extensive local tissue destruction and lots of granulation tissue. They often need multiple every 2–3 weeks debridements and replacement of the drains until they heal, again mostly as a response to medical therapy for the Crohn's disease itself.

Abscesses and fistulae are also strongly associated with anorectal strictures, usually as they heal. Biologicals have a reputation for "causing" strictures, but this is probably because they are so effective at getting fistulas to heal. Short and distal strictures usually respond well to anal dilatation with cervical dilators. This is always done in the OR and usually needs to be repeated periodically, sometimes every 4–6 weeks. It is the rare patients who, after having been taught how to do so in the office, can use a dilator every day at home to keep the stricture from closing down.

Long, recalcitrant, or high strictures can sometimes be treated with periodic dilatation, but these are the patients at risk for perforation of the distal sigmoid colon, especially if the disease extends up into the abdomen. It is therefore best in these cases to recommend ostomy diversion or, if the patient refuses to consent to colostomy, perhaps a single attempt at dilatation in a controlled setting, possibly with balloon dilatation, in the operating room, with all precautions taken in case of a perforation (hospital admission, intravenous antibiotics, frequent radiographic assessment, low threshold for surgical intervention if there are any signs of a bowel injury).

Crohn's disease can also produce vulvar disease and fissures in girls. A fistula should be ruled out by MRI and EUA but can be difficult to identify. Rectovaginal fistula is a feared complication that is often, but not always, considered an indication for fecal diversion. If the inflammatory component can be treated medically but the fistula persists (this is rare—they usually heal), then surgical closure with tissue flap advancement should be considered. Results are certainly better when performed in the setting of a temporary colostomy. It is reasonable in most cases to start with conservative measures but to offer ostomy diversion for those who fail to respond.

Though perianal Crohn's disease is not cured by surgical intervention, it can usually be controlled when managed attentively. This requires frequent office assessment and periodic MRI and EUA. Asking the adolescent with perianal disease to come for follow-up visits only as needed is discouraged because it is important to start therapy before the disease has progressed too far. The goal should be to maintain patient comfort, prevent infectious complications, and stay ahead of strictures and complex fistulae, all the while helping the patient cope with issues related to hygiene, peer interaction, and sexual function.

Postoperative Care

Most patients can be discharged to home after EUA and placement of a drain or seton, unless they require intravenous antibiotics, intravenous pain control, or specific observation. After small bowel resection, ileocecectomy, or subtotal colectomy, patients are admitted and can usually be treated using an enhanced recovery protocol, including no routine nasogastric tube, early oral intake of fluids, advance to regular diet as tolerated, minimal narcotics and intravenous fluids, early ambulation, and administration of a rectal

suppository to initiate a bowel movement on the second postoperative day. Most patients can expect to be discharged on postoperative day 2 or 3 after elective ileocecectomy or on postoperative day 3 or 4 after subtotal colectomy. Criteria for discharge include tolerating a regular diet, ambulating without assistance, good pain control with oral analgesics, and no fever. It is also preferable that they have a bowel movement prior to discharge.

Prophylactic antibiotics should be given within 60 min of incision only—there is no evidence to support the use of postoperative prophylactic antibiotics. Corticosteroids should be weaned slowly in the postoperative period, not because of the risk of adrenal insufficiency, which is actually quite rare in children under these circumstances, but rather because of the risk of prolonged postoperative ileus, which occurs with some frequency when corticosteroids are weaned too quickly after an abdominal operation. Narcotics should be weaned quickly after the night of surgery. Ketorolac and acetaminophen are excellent alternatives that allow most patients to minimize the use of narcotics until oral analgesia is tolerated. There is a general reluctance to use NSAIDs in patients in with Crohn's disease because of the perceived but ill-defined risk of inducing a flare. Nevertheless, we use it routinely in these patients and have had excellent results and no evidence of adverse effects.

The results of surgery for Crohn's disease are generally excellent and durable. The majority of patients have a long period of remission with near-complete resolution of symptoms, significant tapering of their medical regimen, excellent weight gain and growth, and substantial improvement in their quality of life. Long-term results depend on the severity of the underlying disease and patient compliance with their medical regimen, but it is unusual for patients to require a second abdominal operation for Crohn's disease within 8–10 years of their first operation. The hope is, of course, that medical advances will eventually make this disease manageable without surgery or completely curable with drugs alone.

Suggested Reading

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Ileostomy and Colostomy

58

Oliver S. Soldes

In any age group, the creation of an intestinal stoma is a significant event with major physiologic, body image, lifestyle, and psychosocial implications. Management and indications for ostomies in infants and young children are often different than in adolescents and adults. This is a consequence of the differing diagnoses, physiology, size, growth and development issues, complications, and unique patient and parental adjustment concerns.

Intestinal stomas in children are more likely to be temporary adjuncts in the management of surgical emergencies and congenital anomalies. Permanent intestinal stomas are usually only formed for failures of management of some congenital disorders (anorectal malformations, myelomeningocele), inflammatory bowel disease, or, rarely, unresectable pelvic, abdominal, or intestinal tumors (desmoid tumor, giant neurofibroma, sarcoma) and then more commonly in older children after unsuccessful reconstructive procedures. Fortunately, small bowel and colonic stomas of all types are often reversed within a few months or years, and, with rare exception, every effort is made to eventually eliminate the need for another one. There are also several special types of ostomies rarely used outside of pediatric practice that are employed for certain conditions unique to pediatric surgical practice, including the Bishop–Koop ileostomy for meconium ileus and the divided descending–sigmoid colostomy for high imperforate anus.

Indications

The indications for an ostomy are dictated by the diagnosis and the desired function of the stoma (Table 58.1). The function of an ileostomy or colostomy is usually diversion of the fecal stream, decompression of dilated or obstructed bowel, or access for irrigation and evacuation of stool or inspissated meconium. Stomas commonly used for diversion and decompression include the end stoma, the double-barrel stoma, and the loop stoma and its variations (rodless end-loop stoma, divided loop ileostomy). Stomas for irrigation and evacuation include appendicostomies and catheterizable cecal conduits, tube cecostomy, and tube sigmoidostomy. Venting stomas with end-to-side anastomosis and distal vent (Bishop–Koop) or side-to-end anastomosis and proximal vent (Santulli) perform both diverting and irrigation functions and are still occasionally used in the management of meconium ileus.

In pediatric surgical practice, roughly 75 % of ostomies are placed in neonates and infants. In neonates, enterostomies are utilized in the management of diagnoses as diverse as necrotizing enterocolitis (NEC) with perforation, complicated intestinal atresia, volvulus, Hirschsprung disease, meconium ileus, imperforate anus, or cloaca. The young child or adolescent will sometimes require an ostomy for the management of medically refractory Crohn's disease, as part of the staged operative approach to ulcerative colitis, bowel perforation with extensive peritoneal contamination or ischemia (volvulus, trauma, inflammatory bowel disease), and failure of reconstruction and management of congenital anomalies (high imperforate anus, myelomeningocele, Hirschsprung disease).

When fashioning an ileostomy or colostomy, a decision must be made as to whether to use a loop or end stoma or a variant of these types (Fig. 58.1). The type of stoma is determined by a variety of factors, including the indication for diversion, anticipated length of time the stoma will be required, planned future procedures, underlying disease process, and anatomy. Loop ileostomy and colostomy are generally utilized when a temporary stoma is desired to protect a distal anastomosis or to relieve distal obstruction and decompress the proximal bowel prior to definitive surgical management of the obstruction. The main advantages of a loop ostomy are easy access to the distal bowel and ease of reversal. Loop stomas can be reversed with a localized procedure around the stoma, avoiding a full laparotomy. The marginal blood supply to the distal stoma is also more easily preserved with a loop stoma. A major disadvantage of a loop ostomy is a greater tendency

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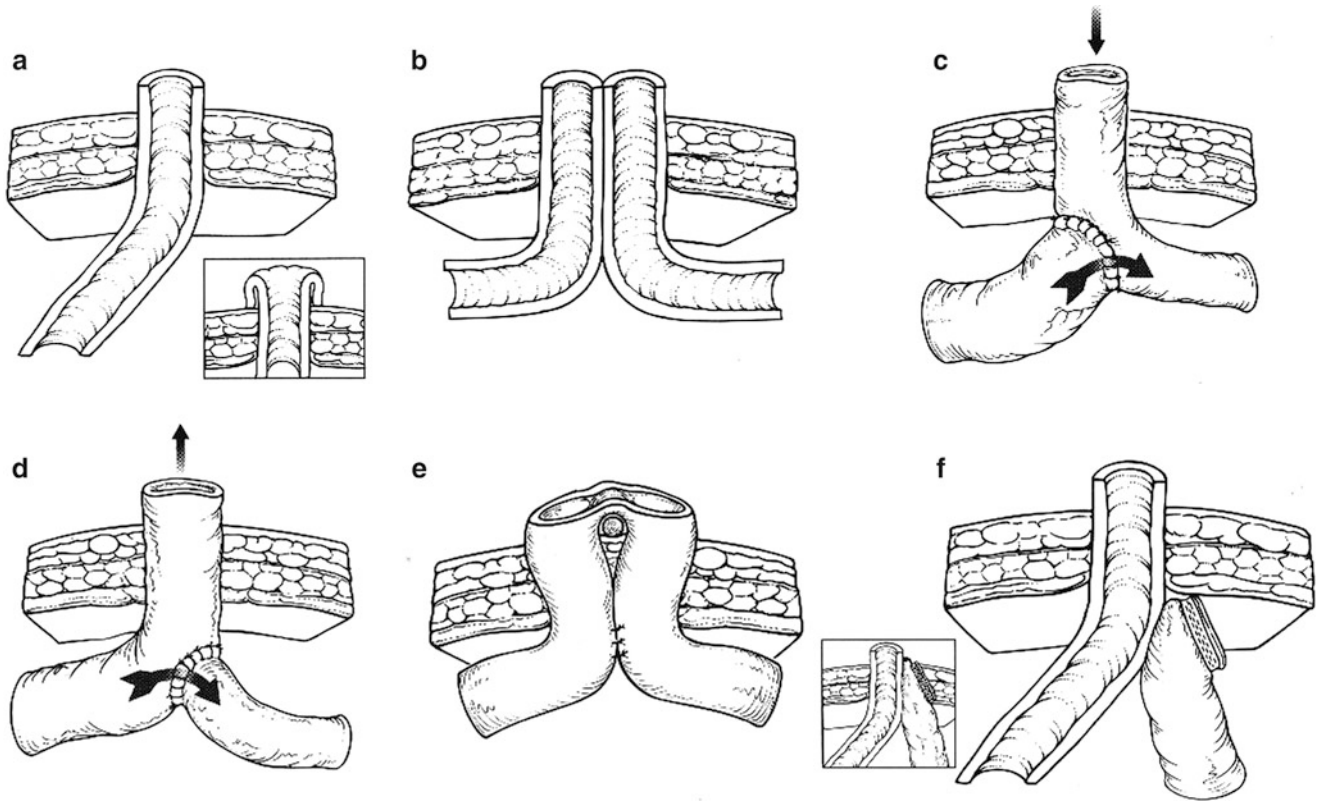

Fig. 58.1 Stoma variants. (**a**) End stoma and Brooke maturation (*inset*). (**b**) Double-barrel stoma. (**c**) Bishop–Koop: distal stoma with proximal end-to-side anastomosis. (**d**) Santulli: proximal stoma with side-to-end distal anastomosis. (**e**) Loop ostomy. (**f**) End stoma with Hartmann's closure and rodless end-loop variation (*inset*) (From Gauderer MWL. Stomas of the small and large intestine, Chapter 96. In: Grosfeld JL, O'Neill JA, Fonkalsrud EW, Coran AG, editors. Pediatric surgery. 6th ed. Philadelphia, PA: Mosby; 2006, with permission from Elsevier)

Table 58.1 Function and types of ileostomy and colostomy

Stomas for intestinal diversion and decompression
End ostomy
Loop ostomy and variants (rodless end-loop stoma)
Double-barrel ostomy
Stomas for irrigation and evacuation
Appendicostomy
Catheterizable cecal conduit
Tube cecostomy or sigmoidostomy
Stomas for both diversion and irrigation/evacuation
Distal venting ileostomy with end-to-side anastomosis
(Bishop–Koop)
Proximal venting ileostomy with side-to-end anastomosis (Santulli)
Divided descending–sigmoid colostomy for high imperforate anus

to prolapse, retract, or develop parastomal hernias, probably due to the larger fascial opening needed to bring out both ends of the bowel. A double-barrel stoma is similar to loop stoma, but the bowel is completely divided.

End stomas are selected in the setting of bowel resection, when a permanent or long duration stoma is anticipated, or complete fecal diversion is desired. End stomas are often employed in the setting of an abdominal surgical emergency, such as one involving bowel necrosis, ischemia, or perforation with gross contamination. An end stoma is usually chosen when a segment of bowel is resected and there is significant concern for leakage following a primary anastomosis (necrotizing enterocolitis with perforation, tenuous blood supply, systemic acidosis, or poor perfusion). It might also be chosen for anatomic considerations, such as limited mesenteric length, that preclude loop ostomies. The end stoma is generally formed at the site of resection. The distal bowel must be managed as either a Hartmann pouch or by the creation of a mucous fistula. In a Hartmann procedure, useful only when there is no risk of distal obstruction, the distal bowel segment is closed and dropped back into the abdomen. Future closure of the end stoma is usually facilitated by tacking the closed distal end to the side of the proximal bowel or to the fascia near the stoma.

If there is a risk of distal obstruction or if there is a reason to need access to the distal bowel segment, then a mucous

fistula is created. The advantage of the end stoma is that it is completely diverting and is less likely to prolapse. The main disadvantage of the end stoma is that it often requires a somewhat bigger operation to bring the two bowel ends together to form an anastomosis.

Several types of permanent stomas are used for daily irrigation of the colon in patients with failed reconstruction of high imperforate anus, Hirschsprung disease, chronic constipation, and overflow incontinence. These irrigating stomas serve to improve cleanliness and the quality of life for children with chronic soiling, poor control of defecation, and leakage of stool. They include intermittently catheterizable appendicostomy and cecal conduits, tube cecostomy, and sigmoidostomy. All are intended primarily to facilitate the instillation of an antegrade enema by intermittent catheterization or indwelling tube. A large-volume (15–20 mL/kg or more) warm tap water or saline colonic enema is given daily, usually in the evening, to achieve a daily bowel movement. The colon is then emptied nightly and allowed to function as a passive reservoir for stool until the next enema. The volume is titrated to effect. The saline enema solution is usually made at home by the caregiver, mixing 1½ teaspoons of table salt in 1000 mL of warm water. The intermittently catheterizable stomas have the advantage of enhanced body image because there is no appliance on the abdominal wall. The umbilical appendicostomy is fashioned by open or laparoscopic technique at the base of the umbilicus, where it is well hidden.

Continuously catheterized tube stomas, such as the cecostomy button (usually a standard gastrostomy button), endoscopically placed ("pull-type" percutaneous endoscopic gastrostomy (PEG)-style tube), or radiologically placed (Chait) tube, leave the patient with an external appliance that allows access to the GI tract. These types of tubes are prone to the usual gastrostomy tube complications (displacement, mechanical malfunction, infection, skin irritation and breakdown, peristomal fistula) and need to be replaced periodically. Intermittently catheterized stomas are complicated by stenosis, retraction, or perforation of the intestine by the intestinal tube. With time, neurologically intact older children and adolescents are often able to completely assume all of the care associated with administering enemas.

Preoperative Preparation

Siting a stoma is critical to good function, minimizing complications and maintaining a good quality of life. On the contrary, a poorly sited stoma is a source of misery for the surgeon, caregivers, and especially the patient. All elective stomas should be sited in the lower abdomen, perhaps as high as the umbilical line in young children, preferably with the help of an experienced enterostomal therapist. The site should be marked and remarked as necessary after watching the patient sit, stand, and lie down. It should not be too close to the anterior superior iliac spine or the umbilicus. Most adolescents prefer that it be lower than the pants line, but this is rarely feasible given the location of typical abdominal skin creases. It should be placed at the leading edge of the major lower abdominal fat bulge. Some prefer to bring it through the rectus sheath, others in a more lateral position if space allows. Ileostomies are generally placed in the right lower quadrant (RLQ), and sigmoid colostomies in the left lower quadrant (LLQ). Transverse colostomies are placed in the upper abdomen and for a number of medical and esthetic reasons should only be used when there is no other option available.

Intestinal stomas in the children are much more likely to be created in the management of unexpected abdominal surgical emergencies and congenital anomalies. As such, the opportunity for preoperative counseling and parental preparation might be limited but should be undertaken whenever possible. A notable exception is in patients undergoing elective or semi-elective procedures for inflammatory bowel disease (IBD), imperforate anus, or Hirschsprung disease. In this setting, preoperative consultation with an enterostomal therapist is useful for counseling, stoma site marking, and education. Discussion of the possible need for an ostomy should be part of the informed consent prior to any procedure likely to involve a bowel resection.

In the case of elective formation or closure of an ileostomy or colostomy, many surgeons still prefer to perform preoperative mechanical bowel preparation for children outside of the neonatal period. At minimum, an oral clear liquids diet is given for 24 h prior to surgery. We prefer a traditional bowel preparation, particularly for colon surgery, in children older than 1 year, who are usually admitted the day before surgery. A slender nasogastric feeding tube (6 Fr) is placed, and polyethylene glycol (PEG) solution is administered at a rate of 25 mL/kg/h until the output is clear. Adolescents can undergo bowel preparation at home with a standard regimen (sodium phosphates oral solution or PEG) used for adult surgery. Sodium phosphate oral solution is sometimes better tolerated by adolescents because a lower volume is needed than for PEG solution. Neonates and infants undergoing ileostomy and colostomy formation or closure require only preoperative clear liquids with or without retrograde distal intestinal irrigation on the floor or in the operating room prior to incision.

Mechanical bowel preparation is usually not possible when there is obstruction or perforation. Three doses of oral antibiotics (erythromycin 15 mg/kg/dose and neomycin 30 mg/kg/dose or metronidazole 7 mg/kg/dose, up to adult dose) are still given by some surgeons, particularly for older children and adolescents, as is distal tap water or 1 % neomycin enemas. Appropriate perioperative intravenous antibiotics are always used in every age group, prior to incision

and for up to 24 h postoperatively. Preoperative contrast studies of the distal bowel (rectal contrast enema, ileostomy injection, or colostogram) are generally indicated prior to elective closure of enterostomies, especially in the setting of previous NEC, ischemia, volvulus, and atresia due to the risk of distal stricture.

Ileostomy

In newborns and infants, an ileostomy is usually performed when an anastomosis is judged to be unsafe during an operation for NEC, meconium ileus, complex intestinal atresia, or volvulus with necrosis. These are most commonly end ileostomies and a mucous fistula is usually created as well. They can be brought up through the primary incision or a separate incision. Using the primary incision has the disadvantage of a higher risk of wound complications and infection. The distal end is also sometimes tacked to the proximal end or the fascia to make later closure easier. In the setting of extensive patchy NEC or multiple atresias, multiple ostomies can be formed to salvage segments of bowel that cannot be safely anastomosed, to preserve bowel length, and to mitigate short bowel syndrome.

When the functional end of the bowel is brought through or close to the laparotomy incision and peritoneal contamination is minimal, we close the remainder of the primary incision with cyanoacrylate topical skin adhesive, which acts as an effective barrier. The bowel is secured to the fascia or skin with interrupted 4–0 polyglycolic acid sutures. In neonates, where possible, at least 1 cm of ileum should be allowed to protrude. The bowel is tacked to the skin edges with partial-thickness 4-0 polyglycolic acid sutures. Maturation of the end of the stoma and mucocutaneous sutures are avoided in small premature infants, in whom the end of the bowel is fragile and easily traumatized. Within 2 weeks, the end of the small bowel will spontaneously roll back to mature itself. In full-term newborns and older infants, a few fine interrupted absorbable sutures should be placed to form a Brooke ileostomy. In the situation where there is concern about additional atresias or the possibility of late strictures, exteriorization of the distal segment as a mucous fistula has the added advantage of facilitating contrast studies of the distal end segment prior to reestablishing intestinal continuity.

A mucous fistula also allows refeeding of stoma effluent to improve nutrient absorption and as a trophic stimulant for bowel growth and adaptation. The intestine distal to an atresia is often diminutive and the proximal end so dilated that an anastomosis between the two, though mechanically patent, is functionally obstructed. A period of diversion with refeeding will allow for growth and salvage of the distal intestine and a better size match later.

A loop ileostomy is commonly used for postoperative diversion following total colectomy and ileal pouch–anal anastomosis for ulcerative colitis or transabdominal endorectal pull-through for Hirschsprung disease. It can also be used to decompress a massively dilated distal colon prior to redo endorectal pull-through procedures for Hirschsprung disease or anastomotic stenosis. The advantages of a loop ileostomy in this setting are the avoidance of the risk of compromise of the marginal colonic blood supply that could occur with the formation of a colostomy and decompression of and access to the distal segment for follow-up contrast studies. Furthermore, the loop ileostomy used to protect the distal colo-anal anastomosis will already have been formed. Another clinical situation in which a loop ileostomy is useful is when total colonic Hirschsprung disease is unexpectedly encountered.

There are several ileostomy variants employed in pediatric surgery for special situations. The Bishop–Koop or double-barrel Mikulicz stomas are sometimes used specifically in the management of obstruction related to meconium ileus. These stomas allow irrigation of the distal intestinal segment to disimpact the inspissated meconium. In the rare situation where a feeding jejunostomy is needed in an infant (multiple failed fundoplications for reflux in the setting of congenital diaphragmatic hernia (CDH) or long-gap esophageal atresia), a Roux-en-Y feeding jejunostomy can be employed. In infants, the application of the Witzel technique can narrow the bowel lumen significantly when the jejunostomy tube is imbricated to form the tunnel. The Roux-en-Y feeding jejunostomy obviates this problem in small diameter bowel. The Roux-en-Y feeding jejunostomy also allows the use of a conventional balloon enterostomy feeding tube or button in larger children, without obstruction of the small bowel lumen by the balloon.

Colostomy

Colostomies formed in the management of NEC, volvulus, or perforation in neonates require the same technical considerations as ileostomy in this age group. Colostomies for Hirschsprung disease and imperforate anus are special categories. In patients with rectosigmoid Hirschsprung disease, colostomy is now rarely performed because of the popularity of single-stage transanal primary endorectal pull-through procedures with or without laparoscopic assistance. In the event that a colostomy is chosen as the initial treatment, a “leveling” colostomy is made in the normal colon just proximal to the level of the transition zone. A loop sigmoid colostomy or end-sigmoid colostomy and mucous fistula are created. The access to the distal colonic segment afforded by a loop colostomy or mucous fistula is preferred so as to allow the passage of mucus or irrigation of the distal colon. The colostomy is generally performed as distal as possible within the normal bowel, taking great care to be well above the transition zone.

In patients with high imperforate anus, a divided descending colostomy is employed. This colostomy has the advantage of decompressing the congenitally obstructed bowel, completely diverting the fecal stream from the fistula to the urinary tract in males and allowing sufficient space on the abdominal wall to apply a proper ostomy appliance. It also allows performance of a distal colostogram and drainage of any urine from the fistula, minimizing its reabsorption and subsequent metabolic acidosis. This ostomy is generally left in place following anorectal reconstruction by posterior sagittal or laparoscopic technique. Unlike the sigmoid colostomy in Hirschsprung disease, care is taken not to perform this colostomy too distally, so as to avoid tethering of the rectosigmoid colon during the anorectal reconstruction.

Colostomies for fecal diversion in older children and adolescents are generally formed using the same techniques as for adults in the settings of perforation, necrosis, or IBD. Some children with Crohn's colitis or ulcerative colitis (UC) benefit from diverting ileostomy, which allows the colon to rest while medical therapy is optimized, some of which can take weeks or months to start to work. While the vast majority of stomas in children are likely to be temporary, children with refractory and severe Crohn's colitis or proctitis are more likely to require permanent ileostomy for colostomy. They are also prone to more complications including dehiscence, fistulas, abscesses, hernias, and Crohn's disease of the stoma itself, all of which require frequent surgical revisions of the stoma over the course of years. Patients with UC often require an ileostomy diversion as part of a staged approach to colectomy and J pouch ileoanal reconstruction. They rarely require a permanent ileostomy diversion for severe and refractory pouchitis or pouch failure.

Stoma Closure

Contrast studies of the distal intestine are generally performed prior to takedown of an enterostomy to detect unanticipated obstruction or stricture, particularly when a full laparotomy with inspection of the distal bowel and lysis of adhesions is not planned. In infants and young children, the ostomy closure anastomosis is generally performed with a single-layer hand-sewn inverting technique because of the small size of the bowel. A single-layer technique with interrupted fine polyglycolic acid sutures is preferred to avoid narrowing of the anastomosis by excessive imbrication of the bowel ends that can occur with a double-layer closure. In adolescents and adults, the anastomosis may be hand-sewn in one or two layers or with the use of a surgical stapling device, according to the surgeon's preference. Loop stomas are closed after local mobilization and anastomosis of the intestinal ends without a larger laparotomy.

Postoperative Care

Parental concerns and education require substantial time and support from the surgeon and an enterostomal therapist. Successful management of an ostomy by a parent at home requires attention to their concerns. Few parents of young children will have had any experience in such home care. Failure to support these needs and provide sufficient education prior to discharge sometimes results in unnecessary readmission and frequent return visits as an outpatient. Parents and patients, when age appropriate, must be instructed in care of an ostomy appliance and recognition of ostomy complications (Table 58.2).

The most important and serious complications include high stoma output with dehydration and electrolyte disturbances, prolapse, and stenosis. Infants and young children, because of their small size, can become rapidly dehydrated from gastroenteritis or overfeeding in the setting of malabsorption. Several weeks of postoperative inpatient feeding titration are required, particularly in the newborn with a very proximal stoma. Neonates with mid-level or high jejunostomies can sometimes be managed successfully on home parenteral nutritional therapy but more typically require inpatient care until the ostomy is reversed. High output from a stoma is generally defined as an output of greater than 30–40 mL/kg/day. This is most likely to occur in the patient with a high jejunostomy. Postoperative advancement of feeding in patients with ileostomy or jejunostomy should be slow, especially once output approaches 30 mL/kg/day, to avoid overwhelming the absorptive capacity of the intestine.

Agents to reduce ostomy output such as loperamide (0.1 mg/kg/dose 3–4 times daily) can be used with variable success. Cholestyramine can be added to the feeds of patients with a colostomy and short small intestinal length, where unresorbed bile acids in the colon produce diarrhea. The

Table 58.2 Complications of ileostomy/jejunostomy and colostomy

Fluid and electrolyte disturbances
Prolapse
Retraction
Ischemia
Stenosis
Parastomal hernia
Peristomal skin excoriation/candidiasis
Fistula
Granulation tissue
Catheter-related perforation
Ostomy appliance complications
Intestinal volvulus
Technical errors (exteriorization of incorrect end)
Spillover of stool into mucous fistula with subsequent stool impaction (Hirschsprung disease, imperforate anus)

ostomy output should be checked for pH and reducing substances. Low pH (<5.5) or positive reducing substances indicate malabsorption. When output exceeds 30–40 mL/kg/day, feeds should be held completely for 12–24 h to allow nonabsorbed sugars to clear. Simply slowing the feed rate will result in continued high output due to the presence of nonabsorbed and osmotically active sugars within the intestinal lumen.

Permanent stomas are relatively rare in pediatric practice. Prolapse or stenosis is most often managed by closure of the temporary stoma. In the event of prolapse, retraction, parastomal hernia, or stenosis of a permanent enterostomy, revision and resiting of the stoma is sometimes necessary.

Editor's Comment

In children, stomas should be rare and reversible. Although the decision to create a stoma is to some degree always a matter of judgment, there are some indications that are largely technical (high imperforate anus, long-segment Hirschsprung disease, and first stage of ileal pouch–anal anastomosis), some that are somewhat obvious because an anastomosis would clearly be unsafe (NEC with necrotic bowel, fecal peritonitis with sepsis), and finally some that are more or less a matter of style or preference on the basis of experience and training of the surgeon. These decisions often serve to define a surgeon as "conservative" or "progressive." Regardless, because stomas are not without complications and make life difficult for the patients and their parents, the decision to create a stoma should not be taken lightly and the surgeon should always be able to justify the decision in that particular patient in that particular circumstance. It is clear that many of the traditional indications for creation of a stoma are historical and based on habit and training. Though data are lacking, luckily there are surgeons with the courage to challenge dogma who have generated a large collective experience that supports the informed and thoughtful decision to avoid a stoma under most circumstances.

The Bishop–Koop ileostomy was a major advance in the surgical treatment of meconium ileus when it was first introduced several decades ago, and some pediatric surgeons might still use it occasionally. But intraoperative evacuation of the inspissated meconium by irrigating through an enterotomy made in the dilated portion of the ileum that is then closed primarily works well and avoids the issues related to the care and closure of a stoma. Stomas should almost never be necessary in healthy children after ileocecectomy for intussusception, appendicitis, or Crohn's disease. Leveling colostomy in healthy infants with short-segment Hirschsprung disease should rarely be necessary as primary repair in newborns is clearly safe and effective. Bowel perforations after blunt or penetrating trauma can almost always be repaired primarily without a stoma unless there is a significant delay in diagnosis, severe chemical peritonitis, or profound sepsis. In the end, a surgeon should be able to justify stoma creation in a child with more than a defensive "this is how I've always done it."

All stomas are essentially either end stomas, in which case they should be matured in the manner of a Brooke ileostomy or some modification of the loop ileostomy. End colostomies can be flush but function better and are easier to care for when they are Brooked slightly. There is rarely a need to use a rod or tube to secure a loop stoma, as proper suture placement and a small but adequate fascial opening should be enough to prevent retraction of the stoma. In the case of Hirschsprung disease or imperforate anus, the mucous fistula should probably be brought up separately so as to avoid spillover and subsequent impaction of stool. To prevent prolapse mucous fistulas should not be matured and in fact are probably best made flush and rather small, by just opening the corner of a staple line. In most other cases, a Turnbull stoma should be used, which involves Brooking the proximal end and leaving the distal end flush with the skin. Most of the other stomas described in the past were designed to allow closure at the bedside because a trip to the operation room was so dangerous. There is little need to use these old-fashioned constructs today.

Complications of stomas are relatively common but largely preventable. Parastomal hernias are often due to an excessively large fascial opening and improper suture fixation of the bowel. The bowel should be tacked to the fascia circumferentially, and when creating a loop ileostomy, the space between the loops should be obliterated with strategic sutures. Prolapse is one of the more frustrating complications of stomas and is more common in mucous fistulas, probably due to the effect of peristalsis—maturing the mucous fistula makes it worse because of the everted bowel peristalses in the direction of prolapse. Prolapse of the proximal segment usually occurs in stomas created when the bowel was extremely dilated and has now decompressed to a more normal size. In these cases, it is probably best to either find a way to remove the stoma or to completely resite it. Proximal jejunal stomas should be avoided if at all possible because of the fluid and electrolyte and skin care problems that arise from the high output. Whenever possible, all stomas should be placed in the lower abdomen at a site that has been carefully chosen by an experienced surgeon or enterostomal therapist. Transverse colostomies should also be abandoned, as they are ugly, prone to prolapse, despised by patients, and almost never the only good option. Bowel obstruction frequently occurs at or near ostomies, sometimes due to adhesions or occasionally due to volvulus around the stoma. Operation should not be delayed simply because the surgeon is convinced that "the stoma is patent" based on digital exam or intubation of the stoma. Finally, an examining finger should rarely if ever be placed in a child's ileostomy due to the significant risk of circumferential injury to the bowel or its blood supply.

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Gastrointestinal Bleeding

59

Katherine J. Deans

Gastrointestinal bleeding accounts for at least 3 in 1000 pediatric emergency department visits. Caring for children with gastrointestinal bleeding requires a thorough understanding of the possible etiologies and their respective symptoms. A detailed history and physical examination serve as the starting point for any work up of the child with gastrointestinal bleeding. The two most important factors are age and the nature of the bleeding episode. These two pertinent pieces of easily accessible information help to form the differential diagnosis, which serves as the basis for the diagnostic and therapeutic algorithm.

Gastrointestinal bleeding is usually classified based on the anatomic relationship between the suspected site of bleeding and the ligament of Treitz. Bleeding from sites proximal to the ligament of Treitz is considered *upper gastrointestinal bleeding* and bleeding from sites distal to the ligament of Treitz is considered *lower gastrointestinal bleeding*. Occult GI bleeding refers to an initial presentation with a positive fecal occult blood test or iron deficiency anemia without visible evidence of blood loss. Patients with upper GI bleeding typically present with melena, hematemesis, or blood clots mixed with emesis. Patients with lower GI bleeding sometimes report bloody diarrhea, hematochezia, blood seen on toilet paper, or blood streaks or clots mixed with stool. Patients with occult GI bleeding sometimes present with nonspecific signs and symptoms including fatigue, pallor, or anemia.

Certain types of bleeding occur in children of any age; however, many etiologies are age specific and warrant additional distinction (Tables 59.1 and 59.2).

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Diagnosis

The first step in the evaluation of a gastrointestinal bleeding episode is to determine if the child is actually bleeding. In the neonate, maternal blood swallowed during birth or from cracked nipples during breast feeding can be mistaken for GI bleeding, in which case an Apt test should be performed to determine whether the blood is maternal in origin. In addition, ingested foods or medicines containing red dye can look like blood in the stool, but is differentiated from GI bleeding based on history and guaiac-based tests for occult blood. Also, children sometimes swallow their own blood from epistaxis or friable mucosa due to nose picking, recent infection, or trauma. A careful history and thorough examination of the oropharynx, nasopharynx, and nares should allow you to safely eliminate these causes of bleeding.

The approach to any patient with gastrointestinal bleeding should begin with an assessment of hemodynamic stability and overall clinical condition (Table 59.3). After determining that the child is truly bleeding, one must characterize the severity of the bleeding and the patient's overall clinical condition to guide the urgency of diagnostic studies and therapeutic interventions. Small-volume or occult bleeding episodes without other clinical signs or symptoms such as altered vital signs, a fall in hemoglobin level, or worrisome findings on abdominal examination are usually not acutely life threatening. Conversely, any bleeding episode accompanied by abdominal tenderness or emesis indicates a potentially life-threatening pathologic process.

Patients with substantial bleeding or who are ill-appearing should have reliable venous access established urgently. Circulating blood volume should be assessed and restored with crystalloid and blood products. Coagulopathy and platelet abnormalities should be corrected with additional blood products. Initial resuscitation should not rely on hematocrit measurements because, due to hemoconcentration, it is an unreliable index of severity of bleeding.

After resuscitation and stabilization is initiated, the site of bleeding must be established and a differential diagnosis

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Table 59.1 Age-based differential diagnosis of gastrointestinal bleeding

	Differential diagnosis	
Age	Upper gastrointestinal bleeding	Lower gastrointestinal bleeding
Newborn (<1 month)	Maternal or swallowed blood	Maternal or swallowed blood
	Allergic enterocolitis (milk or soy)	Allergic enterocolitis (milk or soy)
	Esophagitis	Anorectal fissure
	Gastritis	Necrotizing enterocolitis
	Gastroduodenal ulcers	Malrotation with midgut volvulus
	Mallory–Weiss tear	Hirschsprung disease
	Congenital malformation	Coagulopathy (vitamin K deficiency)
	Intestinal duplication	Liver disease
	Coagulopathy (vitamin K deficiency)	
	Liver disease	
Infancy (1 month–2 years)	Esophagitis	Anorectal fissure
	Gastritis	Allergic enterocolitis (milk or soy)
	Gastroduodenal ulcers	Intussusception
	Varices	Meckel's diverticulum
	Mallory–Weiss tear	Lymphonodular hyperplasia
	Hemangiomas	AVMs
	Dieulafoy's lesion	Infectious colitis
	Allergic enterocolitis (milk or soy)	Intestinal duplication
		Hemolytic uremic syndrome
		Henoch–Schonlein purpura
Preschool (2–5 years)	Esophagitis	Infectious diarrhea
	Gastritis	Juvenile polyps
	Gastroduodenal ulcers	Intussusception
	Varices	Meckel's diverticulum
	Mallory–Weiss tear	Lymphonodular hyperplasia
	Dieulafoy's lesion	AVMs
		Henoch–Schonlein purpura
		Hemolytic uremic syndrome
School age (>5 years)	Esophagitis	Infectious diarrhea
	Gastritis	Juvenile polyps
	Gastroduodenal ulcers	Inflammatory bowel disease
	Varices	AVMs
	Mallory–Weiss tear	
	Dieulafoy's lesion	

should be generated based on the child's age and clinical presentation. A thorough history and physical examination (Table 59.4) will direct subsequent laboratory studies including a CBC, liver function tests, coagulation studies, serum electrolytes, BUN, creatinine, and a type and cross. Signs of cutaneous bruising, jaundice, ascites, or prominent anterior abdominal wall veins suggest coagulopathy or liver disease as the underlying cause of gastrointestinal bleeding. Patients who present with a history of hematemesis, coffee-ground emesis, or melena are more likely to have an upper gastrointestinal source of bleeding, whereas patients who present with bright red blood per rectum, bloody diarrhea, or hematochezia are more likely to have a lower gastrointestinal source of bleeding. Patients with occult gastrointestinal bleeding will need a combined workup to evaluate for both upper and lower gastrointestinal sources of bleeding.

In patients with suspected GI bleeding, a nasogastric tube lavage with room temperature or warmed fluid should be performed to assess the likelihood of an upper source of bleeding and to remove particulate matter and clots from the stomach to facilitate upper endoscopy. A lavage that returns blood or coffee grounds indicates an upper GI source of bleeding. An NG lavage that yields clear fluid does not rule out an upper gastrointestinal source because the pylorus is sometimes closed. Although there is a 20 % false-negative rate with a negative NG lavage, aspiration of non-bloody bilious fluid reflects an open pylorus and makes an upper gastrointestinal source of bleeding very unlikely.

Table 59.2 Common presentation and workup of specific causes of gastrointestinal bleeding

Diagnoses	Suggestive history/physical findings	Age groups	Diagnostic test
Upper gastrointestinal bleeding			
Esophagitis, gastritis, or gastroduodenal ulcers	Vomiting, GERD, epigastric pain, dysphagia, indwelling NGT or gastrostomy tube, critical illness, NSAIDs, alcohol, caustic ingestion	All age groups	EGD
Mallory–Weiss tear	Hematemesis after forceful vomiting	All age groups	EGD
Varices	Hematemesis with hepatomegaly, splenomegaly, jaundice, or ascites	Infancy and older	EGD
Lower gastrointestinal bleeding			
Anorectal fissure	Painful defecation with streaks of red blood on stool	All age groups	Physical exam
Allergic colitis	Blood-stained vomiting or diarrhea within 48 h of introducing formula	Neonates and infants	History
Necrotizing enterocolitis	Nonspecific systemic signs of toxicity with abdominal distention, tenderness, vomiting, thrombocytopenia, or diarrhea with enteral feeding	Neonates (especially preterm)	KUB
Malrotation with midgut volvulus	Melena with abdominal distention and bilious emesis	Neonates	Upper GI series
Hirschsprung disease	Delayed meconium passage (>48 h) or progressive constipation with abdominal distention	Neonates	Contrast enema and suction rectal biopsy
Intussusception	Sudden-onset, severe, colicky pain with vomiting and bloody mucoid stool; possible abdominal mass	Infants, preschool	Contrast enema or ultrasound
Meckel's diverticulum	Well child with large-volume painless bleed	Infants, preschool	Meckel's scan
Lymphonodular hyperplasia	Painless bleeding after viral illness or allergic colitis	Infants, preschool	Colonoscopy
Juvenile polyp	Painless rectal bleeding with blood on top of the stool	Preschool, school age (up to 8 years old)	Colonoscopy
Infectious diarrhea	Bloody diarrhea with fever, pain, or tenesmus	Preschool, school age	History, stool cultures
Inflammatory bowel disease	Chronic bloody diarrhea with weight loss, anorexia, arthralgia, or erythema nodusum	School age	Colonoscopy

Table 59.3 Clinical signs of severe gastrointestinal bleeding or pathology

Signs associated with significant blood loss	Signs associated with significant underlying pathology
Diaphoresis	Abdominal distention
Restlessness	Abdominal pain/tenderness
Pallor	Abdominal mass
Altered mental status	Fever
Delayed capillary refill	Emesis
Orthostatic blood pressure or heart rate	Altered mental status
Lethargy	
Ileus	
Hematocrit drop	

For patients with suspected *upper GI bleeding*, esophagogastroduodenoscopy is the diagnostic modality of choice, as it often allows identification and treatment of the bleeding source and helps one predict the risk of rebleeding (Table 59.2). EGD can be performed safely in children, but requires deep sedation or general anesthesia and the use of small endoscopes, which can limit interventional capabilities. It should be performed in children who present with severe bleeding, persistent low-grade bleeding, or recurrent episodes of bleeding. Elective intubation should be considered in patients with ongoing hematemesis or altered respiratory or mental status to prevent aspiration and make EGD easier to perform. Also, the use of NG lavage and intravenous erythromycin (a motilin receptor agonist) prior to EGD might improve visualization and improve the diagnostic and therapeutic yield. When one is unable to determine the source of bleeding by EGD, angiography or a

Table 59.4 Important components of history and physical exam

History	Physical exam
Blood in emesis, stool, or occult	Vital signs (orthostatic)
Time course of bleeding	Mental status (lethargy, restlessness)
Amount of bleeding	Skin color
Color and consistency of stool	Capillary refill
Location of blood in stool	Cutaneous bruising
History of previous GI bleed	Jaundice/scleral icterus
History of bleeding disorders/bruising	Oropharyngeal/nasopharyngeal mucosa
History of liver disease/varices	Abdominal distention/ascites
Medication/drug history	Abdominal tenderness/masses
Heart burn/dyspepsia symptoms	Abdominal wall veins
Abdominal pain	Nasal mucosa
Dysphagia/regurgitation	Rectal/perianal exam
Fever	
Weight loss/poor feeding	
Irritability	

tagged red blood cell scan are useful diagnostic adjuncts. Angiography can allow detection of bleeding at a rate of 1–2 mL/min and tagged red cell scans can be used to detect bleeding at a rate as low as 0.1 mL/min. Barium studies are contraindicated because they make other studies (including EGD and angiography) more difficult to interpret.

The diagnostic workup for *lower gastrointestinal bleeding* depends on the patient's presentation and age (Table 59.2). Anorectal fissure can be confirmed on physical exam by spreading the perineal skin to evert the anal canal. Infants with recurrent fissures or patients with fissures occurring at older ages should be assessed for inflammatory bowel disease, sexual abuse, or rectal trauma secondary to a foreign body.

Milk- or soy-induced enterocolitis (allergic colitis) can be diagnosed presumptively by presenting three challenges with milk or soy formula and documentation of the resolution of symptoms upon elimination of the formula. Infants with milk protein allergy should be switched to a casein hydrolysate formula. Gross bleeding should resolve within 3 weeks and occult bleeding by 12 weeks.

For neonates with concern for necrotizing enterocolitis (NEC) or intestinal obstruction, an abdominal radiograph might reveal an abnormal bowel gas pattern, a dilated solitary loop of bowel, or pneumatosis intestinalis. Neonates and infants with bilious emesis and melena need an urgent upper gastrointestinal series to rule out malrotation, unless they are ill-appearing or have a tense abdomen, in which case they should be prepared for urgent laparotomy. Infectious colitis (caused by organisms that produce a shiga-like toxin or are invasive) and pseudomembranous colitis (*Clostridium difficile*) are relatively common causes of lower gastrointestinal bleeding and are confirmed or ruled out with the appropriate stool culture or toxin assay.

For patients with suspected intussusception, an ultrasound or contrast enema should be performed. In patients with suspected Hirschsprung disease, a contrast enema is indicated and in many cases will demonstrate a segment of dilated colon proximal to the aganglionic segment. These patients should subsequently undergo a suction rectal biopsy to document aganglionosis. Rarely, a patient with Hirschsprung disease will present with large amounts of bleeding due to enterocolitis or megacolon and need immediate rectal decompression or urgent colostomy.

Children who present with painless rectal bleeding should be evaluated for Meckel's diverticulum. Bleeding is often profuse but often intermittent and the child is typically otherwise asymptomatic. It is caused by a peptic ulcer within the diverticulum or in the adjacent ileal mucosa due to acid secreted by ectopic gastric mucosa that is sometimes present within the diverticulum. Patients with "painless rectal bleeding" suggestive of a Meckel's diverticulum should undergo a [99] technetium pertechnetate nuclear medicine ("Meckel's") scan. The tracer binds to gastric mucosa and is highly accurate, especially when enhanced by pretreatment with pentagastrin or an H2-blocker, but it is not 100 % accurate. Therefore, if the clinical suspicion is high, it might still be reasonable to recommend diagnostic laparoscopy despite a negative scan.

Colonoscopy is indicated for suspected lower GI bleeding that cannot be explained on the basis on the patient's presentation and the studies outlined above. In patients for whom an upper gastrointestinal source of bleeding cannot be excluded, EGD should be performed in the same setting as colonoscopy. Other studies that can sometimes help localize a lower gastrointestinal bleeding source include CT, US, tagged-RBC scan, angiography, capsule endoscopy, and CT enteroclysis.

Treatment

Most patients with upper GI bleeding are hemodynamically stable. Bleeding mucosal lesions from gastritis or esophagitis are usually self-limited. Patients with suspected gastritis or esophagitis who are clinically well and have normal laboratory values may be placed on acid suppression therapy and followed as an outpatient. Patients presenting with significant hemorrhage from suspected gastroduodenal ulcers, gastritis, or esophagitis should be placed on intravenous proton pump inhibitors and undergo EGD. An octreotide infusion might also be beneficial while awaiting EGD. Endoscopic therapies to stop bleeding include clipping, epinephrine injection, and contact thermal coagulation.

Patients with continued bleeding from an identified source after EGD should be considered candidates for emergent surgical exploration with either oversewing or resection of the bleeding site. Angiography may also be considered for patients with continued bleeding prior to an operation. Once bleeding is controlled, all patients should be placed on acid suppression therapy with antacids, sucralfate, H2 blockers, or proton pump inhibitors to prevent rebleeding.

For patients with bleeding esophageal varices, an intravenous octreotide infusion should be started. Stable patients should undergo urgent EGD with sclerotherapy or banding of the varices. Unstable patients with bleeding varices should be admitted to the intensive care unit, intubated, and fluid resuscitated. A Sengstaken–Blakemore tube may be used to tamponade the bleeding while preparations are made to perform EGD when the patient has been adequately resuscitated. The incidence of rebleeding from varices can be decreased by performing endoscopic sclerotherapy and banding and using nonselective beta-blockers. In children, sclerotherapy can cause ulceration and is associated with a 15 % incidence of esophageal stricture. Based on data in adults, banding might be more effective than sclerotherapy as it appears to result in improved survival, fewer episodes of rebleeding, and a lower complication rate. Patients with portal hypertension and intractable variceal bleeding may be considered for urgent transjugular intrahepatic portosystemic shunt, surgical portosystemic shunt, or liver transplantation.

Patients with lower GI bleeding are usually stable and well-appearing. Children with lower GI bleeding and abdominal pain should be evaluated for intestinal ischemia from midgut volvulus, intussusception, mesenteric thrombosis, or an incarcerated hernia. These children should be aggressively resuscitated and prepared for emergency laparotomy. Patients with Meckel's diverticulum should undergo diverticulectomy or bowel resection, which can usually be performed using a laparoscopic-assisted or minilaparotomy approach. Patients with Hirschsprung disease require rectal decompression and subsequent surgical resection of the aganglionic segment and a pull-through procedure.

Stable patients with intussusception should undergo an air or water contrast enema to attempt reduction, with surgery reserved for radiographic failure. Patients with suspected intussusception and severe hemorrhage or shock should be resuscitated and brought immediately to the operating room. Colonoscopy can be used to treat polyps with snare polypectomy and cautery. Colonic ulcers, telangiectasias, and hemangiomas can be treated during colonoscopy with epinephrine injection and either cautery or clipping. In patients with multiple polyps, polyposis syndromes (including Peutz–Jeghers syndrome) should be considered and repeat colonoscopy should be performed every few years.

Neonates with NEC should be treated with ICU monitoring, bowel rest, and antibiotics, with surgical intervention reserved for disease progression or evidence of perforation. Milk or soy protein allergic colitis is treated by changing formulas. Children with anal fissures associated with constipation should be treated with stool softeners and lubricants and those associated with diarrhea should be treated by keeping the perineum clean and dry.

The approach to any patient presenting with gastrointestinal bleeding should begin with an assessment of hemodynamic stability and overall clinical status. Resuscitation is the first therapeutic step in any severe gastrointestinal bleeding episode. Subsequently, based on the patient's age, presentation, and the presumed source and severity of bleeding, appropriate and timely diagnostic and treatment algorithms should be instituted.

Editor's Comment

Determining the source of GI bleeding in children, as in adults, can be challenging and time consuming, but a systematic algorithm-based approach is usually best. In most institutions, the diagnostic and initial therapeutic steps are undertaken by pediatric gastroenterologists rather than surgeons, though a pediatric surgeon is usually made aware early in the process. The approach includes initial assessment and resuscitation (ABCs), careful history and physical examination, search for and correction of coagulation abnormalities, distinction between upper and lower GI sources of bleeding (NG lavage), and focused endoscopy and imaging studies. It is not uncommon for the clinicians treating these children to be anxious, disorganized, and quick to recommend surgery despite not yet having identified a source for the bleeding. The role of the surgeon is to maintain equanimity, keep the patient safe, and help guide a systematic diagnostic approach.

A true exploratory laparotomy in a child with GI bleeding is rarely a good idea. However, an operation will sometimes be necessary despite the source of bleeding having been only partially localized (right colon, stomach, mid-small bowel). Intraoperative techniques to localize the bleeding include sequential isolation of short segments of the bowel using non-

crushing bowel clamps, which might demonstrate a specific segment that fills with blood; intraoperative endoscopy, in which the bowel is placed over the end of an endoscope passed through a natural orifice by the gastroenterologist; serial enterotomies in the area of interest (stomach, duodenum, jejunum, ileum, colonic segment) with gross visualization of the mucosa; empiric resection of the bowel segment in question; and, only as a last resort, one or more temporary enterostomies to see, over the course of several hours or days postoperatively, which part of the bowel the blood is coming from. Though none of these techniques are easy to perform or particularly effective, they are listed here in decreasing order of preference. In general, it is best to avoid finding oneself in such a predicament by utilizing any and all localization techniques available *before* taking the patient to the operating room.

Given its limited effectiveness and relatively high complication rate, the Sengstaken–Blakemore tube should rarely, if ever, be used in children with suspected variceal bleeding, except as an extreme measure to save a life or temporize. It is more appropriate to use drugs, aggressive resuscitation with blood products, and emergent upper endoscopy by an experienced gastroenterologist or surgeon who is prepared to definitively treat the underlying varices.

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Enterocutaneous Fistula

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Enterocutaneous fistula (ECF) is an uncommon but complex problem faced by pediatric surgeons. While there have been significant improvements in the management and care of patients with ECF, they still carry a high morbidity and the associated mortality remains high (up to 20 %). The majority (approximately 80 %) of ECFs in children arise as a complication of surgical or radiologic intervention. Causes of spontaneous ECF include inflammatory bowel disease, infectious causes (especially in areas where tuberculosis, actinomycosis, and typhoid are endemic), trauma, and malignancy. There is a paucity of data on ECF in the pediatric population, and the majority of the management strategies are extrapolated from experience in adult populations, which is itself largely based mostly on case series and expert opinion. Effective treatment of ECF requires comprehensive, multidisciplinary management and the disease often has a prolonged clinical course.

The management of ECF can be broken down into two phases: the initial acute phase followed by the planning and execution of definitive management (Table 60.1). During the acute phase, the goals of treatment are to control sepsis, correct fluid and electrolyte abnormalities, support the patient's nutrition, and provide wound care and skin protection.

Presentation and Initial Management

Sepsis frequently accompanies the development of an ECF. In postoperative patients, ECFs result from anastomotic leak, missed enterotomy, bowel ischemia, or injury during fascial closure. Spontaneous ECFs result from underlying pathology that leads to a bowel perforation and subsequent fistula development. All patients presenting with an ECF should be investigated for an associated abdominal abscess. CT is the investigation of choice in older children. In premature infants and neonates, an US is often sufficient for detection of an abscess.

Initial control of abdominal infection should include percutaneous drainage procedures when possible, as early surgical intervention is associated with increased morbidity. However, patients presenting with peritonitis or frank sepsis may require emergent surgical intervention. Rarely can an ECF be closed in the acute setting and exteriorization and proximal diverting stoma are preferred operative strategies. Antibiotic therapy is typically required in the acute management of patients with ECF. The choice of antibiotics should be directed toward the etiology and location of the fistula and guided by local bacterial nomograms and sensitivities. In some patients, antifungal therapy may be required. Patients that have had recent hospitalizations or live in assisted living facilities should be screened for drug-resistant pathogens.

Dehydration and acid–base and electrolyte abnormalities, especially hypokalemia, frequently accompany an ECF. Upon presentation the patient's fluid status should be assessed and their intravascular volume replaced with intravenous fluid. Fistula output should be closely monitored and recorded so that fluid administration can be adjusted to losses. Fistula losses are typically high in potassium and patients should be given an IV solution containing supplemental potassium. Patients with proximal duodenal or pancreatic fistulas may require replacement of bicarbonate losses. During the initial work-up and management of an ECF, patients should have frequent monitoring of serum electrolytes in order to adjust fluid management. Younger infants and neonates have diminished ability to regulate their serum sodium and should be monitored for hyponatremia, especially in the setting of a high-output fistula. Sodium supplementation of feeds may be needed to support maintenance of fluid and electrolyte balance and promote weight gain.

Somatostatin analog (octreotide) has been shown to decrease GI fluid secretion. It also diminishes splanchnic blood flow and intestinal transit time. Somatostatin and octreotide have been used to facilitate spontaneous closure

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Table 60.1 Principles for the management of enterocutaneous fistula in children

Acute phase	
Sepsis control	■ Assess for associated intra-abdominal abscess/contamination
	■ Radiology-guided control when possible in the acute setting to avoid further bowel injury
	■ Broad-spectrum antibiotic coverage
Fluids and electrolytes	■ Close monitoring of fistula output and serum electrolytes
	■ Replacement of losses to euvolemia and normal serum electrolytes
	■ Consider somatostatin and somatostatin analogs to decrease fistula output
Nutrition support	■ Initially minimal oral intake to assess fistula output/volume
	■ Enteral nutrition preferred if the patient tolerates and there is minimal change in fistula output
	■ If TPN is required, consider early introduction of liver protective strategies
	■ A combination of enteral and parenteral nutrition is often required
Wound care	■ Essential to facilitate fluid and electrolyte management
	■ Ostomy appliance is helpful
	■ Negative-pressure wound therapy is safe in children with appropriate modifications
Definitive care	
Anatomic definition	■ Combination of imaging modalities often required
	■ Essential to rule out distal obstruction
Predictors of non-healing ECF	■ Distal obstruction
	■ Foreign body
	■ Short fistula tract
	■ High-output fistula tract
	■ Previous radiation
	■ Nonsurgical cause
Surgical repair	■ Defer until abdominal infections have resolved and patient is nutritionally optimized
	■ Dedicate sufficient operative time
	■ Careful lysis of adhesions
	■ Resection of the fistula associated with better outcome than suture repair
	■ Improved outcomes with abdominal wall closure

of ECF in adults. These agents are associated with increased likelihood of spontaneous ECF closure and decreased time to closure. There have been few case reports on the use of these agents in the management of ECF in children. Most patients tolerate somatostatin well; however it must be used with caution in infants with a history of bronchopulmonary dysplasia as its nonselective vasoconstrictive effects can worsen pulmonary hypertension. Other agents that may be effective in decreasing fistula output include proton pump inhibitors, H_2 blockers, and antimotility agents such as loperamide and codeine.

Malnutrition frequently accompanies an ECF, and correction of nutritional deficiency is essential to promote healing. Many patients will have a marginal nutritional status prior to the development of the ECF. High-output fistulas and proximal small bowel fistulas can result in significant protein loss in the fistula effluent. They can also result in the patient having a functional short bowel in which there is insufficient intestinal length for nutrient digestion and absorption. Patients are also frequently in a catabolic state due to sepsis or inflammatory conditions. Energy and protein requirements must not only meet the patient's immediate metabolic demands but also provide adequate substrate to support ongoing growth and development.

The decision to provide enteral versus parenteral nutrition should be individualized to each patient based on their fistula output, ability to tolerate oral/enteral nutrition, and their specific anatomy and intestinal length in continuity. There is insufficient evidence to promote one modality over the other in terms of facilitating ECF healing and closure. Correction and prevention of malnutrition is the primary goal of nutritional support, and this can be achieved by several modalities. Total parenteral nutrition has traditionally been used, as bowel rest was advocated to slow fistula losses and encourage closure. While TPN has been shown to reduce the volume of gastrointestinal secretions, there is a lack of evidence to support this translating to improve ECF closure.

Enteral nutrition has the benefit of preserving intestinal mucosal integrity and avoiding the complications associated with TPN (mechanical line issues, electrolyte abnormalities, infectious complications). Enteral nutrition is also easier for parents and caregivers to provide out of hospital. In some

situations, it may be possible to collect the fistula effluent and refeed it into the distal intestine, essentially simulating intestinal continuity, thereby minimizing fluid losses and maximizing enteral function. While distal intestinal refeeding can be beneficial, it requires nursing staff that are familiar with the process and acceptance and compliance from both nursing staff and parents. Infants and neonates are at increased risk of TPN-induced cholestasis, should long-term TPN be required. Septic episodes such as those seen with the development of an ECF can also worsen cholestasis. Liver protective strategies, including lipid minimization, early initiation of enteral nutrition, and alternative lipid sources, should be used when available. Partial enteral nutritional support should be considered, even when parenteral nutrition is required to meet the patient's nutritional needs, as the enteral intake will serve to mitigate the potential hepatotoxic effects of TPN. Whichever nutritional modality is chosen, these patients have complex nutritional care needs and are best managed by a multidisciplinary team with experience in intestinal rehabilitation.

Control of the fistula output and wound management are important early priorities for patients with ECF. The goal of wound management is to collect the fistula effluent in a way that preserves the integrity of the patient's skin, protecting it from the corrosive effects of the effluent, and promotes healing of the fistula. Detailed recording of losses can help direct replacement therapies for fluids and electrolytes. The approach used must be tailored to each patient, their size, and the anatomy of their fistula. Two commonly used strategies include wound drainage bags (a modified ostomy appliance) and negative-pressure wound therapy (NPWT). A variety of barrier creams, dressings, and wound–stoma management devices are available. The successful care of patients with ECF requires a nurse or enterostomal therapist familiar with their use and application.

Negative-pressure wound therapy is a useful addition to the management strategies available for patients with ECF. Application of NPWT has several advantages including promotion of spontaneous closure, decreased frequency of dressing changes, and portability, which facilitates mobility and patient's participation in care. NPWT can also be managed in an outpatient setting allowing children to continue to attend school and other extracurricular activities. There have been some concerns about the safety of NPWT in young children; however several centers have successful used NPWT to manage open abdomens and ECF in infants and premature neonates. The devices require adaptation to the patient's size, and in premature and low birth weight infants, the suction pressure should be reduced (typically to −75 mmHg or lower if applied directly to bowel). If being used in the setting of an open abdomen, care needs to be taken to place a protective layer of plastic against the bowel to prevent the formation of further fistulas.

Enteroatmospheric fistula (EAF) is a subset of ECF in which the bowel communicates with the air. These typically arise in the setting of an open abdomen in patients who are critically ill following abdominal sepsis or trauma. EAF can be classified as superficial if the opening in the intestine drains at the surface of the abdominal cavity and deep if the fistula drains somewhere deep within the peritoneal cavity. Superficial EAF can be managed by either direct suture closure or conversion of the EAF to a stoma. Direct suture closure is accomplished by limited dissection of the fistula, primary suture repair, and then protection of the repair with a skin graft or biologic mesh. Suture closure has a low success rate and multiple attempts at closure are often required but can be attempted with low risk. Alternatively a wound care or NPWT system can be devised that converts the superficial EAF into a functional stoma. This requires the availability of an experienced enterostomal therapist.

Deep EAF are much more difficult to manage. They typically present with peritonitis in a critically ill child. The initial goal is resuscitation, followed by operative intervention for source control and drainage of the peritoneal contamination. NPWT can then be used to provide continuous drainage of the peritoneal cavity and encourage wound granulation. One useful technique for the management of a deep or multiple EAF is to intubate the fistula (Foley catheter, T-tube, Malecot) and to bring the tube out through the vacuum sponge. With time the goal is to convert a deep EAF to a superficial EAF that can then be managed with closure or an ostomy device. Caution needs to be applied when using an NPWT system in the setting of an open abdomen as it has been associated with the formation of new EAF. A protective layer should always be placed between the bowel and the sponge, care should be taken when changing the system to avoid abrading the bowel, and in smaller children and infants, the negative pressure should be reduced (typically to −50 mmHg).

Surgical Planning

Following the acute phase of resuscitation, sepsis control, and stabilization, attention is turned to the planning and execution of definitive management of the ECF. This process involves careful and detailed demonstration of the specific anatomy of the ECF, identification of factors that will either encourage or preclude spontaneous closure, initiation of medical therapy for those patients with underlying inflammatory or infectious conditions, and planning definitive surgical care should it be required.

In both the resuscitation phase and definitive stage of management, the patient will require imaging studies to look for associated abscesses and to determine the origin, length, and complexity of the ECF. The choice of study will depend on the patient's age, size, and stability, and often more than

one modality is required to fully delineate the ECF. A contrast fistulogram can confirm the diagnosis of the ECF may be sufficient to demonstrate the anatomy of the tract and involves less radiation exposure than a CT scan. However in the setting of ongoing abdominal sepsis or a complex ECF, a fistulogram will not identify associated fluid collections. CT with oral or rectal contrast will provide detailed information regarding the ECF and on associated abscess and other pathologies such as distal obstruction. In premature infants and neonates, the radiation exposure of a CT scan should be avoided and consideration should be given to the use of MRI. MR enterography with contrast can provide excellent anatomic detail; however it does require patient cooperation and younger children require sedation or anesthesia. In children with chronic diseases such as inflammatory bowel disease (IBD) who will require numerous imaging studies, non-radiation imaging modalities, such as US and MRI, should be used when appropriate in order to limit their lifetime radiation exposure.

Rates of spontaneous closure of ECF vary widely depending on the population studied, and the expectation of spontaneous closure needs to be individualized to each patient. Factors that have traditionally been thought to preclude spontaneous closure include *distal obstruction*, *foreign body*, a well-established *epithelialized tract*, a *high-output fistula*, ongoing *inflammation* or *infection*, previous *radiation exposure*, and a *short* fistula tracts.

In adults, a high-output fistula is defined as one that drains more than 500 mL in 24 h. No specific definition exists in children; however extrapolating from the adult definition, an output of more than 5–10 mL/kg/24 h in a child would be considered high output.

Patient-specific factors also need to be considered in the prediction of spontaneous closure of an ECF. Patients who are malnourished, have underlying inflammatory etiology, or have ongoing or recurrent septic episodes are unlikely to have spontaneous closure of the fistula. Patients who develop an ECF secondary to Crohn's disease may have spontaneous closure of the fistula with the initiation of biologic therapy. Patients with IBD and ECF should be managed collaboratively with both a surgeon and a gastroenterologist in order to provide both optimal medical and surgical care and maximize potential for spontaneous ECF closure.

Surgical Treatment

Definitive surgical intervention is required for non-healing fistulas. The timing of surgery must be individualized. Prior to surgical intervention, the patient should be free from infection, nutritionally optimized (based on both clinical and biochemical assessments), and far enough out from their most recent operation (6–8 weeks) so that peritoneal inflammation and vascularized adhesions are minimized. Goals of surgical intervention are safe entry into the abdominal cavity with preservation of the abdominal wall in a manner that provides adequate tissue for closure, mobilization of the entire GI tract to identify and address areas of obstruction, resection of the ECF and involved bowel, and reestablishment of intestinal continuity. Adequate operative time should be allotted, as safe conduct of the operation requires patient, careful adhesiolysis, and avoidance of secondary bowel injury.

Bowel anastomoses should be separated from each other where possible to avoid re-fistualization. In the setting of multiple anastomoses, proximal intestinal diversion (enterostomy) should be considered to protect the distal reconstructed bowel. If mesh is required to reconstruct the abdominal wall, a biological or absorbable product should be used to minimize the risk of re-fistualization. Despite optimal medical and surgical care, there remains a significant risk of recurrence.

Outcomes

In adults and possibly in children as well, mortality in this population remains high at 10–15 %, with a successful closure rate ranging from 70 to 90 %. Spontaneous closure is achieved in a minority of patients, up to about a third. Morbidity associated with an ECF remains high, with reports of close to 90 % of patients experiencing a significant complication. Morbidity arises from both the disease process itself and the high rate of comorbidity among those with ECF. Operative complications associated with repair of ECF approach 85 % in most series and include anemia, sepsis, wound problems, and pulmonary complications with up to 25 % of patients requiring prolonged (>48 h) ventilation.

Particular attention is being paid to assessing factors that are predictive of spontaneous closure, recurrence, and mortality. Spontaneous closure appears to be more likely in patients who have a surgical cause of the ECF, have low-output fistulas, and have an intact abdominal wall. Recurrence after surgical repair is predicted by operative complications, including organ space infection, mechanical ventilation >48 h, perioperative blood transfusion, and sepsis. Some find that recurrence is lower after resection and primary anastomosis than if the fistula is just oversewn. Multiple predictors of mortality from ECF have been described including an admission serum albumin less than 3.0 g/dL, high-output fistula, sepsis, and multiple or complex fistulas.

ECF is an uncommon but complex and potentially devastating problem encountered by pediatric surgeons. There is a paucity of data on the management of this problem in pediatric patients. Future work needs to focus on the reduction of the associated morbidity and mortality and to refine the modalities

currently in use in adult populations to make them safe and applicable in children. As ECFs in children are infrequent and their management complex, they should be managed in a multidisciplinary fashion including input from surgery, gastroenterology, dietitians, social work/psychologists, pharmacy, and nurses comfortable with complex wound management.

Editor's Comment

Enterocutaneous fistula remains a rare but vexing problem for the pediatric surgeon. Source control of sepsis and effluent is critical for early management, and long-term outcomes are dependent on excellent nutritional replenishment. The surgeon should keep in mind the possibility of underlying IBD when these occur in older children. We tend to use MRI more frequently to define the anatomy of the fistula, thereby avoiding exposure to ionizing radiation.

When faced with an enterocutaneous fistula that was unexpected or one that will not close spontaneously despite optimal nutrition and sufficient delay, the surgeon would do well to recall the traditional factors that are well known to prevent fistula closure: foreign body, radiation, infection/inflammation, epithelialization, neoplasm, distal obstruction, and a short fistula. These need to be ruled out or addressed systematically every time, and it should be kept in mind that more than one could be applicable in a given patient. It is also important to consider variations on these common themes: The foreign body could be silk suture material, an anastomotic staple line, a fecalith, or ingested vegetable matter. Inflammation might refer to the normal inflammatory phlegmon that accompanies healing from an anastomosis or occult IBD. Distal obstruction could be from a segment of dysmotile bowel, undiagnosed Hirschsprung disease, or some other forms of pseudo-obstruction. A short fistula that arises adjacent to the fascial wound can often be closed with absorbable mattress sutures in the fascia itself, assuming the edges of the fistula are adherent to the fascial opening all around—although the epithelialized tract should be excised or debrided, no attempt should be made to mobilize the bowel away from the fascia.

The operation for closure of an enterocutaneous fistula should be delayed as long as possible and can be expected in most cases to take many hours to complete. The parents should be warned of a high risk of recurrence. A contrast enema should be performed preoperatively to rule out colonic stricture, dysmotility, IBD, and Hirschsprung disease. Every adhesion must be taken down and enterotomies avoided. Repairs should be made with absorbable suture, and anastomoses need to be separated from each other and from the fascial closure by viable tissue, healthy bowel, or omentum. Staple lines should be buried with absorbable Lembert sutures.

Vacuum dressings are a huge advance and can help protect the skin and control fluid losses. However if used improperly, they can be dangerous. The degree of suction needs to be the absolute lowest necessary to maintain flow. This is to minimize the gradient across the fistula, prevent small ischemic areas in the exposed bowel which then become secondary fistulas, and avoid a bean-bag phenomenon that can occur in the abdomen when excessive negative pressure is applied in small children resulting in bowel ischemia and vessel thrombosis (compartment syndrome caused by excessively negative pressure and subsequent collapse of the intra-abdominal organs into a tightly compacted mass).

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Part VIII

Colon, Rectum, and Anus

Constipation and Fecal Incontinence

61

Michael D. Rollins II and Desale Yacob

Severe chronic refractory constipation results in a significant burden on the affected child and his or her family. Idiopathic or functional constipation is a diagnosis of exclusion when no anatomic, physiologic, or histologic etiology for constipation can be identified. The Rome III criteria have been created to help standardize the definition of functional constipation. Definitions exist for children less than 4 years of age and those over the age of 4 years. For a child with a developmental age of at least 4 years, two or more of the following symptoms must be present each week for at least 2 months: a maximum of two stools, an episode of incontinence, volitional stool retention, painful bowel movements, large diameter stools, or a large fecal mass in the rectum. Difficult and painful bowel movements often promote withholding behavior and stool accumulation, perpetuating the cycle of constipation.

In addition to physical symptoms, constipation can lead to school absence, multiple medical consultations, exclusion from social activities, and embarrassment, especially if the patient has fecal soiling. These children and their caregivers often suffer from emotional distress including anxiety, depression, and low self-esteem and have a decrease in their quality of life necessitating a behavioral component to their therapy.

Severe constipation or fecal incontinence may be secondary to a variety of conditions that are treated by pediatric surgeons. True fecal incontinence must be distinguished from overflow incontinence or encopresis. Children with true fecal incontinence can include some surgical patients with an anorectal malformation (ARM), Hirschsprung disease, and congenital or acquired spinal cord problems. Patients with encopresis, who have the potential for bowel control but continue to soil, likely suffer from severe constipation with rectal fecal impaction.

Most patients who have undergone repair of an ARM suffer from some degree of a functional defecation disorder secondary to an abnormality in their fecal continence mechanism. Some patients with Hirschsprung disease suffer from fecal incontinence because of surgical damage to their anal canal or sphincters while others may struggle with constipation. These patients may require an artificial means to overcome fecal soiling involving a daily enema. Patients with encopresis, on the other hand, require optimal medical treatment of constipation. This major difference is the key to determining the correct bowel management program that is effective for the individual patient.

Mechanism of Continence

Fecal continence depends on three factors: voluntary sphincter muscles, anal canal sensation, and colonic motility. In the normal patient, the voluntary muscle structures are represented by the levators, the muscle complex, and the parasagittal fibers. Patients with ARMs have abnormal voluntary striated muscles with different degrees of hypodevelopment.

Voluntary muscles are used only when the patient has an intact anal sensory mechanism that triggers activation. Most patients with anorectal malformations, excluding those with rectal atresia, are born without an anal canal. Therefore, sensation does not exist or is rudimentary. Another group of patients who may lack anal canal sensation are those with spinal cord problems. Those with Hirschsprung disease are born with a normal anal canal, but this can be injured at the time of their colonic pull-through procedure. Patients with perineal trauma may have an injured or destroyed anal canal.

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Most individuals can perceive distention of the rectum. This point is important for patients undergoing repair of imperforate anus. The distal rectum and anus must be placed within the sphincter mechanism in order for patients to sense stretching of the voluntary muscles (proprioception). These children might not feel liquid or soft fecal material because the rectum is not adequately distended. Thus, to achieve some degree of bowel control, a patient must have the capacity to form solid stool.

Most patients with an ARM suffer from some disturbance of bowel motility. Constipation is the main clinical manifestation of this and seems to be more severe in patients with lower defects. Constipation that is not aggressively treated eventually results in an ectatic, distended colon with or without rectosigmoid dilation which causes more severe constipation and overflow incontinence.

Evaluation

The diagnostic evaluation of the child with constipation or incontinence varies depending on their age and developmental stage. The differential diagnosis will vary, as will the available management options.

Newborns/Infants

The first stool is passed within 24 h of birth in about 90 % of newborns and close to 98 % will have passed their first meconium stool within 48 h. A newborn who fails to pass stool within the first 48 h of life should be closely monitored and evaluated. A careful examination of the perineum should be performed to rule out a rectoperineal fistula, anal stenosis, or a presacral mass. Plain abdominal radiographs will sometimes suggest a particular diagnosis, such as a hemisacrum associated with a presacral mass, or simply reveal evidence of distal intestinal obstruction. Unless the patient has evidence of peritonitis, a water-soluble contrast enema should be performed to evaluate for small left colon syndrome, meconium ileus, meconium plug syndrome, or Hirschsprung disease. A suction rectal biopsy should be performed if there is clinical or radiographic concern for Hirschsprung disease. In patients older than 1 year, a full thickness biopsy is often required in order to obtain an adequate specimen. It is important to note that premature infants may have a delayed passage of meconium without an underlying problem.

Organic etiologies such as cystic fibrosis, neuromuscular, metabolic, or endocrine disease are other possible causes of constipation. However, constipation in infants is more likely to be of functional nature. The typical onset of functional constipation in this age group is around the time of transition from breast milk to formula or introduction of solid foods. The infant may have hard stools that are difficult to pass and painful. This traumatic stooling experience may result in voluntary withholding of stool. This behavior is characterized by grunting, arching of the back, and stiffening of the legs and the body.

Infants with functional constipation may respond to the addition of fruit juices to their intake. Changing formula, especially if the current formula contains iron, may be helpful. Some solid foods that are introduced to the infant's diet such as rice cereal may also be constipating.

If dietary modification is unsuccessful, then a stool softener or a stimulant should be added to the regimen. In patients with mild idiopathic constipation, a trial of polyethylene glycol, milk of magnesia, lactulose, or sorbitol, which are all stool softeners, should be considered. When initiating a stimulant laxative, it is imperative that the parents be educated on how to adjust the dosage in order to achieve a soft and easy-to-pass daily bowel movement. In children with more severe idiopathic constipation, a history of ARM repair or surgery for Hirschsprung disease, a stimulant laxative by itself or in addition to a stool softener should be used. The addition of a water-soluble fiber to promote stool bulk often makes the laxative more effective.

It is important to be aware of a small group of infants who are exclusively breastfed who may not have a daily bowel movement. These patients have a bowel movement once every 2–14 days (average of 5 days). They do not exhibit any discomfort and their stools are soft to loose in consistency. These infants do not require further work up. Infant dyschezia is another entity often mistaken as constipation. These infants will typically present in the first few months of life with excessive discomfort and straining during bowel movements and eventually pass soft or loose stool. This is due to the lack of coordination between the increased intra-abdominal pressure and pelvic floor muscle relaxation. In this scenario, parental reassurance is all that is needed as the problem is self-limited.

Toddlers

A new onset of constipation in the toddler age group is often related to toilet training. It is still prudent to closely review the stooling history of the patient, as organic etiologies in the appropriate clinical setting could be a cause of constipation. If history, physical examination, and contrast enema do not reveal an anatomical reason for the constipation and medical therapy is not effective, then motility studies may be indicated. Some of these studies may not be readily available at all institutions requiring referral to specialty centers. However, transit studies such as a Sitz marker and a plain x-ray done the day after a contrast enema should be available in most institutions. Anorectal and colonic manometry, when indicated clinically, can play a key role in the diagnostic and therapeutic approaches.

Treatment in this age group generally includes dietary modifications, teaching good toileting habits, and use of stool softeners with or without stimulant laxatives. ARM patients usually require a more aggressive bowel management program.

School-Age Children

New onset of constipation in this age group is uncommon. It must be determined if the constipation is really a new issue or a chronic problem that has never been investigated or treated effectively. If it is truly a new problem then one must consider a behavioral cause or possibly physical or sexual abuse. The start of a new school is sometimes associated with new onset constipation. Also, *constipation predominant irritable bowel syndrome* (IBS) is another common diagnosis to be considered. Other potential etiologies include tethered spinal cord or occult spina bifida. The evaluation of these children should include at least a contrast enema and possibly more advanced motility studies.

Evaluation of children with corrected Hirschsprung disease who are struggling with severe constipation might include a full thickness rectal biopsy to rule out a transition zone pull-through. A contrast enema may also help rule out obstructive etiologies due to the surgical approach that was chosen during the pull-through such as a Soave cuff.

Internal anal sphincter achalasia (IASA) should be considered in children with severe medically refractive constipation. The diagnosis is made when anorectal manometry demonstrates absence of the recto-anal inhibitory reflex in a child who has a normal rectal biopsy. While not common, IASA can be identified in approximately 4 % of chronically constipated children. Intrasphincteric injection of *Clostridium botulinum* toxin has been used to treat this condition. It is safe but has variable success. Typically a total of 100 IU of botulinum toxin is equally divided and injected into four quadrants of the anal sphincter. Over time, the child learns the timing for anal sphincter relaxation and the symptoms subside.

Older children with constipation will occasionally present with fecal impaction. An initial attempt at disimpaction with retrograde enemas is reasonable, but manual disimpaction in the operating room under general anesthesia may be required. It is important to ensure that the patient does not have stool impacted in the rectum prior to initiating oral cathartics as this clinical scenario represents a distal bowel obstruction.

Pseudoincontinence (Encopresis)

Patients with ARMs, severe constipation, and the potential for bowel control, as well as those with severe idiopathic constipation, may have overflow incontinence. This occurs due to hypomotility of colon, which results in severe stool impaction and leakage of liquid stool around the impaction. If the child's ARM is associated with a good prognosis (vestibular fistula, perineal fistula, rectal atresia, bulbar urethral fistula, or imperforate anus with no fistula), one should expect that the child will have voluntary bowel movements by the age of 3–4 years (provided the sacrum and spine are normal). About half of these patients occasionally soil their underwear. These episodes of soiling are usually related to constipation and when this is treated properly, the soiling frequently disappears. Children with repaired ARMs and good bowel control may still suffer from temporary episodes of fecal incontinence, especially when they experience a viral gastroenteritis, as they are dependent on the ability to feel solid stool.

True Fecal Incontinence

True fecal incontinence means the patient cannot have voluntary bowel movements. For children with ARM, the provider should be able to predict which patients are likely to have a poor prognosis. Children with an abnormal sacrum, associated myelomeningocele, or flat perineum (poor muscles) are more likely to suffer from incontinence. Also certain types of ARMs, including recto-bladder neck fistula, cloaca with a common channel >3 cm, and complex cloacal malformations, are at risk for true fecal incontinence. Certain patients with Hirschsprung disease and those with spinal problems might also suffer from true fecal incontinence.

A bowel management program with enemas should be implemented at 3–4 years of age. Children with ARMs ready for the bowel management program can be divided into two well-defined groups that require individualized treatment plans. The first and larger group has fecal incontinence and a tendency toward constipation. The second group has fecal incontinence with a tendency toward loose stools. Patients with fecal incontinence after operations for Hirschsprung disease and those with spinal disorders usually fall into the first group and have a tendency toward constipation. A small group of Hirschsprung patients fall into the hypermotile group. These patients have multiple daily stools and a nondilated colon seen on a contrast enema.

Contrast Enema

A contrast enema provides information regarding the diameter and length of the colon and stool burden and also provides catharsis (disimpaction). A stricture or transition zone may also be assessed. A plain abdominal radiograph the following day provides useful information regarding the motility of the colon—if much of the contrast remains, it can be assumed that the child has a hypomotile colon. Colonic

hypermotility is suspected if the patient has fecal incontinence with a tendency toward diarrhea, a normal caliber colon, and no contrast on the follow-up x-ray.

Sitz Marker

A Sitz marker study is an efficient, inexpensive, and readily available colonic transit study. It involves having the patient swallow radiopaque rings (markers) and subsequently have a series of timed plain abdominal radiographs. A child with normal motility will have passed the majority of the markers by day 4 and all of them by day 7. In a patient with total colonic inertia and diffuse dysmotility, these markers accumulate in the right colon. In patients with more of an outlet obstruction and normal colonic motility, the markers will be located predominately in the rectosigmoid colon. Other patients with segmental colonic dysmotility may have markers retained in the affected segment (Fig. 61.1).

Manometry

Children with chronic constipation with or without encopresis who have failed aggressive medical therapy are good candidates for colonic manometry. It can be useful to evaluate colonic motility prior to surgical intervention such as a diverting stoma, antegrade enema procedure, or segmental colonic resection. This evaluation entails functional and anatomic mapping of the colon and is enhanced by performing anorectal manometry to assess the function of the pelvic floor musculature and the anal sphincters.

Colonic manometry requires an adequate bowel prep. The study begins with placement of a manometry catheter with equally spaced recording sites either endoscopically or using fluoroscopic guidance. Typically the study is performed over 6 h. The patient's motility is observed for the first 2 h while still fasting and is then given an age-appropriate meal. This is followed by a postprandial observation period. The colonic motility index is expected to increase following a meal due to the gastrocolic reflex mechanism. An abdominal x-ray is typically done following the postprandial observation period to document the location and course of the catheter as well as the position of the pressure sensors. A colonic stimulant such as liquid bisacodyl or glycerin is then infused through the catheter to induce high-amplitude propagating contractions (HAPCs). If and when the patient has a response to the stimulant medication one is able to accurately localize the origin of each HAPC, as well as the duration and distance (Fig. 61.2). A normal HAPC is defined as contractions with a pressure amplitude greater than 60 mmHg, lasting at least 10 s and propagating 30 cm or more.

The information obtained from a colonic manometry study may demonstrate that a patient has:

1. Normal motility with strong HAPCs that propagate fully to the rectosigmoid junction where they are normally expected to stop

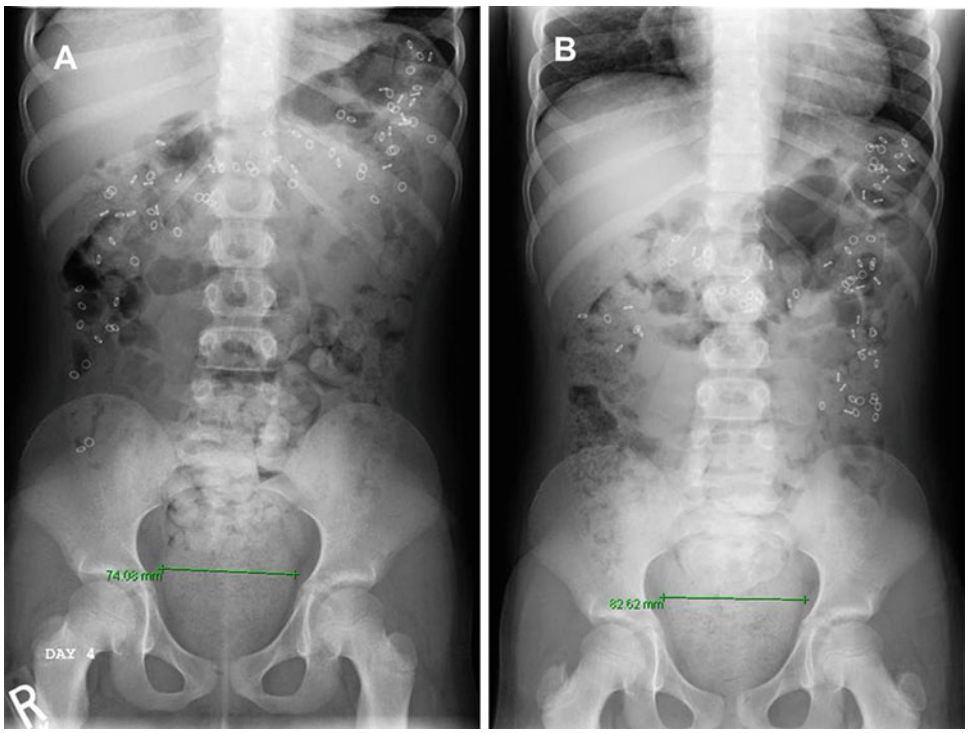

Fig. 61.1 Sitz marker study radiographs taken (**a**) on day 4 and (**b**) on day 7 after daily intake of the 24 markers for 3 days. Most markers are retained in the descending colon by day 7 due to distal colon dysmotility

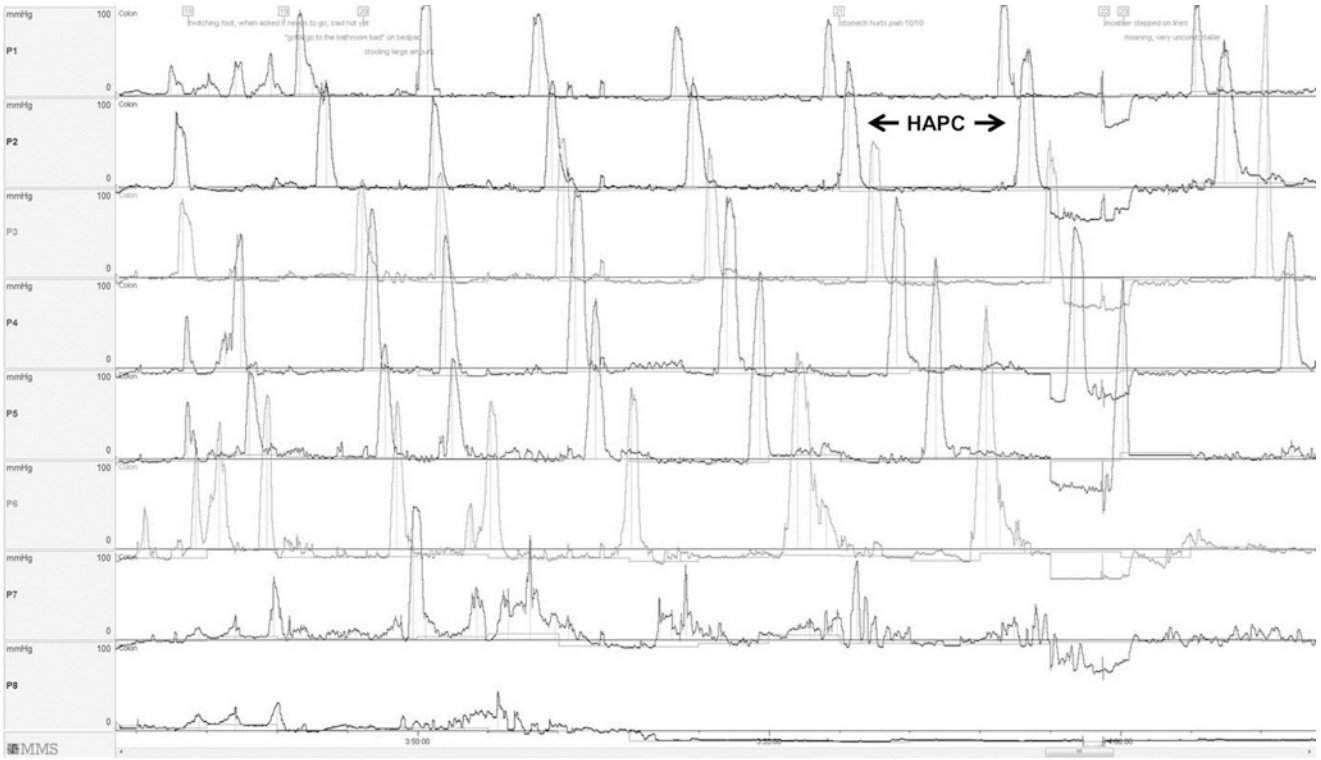

Fig. 61.2 High-amplitude propagating contractions (HAPCs) in a patient with normal colonic motility. The contractions at the *top* represent the proximal colon, while those at the *bottom* are from the distal segments. This study was done with a water-perfused catheter with recording sites spaced by 10 cm

2. Absent motility without any HAPCs in the entire colon despite repeated and escalating doses of a stimulant laxative
3. Normal motility in the proximal colon with HAPCs that terminate at some point prior to reaching the rectosigmoid junction (Fig. 61.3).

Identifying the affected segment of colon is important prior to therapeutic intervention.

Treatment

The treatment of the child with severe refractory constipation is usually a combination of multiple modalities and must be tailored to his or her individual needs. Our approach, though systematic and based on evidence- and experience-based principles, also requires a patient and thoughtful trial-and-error approach to achieve optimal results.

Bowel Management

Children with severe constipation or fecal incontinence will initially go through an intensive week of a tailored bowel management program. This begins with a water-soluble (never barium) contrast enema the day before the office visit and an abdominal x-ray the day of clinic evaluation. The provider is able to determine the diameter and length of the colon and stool burden. This also provides catharsis. Motility can usually be roughly assessed based on the x-ray obtained the day after the contrast enema. A treatment plan is designed based on the patient's history and imaging results, with the therapeutic goal to have the patient empty their colon daily and to be free of soiling.

Management plans generally consist of either high-dose senna-based stimulant laxatives or a daily large-volume enema. However, there is a small group of patients with foreshortened colons and a tendency toward diarrhea who are managed with small-volume enemas, a constipating diet, pectin, and loperamide. In older patients who have been toilet trained in the past but have soiling from encopresis or severe constipation without soiling, high-dose laxatives are initiated following disimpaction. In patients who have never been toilet trained and have a history of soiling or in those patients with a megarectum, daily large-volume enemas are initiated. It is important for a child to have been toilet trained prior to initiating a laxative program. This may be more easily accomplished with the initial use of enemas, which help the child learn what it is like to be clean. Children who do not tolerate retrograde enemas or laxatives, such as those with severe autism, severe anxiety disorder, or a history of abuse, a manual disimpaction under

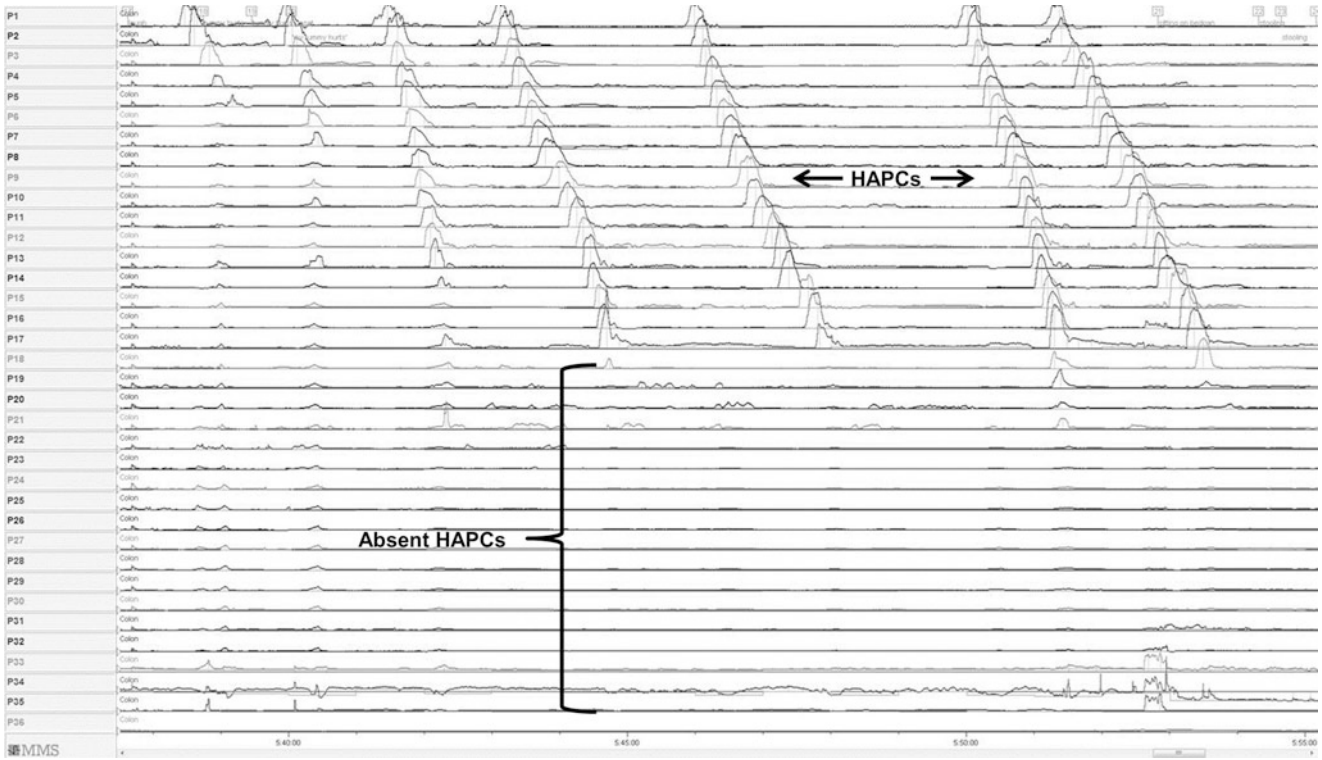

Fig. 61.3 Abnormal colonic manometry with the normal HAPCs terminating early. There are no contractions in the distal rectosigmoid colon. This particular high-resolution solid-state catheter has 36 recording sites each 3 cm apart making it possible to determine the length of the colon with abnormal motility

general anesthesia followed by behavioral and aggressive medical therapy is reasonable. An antegrade continence enema procedure is the next resort if the above strategy fails.

Laxatives

A more aggressive management regimen is required when dietary changes or gentle laxatives fail. Medications that are designed to increase the colon's motility are best when compared with stool softeners. One common misconception is that softening of the stool without a stimulant is all that is needed for effective bowel movements. This approach however may be self-defeating, because loose stool may not result in adequate rectal distention that triggers an urge to defecate. High-dose stimulant laxatives and a water-soluble fiber are initiated once the patient has been disimpacted. The disimpaction process is a vital and often neglected step. This includes the administration of enemas three times a day until the patient is disimpacted (confirmed radiographically). If the patient remains impacted after 3 days despite enemas, then an oral bowel preparation along with manual disimpaction under anesthesia should be considered.

Laxative therapy includes senna-based products at a starting dose of 2 mg/kg. Bisacodyl is another stimulant that has been effective in inducing colonic contractions and stool evacuation. If the child does not have a bowel movement within 24 h, a sodium phosphate enema is administered to evacuate the distal stool, and the laxative dose is increased. The volume of the enema is based on the child's age. In patients less than 4 years old, half of a pediatric phosphate enema (30 mL) is administered, one pediatric enema (60 mL) in children aged 4–10 years, and one adult enema (120 mL) in patients older than 10 years. This process is repeated until the child has one to two soft bowel movements per day and a radiograph confirms an empty rectosigmoid. However, due to the high phosphate concentration in these enemas, no more than one should be administered each day. Water-soluble fiber is administered to patients receiving laxatives to add bulk and increase the efficacy of the laxative. This is dosed at one tablespoon three times a day.

It is important to remember that patients may have laxative requirements that are much higher than the manufacturer's recommendation. Occasionally, in the process of increasing the amount of laxatives, patients may experience severe abdominal cramping, nausea, or vomiting before reaching the desired effect. In these patients, a different medication can be tried but some patients may not tolerate any of these laxatives at a dose that successfully empties the colon, or the colon empties but the patient has severe symptoms.

These patients are considered to have intractable disease and may need to be switched to enemas or considered for surgical intervention. Surgical intervention might include an antegrade continence enema (ACE) procedure, segmental resection of the colon if there is a redundant and dilated segment that is dysmotile on manometry, or a combination of the two.

Enemas

Patients with true fecal incontinence and a tendency toward constipation (*hypomotility*) should not be treated with laxatives but instead need an enema program. The patient and the parents are taught how to clean the colon once daily with an enema so the child stays completely clean for 24 h until the next enema. A plain radiograph will confirm an empty rectosigmoid colon. If "accidents" occur many hours after the enema and the x-ray shows persistent stool in the rectosigmoid colon, then the patient needs a larger-volume enema, a more irritating enema, or both. If accidents occur within a few hours after the enema and the x-ray is clean, then the enema could be too irritating.

Children with true fecal incontinence and loose stools (*hypermotility*) are a very small group of patients with fecal incontinence. This scenario is generally the result of resection of the rectum and sigmoid colon. Rapid transit of stool results in frequent episodes of diarrhea even when an enema effectively cleans their colon. To treat this situation, laxative-type foods are eliminated, and a constipating diet with or without medications (loperamide and water-soluble fiber) to slow down the colon are necessary.

Large-volume enema therapy includes a saline solution (0.9 % saline can be made by adding 1.5 teaspoons of salt to 1000 mL of water) and often requires the addition of irritants. The initial enema volume is generally 20 ml/kg of normal saline. It is rare to use a volume greater than 1000 mL. We have not found the volume of contrast used on the contrast enema to be predictive of the therapeutic volume of saline. If normal saline alone is ineffective, the following irritants are added in succession: glycerin (10–30 mL), Castile soap (1–3 packets, 9–27 mL), and sodium phosphate (30–120 mL). Children should never receive more than one phosphate enema a day because of the risk of phosphate intoxication; those with impaired renal function should avoid them entirely. We generally try to limit the addition of phosphate to the enema to two or three times a week due to the risk of phosphate-induced colitis. Colitis has also been reported with enemas containing soaps.

Patients are taught to hold the enema for 10 min and then sit on the toilet for 30–45 min. The solution is adjusted until the child effectively empties their colon with the enema and has no accidents between enemas. Bowel management may be performed in a similar way in children with a colostomy who are being considered for definitive repair. A child with cloacal exstrophy who has a short amount of colon would be a candidate for bowel management in this way. If the patient has the ability to form solid stool and the stoma bag remains empty of stool for 24 h after the enema, then the child can potentially undergo a pull-through of the stoma.

During the initial week of bowel management, a daily outpatient abdominal x-ray is obtained and the patients and parents are contacted by phone to evaluate treatment. Treatment regimens are adjusted based on the child's clinical and radiographic response. The treatment plan is considered successful when the abdominal radiograph is clear of stool in the left colon and rectum and the child has had no soiling. It is acceptable to have stool present in the right colon on the abdominal radiograph, as that stool will not reach the rectum until it is time for the next enema.

Diet

Children with loose stools have an overactive colon. In these patients, a constipating diet, bulking agents (water-soluble fiber), medication to slow down the colon (loperamide), or some combination of these is used. Patients and their families should be taught the difference between constipating and laxative foods and which to avoid (Table 61.1). If the patient has a foreshortened colon, a daily small-volume enema may also be required. To determine the right combination, treatment is initiated with enemas, a very strict diet, loperamide, and a water-soluble fiber. Most children respond to this aggressive management within 1–2 weeks. The child should remain on a strict diet until clean for 24 h for 2–3 days in a row. This diet includes three scheduled meals and no snacks. They can then choose one new food every 2–3 days and the effect of this new food on the child's colonic activity is observed. If the child soils after eating a newly introduced food, that food must be eliminated from the diet. Over several months, the most liberal diet possible should be sought. If the child remains clean with a liberal diet, the amount of the medication can gradually be reduced to the lowest effective dose to keep the child clean for 24 h.

Follow-Up

After a successful regimen has been initiated, children are followed closely. When a child has been successful on enemas for 3–6 months, we attempt a laxative trial if the child is felt to have the potential for bowel control. The laxative trial is performed as previously described. Patients who are repeatedly unsuccessful with laxatives are given the option to continue retrograde enemas and try laxatives again in

Table 61.1 Food products and stool consistency

Constipating foods	Laxative foods
Refined foods	*Whole grain foods*
White bread	Whole wheat bread
White rice	Whole grain pasta
Pasta	Brown rice
Sweets (chocolate)	Bran cereal
Fruits	*Fruits and vegetables*
Banana	Apples with skin
Apple without skin	Berries, dried figs
Apple sauce	Carrots, peas, broccoli
	Pears, peaches, prunes
	Fruit juices
Foods high in fat	*Beans*
French fries	Black beans
Fast food	Kidney beans
Fried foods	Pinto beans
Meats	*Dairy*
Red meat	Yogurt
Boiled, broiled, baked chicken or fish	
Dairy	
Cheese	
Milk	

6–12 months or undergo an ACE procedure. A Malone appendicostomy or a cecostomy tube may be used for antegrade continence enemas. Patients are also encouraged to undergo laxative trials periodically following the ACE procedure, if appropriate. If the enema volume is very large and causes severe abdominal discomfort or the enema process takes longer than 90 min, then a sigmoid resection can be performed to reduce the necessary enema volume and time.

Surgical Treatment

Although surgical intervention is generally considered a last resort for medically refractory disease, some will be considered good candidates for an operation based on specific anatomic or functional characteristics or their proven response to enemas or certain medications.

Appendicostomy

When bowel management with retrograde enemas has been successful, patients can be offered an ACE procedure, also known as a Malone procedure. An appendicostomy is created within the umbilicus or in the right lower quadrant. This allows enemas to be administered in an antegrade fashion. The cecum should be plicated around the base of the appendix to create a valve that prevents stool from leaking back through the umbilicus. This operation is usually recommended when the patient wants to become more independent, as it allows the administration of the enema without parental assistance. The Malone procedure is essentially just another way to administer an enema; therefore it should generally be performed in patients for whom bowel management has been successful. Sometimes the Malone is created first and the ideal flush determined with the bowel management program. This may be appropriate in patients who will not allow retrograde enemas to be performed.

Some children with spina bifida or other urologic problems either already have a Mitrofanoff stoma for self-catheterizations of the bladder through the umbilicus, or they will need one. If the child is in need of both a Mitrofanoff and an ACE, a preoperative discussion with the urologist is necessary to determine which procedure the appendix will be used for or if splitting the appendix is an option. In obese patients, the appendix may not reach the abdominal wall without compromising the blood supply. This point should be carefully considered preoperatively.

If the patient only requires an ACE and there are no contraindications, then laparoscopic-assisted procedures are ideal. No bowel prep is needed before surgery. A second-generation cephalosporin is administered prior to incision. The right colon is mobilized so that the appendico-cecal junction can be externalized for cecal plication around the base of the appendix.

The most frequent complication of appendicostomy is stomal stricture. The V-V advancement technique for the umbilical-appendiceal anastomosis decreases the incidence of this complication and is our preferred technique. A broad V-shaped skin incision is made with the apex of the V at the base of the umbilicus (Fig. 61.4). The incision is extended inferiorly through the skin and fascia to externalize the appendico-cecal junction for cecal plication. The tip of the appendix is spatulated away from the mesentery and the circumferential anastomosis is begun by approximating the apex of the skin flap to the spatulated portion of the appendix (Fig. 61.4). The completed anastomosis is partially lined with epithelium, which reduces the risk of stricture. Occasionally patients or parents will elect to have an indwelling device such as a Chait trap-door tube placed through the appendicostomy in order to avoid daily catheterization. We initiate antegrade enemas in the postoperative period according to an established protocol (Table 61.2).

Neo-appendicostomy

If there is no appendix, creating a tube from a flap of cecum (continent neo-appendicostomy) is an option. A triangular skin flap is created at the umbilicus as in the Malone procedure. The right colon is mobilized. A location on the ascending colon away from the ileocecal valve is selected for

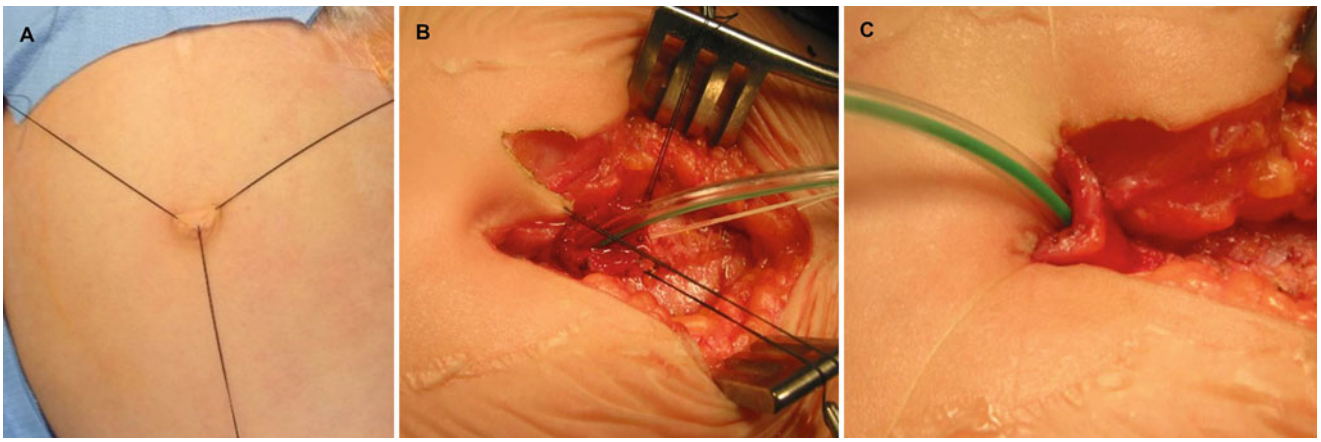

Fig. 61.4 The V-V advancement technique for the umbilical-appendiceal anastomosis. (**a**) The broad V-shaped skin incision with the apex of the V at the base of the umbilicus oriented toward the *bottom* of the photograph. (**b**) and (**c**) The tip of the appendix is spatulated away from the mesentery and the circumferential anastomosis created by approximating the apex of the skin flap to the spatulated portion of the appendix (Courtesy of Marc A. Levitt)

Table 61.2 Postoperative antegrade enema protocol

Appendicostomy (*native appendix*)
Begin antegrade enema postoperative day 1
Postoperative day 1: ½ volume (pre-op enema solution) × 1
Postoperative day 2: full-volume flush, daily
Follow-up: tube stays in place for 4 weeks
Neo-appendicostomy
Begin antegrade enema when starting solid food
Day 1 (of solid foods): ½ volume (pre-op enema solution) × 1
Day 2 (of solid foods): ½ volume (pre-op enema solution) twice a day
Discharge enema: ½ volume (pre-op enema solution) twice a day × 4 weeks
Follow-up: tube stays in place for 4 weeks

creation of the flap. Two feeding vessels from the mesentery are identified and the transverse flap created. The flap must be large enough to be tubularized over an 8-Fr feeding tube. The colonic wall is then plicated around the neo-appendix taking care to avoid apposition of the two suture lines. The umbilical-appendiceal anastomosis is then performed as in the Malone in a V-V fashion.

Cecostomy

An alternative to an appendicostomy for antegrade enemas is a skin-level device such as a Chait trapdoor cecostomy or Silastic low-profile gastrostomy button. These tubes can be placed through the abdominal wall in the right lower quadrant directly into the cecum using a laparoscopic or percutaneous technique. Benefits include avoidance of daily catheterization and the risk of stomal stricture. However, issues such as abscess, granulation tissue, leakage, parastomal cutaneous fecal fistula, and inadvertent tube dislodgement are not uncommon.

Colon Resection

In children with a megarectosigmoid, very redundant sigmoid colon, or dysmotile left colon, segmental resection will reduce their daily laxative requirement or required daily enema volume. The rectum is generally divided at the level of the peritoneal reflection although some recommend a more extensive distal resection to just above the dentate line. These patients must be followed closely because the remaining rectum is most likely abnormal. In patients with ARMs, the rectum should remain intact because they need it for continence. In this group of patients, a laparoscopic low anterior resection, leaving behind 6–8 cm of rectum, is effective and avoids postoperative soiling.

The most dilated part of the colon is resected because it is presumed to be the most dysfunctional segment. It seems that the patients who improve the most are those who have a more localized form of rectosigmoid dilation. Patients with more generalized dilation of the colon often do not respond well and sometimes require a more extensive resection with or without an appendicostomy. In a very small subset of patients with diffuse colonic dysmotility and failure to thrive, an ileostomy is an option. We recommend reserving rectosigmoid or sigmoid colon resection for those patients unresponsive to a structured bowel management program.

Outcomes

No standard definition exists for successful bowel management. Also, depending on the child's overall situation, the goal for bowel management may vary. We consider bowel management to be successful when a patient is able to wear normal underwear and stay totally clean for 24 h. This is achievable in approximately 85–95 % of children with

ARMs, Hirschsprung disease, or severe intractable idiopathic constipation. Regardless of the underlying disorder, bowel management plans often require modification over time. Thus, careful follow-up is a key component to a successful program.

Surgical Complications

Stomal stricture is the most common indication for appendicostomy revision. This complication occurs in up to 50 % of patients and is used by many surgeons to support placement of a cecostomy tube. By creating the stoma using the V-to-V technique, this complication can be reduced. Stomas require revision in up to a third of cases and *leakage* accounts for approximately a quarter of these. The cause of leakage is likely multifactorial. In our experience, leakage will often occur when the patient is becoming progressively impacted by not effectively emptying the colon with the antegrade enemas. Once a successful enema is found, the leakage will improve or resolve. In some patients, leakage is related to loosening or breakdown of the cecal plication. The need for cecal plication is debated as the appendix has a normal antireflux valve in many patients and no consensus or large prospective series exist evaluating this technical aspect of the procedure. *Stomal prolapse* occurs in less than 5 % of patients but requires a skin-level revision to prevent mucous from constantly soiling the clothing.

Future Considerations

Colonic manometry performed at an experienced center can be very helpful in mapping out colonic function to guide subsequent surgical intervention. If the manometry study is consistent with absent motility in the entire colon, a diverting ileostomy with a plan to repeat motility studies in the future or a more extensive colectomy is considered. In a patient with normal motility in the right and transverse colon but abnormal distal motility, an ACE with distal bowel resection should be considered. If a child with severe functional constipation and encopresis is found to have normal motility or limited dysmotility of the sigmoid colon, an ACE alone will likely be effective.

The effect of *sacral nerve stimulation* (SNS) on bowel function was initially appreciated in studies evaluating its effect on voiding dysfunction. The exact mechanism of action is unknown, but some evidence suggests that SNS normalizes intestinal transit by modulation of the enteric nervous system or reflex pathways at the spinal cord level. Studies in children are limited with variable outcomes measures. However, the data suggest that when used in carefully selected patients, SNS results in an increased frequency of defecation and decrease in abdominal pain. This may emerge as an effective adjunct to other surgical interventions.

Editor's Comment

Children with constipation are generally referred to a pediatric surgeon for one of three indications: for fecal disimpaction, for consideration of an antegrade enema procedure, or for "rule out Hirschsprung disease." Though sometimes unpleasant or difficult, fecal disimpaction is also usually rewarding. It should be performed with an aggressive but careful bimanual technique and saline irrigation of the sigmoid colon through a red-rubber catheter can be a useful adjunct. The anal dilatation that invariably occurs can be helpful for a time after the procedure but deliberate forceful dilatation of the anal sphincter is no longer recommended because of the risk of incontinence.

Antegrade continent enemas are not meant to treat the underlying disorder but are instead designed to help patients with intractable constipation and encopresis stay clean throughout the day. The procedure should be done laparoscopically whenever possible and, to prevent stool leakage, an antireflux valve should be created at the base of the conduit. This procedure is somewhat undervalued and not offered nearly as often as it should for patients who could clearly benefit, probably because not only can it be technically challenging, but the postoperative care is laborious, there are frequent minor complications (recurrent stenosis, stool leakage), and some are uneasy recommending a procedure that treats a symptom rather than an underlying disease. There is also the prerequisite many surgeons still stubbornly adhere to that the child prove that they respond to retrograde (trans-anal) enemas before they can be considered a candidate for antegrade enemas. This is unfair for some patients who cannot tolerate enemas for any number of reasons but who might very well respond nicely and have a better quality of life with an antegrade enema procedure.

Hirschsprung disease can generally be excluded by a careful history, but once the possibility has been raised it is sometimes nearly impossible to rule out without a rectal biopsy. In children older than about 4–6 months, this needs to be done as an open procedure under general anesthesia. A contrast enema should also be performed, but the accuracy of this test for Hirschsprung disease is disappointingly low.

We should be careful not to dismiss any child's symptoms as due to "just constipation," as this can make some parents angry or offended – they might see it as a lack of empathy or an overt criticism of their parenting. Severe constipation can be a serious issue that causes a great deal of anxiety and physical discomfort. It is also conceivable that most cases of "functional" constipation will someday prove

to have a genuine underlying pathophysiologic mechanism that we simply have yet to understand. Finally, the traditional and sometimes self-righteous recommendations that clinicians frequently give (drink more water, increase dietary fiber intake, avoid "constipating" foods) are often simply not enough for children with severe or symptomatic constipation. Laxatives or cathartics are often necessary in these cases and should not be withheld for specious reasons or misplaced parental guilt about not making their kid eat enough fruits and vegetables.

Suggested Reading

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Hirschsprung Disease

62

Jeffrey R. Avansino and Marc A. Levitt

Hirschsprung disease (HD) results from an abnormal development of the enteric nervous system leading to the absence of ganglion cells in the myenteric and submucosal plexuses of the distal intestine. Aganglionosis is due to a failure of migration of the ganglion cells, which are derived from the neural crest. Gene mutations may be the cause, particularly the Ret proto-oncogene and the endothelin family of genes. HD occurs in one in 5000 live births, resulting in absent peristalsis in the affected bowel and a functional intestinal obstruction. In the majority of cases, the affected segment involves the rectum or recto-sigmoid, but the aganglionosis can extend for varying lengths to involve the entire colon, sometimes the small intestine and rarely the entire length of the large and small bowel.

Hirschsprung disease typically presents as a neonatal bowel obstruction with or without enterocolitis. More benign phenotypes present later with constipation and chronic distension. Failure to thrive is also common in those with a delayed presentation. The newborn has distension, poor feeding, and bilious emesis. Free air with a cecal perforation occasionally is seen. Distal bowel obstruction on plain abdominal X-ray could be Hirschsprung disease but could also be meconium ileus, meconium plug, ileal atresia, ileal stenosis, or one of the number of medical conditions such as hypothyroidism, narcotic overdose, gestational diabetes, and effects of magnesium sulfate.

The cases diagnosed outside the newborn period may show constipation symptoms on breast milk, or dramatic worsening of constipation when transitioning to normal foods. These patients usually have short-segment disease, but rarely total colonic cases can have a delayed diagnosis as well. The most worrisome condition is enterocolitis, which can be life-threatening and is thought to be due to stasis, bacterial overgrowth, and bacterial translocation. It is clear that there is a difference in mucosal immunity in Hirschsprung patients, but this is not well understood. Patients with trisomy 21 are particularly prone to enterocolitis.

Anomalies such as malrotation, genitourinary abnormalities, congenital heart disease, limb abnormalities, cleft lip and palate, hearing loss, cognitive delays and dysmorphic features, and certain syndromes such as trisomy 21, congenital hypoventilation syndrome, Mowat–Wilson, or a neurocristopathy can be associated with Hirschsprung disease.

Diagnosis

With signs and symptoms consistent with Hirschsprung disease and an X-ray showing distal bowel obstruction, the clinician should proceed with a water-soluble contrast enema, which in a majority of cases shows a transition zone (Fig. 62.1). A pathologic confirmation of HD is made with tissue from a suction rectal biopsy. A full-thickness biopsy should be performed in a child over one year of age.

The pathology specimen reveals the absence of ganglion cells and the presence of hypertrophic nerves (>40 μm). The specimen much be taken at least 0.5 cm above the dentate line to avoid the normally aganglionic area of the anal canal. Acetylcholinesterase staining is often used as is calretinin, which is more sensitive. Calretinin is a calcium transporter found on enteric ganglion cells, thus an absence of it suggests HD.

Anorectal manometry can be used in the older child. In the patient with HD, manometry demonstrates a failure to relax the internal sphincter when the rectum is distended. The constipated patient with normal manometry can sometimes avoid an unnecessary rectal biopsy. In the patient following a

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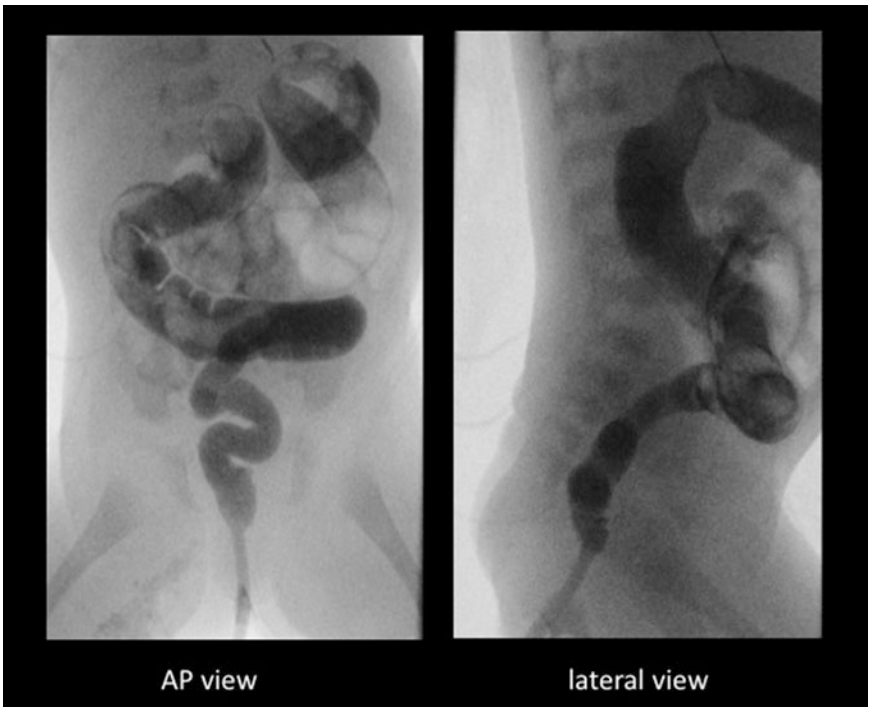

Fig. 62.1 Water-soluble contrast enema (AP and lateral views) demonstrating a transition zone in the recto-sigmoid colon. The lateral view is the most important one to identify a low transition zone. Other findings on the contrast enema that suggest the diagnosis of Hirschsprung disease include a recto-sigmoid index (the ratio of rectal diameter/sigmoid diameter) <1.0, and retention of contrast on a 24-hour post-evacuation film

pull-through who is soiling, anorectal manometry is used to objectively assess the quality of the sphincters.

Treatment

Neonates require intravenous resuscitation and antibiotics, as well as nasogastric decompression. Distension and enterocolitis are treated with colonic irrigations 20 mL/kg every 4–6 h (Fig. 62.2). If the child is extremely ill and not responding to antibiotics and irrigations, an urgent ostomy should be performed. In these very rare cases, we prefer to perform multiple colonic biopsies and an ileostomy. Frozen section analysis for leveling colostomy requires sophisticated pediatric pathologic analysis and surgery performed in the urgent setting often occurs after hours when pediatric pathology is not widely available. An ileostomy is the safest and most reliable diversion, although it will require a third stage surgery (following the 2nd stage pull-through) to close the ileostomy.

Once stable, surgery can be done semi-electively. While waiting for surgery, most children can be fed breast milk or an elemental formula, while continuing with rectal irrigations. Our preference is to perform surgery in the newborn period. In the older child with a very dilated colon, a period of irrigations is helpful before proceeding with surgery. Sometimes, in such a case, an ileostomy is required as a first step. A definitive pull-through procedure can be done months later. A repeat contrast enema at that time might more clearly show a transition zone.

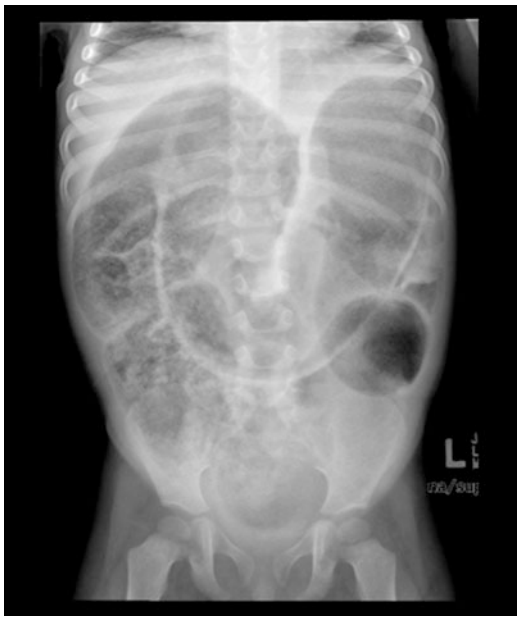

Fig. 62.2 Abdominal radiography showing colonic distension in a patient with enterocolitis. (Reprinted from Levitt MA, Dickie B, Peña A. Levitt MA, Dickie B, Peña A. Evaluation and treatment of the patient with Hirschsprung disease who is not doing well after a pull-through procedure. Semin Pediatr Surg. 2010 May;19(2):146-53, with permission from Elsevier.)

The goals of surgical management for Hirschsprung disease are to remove the aganglionic bowel, pull-through ganglionated bowel, and preserve the anal canal and sphincter mechanism. Orvar Swenson described the first operation in

1948. Since that time the surgical management has evolved to include Swenson's full-thickness recto-sigmoid dissection, Soave's endorectal dissection, and creation of the Duhamel partially aganglionic rectorectal pouch (Fig. 62.3). Rehbein's operation, essentially a low anterior resection, more commonly done in the past in Europe, is becoming increasingly rare. These definitive procedures were often preceded by a diverting colostomy due to the high incidence of complications seen with the initial experience. Dr. Henry So in the Philippines first did a primary pull-through with no stoma, and this was related to his desire to avoid creating a stoma, fearing parents would not care for the child given the significant social stigma associated with a colostomy.

Despite the trend to avoid stomas, it is important to remember that a stoma may still be indicated for children with severe enterocolitis, perforation, malnutrition, or massively dilated proximal bowel. A staged approach should also be used in situations where there are inadequate pathology services to reliably identify the transition zone on frozen section from the operating room. Modifications to the procedures have included the transanal approach (de la Torre and Langer) with or without laparoscopy (Georgeson). Currently,

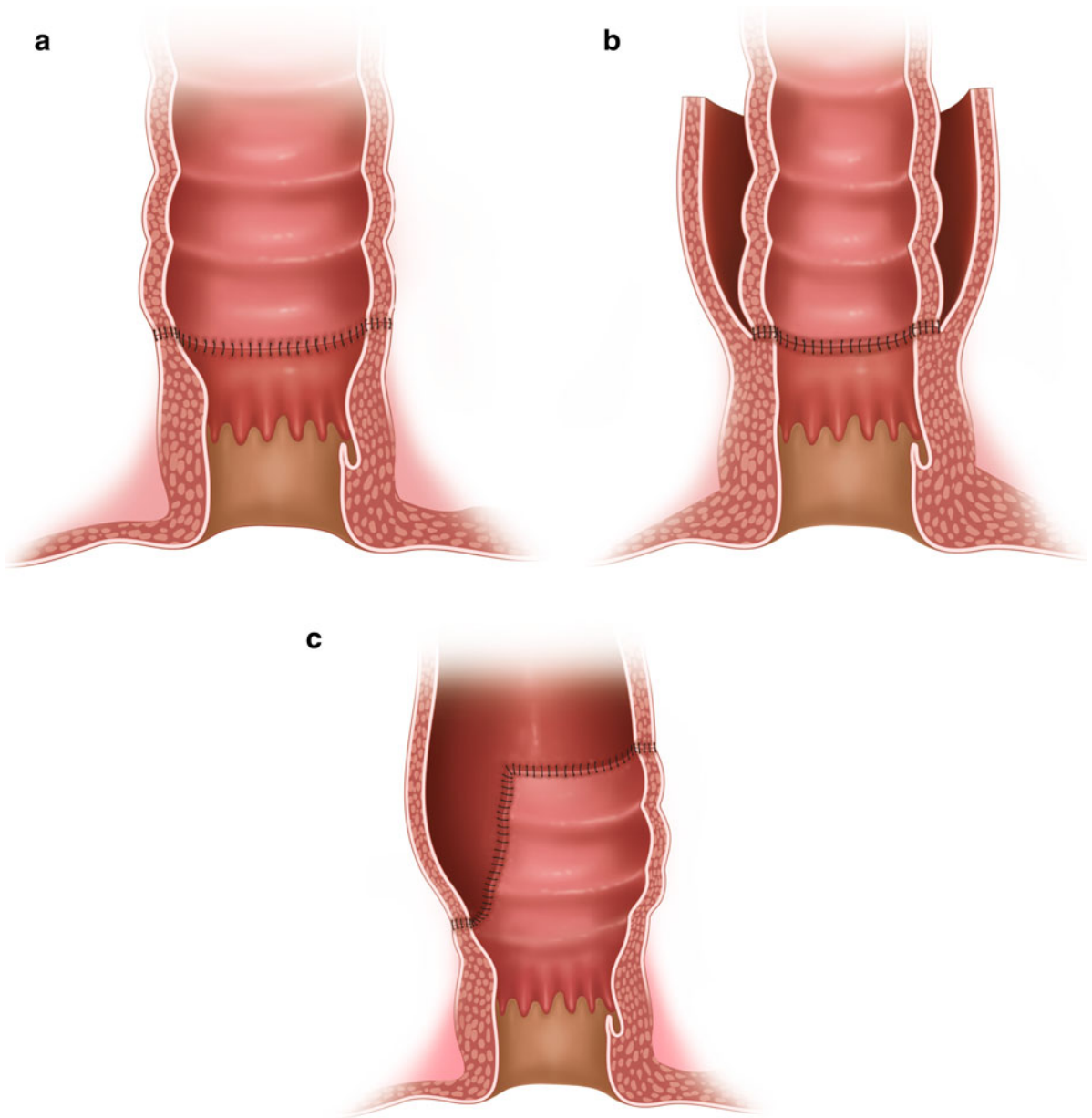

Fig. 62.3 (**a**) Swenson's full-thickness recto-sigmoid dissection. (**b**) Soave's endorectal dissection. (**c**) Rectorectal pouch (Duhamel)

there is no compelling evidence that any technique is best and all are acceptable options in the hands of a well-trained and experienced surgeon. Long-term outcomes studies comparing the various approaches are lacking.

The Swenson procedure is the only operation that leaves behind essentially no aganglionic bowel (except for the 1 cm preserved adjacent to the dentate line). The Soave procedure leaves behind the outer rectal wall but this cuff has been created shorter and shorter over the years to the point where only a 1 cm cuff is now recommended for this technique, sometimes referred to as a "Soaveson." The Duhamel and Rehbein intentionally leave behind aganglionic bowel, connected to ganglionated bowel. These techniques were developed due to complications occurring with the Swenson, which were likely due to an extensive rectal dissection that was too wide. We prefer the Swenson technique performing a full-thickness dissection in the avascular plane.

Leveling biopsies are performed via a laparoscopic or umbilical approach, although in certain cases when the transition is clearly in the rectum or mid-sigmoid, a transanal-only approach can be used. In both approaches, the bowel is inspected and findings correlated with the preoperative contrast enema. A biopsy is taken above the suspected area of aganglionosis, full-thickness or seromuscular. Seromuscular biopsies prevent spillage; however, biopsies taken at this level can provide false reassurance that one is outside the transition zone as hypoganglionosis and hypertrophic nerves could still be present in the submucosal layer despite seeing ganglion cells in the seromuscular layer. We request that our pathologist measure the size of the nerves, as nerves greater than 40 μm are considered hypertrophic. Due to an irregular distribution of ganglion cells in a transition zone, hypoganglionosis may exist at the same level of a biopsy demonstrating an adequate distribution of ganglion cells. Transition zone length is variable, which is why assessment of the nerve size is so valuable. In addition, transition zones have been described to measure anywhere from 1 to 10 cm so it is recommended to perform an anastomosis some distance (3–10 cm) above the biopsy site to ensure one is out of the transition zone. In patients with total colon aganglionosis, the appendix is an inadequate specimen to evaluate the transition zone, as even in normal children it might be aganglionic.

In the umbilical approach, an infra-umbilical incision is made and the fascia split vertically being mindful of the bladder. A Hegar dilator is passed through the anus to allow identification of the rectum and sigmoid. The bowel is exteriorized and inspected, and the biopsy is taken and sent for frozen section. In the laparoscopic approach, the biopsy can be performed using laparoscopic endoshears or an endoloop. Alternatively, the segment can be identified laparoscopically and the biopsy performed at the umbilicus with the colon exteriorized. Once the level has been confirmed, mobilization of the recto-sigmoid colon can be performed; ideally it is mobilized as far distally as possible to minimize the amount of transanal dissection required. This is preferable to the potential over-stretching of the sphincters during a transanal-only approach.

Transanal Dissection

The transanal dissection can be done in the prone or lithotomy position. If a laparoscopic biopsy and mobilization is performed, the dissection is performed in the lithotomy position; otherwise we prefer the prone position if a transanal-only approach is being utilized. We begin our dissection by placing a lone-star retractor (Cooper Surgical) at the ano-cutaneous junction. We identify the dentate line and replace the hooks in the rectal mucosa to protect the dentate line (Fig. 62.4). Next, we place a series of retraction sutures and make a full-thickness circumferential incision 1.0 cm above the dentate line and continue the dissection on the rectal wall dividing vessels as they enter the rectum. This is a readily identifiable areolar plane. If doing a transanal-only technique, the anterior rectum frees up more easily than the posterior rectum. One can then enter the peritoneum, pull out the sigmoid, send a biopsy, and then continue with the posterior dissection. This makes for an efficient procedure, with minimal delay waiting for the biopsy result. A two-layered anastomosis is then performed suturing the seromuscular layer of the pull-through segment to the musculature of the anal canal, followed by a separate mucosal layer. It is important to reposition the hooks at the ano-cutaneous junction prior to doing the mucosal anastomosis. While doing the anastomosis, the proximal margin of the resected specimen is sent for confirmation of adequate distribution and quality of ganglion cells and nerves.

In the Soave procedure, the mucosa is separated from the underlying muscle for a distance of a few centimeters before transitioning to a full-thickness dissection. The operation then proceeds as described above for the Swenson. The retained muscular cuff is split posteriorly to prevent obstruction.

Pure Transanal Pull-Through

The pure transanal pull-through was first described by de la Torre and Langer. This procedure is reserved for biopsy-proven HD in patients with a clear transition zone in the recto-sigmoid region on the contrast enema. Whether to determine the level of transition first with a biopsy or start transanally is a point of controversy. Proponents of a preliminary biopsy point to the inaccuracy of the contrast enema in predicting the level of aganglionosis. Approximately 8 % of children with an apparent recto-sigmoid transition zone on contrast study turn out to have a more proximal patho-

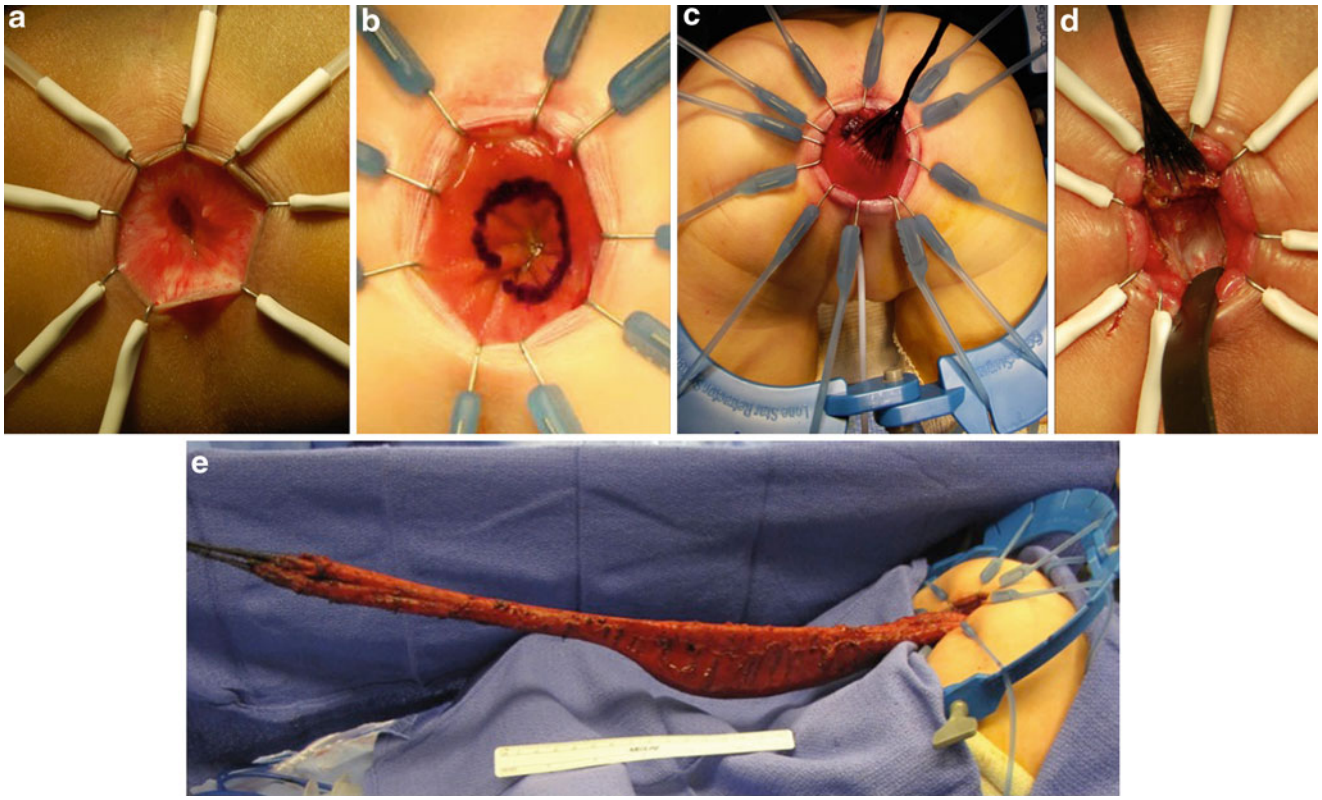

Fig. 62.4 Transanal Swenson. (**a**) The dentate line. (**b**) Line 1 cm above the dentate line where dissection into full-thickness Swenson plane begins. Note the dentate line is protected by placing the lone-star hooks into the rectal mucosa. (**c**) Circumferential silk sutures are placed to provide traction. (**d**) The areolar Swenson plane. (**e**) The fully mobilized segment, by transanal technique in prone position

logical transition zone at operation. This is particularly important for the surgeon who prefers a different operation for long-segment disease than for recto-sigmoid disease (an ileal-Duhamel procedure for total colonic HD), in which case it would be best to have avoided a transanal dissection.

The transanal approach has a low complication rate, requires minimal analgesia, is associated with early feeding and discharge and can be done by any pediatric surgeon, including those without laparoscopic availability. The key technical issue is to avoid over-stretching from retraction during the rectal dissection. For the Swenson approach, finding the perfect full-thickness plane is key to a comfortable dissection.

Long-Segment Hirschsprung Disease

Aganglionosis extending proximal to the sigmoid will require additional colonic mobilization. Disease extending to the proximal sigmoid often requires ligation of the inferior mesenteric artery near its base to adequately mobilize the sigmoid colon. It is vital to identify the "Y" of the mesenteric vessel, ligate the stem of the "Y" and then once ligated, the top part of the "Y" extends and lengthens the pull-through, with a nicely preserved arcade (Fig. 62.5). Aganglionosis ending in the left colon requires mobilization of the splenic flexure and division of the left colic artery with careful preservation of the sigmoid arcade. Aganglionosis at the hepatic flexure provides an interesting dilemma of whether to bring the colon down the right or left colic gutter. Our preference is to bring the colon down the right gutter by dividing the blood supply at the middle colic artery, mobilizing the hepatic flexure and right colon, and detaching the small bowel mesentery from the retroperitoneum (Fig. 62.6). The right colic artery usually must be ligated to gain adequate length with distal perfusion dependent on preservation of the ileocolic arcade to the right colon.

Total Colonic Hirschsprung Disease

Total colonic aganglionosis occurs in about 5–10 % of patients with HD, and usually involves part of the distal ileum. In rare cases, most or all of the small bowel is also involved. Contrast enema typically shows a shortened, relatively narrow colon, often with a transition zone in the small bowel. The rectal biopsy shows absence of ganglion cells, but in many cases there are no hypertrophic nerves or abnormalities of acetylcholinesterase staining and frozen section of these cases is particularly challenging. Once the level of

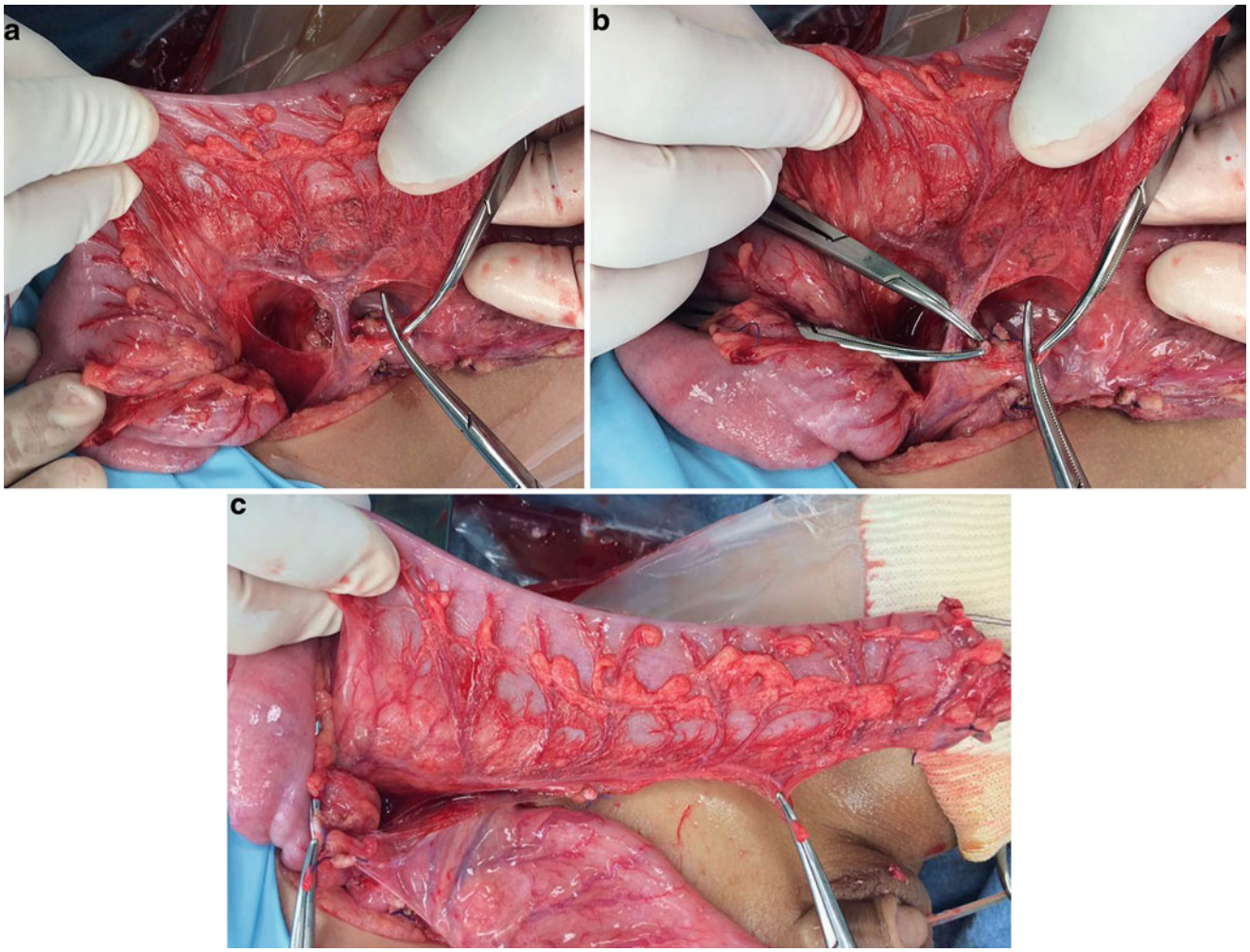

Fig. 62.5 Mobilization of colon with division of mesentery. (**a**) Arcade of the colon showing the "Y" of the vessel. (**b**) Division of the mesenteric vessel. (**c**) Straightening of the "Y" to gain additional length on the colon

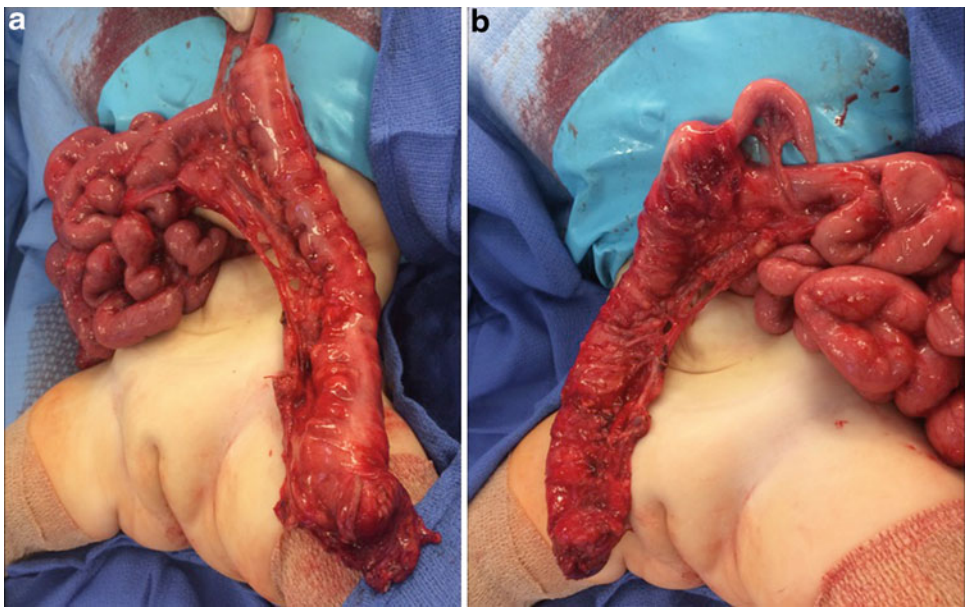

Fig. 62.6 Options for a hepatic flexure pull-through, down the right or the left pelvis. (**a**) Pull-through down left side into pelvis. (**b**) Pull-through down right side into pelvis

aganglionosis has been identified, a stoma is created and a definitive reconstructive procedure performed at 6–12 months of age. We recommend repair after the stools have thickened and the child is demonstrating adequate growth and nutrition. Skin care to avoid perineal rash has dramatically improved in recent years and thus the pull-through can be done earlier than previously recommended. Parents need to be taught how to do rectal irrigations as the incidence of enterocolitis is highest in this patient group and prophylactic irrigations after pull-through are very helpful. This timing for a pull-though needs to be balanced with the advantage of waiting until the child can sit on a toilet and is toilet trained for urine, which dramatically reduces the perineal rash that occurs with an earlier in life pull-through. Although primary pull-through without ileostomy for total colonic disease has been reported, we strongly urge against this practice as frozen section can be misleading and permanent section and immunostaining are required for definitive diagnosis and level.

Reconstruction for total colonic HD traditionally included an ileal Duhamel, or a longer patch (Martin) or a J-pouch. Our preference is a straight ileoanal, but many centers prefer a Duhamel approach. If this method is chosen, we recommend a relatively short colonic segment below the peritoneal reflection. Although the colon patch procedures theoretically result in decreased stool output due to better water absorption, the aganglionic colon tends to gradually dilate, for reasons that are poorly understood. As the Duhamel pouch dilates, stasis ensues and some of these patients develop severe enterocolitis requiring removal of the pouch. We believe the issue is not the stasis induced by the Duhamel but rather the inability of the ganglionic bowel to work well and overcome stasis. Why some ganglionated bowel works poorly is a mystery, but probably relates to the wide phenotypic expression of HD. The J-pouch procedure is the same as that done commonly for children and adults with ulcerative colitis and familial polyposis syndrome. And like the Duhamel risks inducing stasis.

Postoperative Care

Following surgery, the child is fed when bowel function has commenced and the abdomen is not distended. The anastomosis should be calibrated with a dilator four weeks after surgery. We recommend daily dilations if any narrowing is detected (Table 62.1) and calibration daily for the postoperative infant to help stimulate stooling for several months. Children with a late diagnosis typically do not require dilations with the two-layered anastomosis. Protection of the buttocks with a barrier cream is mandatory, since at least 50 % of children will have frequent stools postoperatively and are prone to perineal skin breakdown. These products have improved dramatically, which may allow for earlier pull-through in patients with total colon disease. Fortunately, this is a problem that tends to resolve over time.

Table 62.1 Dilator size by age

Dilator size by age (mm)	
Newborn	11/12
1 year old	14/15
2–5 year old	15
>5 year old	16

Post Pull-Through Problems

We categorize patients with long-term problems following surgery for HD into: (1) fecal incontinence with soiling and (2) obstructive symptoms and recurrent enterocolitis (Fig. 62.7). Sometimes an individual child may have a combination of problems. These complications are more common than previously recognized and it is incumbent upon the surgeon to follow these children closely and determine whether an anatomic or pathologic problem is present.

The initial evaluation begins with a thorough history asking about constipation, enterocolitis, abdominal distension, failure to thrive, laxative and enema use. It is also imperative to know the type of operation performed and have the original pathology reviewed if possible. We perform a contrast enema in all patients, examining the post pull-through anatomy. An examination under anesthesia is also performed to evaluate the following: (1) integrity of the anal canal/dentate line, (2) presence of a stricture, (3) status of the sphincters, (4) presence of a large rectal (Duhamel) pouch, and (5) presence of an obstructive Soave cuff. We perform a full-thickness biopsy to assess for aganglionosis or transition zone bowel and obtain anal manometry to analyze the sphincter function.

Fecal Incontinence

We define fecal continence as having voluntary bowel movements without soiling or need for enemas. Patients with HD are born with a normal continence mechanism (normal sphincter function and anal canal sensation) and should not experience fecal incontinence after surgical management. Disruption of the anal sphincter, anal canal, or colonic motility may result in soiling. Pseudo-incontinence occurs when the continence mechanism is intact but the child continues to soil. This is usually due to severe constipation and is treatable with the right medical regimen, usually laxative treatment. Uncommonly, pseudo-incontinence is secondary to a hypermotile colon.

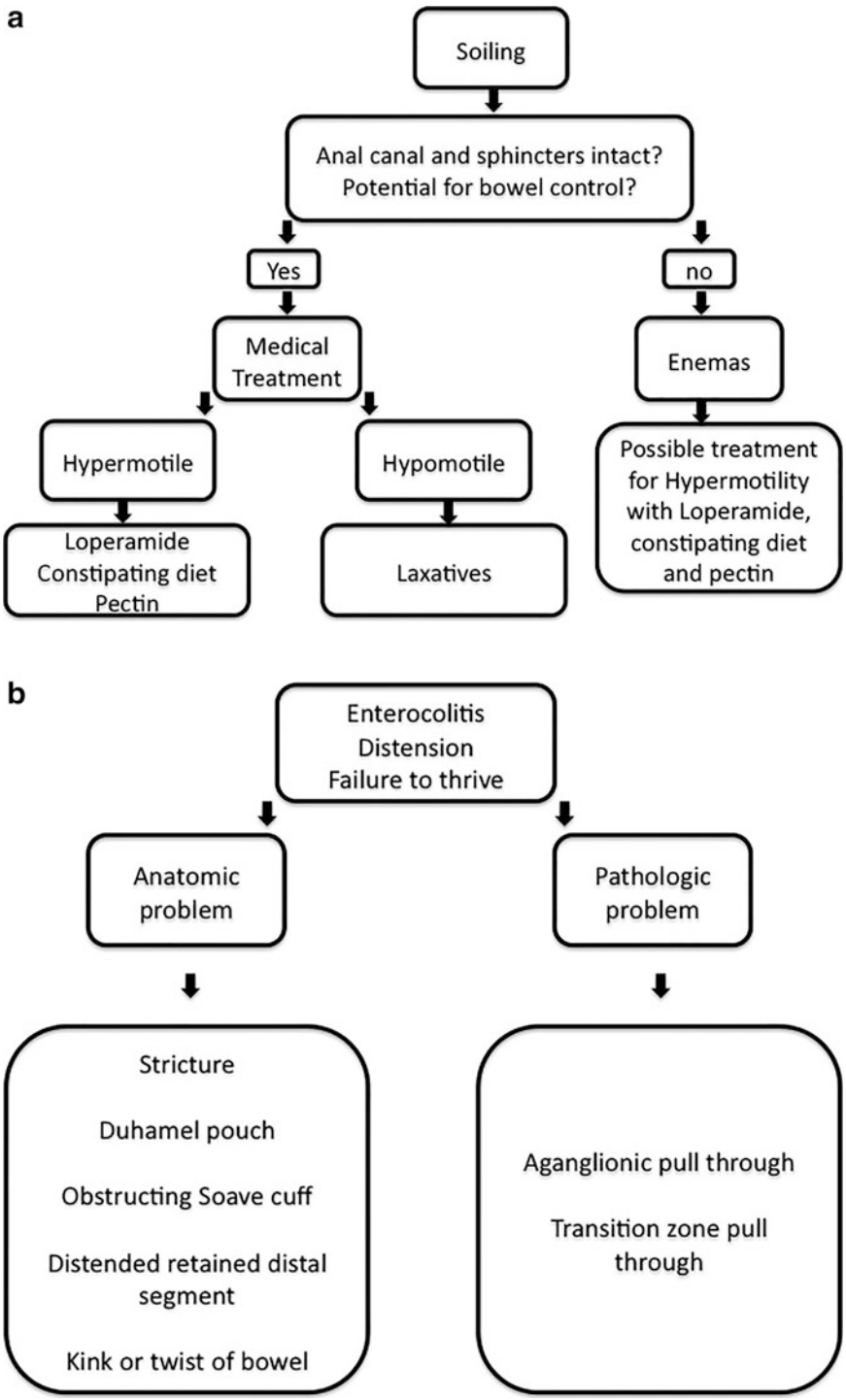

Fig. 62.7 Algorithm for care of the post pull-through problem patient. (**a**) Post pull-through patient with soiling. (**b**) Post pull-through patient with recurrent enterocolitis

It is important to differentiate between fecal incontinence and pseudo-incontinence. This can be determined during the exam under anesthesia. A patulous anus signifies damage to the anal sphincter muscle complex. Disruption of the dentate line, from a dissection that was started too low, results in diminished anal canal sensation. These findings may suggest irreversible incontinence requiring treatment with an enema program to achieve social continence.

Children with an intact sphincter mechanism and intact dentate line should be able to have voluntary bowel movements. Those with a dilated colon on contrast enema are considered to be hypomotile and can be managed with a daily senna-based (stimulant) laxative program. The dose of the laxative is titrated during a week-long laxative trial so the child has one to two large bowel movements per day, no accidents, and an abdominal radiograph showing a distal

colon devoid of stool. Addition of water-soluble fiber to produce bulk makes the laxative more effective and avoids loose stools. Success with this program confirms the diagnosis of pseudo-incontinence. Patients failing this regimen can be managed with large-volume saline enemas (400–600 mL) with a colonic stimulant such as glycerine added to the solution. This allows the child to experience social continence. Children who achieve success with enemas and have an intact sphincter mechanism can trial a laxative program every 6–12 months, as they now know what it is like to be clean after enemas.

Children with contrast enemas demonstrating a non-dilated colon and fecal incontinence may be hypermotile. Although hypomotility is more common after a pull-through for HD, hypermotility happens and is treated differently. As a result, we recommend slowing the colon using a combination of a constipating diet, water-soluble fiber, and antimotility agents (loperamide and diphenoxylate/atropine). In patients unable to have a voluntary bowel movement, we add a daily low volume enema (200–300 mL) to clean the distal colon and slow the colon transit.

Obstructive Symptoms and Recurrent Enterocolitis

Abdominal distention and enterocolitis can be due to either pathologic or anatomic problems. Enterocolitis may be present both before and after surgical correction of the disease and can be very severe, even life-threatening. Although the clinical features of enterocolitis are generally agreed upon (fever, abdominal distention, diarrhea), a precise definition has not been developed and as a result there is a varied reported incidence. The treatment of postoperative enterocolitis involves nasogastric drainage, intravenous fluids, broad-spectrum antibiotics, and decompression of the rectum and colon using rectal irrigations. The goal of rectal irrigations is to wash the colon using aliquots of 10–20 mL of saline at a time. Using a large bore catheter (20–24 Fr), up to 1–2 L of saline can be used; however, a child should not retain more than 20 mL/kg. Irrigations can be administered one to three times per day depending on disease severity. It is extremely important that the family is taught to administer the irrigations and has the needed supplies. We will also send the family home with a prescription for oral metronidazole. We instruct families to begin irrigations and start oral metronidazole at the first sign of enterocolitis, and urgent early return to the hospital if the symptoms worsen. In rare cases where patients are resistant to irrigations and antibiotics, a diverting ileostomy or colostomy may need to be created while an anatomic or pathologic cause is sought.

In patients with recurrent abdominal distension or enterocolitis, a systematic workup is needed to determine the etiology. We begin by requesting the pathology from the original resection and ask our pathologist to determine if the proximal margin has a normal distribution of ganglion cells and normal sized nerves (<40 μm). If the pathology is not available or the proximal margin is consistent with aganglionosis or a transition zone, we perform a full-thickness biopsy. Absent or abnormal distribution of ganglion cells or the presence of hypertrophic nerves with ganglion cells present in the setting of recurrent obstruction and enterocolitis requires surgical revision of the pull-through segment.

Anatomic problems from the original operation can cause an obstruction that leads to stasis and enterocolitis. Three anatomic problems that can occur regardless of the initial procedure include stricture (typically at the anastomosis), retained dilated segment, or a twist or a kink of the pull-through segment (Fig. 62.8). Additionally, an obstruction can be related to mechanical issues specific to the type of pull-through. The muscular cuff of a Soave procedure can cause an obstruction if it is too long or not adequately split. The result is a constricting fibrotic ring and an outlet obstruction. Furthermore, a previously split cuff may scar down or roll up to cause an obstruction. The presence of an obstructing muscular cuff can be seen on contrast enema. (Fig. 62.9) and palpated during an examination under anesthesia.

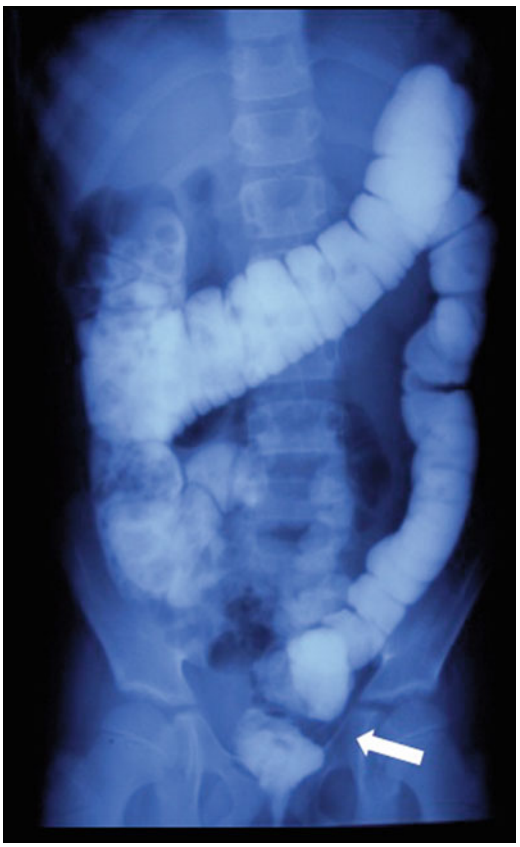

Fig. 62.8 Contrast enema demonstrating a twist of the distal pull-through segment (*white arrow*)

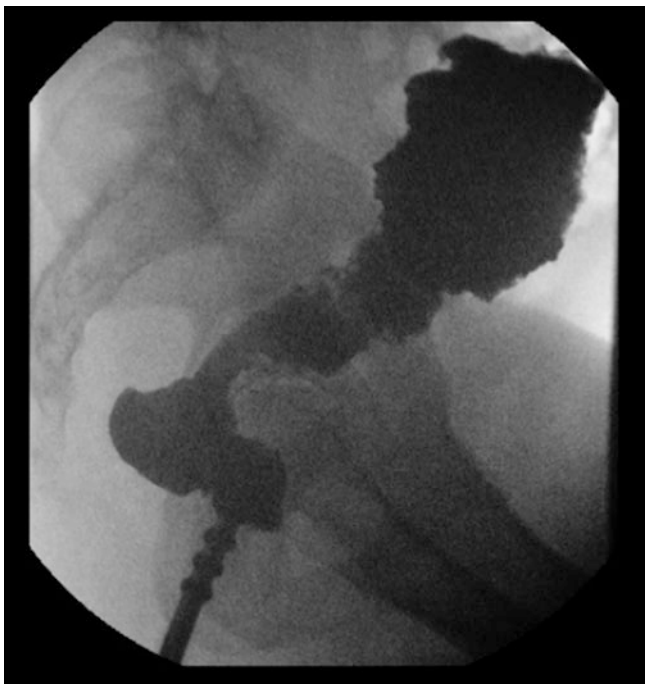

Fig. 62.9 Contrast enema demonstrating an obstructing Soave muscular cuff. (Reprinted from Levitt MA, Dickie B, Peña A. Levitt MA, Dickie B, Peña A. Evaluation and treatment of the patient with Hirschsprung disease who is not doing well after a pull-through procedure. Semin Pediatr Surg. 2010 May;19(2):146-53, with permission from Elsevier.)

Historically, a long muscular cuff was left with the Soave procedure; however, more recently the trend has been to leave only a few centimeters, which should reduce the incidence of cuff problems.

The Duhamel procedure was designed to create a pouch using a portion of aganglionic rectum in an effort to slow colonic transit and create a reservoir for stool. This is commonly used in children with total colonic HD but is the preferred technique of many surgeons for every pull-through. Inadequate emptying of the pouch can result in a "megarectum" that leads to stasis and enterocolitis (Fig. 62.10).

Functional and mechanical obstructions in post pull-through patients are frequently managed with a redo operation. It is our contention that until the distal pull-through has no anatomic or pathologic obstruction, evaluation or treatment of dysmotility problems is unhelpful. The clinician must seek to find the cause of the distal obstruction.

Once identified, we perform a redo transanal pull-through using a Swenson technique with the addition of laparotomy or laparoscopy as necessary. If the rectum is surrounded by dense scar, a posterior sagittal approach may sometimes be necessary for mobilization. There are many patients with persistent obstructive symptoms who are being followed, waiting for improvement. We believe such patients require an evaluation searching for an anatomic or pathologic cause and redo the pull-through if necessary.

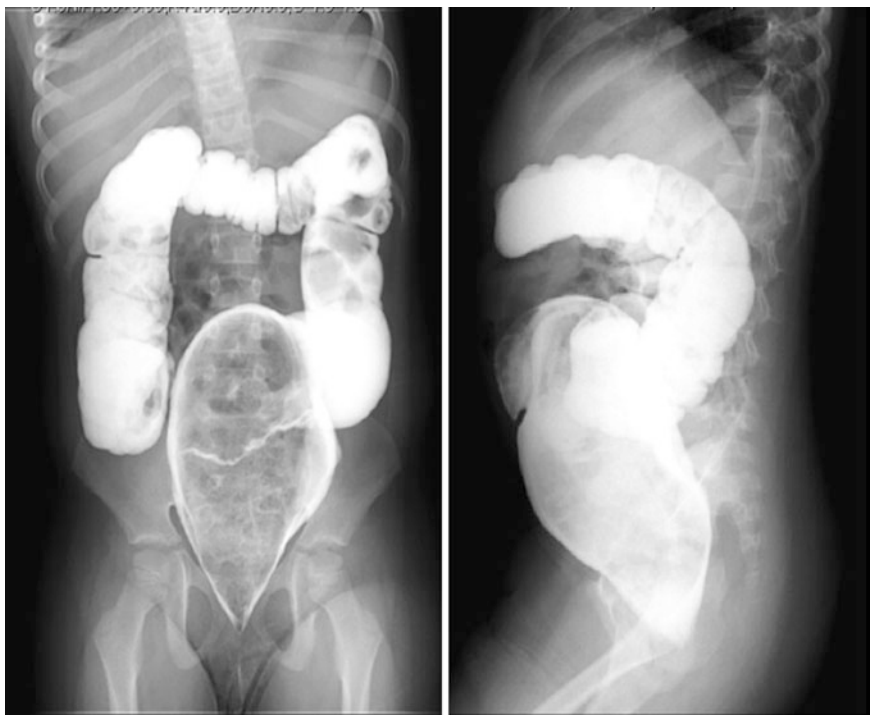

Fig. 62.10 Contrast enema demonstrating a "megarectum" in a patient after a Duhamel procedure. (Reprinted from Levitt MA, Dickie B, Peña A. Levitt MA, Dickie B, Peña A. Evaluation and treatment of the patient with Hirschsprung disease who is not doing well after a pull-through procedure. Semin Pediatr Surg. 2010 May;19(2):146-53, with permission from Elsevier.)

Internal Sphincter Achalasia

Internal sphincter achalasia refers to the lack of a normal recto-anal inhibitory reflex that is present in all children with Hirschsprung disease but in some significantly impairs normal defecation after definitive pull-through. This is a diagnosis of exclusion, after ruling out mechanical obstruction, aganglionosis, and dysmotility. The diagnosis is confirmed with anal manometry. Since this problem tends to resolve on its own in most children, we prefer the use of intrasphincteric botulinum toxin (6 units/kg, max 100 units, 25 units given in each quadrant of the anal canal). In many cases, repeated injection of botulinum toxin, application of nitroglycerine paste or topical nifedipine is necessary while waiting for resolution of the problem. Because of the spontaneous resolution of this problem as children grow and become more effective at defecating and coordinating sphincter relaxation, we believe internal sphincterotomy or myectomy should be avoided, as it could lead to permanent fecal incontinence.

Near-Total Intestinal Aganglionosis

Intestinal failure and the need for total parenteral nutrition from birth is present in total intestinal aganglionosis and is associated with a very high risk of mortality from liver failure. The extent of aganglionosis should be established at the time of the first laparotomy and a stoma brought out at the most distal point that has normally innervated bowel. The practice of bringing out a more distal stoma risks chronic intestinal obstruction and bacterial overgrowth. Long-term total parenteral nutrition and a gastrostomy for trophic feeding are usually required.

Surgical options for such patients include tapering, imbrication, or bowel lengthening procedures such as the Bianchi or serial transverse enteroplasty (STEP) particularly to enhance absorptive capacity. For children with ongoing liver failure, small bowel or combined small bowel-liver transplantation might offer the only chance for survival. Patch procedures of the left and right colon (Martin and Kimura) are no longer done as they cause too much stasis in their attempt to slow motility and increase absorption.

Conditions that Mimic Hirschsprung Disease

There are a number of conditions that resemble Hirschsprung disease in presentation and clinical course but are not characterized by the absence of ganglion cells on rectal biopsy. *Intestinal neuronal dysplasia* (IND) in its usual form consists of dysplasia of the submucosal plexus with thickened nerve fibers and giant ganglion cells, increased acetylcholinesterase staining and ectopic ganglion cells in the lamina propria. However, this condition is often described in a patient with Hirschsprung disease that has been previously operated on and therefore may indicate that the original pull-through was performed in the transition zone.

Hypoganglionosis is even less common and is characterized by sparse, small ganglion cells, usually in the distal bowel. There can also be abnormalities in acetylcholinesterase distribution. A similar condition might occur in a premature infant and thus the concept of "immature ganglion cells" has been described. This is usually self-limited and should not be treated surgically, except sometimes a temporary ileostomy is required.

Almost all children with HD lack the recto-anal inhibitory reflex. However, there are some children with ganglion cells present on rectal biopsy who also lack the inhibitory reflex and develop similar obstructive symptoms, although usually these patients develop constipation and impaction rather than enterocolitis. This condition has been termed *internal sphincter achalasia* or *ultra-short segment HD* (although we prefer to save the latter term for children with a documented aganglionic segment of less than 3–4 cm).

These children should be initially managed with a bowel management regimen. If this is unsuccessful, some surgeons advocate anal sphincter myectomy. We prefer temporary sphincter-relaxing measures such as botulinum toxin or nitroglycerine paste and strongly recommend against a sphincter myectomy as it can cause permanent fecal incontinence. The symptoms normally improve significantly over time in most of these children as they learn to better coordinate sphincter relaxation with defecation, so minimal intervention is recommended.

Future Considerations

Hirschsprung disease has a widely variable phenotype even in families with the same apparent genetic mutation. The incidence and severity of Hirschsprung-associated enterocolitis is also variable. Further genetic investigation is necessary to aid with prognosis, as patients with long-segment disease tend to have worse outcomes. A universally agreed upon definition of enterocolitis is needed in order to ensure that this outcome measure is reported similarly. Finally, long-term functional outcome and quality of life studies are needed to accurately assess the burden of this disease.

Editor's Comment

Radiographic identification of the transition zone in Hirschsprung disease needs to be regarded with caution. The contrast enema will identify what appears to be an obvious transition zone in the majority of cases, but the concordance between radiology and pathology is in the range of 50–90 % and perhaps as low as 30 % for long-segment disease. This should be recognized, particularly when planning a one-stage transanal pull-through.

The absence of calretinin staining suggests HD. However, claretinin staining can be misleading in ultra-short-segment disease (2–3 cm aganglionic segment) as mucosal nerves that stain positive for calretinin can extend into the proximal 1–2 cm of aganglionic bowel. This must be considered in rectal biopsies in which ganglion cells are not observed and calretinin staining is positive. In this scenario, more than four nerves >30 μm thick/×200 field or more than two nerves >40 μm thick/×200 field confirms the diagnosis of HD.

A common belief is that HD is rare in premature infants, though this has been disproved in large population-based studies. Many premature infants have an abnormal stooling pattern due to poor GI motility, which often results in a delayed diagnosis. Clinical features (failure to pass meconium, bilious emesis) are the same but contrast enema fails to demonstrate a transition zone in a higher percentage of premature babies with HD even though the distribution of the level of aganglionosis is similar to term infants.

Approximately one-third of patients will experience enterocolitis following surgery. This is less common after about two years. Trisomy 21, poor nutrition and anastomotic stricture are risk factors. Routine rectal saline irrigations beginning 3–4 weeks postoperatively and continuing for 1–3 months seem to decrease the occurrence of enterocolitis, especially in infants at higher risk.

Parents need to be told that any operation for HD is essentially palliative, not curative in the traditional sense. Patients should expect to be able to stool voluntarily with less difficulty and have a lower risk of enterocolitis but many will still have some degree of constipation and all patients should be followed closely for many years after surgery. Most will have some degree of intestinal dysmotility or sphincter dysfunction despite a technically excellent operation. Constipation is managed with diet modification but often requires a structured bowel management program. The need for a stimulant laxative is not uncommon and routine long-term follow-up is critical to avoid the morbidity associated with severe constipation such as megarectum and overflow pseudo-incontinence.

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Perianal Disease

63

Bennett W. Calder and Robert A. Cina

Pediatric perianal disease includes a variety of disorders affecting the anal canal, anal sphincters, and surrounding tissues. While these disorders can be quite painful and induce a great amount of parental anxiety, they usually pose little danger to the patient and often resolve with conservative management. Nonetheless, the diagnosis and management of these problems in children can be quite challenging. The correct diagnosis of perianal problems requires an intimate knowledge of the relevant anatomy, the patient's developmental stage, and the presenting history. While the etiology and management of perianal disorders in older children, adolescents, and adults can be similar, this is often not true for younger children and infants. Furthermore, one must consider that perianal disease may herald a serious underlying condition.

Anatomic Considerations

Anatomically, the perianal region includes the anal canal, the external and internal anal sphincters (IASs), and several soft-tissue spaces. The functional or surgical anal canal extends from the anorectal ring, at the level of the puborectalis muscle, to the anal verge. The puborectalis muscle is the caudal extension of the levator ani, and when contracted in the conscious patient, can be felt on digital exam. The embryologic anal canal extends from the dentate line to the anal verge. The dentate line, also referred to as the pectinate line, is found at the junction of the upper, or proximal 2/3 and the lower 1/3 of the anal canal. This marks the location of the mucocutaneous junction between the stratified squamous epithelium of the anoderm and the transitional epithelium of the anal transitional zone. The anal transitional zone extends cranially for a short distance and serves as an intermediary between the intestinal-like stratified columnar epithelium of the proximal anal canal and the anoderm. The histologic changes in epithelia correlate with patterns of sensory innervation. The anal canal below, or distal to the dentate line, receives somatic innervation and is sensitive to pain and temperature. In contrast, the sensory innervation above the transitional zone is exclusively visceral, sensitive only to stretch.

The muscles of the anal canal include the internal and external anal sphincters (EASs). The IAS, control of which is involuntary, is a distal extension of rectal circular smooth muscle that terminates just below the dentate line. The IAS is normally contracted at rest, but will relax upon distention of the rectum in what is known as the rectosphincteric reflex, which is characteristically absent in patients with Hirschsprung disease. The EAS is a complex of striated voluntary muscle that extends from the anorectal ring proximally to the subcutaneous tissues of the perianal skin distally. Control of the EAS is predominantly voluntary and it is variably contracted at rest. Anatomically, the EAS has subcutaneous, superficial, and deep components that form a sling-like mechanism around the anal canal and IAS to control the anorectal angle. Located between the muscles fibers of the IAS and EAS is an extension of the longitudinal muscle of the rectum. These fibers continue distally and insert into the subcutaneous tissue below the dentate line to form the intermuscular groove.

Rectal Prolapse

Rectal prolapse in children is generally a self-limiting condition found most commonly in patients <4 years of age. It is described as either partial or complete. Partial prolapse involves only the rectal mucosa while complete prolapse, or procidentia, involves the entire thickness of the rectal wall.

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Fig. 63.1 Partial rectal prolapse in an 18-month-old patient with chronic straining

On examination, the protruding tissue of a partial prolapse has radial mucosal folds and is usually quite small (Fig. 63.1). In contrast, a complete prolapse has circular mucosal folds, is usually larger, and the examiner can identify the full thickness of the rectal wall on palpation. In children, the underlying cause of rectal prolapse is multifactorial and related to increased intra-abdominal pressure, anatomical predisposition, infectious disease, or an underlying congenital or acquired disorder. Constipation with excessive straining during defecation is reported in most patients with rectal prolapse and is an important risk factor. Constipation alone, however, is unlikely to result in rectal prolapse as it occurs in only 3 % of children with constipation. Infants and toddlers are predisposed to prolapse due to the normal anatomic features found in this age group. Specifically, the rectum is more vertically oriented, positioned lower within the pelvis and has a more loosely attached and redundant mucosa. There are several conditions, both acquired and congenital, known to increase the risk for rectal prolapse (Table 63.1). However, cystic fibrosis is of particular importance. More than 20 % of children with cystic fibrosis will have rectal prolapse and for many it is the first sign of the disease.

Children with rectal prolapse commonly present with intermittent partial prolapse that spontaneously reduces. The diagnosis is usually based on the history, as the prolapse is rarely present or reproducible on examination. However, a useful maneuver to reproduce the prolapse in the office is to have the child squat down and strain. Additional history is often non-specific and can include constipation, fecal incontinence, blood per rectum, or painful bowel movements.

Table 63.1 Rectal prolapse: contributing factors in children

• Congenital/inherited: – Cystic fibrosis – Spina bifida occulta – Rectal polyposis – Anorectal malformations – Connective tissue disease – Autism spectrum disorder – Congenital neuromuscular disease
• Acquired: – Malnutrition – Chronic diarrhea – Parasitic infections – Chronic cough – Chronic constipation
• Age related anatomical considerations of the rectum: – Straight, vertically oriented course – Low position within pelvis – Redundant, loosely adherent mucosae

On digital exam, reduced sphincter tone is occasionally detected. This seems to occur shortly after a prolapse and quickly resolves. Any prolapse present during the encounter should be reduced to prevent edema and injury to the rectum. If edema is already present, sustained, gentle pressure should be applied to reduce swelling and permit reinsertion of the rectal tissue through the anal orifice. Though prolapsed tissue itself is not tender, conscious sedation may be helpful in case of a difficult reduction or an anxious patient. After reduction, rectal position should be confirmed with a digital exam.

The differential diagnosis includes sigmoid and ileocolic intussusception, rectal polyp, and hemorrhoid. Intussusception can be distinguished from rectal prolapse by inserting a finger along the protruding mucosa through the anal canal. This is not possible in rectal prolapse because the mucosa is continuous with the perianal skin. Furthermore, patients with intussusception are often much more ill appearing on presentation and complain of severe abdominal pain. In contrast to rectal prolapse, prolapsed hemorrhoids and polyps do not involve the entire mucosal circumference of the anal canal and characteristically lack an opening in the protruding tissue.

Once rectal prolapse has been confirmed and successfully reduced, the initial steps in the patient's care should address constipation and excessive straining during defecation as well as a sweat chloride test to rule out cystic fibrosis. Laxative therapy, dietary modification, and proper toilet training education will prevent prolapse recurrence in most patients. Digital examination can identify a rectal polyp, which may be the lead point for recurrent prolapse. A contrast enema may be useful to rule out a more proximal polyp or polyposis. The contrast enema is also cathartic which will allow for a more effective initiation of laxative treatment. If there is a history of significant bleeding, endoscopy should be considered to identify the source. Most patients, including those with cystic fibrosis, will respond to medical management.

For rectal prolapse that is refractory to medical therapy, surgical options should be considered. Injection sclerotherapy using concentrated dextrose (D_{50}) or hypertonic saline is both well tolerated and efficacious, and is considered first line treatment in medically refractory cases. This is best achieved by longitudinally injecting each of four quadrants with the sclerosing agent to promote scarring and adherence of the mucosa to the rectal wall. In addition, we routinely score the mucosa longitudinally with the electrocautery between injection sites. The procedure should be performed in the operating room to permit a complete examination of the anus and rectum under anesthesia. Although more than one treatment may be required, sclerotherapy is ultimately successful in more than 80 % of patients.

Surgical techniques that have been described for the management of refractory rectal prolapse include anal encirclement with a non-absorbable suture (Thiersch procedure), the Ripstein transabdominal proctopexy, posterior sagittal rectopexy, and open retrorectal sclerotherapy. Our preference in refractory cases is laparoscopic rectopexy with suture fixation of the rectum to the sacral promontory, with or without segmental colectomy as necessary. This is a relatively straightforward procedure with an umbilical camera port and two laterally placed working ports. The recto-sigmoid colon is mobilized and dissected below the peritoneal reflection, after which the mesentery is taken with the Ligasure, and the redundant sigmoid colon removed. The anastomosis can be performed with an EEA stapler. Following anastomosis, the rectum is secured to the presacral fascia with several non-absorbable braided permanent sutures.

Parents and caretakers should be educated on the importance and technique of reduction of rectal prolapse. At our institution, we perform a six-month trial of conservative management in all patients under age four. For those who fail conservative management, we routinely use D_{50} sclerotherapy with good outcomes. In patients with neuromuscular disorders, anatomic malformations, significant bleeding, damage to the rectal tissue by repeated prolapse, recurrence after injection sclerotherapy or, frequent, difficult to reduce prolapses, we offer laparoscopic rectopexy.

Perianal Abscess and Fistula-in-Ano

Perianal abscess is a relatively common problem in children. The majority of pediatric patients presenting with perianal abscesses are male and <1 year of age. In older children the causes of perianal abscess include Crohn's disease, immunodeficiency, and diabetes. On examination, a tender subcutaneous mass is usually easy to identify. The area may be erythematous and the mass firm or fluctuant. Systemic signs of infection are generally absent.

For very small, non-fluctuant abscesses in patients with no physical or laboratory signs of bacteremia, initial non-operative treatment with oral antibiotics is appropriate. Recurrence is not uncommon. A second trial of non-operative treatment is warranted if the child is clinically well. Large fluctuant abscesses or those that have failed conservative management should be incised and drained under conscious sedation. We prefer to make two opposing incisions, break any loculations with a hemostat, wash out the abscess cavity with saline and insert a vessel loop to facilitate continued drainage. This can be removed with little discomfort 7 days later.

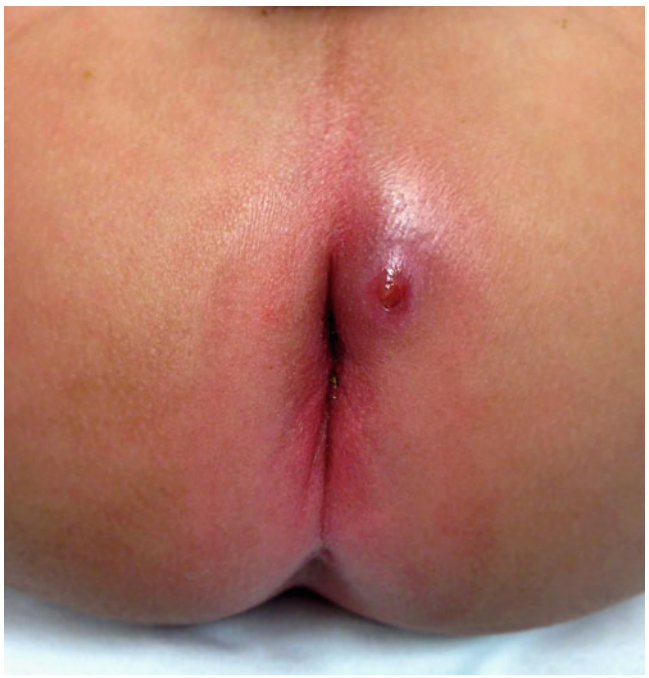

Fig. 63.2 Fistula-in-ano in an otherwise healthy young patient who presented with a chronically draining abscess

Fistula-in-ano typically follows the presentation and treatment of a perianal abscess and is also predominantly found in young male infants. A fistula should be suspected in a patient who has recurrent episodes of a draining abscess or a persistently draining opening in the skin several weeks after incision and drainage of an abscess (Fig. 63.2). The optimal treatment of fistula-in-ano is actively debated with recurrence rates as high as 85 %. While conservative management of fistula-in-ano has been reported with high success rates, that has not been our experience. In infants, we do not routinely treat fistulas during drainage of an abscess. We prefer a trial of non-operative management before proceeding to a fistulotomy. In older children and adolescents, the etiology of fistula-in-ano is likely comparable to that of adults. Therefore, these patients should be treated similarly.

Anal fistulotomy is begun with an exam under anesthesia and identification of the fistula with a fine lacrimal duct probe. If the internal opening of the fistula is unclear, diluted hydrogen peroxide injected into the external opening of the fistula is helpful. Once the lacrimal duct probe is placed

completely through the fistula tract, electrocautery is used to un-roof the fistula. The tract is then debrided and cauterized, and the wound left open to heal by secondary intention. It is important to carefully search for additional fistula tracts. Excision of the associated underlying crypt is not necessary unless there is a recurrence. Postoperative care includes Sitz baths twice daily and after bowel movements. The edges of the wound should be manually separated during each Sitz bath. Though parents are often nervous to manipulate the wound, it is important to inform them that this causes minimal discomfort to their child.

In older patients, especially those in whom inflammatory bowel disease is a primary concern, pelvic MRI should precede any attempt at surgical intervention, including examination under anesthesia. Examination under anesthesia is best achieved with the patient in dorsal lithotomy position with all pressure points padded. In infants, this is most easily achieved by taping their feet together in a frog-leg position with a piece of foam between their feet, and bringing them up over their head and attaching them to an Ether bar with cling gauze or Coban. In older children and adolescents, "candy-cane" stirrups work well. It is important to avoid probing tracts against resistance so as to avoid the creation of false tracts. Finally, if an abscess requires drainage, we find that a vessel loop passed through two small incisions at the limits of the abscess cavity and tied to itself results in less discomfort and faster healing than a single incision and gauze packing.

Anal Fissure

Anal fissure, defined as a tear in the distal epithelium of the anal canal, is the most common cause of hematochezia in children and is associated with constipation, inflammatory bowel disease, and sexual abuse. The etiology is usually cryptogenic, however, the passage of large, hard stools is traditionally thought to be the most important contributing factor. While constipation may or may not be the cause, it certainly prolongs fissure resolution. Once an anal fissure develops, pain during defecation perpetuates a cycle of avoidance and worsening constipation. Patients usually present with blood streaks on the stool, pain, and fecal withholding. The diagnosis is made by visual inspection and identification of a longitudinal tear in the anoderm. The majority of fissures are single and located in the midline, though they may be multiple or present elsewhere, especially in infants. When fissures are found in other locations, are multiple or very large, causes other than constipation should be considered. These include inflammatory bowel disease, sexual abuse, sexually transmitted infections, and immunodeficiency.

Most acute idiopathic anal fissures will heal without further intervention. Appropriate dietary modifications and implementation of stool softeners or laxatives can hasten healing and prevent recurrence. Sitz baths and topical analgesics are added to the treatment regimen as needed. In those unresponsive to this management, strategies to relax the anal sphincter muscles, such as the application of nitroglycerin ointment or botulinum toxin injection should be considered. However, the optimal management of refractory fissures is unclear and patients will often undergo lateral internal anal sphincterotomy in this situation. Non-operative management of anal fissure in children, including botulinum toxin injection and nitroglycerin ointment application, though not associated with an increased risk for fecal incontinence, is apparently only marginally more effective in children than placebo and less effective than operative intervention. In contrast, nifedipine gel with lidocaine may result in healing in over 90 % of children with low rates of recurrence.

When caring for patients with anal fissure, constipation should be addressed first. Parental education, diet modification, and laxative/lubricant therapy will usually lead to fissure resolution. Though the efficacy of topical anesthetic ointment is in question, we find that patients experience less pain and prefer a combination of 2.5 % lidocaine and 2.5 % prilocaine cream. In children who do not achieve fissure resolution by 8 weeks, we add topical 0.2 % nitroglycerin to the treatment regimen. For those patients with chronic fissures or who have failed all medical therapy, operative treatment is appropriate. We no longer use dilation given high reported rates of incontinence. Fissurectomy, which preserves the internal sphincter, is effective, however, the data in children are limited. Lateral internal anal sphincterotomy, with or without fissurectomy, has excellent cure rates. However, due to the risk of fecal incontinence we reserve this procedure for refractory and complicated cases.

Internal Anal Sphincter Achalasia

Internal anal sphincter achalasia (IASA) remains an incompletely understood disorder characterized by failure of the rectosphincteric reflex to induce IAS relaxation. IASA can mimic Hirschsprung disease and is at times considered to be a variant of the disease. However, in patients with IASA, suction rectal biopsy will demonstrate normal ganglion cells, suggesting a unique pathogenesis. The true incidence of IASA in children is unknown. Approximately 4.5 % of children with chronic constipation are diagnosed with IASA. The diagnosis should be suspected in patients presenting with a history of severe constipation refractory to treatment with laxatives and stool softeners. The diagnosis is established by anal manometry and suction rectal biopsy which will show an absent rectosphincteric reflex despite the presence of ganglion cells with normal acetylcholinesterase activity. If any doubt remains, the diagnosis can be confirmed by response to botulinum toxin injection.

Treatment has traditionally included posterior internal sphincter myectomy. This procedure entails resecting a strip of smooth muscle 0.5–1 cm wide in the posterior midline of the anal canal beginning at the dentate line and extending proximally for 1.5–5 cm. In the last two decades, intersphincteric botulinum toxin injection to treat IASA has become increasingly popular. Initial outcomes of IASA treatment with this technique were promising. However, newer data is mixed: short-term responses (<6 months) for myectomy and botulinum toxin injection are around 90 % and 80 %, respectively, but after 6 months response for myectomy is roughly 85% compared to barely 60 % for botulinum toxin injection. Posterior IAS myectomy appears to be the most effective treatment option for IASA. We offer botulinum toxin as an initial treatment for these patients. Often one or two treatments will result in resolution of symptoms. In those patients who develop recurrent symptoms after improvement with two rounds of chemical denervation, we offer myomectomy. Regardless of the treatment, patients and parents should be counseled on the chances of post-procedure fecal soiling, procedural failure, and the need to continue medical therapy for constipation.

Hemorrhoids

Hemorrhoids are an unusual finding in a child unless accompanied by portal hypertension or a vascular malformation. One-third of patients with portal hypertension will have hemorrhoids. In other children with hemorrhoids, straining during defecation is usually the precipitating factor. External hemorrhoids are found distal to the dentate line and cause pain (Fig. 63.3).

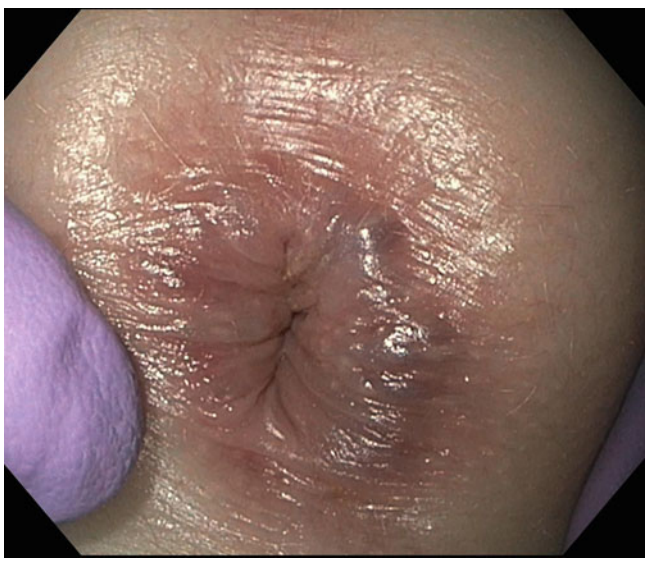

Fig. 63.3 Small external hemorrhoids in a 2-year-old child secondary to chronic straining during defecation. (Courtesy of J. Antonio Quiros, M.D.)

Internal hemorrhoids occur proximal to the dentate line, which is innervated by visceral nerve fibers and are therefore usually painless.

Patients may be asymptomatic or have complaints related to bleeding, discomfort, or itching. Parents may notice prolapsed hemorrhoids during diaper changes and bathing. External hemorrhoids can be diagnosed visually as a swollen, bluish mass protruding from the anoderm. When thrombosed, external hemorrhoids are extremely tender. Skin tags may represent the sites of healed thrombosed external hemorrhoids. Internal hemorrhoids, unless prolapsed through the anal orifice, can be palpated on digital exam or diagnosed using anoscopy. Internal hemorrhoids are graded based on the degree of prolapse. Grade I are limited to the canal and will not prolapse. Grade II prolapse, but reduce spontaneously. Grade III require manual reduction of the prolapse. Grade IV are prolapsed hemorrhoids that cannot be reduced.

Treatment is primarily aimed at addressing underlying causes such as constipation. Most hemorrhoids will respond to conservative management. Thrombosed external hemorrhoids can be excised to provide symptomatic relief, although the window in which this is effective is narrow. Internal hemorrhoids that have failed conservative management can be treated with rubber band ligation. In the unusual case of high-grade internal hemorrhoids that have failed conservative treatment, hemorrhoidectomy is also an appropriate option. For all patients, we find that Sitz baths twice daily and after defecation provide symptomatic relief and may speed recovery.

Sexual Abuse

Sexual abuse in children is a common problem worldwide. In the USA, 10 % of adults report a history of childhood sexual abuse. A significant proportion of victims of anal abuse have at least one associated perianal finding on exam. The most common findings are reflex anal dilation, reduced anal tone, erythema, and perianal venous congestion, all of which are present more than 20 % of the time. Anal fissure is also quite common and is found in 14 % of anal abuse victims.

The detection of a sexually transmitted infection in a child should always lead to a thorough abuse investigation. Particularly distressing to patients and caregivers are anal condylomata. Although these can be vertically transmitted from parents through non-nefarious means, they can also be a sign of abuse and further history should be obtained. The type of treatment depends on the extent of the lesions at presentation. We prefer an initial trial of topical imiquimod in patients without extensive carpeting disease. For patients for whom this fails or who have extensive disease, we proceed to fulguration in the operating room. This is additionally helpful as general anesthesia facilitates a complete anorectal exam.

Editor's Comment

Rectal prolapse can be painful and frightening, but is rarely dangerous and usually self-limited. Straining at stool seems to be the common precipitant, mostly in the setting of constipation, but some children with loose stool or diarrhea can prolapse if they strain. There is probably an anatomic predisposition and it seems likely that some degree of mild mucosal prolapse is normal; but if it is associated with pain, bleeding, or a need for manual reduction, referral to a pediatric surgeon is reasonable. Once cystic fibrosis (regardless of the age of the patient) and other conditions like rectal polyp and sphincter laxity due to abuse have been ruled out, most children respond to conservative measures to minimize straining at stool. This usually includes a stool softener or gentle stimulant laxative (excessive stimulants might worsen straining), elimination of spicy foods, a trial of avoiding dairy products, and advice to avoid prolonged toilet time. It is also advisable to reassure parents, some of whom obsess over every bowel movement, that this will likely resolve and poses minimal danger—if the child is asymptomatic, it seems reasonable to monitor but essentially ignore the problem.

In the rare case of truly refractory case of symptomatic prolapse, it is reasonable to offer surgical intervention. While many prefer to start with sclerotherapy, we have had excellent results with the Altemeier procedure, in which the distal rectal mucosa is resected circumferentially and an anastomosis is created above the dentate line. We also usually add a modified Thiersch cerclage using a heavy absorbable suture around a cervical dilator placed in the anus. It is well tolerated and recurrence is uncommon. For the rare recurrence, a laparoscopic or low transverse rectopexy with or without bowel resection is an excellent next step.

Fissures and their resultant skin tags create a lot of anxiety for some parents but are generally harmless and treated with stool softeners and laxatives. Surgery is rarely needed, though some oncology patients will have a deep fissure that becomes painful or bleeds when their counts drop after chemotherapy. Surgical excision with primary closure can be performed between cycles with good results. Given the high risk of irreparable incontinence, no child should undergo sphincterotomy.

Fistulas in infants always eventually resolve but might require fistulotomy or fistulectomy if very painful or at the insistence of a parent. Older children or adolescents with a new fistula or abscesses should be evaluated for Crohn's disease before being subjected to surgical intervention. The manifestations of perianal Crohn's disease should be treated using the least invasive techniques available (drainage, setons, dilation)—open perianal wounds will never heal in the setting of active Crohn's inflammation.

Extensive anal condylomata are no longer automatically considered a harbinger of abuse and rarely require surgical excision anymore. When they do, it should be done in stages to avoid a circumferential stricture and a plume evacuator must be used to prevent pulmonary papillomatosis for the OR staff. True internal hemorrhoids are almost never seen in children but can be treated using standard techniques after portal hypertension has been ruled out. Thrombosed external hemorrhoids occasionally require incision and thrombectomy for pain relief, which can often be done in the office setting.

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Pilonidal Disease

64

Brian G.A. Dalton and Shawn D. St. Peter

Pilonidal sinus disease was first described in 1833 and has an incidence of roughly 25 in 100,000 with a 2:1 male predominance. There are about 70,000 new cases each year in the USA. Pilonidal disease is most common in people under 40 years old with its peak at ages 15–30. Morbidity due to pilonidal disease results in significant loss of productive workdays and education days.

The widely accepted hypothesis for the development of pilonidal diseases is that it is an acquired condition. This hypothesis is supported by the occupational incidence of jeep drivers and barbers and recurrence despite surgical intervention. It is most likely an acquired disease that begins after puberty when the adult body hair pattern develops, and sex-hormone-related changes of the pilosebaceous glands occur. Three factors seem to contribute to pilonidal disease: loose hair, force causing insertion of the hair, and vulnerability of the skin to insertion of hair at the natal cleft. Hair penetrates the skin and a pilonidal sinus results from a foreign-body reaction. As the disease requires hair as the nidus of disease, it is more common in hirsute individuals. The sinuses are thought to result from hairs burrowing into the skin, most commonly in the area of the superior gluteal cleft. The suspected mechanism is that hairs along the cleft are captured within the crease and advanced deeper by normal body motion. Once at the base the hairs can burrow through the skin into the subcutaneous space. Sitting produces pressure to drive this process. This may leave a pit in the form of an epithelialized tract that is apparent at the cleft base. Multiple pits result in tracts, with the collection of hair causing a foreign-body reaction resulting in a pseudocyst cyst that can become a true abscess.

The sinus can present acutely as an abscess or can cause chronic pain, bleeding, and drainage. Pilonidal disease is often frustrating to treat and burdensome for patients. The operations are not trivial in their morbidity and they are fraught with wound breakdown and recurrence. Furthermore, optimal treatment and prevention strategies have yet to be completely elucidated.

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Pilonidal Abscess

Approximately half of the patients with a pilonidal sinus will present with an acute infection. This is usually manifest as an inflamed, fluctuant, and painful abscess in the superior aspect of the gluteal cleft. In most cases, the appearance is diagnostic and no further imaging is needed. However, if the diagnosis is in question then an ultrasound may be obtained, which will demonstrate a heterogenous subcutaneous fluid accumulation consistent with an abscess.

The initial treatment consists of simple incision and drainage. Abscesses often erupt or have a point of maximal fluctuance off-midline, avoiding the need for a drainage incision in the gluteal cleft. An incision lateral to the midline promotes healing, which is difficult at the base of a deep cleft. The abscess drainage is most often performed as a bedside procedure with local anesthetic or intravenous sedation. Manual lysis of any septations and removal of any visible hair tufts in the abscess are key steps in the treatment of an acute abscess associated with pilonidal disease. Therefore, an incision large enough to accomplish these goals should be made. Thorough irrigation is then carried out to enhance emptying the cavity and removing any residual hair. Patients may be discharged home after initial incision and drainage without antibiotics unless the abscess is accompanied by surrounding cellulitis or the patient is immunocompromised. Given the mechanism of pilonidal disease, we advocate shaving the area to reduce the chances of loose hairs remaining in the wound, thereby decreasing the chance for recurrence.

The initial incision and drainage is curative in about 60 % of patients and complete healing can be expected within 10 weeks. The remainder of these patients progress to have chronic wound problems or recurrent abscess associated

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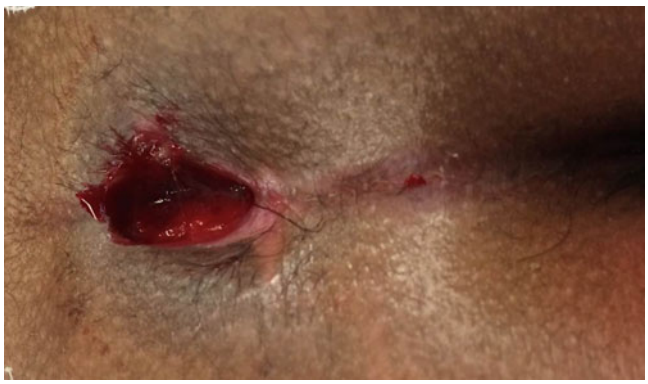

Fig. 64.1 Chronic open pilonidal sinus with subcutaneous tunneling moving toward the right of the picture

with pilonidal disease (Fig. 64.1), which should prompt an attempt at definitive management.

Chronic Pilonidal Disease

The management of the chronic pilonidal wound or painful pilonidal sinus is controversial with no single procedure accepted as standard. Excision should include the entire cavity of pits, granulation tissue and hair, and should begin outside of the expected extent of the pilonidal disease so that a rim of normal tissue is removed. One should not enter the cavity and then work outward. The deep limit of the dissection might need to extend to the sacrococcygeal fascia to ensure complete excision of the disease.

Excision and Leaving the Wound Open

For patients who experience a recurrent abscess or present with chronic pilonidal disease, multiple surgical options exist. Recent reviews reveal no clear benefit of surgical excision with healing by secondary intention compared with primary closure. However, infection and recurrences are higher following primary midline closure compared to off-midline closure techniques. Complete excision of the infected tissue and leaving the wound open to heal by secondary intention avoids the risk of a wound infection, but does not prevent recurrence. Furthermore, healing and recovery are significantly prolonged with this approach. Allowing the wound to close by secondary intention requires routine packing and the commitment of both the patient and the caregiver, as the patient often cannot perform the necessary wound care. Vacuum-assisted closure devices have been employed to facilitate this process by promoting earlier healing, but they can limit patient mobility. Portable VAC systems allow for improved patient mobility, but are more unwieldy than traditional packing. Packing the wound most often allows patients to return to normal activity in a few days.

Excision with Midline Closure

Operative techniques vary regarding the location of the incision, either in the midline or off the midline. Some advocate a midline elliptical-shaped incision with simple layered closure after excision. The midline technique does not change the location or depth of the gluteal cleft, so this may not be favored in a patient with dense hair and a deep gluteal cleft. This can be a simple approach to less complicated disease as is often seen in females or those with a shallow cleft.

In our experience, the partial wound breakdown after primary closure is common and does not limit patient activity. It can be managed by the surgeon on an outpatient basis without a substantial investment from the caregivers. Local wound care and the use of silver nitrate for granulation tissue will usually facilitate complete healing and avoid the need for deep packing or a wound VAC. In a review of our experience, recurrence rates are similar between patients treated with excision and primary closure and those left open to heal by secondary intention. However, the primary closure group had significantly fewer subsequent operations, post-operative visits, and a trend toward lower costs despite slightly longer operative times.

Off-midline Closure

Flap or off-midline closures are theorized to reduce recurrence by placing the scar off-midline so native dermis is at the point of possible hair penetration and by flattened the cleft so as to diminish propulsive forces. Outcomes following a variety of off-midline closure techniques have been extensively examined. Prospective randomized trials have variably supported both the Karydakis flap and the Limberg flap. While the Karydakis flap has resulted in lower complication rates, higher patient satisfaction, lower pain scores, shorter length of stay, and less wound disruption compared to the Limberg flap, other studies have demonstrated lower recurrence and complication rates with the Limberg flap. Meta-analyses have confirmed the benefit of off-midline closure in regards to wound infection and dehiscence, but have found no difference in recurrence or wound complication rate between the two techniques. Without a standard procedure, the type of off-midline closure after excision of pilonidal disease is left to surgeon preference.

Our preferred method is an off-midline approach, made popular by Karydakis, uses a sail- or D-shaped incision. Thevertical side of the incision is to one side of the midline

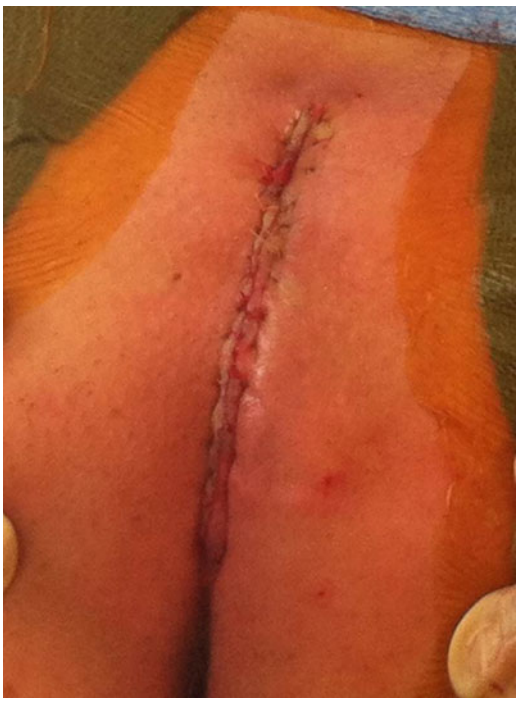

Fig. 64.2 Closure after complete excision showing the shallowness of the gluteal cleft and raised wound closure created by the mattress sutures

and parallel to the midline while the curvilinear side courses out lateral to the midline. This technique lateralizes the cleft away from midline and flattens the cleft. The excision is a complete resection down to the sacrococcygeal fascia and then a subcutaneous flap is created at the level of the fascia on the straight side of the incision along the midline. This side is then brought out to the curvilinear side to move the new cleft, which is the incision scar, away from the midline. The wound is then closed in four layers. A drain is placed in select cases of a very large defect or excessive intra-operative bleeding. Regardless of the final location of the incision, midline, or off-midline, another surgical goal is to decrease the depth of the gluteal cleft (Fig. 64.2). We close the final skin layer with interrupted mattress sutures using 4–0 absorbable braided suture to elevate the skin edges to create a tension-free approximation.

Preoperative antibiotics are routinely given, but post-operative antibiotics are not generally necessary. The surgery is most often performed as an outpatient. Discharge instructions include maintenance of hair removal and notifying the surgery team for any sign of a wound complication. Follow-up is scheduled 3–4 weeks post-operatively and any wound dehiscence is treated aggressively with silver nitrate and close follow-up. This usually allows complete healing. In the immediate post-operative period it remains imperative to keep the area around the wound free of hair.

Peri-operative Care

The use of drains following pilonidal excision and primary closure is highly variable. A trend toward lower recurrence and infection rates has been reported although randomized control trials have shown no difference in infection or recurrence rates.

Use of antibiotics in pilonidal disease is another area without clear guidelines. No difference in healing or wound infection rates has been demonstrated using a single dose of antibiotics compared with a longer course (4–7 days). Gentamicin collagen sponges have been used in both primary and secondary closure techniques without a clear benefit. We routinely administer preoperative antibiotics only.

Recurrence

Up to 20 % of patients will experience recurrent disease, which can be very challenging. After complete healing, hair can still penetrate the scar, which is weaker than the dermis, leading to recurrence (Fig. 64.3). Recurrent disease is treated with re-excision. A second recurrence will prompt a

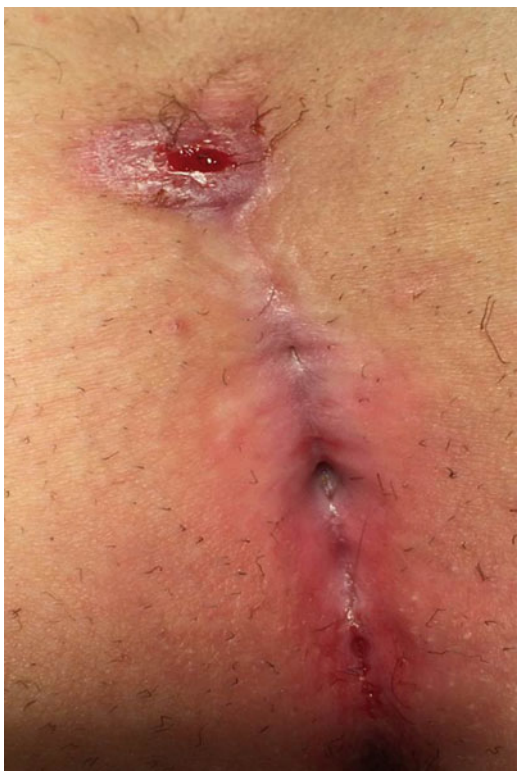

Fig. 64.3 Recurrent pilonidal disease. After complete excision and closure, the wound healed nicely. After regrowth of hair, the disease recurred through the previous scar. Several pits can be seen inferiorly which allowed subcutaneous access to the hairs and the cavity erupted through the skin surface superiorly. This is also a classic appearance of chronic primary disease

Table 64.1 Proposed protocol for surgical care of pilonidal disease

Acute abscess	Incision and drainage—monitor for recurrence
Chronic sinus/cyst	Recommend surgical excision with midline closure in mild disease or Karydakis flap for severe disease
Drain left?	If significant dead space or excessive bleeding
Antibiotics	Single dose administered pre-operatively
Post-op instructions	Remove hair in effected area, limited activity
Wound dehiscence	Treat often with silver nitrate, local wound care, repeat hair removal
Recurrence	Re-do excision with off-midline closure

multidisciplinary approach that includes plastic surgery to help with a flap transposition following a re-excision (Table 64.1).

While off-midline closure techniques result in lower recurrence rates, certain adjunct treatments may help reduce recurrence. Hair removal around the surgical site as part of primary therapy may prevent recurrence. However, hair removal via shaving may actually increase recurrence rates. Laser hair epilation is a promising technique to reduce recurrent pilonidal disease after excision with primary closure. Intra-operative use of methylene blue has also been touted to reduce recurrence rate. Obesity and smoking are risk factors for post-operative complications. Therefore, weight loss and smoking cessation are both advised after diagnosis and treatment of pilonidal disease if applicable.

Additional Treatments

Several other techniques to treat pilonidal disease have been successful in series with limited numbers of patients. After removing the imbedded hair, the pilonidal tracts have been treated with phenol, fibrin glue and laser ablation. If injection of phenol is performed, one must be aware that damage to the surrounding skin can occur and this can compromise wound healing.

Editor's Comment

Pilonidal disease, also referred to as pilonidal sinus disease (these are not true cysts and therefore any reference to a "cyst" should be avoided), is clearly of the acquired variety in most patients, with drill hairs trapped within midline pits causing a local foreign-body reaction, granulation tissue, and eventually infection. But there are some who clearly have an anomalous and presumably congenital pattern of hair growth in which the hairs are literally arising from and trapped within the subcutaneous tissues of the gluteal cleft. The amount of hair growing in the subcutaneous cavities can be astonishing. Regardless, meticulous hair removal and excellent hygiene form the basis of initial non-operative management. We recommend a depilatory cream or shaving the area every 2 weeks, even in the significant minority of patients who are not overtly hirsute. We also see them back in the office every 4–6 weeks for inspection and removal of hair from within the pits. Many respond well to this approach and never need surgical intervention.

Surgery for pilonidal disease is crude, painful and prone to prolonged healing, severe limitations in physical activities, and a high risk of recurrence. It is not to be recommended lightly. It is also clear that off-midline approaches are far superior to midline approaches. But perhaps the most important factor in successful repair is volume—like many technically demanding operations, outcomes are clearly better for surgeons who perform them frequently. Closed-suction drainage is optional but probably best in most cases. Rapid return to sports or excessive sitting probably contributes to a number of recurrences though the majority are probably due to technical issues (too much tension, insufficient excision, post-operative seroma, surgical site infection).

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Appendicitis

65

Feroze Sidhwa, Charity Glass, and Shawn J. Rangel

Appendicitis is the most common abdominal surgical emergency in children, yet variation in care regarding diagnosis and management remains considerable. Recently, an increase in the number of randomized controlled trials and multicenter cohort studies have shed light on several longstanding controversies. New approaches to the diagnosis and management challenge traditional dogma, from the need to treat uncomplicated appendicitis as a surgical disease to the need for extended antibiotic therapy in perforated appendicitis.

Diagnosis

Effective and efficient management of a child with suspected appendicitis requires a timely diagnosis while minimizing radiation exposure and the risk of a negative appendectomy. Considerations surrounding resource utilization and patient-centered care such as minimizing patient and family anxiety and time away from school and work should also be considered. To accomplish these goals, a collaborative approach between emergency medicine physicians, surgeons and radiologists, and optimal use of clinical, laboratory, and imaging data is required.

Clinical Evaluation

Diagnosing appendicitis with an acceptable level of confidence based on history and physical exam alone is challenging, especially in younger children and adolescent girls. Several clinical scoring systems have been created to assist in the clinical diagnosis of appendicitis. The best studied of these scoring systems are the Pediatric Appendicitis Score (PAS, also known as the Samuel score) and the Alvarado score. Although these two scoring systems are the only ones that have undergone prospective validation in multiple settings, a wide range of predictive values have been reported. Furthermore, the relatively poor quality of previous studies makes it difficult to support a pooled analysis. Overall the PAS has outperformed the Alvarado score in validation studies with a sensitivity ranging from 82 to 100 % (median 93 %) for the PAS and 72–93 % (median 88 %) for the Alvarado. Thus, the existing scoring systems are neither sensitive nor specific enough to accurately diagnose appendicitis in children as a stand-alone approach. Variation in the reported effectiveness of these scoring systems is also likely to reflect differences in the experience of clinicians using the scoring tools, as well as the relatively subjective nature of many of the individual scoring elements.

Laboratory Studies

Laboratory data are an important adjunct to the clinical history and physical exam. A white blood cell count less than 9000 cells/μL is a risk factor for a negative appendectomy, although only 62 % of patients with appendicitis have a WBC count over 9000 cells/μL. The diagnostic value of C-reactive protein level is similarly limited; positive and negative predictive values for CRP are approximately 60 and 80 %. The combined use of WBC and CRP data has not been shown to improve predictive value in identifying patients with appendicitis or to rule out appendicitis.

Imaging Studies

Ultrasound is often used as the initial imaging modality in children with suspected appendicitis, and can be a definitive study in experienced hands. Abdominal US is less costly than CT and does not expose patients to ionizing radiation or require intravenous contrast. As such, the American College

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of Radiology recommends the use of US prior to CT in all children with suspected appendicitis. However, US is less accurate than CT, and effective utilization requires technicians and radiologists who are experienced in performing and interpreting exams in the children. The sensitivity and specificity of ultrasonography for diagnosing appendicitis in children ranges between 35–88 % and 46–99 %. US test characteristics have been shown to be heavily dependent on user and institutional experience, patient selection, and patient-related factors. Patient-related factors include body habitus, cooperation with the exam, and painful graded compression maneuvers and ability to articulate a sensation of pain. Furthermore, unlike criteria used for establishing a diagnosis of appendicitis by CT, the criteria for a positive US are subjective and not universally agreed upon. Standardization of sonographic technique and radiologist reporting is needed to improve diagnostic accuracy and reduce the need for CT.

CT with intravenous contrast remains an accurate and popular imaging modality for children with suspected appendicitis. The sensitivity and specificity ranges from 87 to 100 % and 89 to 99 %. Unlike US, CT is not user-dependent and is minimally impacted by body habitus. The major concern with CT use in children remains one of patient safety: nearly 5000 radiation-induced cancers are estimated to result from the approximately 4,000,000 CT scans received by children in the USA annually. Although rare, complications from intravenous contrast also carry significant risk of morbidity. The risk of radiation-induced neoplasia may be decreased by reduced-radiation protocols, which can be used without sacrificing diagnostic accuracy.

MRI has been investigated as a tool for diagnosing appendicitis in children to avoid radiation. It has been used in children as young as 3 years of age without the use of intravenous contrast or sedation. Sensitivity, specificity, positive predictive value, and negative predictive values are apparently quite high. Institutional protocols in which US is the primary imaging modality and MRI is used as a secondary modality when ultrasound was nondiagnostic, seem to have similar time to first dose of antibiotics, time to appendectomy, and length of stay compared to the same protocol in which CT scan was the primary imaging modality.

While MRI does not expose the patient to ionizing radiation, it is a higher-cost modality than either ultrasound or CT scan. Further data are needed to clarify the role, safety profiles (for younger or impaired children who may require sedation) and cost-effectiveness of MRI for this indication.

Diagnostic Pathway

We have implemented a standardized approach to the diagnostic evaluation of appendicitis that incorporates a modified PAS and leverages the combined predictive value of ultrasound findings and laboratory data. We agree that appendicitis scoring systems have limited diagnostic utility but the modified PAS is a useful screening tool for identifying patients at very low risk of appendicitis for whom further imaging and surgical consultation are unwarranted (Fig. 65.1 and Table 65.1).

All moderate- to high-risk patients have a WBC, a US, and a surgical consultation. Patients are then risk-stratified on the basis of their sonographic findings and WBC count. This algorithm was derived from an audit of pathologically confirmed appendicitis in 845 consecutive patients evaluated for appendicitis at our institution. Combining these data allows for risk-stratification superior to that achieved by US alone. This is especially true for studies in which definitive signs of appendicitis or a normal appendix are not found, and in identifying patients who were at high risk of negative appendectomy, namely those with normal WBC count in the presence of what appeared to be primary or secondary signs of appendicitis on ultrasound (Fig. 65.2). Using previously described methods (Table 65.2), we have improved the diagnostic accuracy of ultrasound though standardization of imaging technique and reporting of results.

Further management is based on the patient's risk profile (Fig. 65.2). Low-risk patients (<4 % risk) are discharged home without further imaging or are admitted to the pediatrics service for further evaluation. High-risk patients (>94 % risk) are taken to the operating room for appendectomy without further imaging unless advanced perforated disease is suspected. In these children, a CT is obtained to rule out the presence of an abscess. If a well-formed abscess is identified, a radiologist performs image-guided percutaneous drainage. Moderate-risk patients are observed for a 6-h period in the ED and then reassessed. Those who improve and can be safely discharged are instructed to call the surgery clinic the following morning to arrange a drop-in appointment as needed for further evaluation. Those who do not improve are admitted to the hospital and re-evaluated the next morning with a repeat WBC count and US.

Indications for CT include: (1) clinical presentation or duration of symptoms for at least 5 days, suggesting advanced disease with a well-formed abscess, (2) when other pathology is suspected that may require operative intervention, or (3) when the clinical situation remains unclear after repeat laboratory studies and US. When performing a CT for these indications, a reduced-radiation protocol is used. The use of MRI (rather than inpatient admission) for patients with equivocal risk profiles who do not improve during their initial observation period is under investigation and might prove to be useful.

Treatment

Timely appendectomy has long remained the standard of care for acute appendicitis. However, this dogma is being challenged. The timing (or necessity) of appendectomy in cases of uncomplicated appendicitis, the need for interval appendectomy following non-operative management, and the optimal

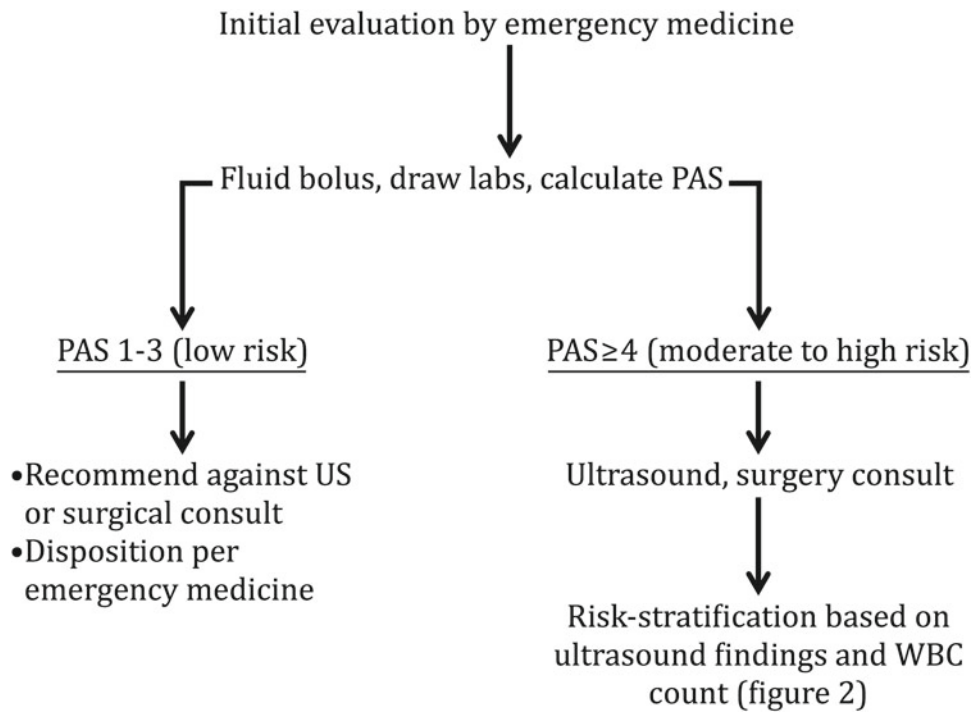

Fig. 65.1 Multidisciplinary diagnostic pathway used at our institution for children with suspected appendicitis. A modified version of the Pediatric Appendicitis Score is used as an initial screen to identify children at moderate to high risk for surgical consultation and ultrasound examination

Table 65.1 Modified version of the Pediatric Appendicitis Score (as originally proposed by Samuel) used in our Emergency Department for initial risk assessment

Original PAS elements	Our questions	Points if "yes"
Migration of pain	Did the patient report pain that started anywhere, migrated to the RLQ, and remained there?	1
Anorexia	Did the patient report decreased appetite at the time of presentation?	1
Nausea/emesis	Did the patient report any of the following in the past 48 h: emesis, nausea, retching, or gagging?	1
Tenderness in right lower quadrant	Was the point of maximal tenderness on physical examination in the RLQ?	2
Cough/percussion tenderness	Did the patient report pain with coughing or hopping, or did the patient refuse to cough or hop because of pain?	2
Pyrexia	Was there a documented temperature ≥38.5 °C (101.3 F) in our ED or the transferring ED?	1
Leukocytosis	Did the patient have a WBC ≥9000 cells/μL?	1
Polymorphonuclear neutrophilia	Did the patient have a WBC differential with ≥65 % neutrophils?	1
Total possible score		10

Each element was modified to reduce subjectivity and improve the consistency of definitions and parental responses

duration of antibiotic coverage are all being debated. In regards to value-based care for uncomplicated appendicitis, standardization of operative technique, and fast-track discharge protocols have been proposed to reduce resource utilization without compromising patient outcomes.

Uncomplicated Appendicitis

Appendicitis has traditionally been considered a surgical emergency, under the assumption that delaying appendectomy increases the risk of perforation. This has not been proven in large single or multicenter retrospective studies in adults. Some have suggested there might be a slight increase in SSI (from ~2 to ~3 %), but this has not been demonstrated in multicenter retrospective reviews using the National Surgical Quality Improvement Project (NSQIP) database. Similar equivalent findings between emergent appendectomy and urgent appendectomy (less than 8 h or after 8 h) have been demonstrated in children. No significant differences in readmissions or surgical-site infections have been shown with a delayed approach. Average hospital stay and average hospital charges were comparable between the two groups.

Even the need for actual appendectomy in cases of uncomplicated appendicitis is argued. Meta-analyses of randomized controlled trials comparing operative treatment to

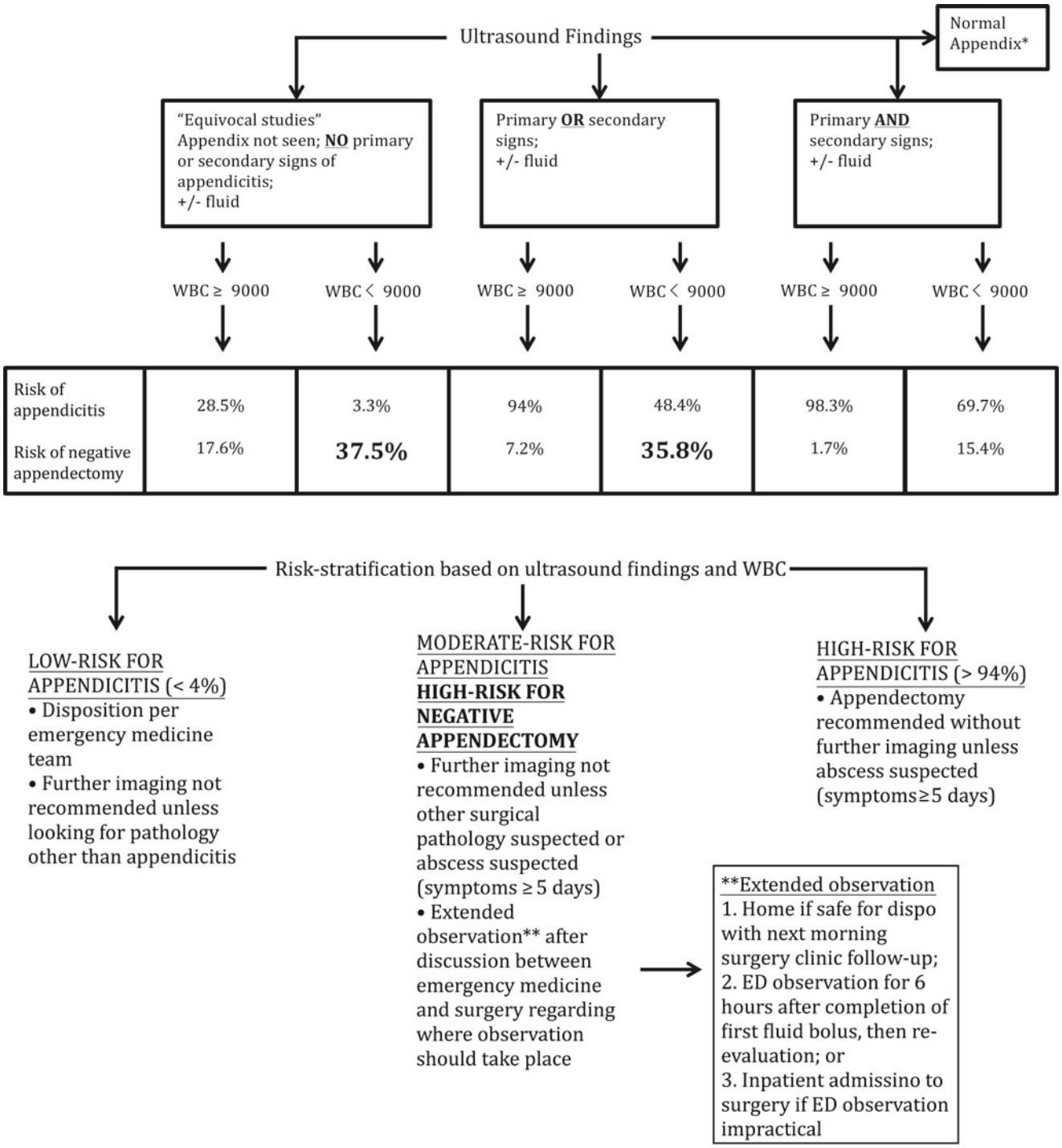

Fig. 65.2 Risk-stratification algorithm and disposition guidelines based on the combined predictive value of ultrasound findings and laboratory data in children with suspected appendicitis. Risk profiles were derived from a retrospective review at our hospital

antibiotics in adult patients have found that non-operative management has a 5–10 % failure rate and 10–15 % recurrence rate with a follow-up period between 4 and 12 months. Also, complications are approximately 30 % less likely in patients treated non-operatively. However, other systematic reviews have concluded that the evidence for non-operative management of uncomplicated appendicitis is insufficient to consider it non-inferior to operative management. Non-operative

Table 65.2 Multidisciplinary strategies to improve the diagnostic utility of ultrasound in the evaluation of children with suspected appendicitis

Improvement strategy or bundle	Outcomes
• One-to-one training by lead sonographer of new ultrasonographers • Mandatory 30-min scanning times • Assessment of every scan after surgical findings available • Coordination with emergency medicine and surgery • Standardized technologist worksheet • Standardized radiologist reporting template	• Decrease in percentage of US with non-visualized appendix from 30 to 11 % • Improved communication between radiology, emergency medicine, and surgical teams
Standardized ultrasound reporting template created through collaboration between radiology, emergency medicine, and surgery teams	• Reduction in percentage of patients undergoing CT scan from 44 to 14.5 % • US sensitivity improved from 67 to 92 %, NPV improved from 89 to 98 %, specificity and PPV unchanged • Increased use of US • No change in negative appendectomy rate • By the end of implementation, 95 % compliance with reporting template

management has recently been examined in the pediatric population using a protocol that includes IV piperacillin-tazobactam for at least 24 h, followed by a transition to amoxicillin-clavulanic acid when tolerating a diet for a total antibiotic course of 10 days. Failure rates during the index hospitalization are 5–10 % and 10 % through 30-day follow-up, with no reports of those requiring conversion to operative management progressing to perforation. Non-operative patients tend to have a longer median hospital stay of about 18 h, but return to normal activities a median of about 14 days sooner. And quality of life scores are reportedly significantly higher for non-operative patients.

The preliminary data for non-operative management of acute appendicitis is compelling, but several questions remain surrounding patient selection. This is particularly relevant for hospitals where the quality or availability of ultrasound is poor, which then requires a CT to differentiate between early and advanced appendicitis. This among other considerations will need to be evaluated in the risk-benefit analysis of the non-operative management of uncomplicated appendicitis.

Complicated Appendicitis

In children with complicated appendicitis associated *with* an intra-abdominal abscess, some have suggested that immediate appendectomy is superior to non-operative management followed by interval appendectomy. The total number of healthcare visits and CT scans is reduced, though children who undergo immediate appendectomy in this setting might experience longer times to goal oral intake compared with the non-operative group. Operative times, total length of hospitalization, post-operative or recurrent abscess formation, narcotic use, and total charges appear to be similar. Immediate appendectomy has also demonstrated superior outcomes to non-operative management in children with perforated appendicitis *without* a well-formed intra-abdominal abscess. Following immediate appendectomy, significantly shorter time to return to normal activities, shorter total length of hospital stay, lower rates of discharge with central venous catheters, and lower rates of adverse events are the purported benefits.

Interval Appendectomy

The need for interval appendectomy following non-operative management of complicated appendicitis remains controversial. Based on systematic reviews of observational studies, the overall incidence of recurrent appendicitis in patients who did not undergo interval appendectomy appears to be approximately 20 %, while 3–4 % of patients who undergo an interval appendectomy are estimated to experience a complication (wound infection, ileus, small bowel obstruction, or hematoma). Although the available evidence is of relatively low quality, it seems that nearly four out of five children undergoing interval appendectomy following initial non-operative management may not benefit from the procedure.

Goal-Directed Approach to Antibiotic Therapy

Patients with uncomplicated appendicitis should receive one dose of pre-operative broad-spectrum antibiotics to minimize the risk of surgical-site infection. Additional doses of antibiotics following surgery for uncomplicated appendicitis are unnecessary. Guidelines from the Surgical Infection Society and the Infectious Disease Society of America in adults and children with intra-abdominal infections resulting from appendicitis are for single-agent antibiotic regimens, which include ertapenem, meropenem, imipenem-cilastatin, ticarcillin-clavulanate, and piperacillin-tazobactam.

The need for extended intravenous antibiotic therapy once patients are able to tolerate oral intake has been debated. Children who undergo appendectomy for perforated appendicitis without

an intra-abdominal abscess can be transitioned from intravenous to broad-spectrum oral antibiotics without experiencing an increase in post-operative infections. The use of goal-directed therapy—using clinical, laboratory, or imaging endpoints to guide the duration of antibiotic therapy—has become increasingly popular. The American Pediatric Surgical Association Outcomes and Clinical Trials Committee found in a systematic review that failure rates were similar among patients with perforated appendicitis who received a mandatory 10–14 day course of antibiotics (26 %) compared to those managed with goal-directed antibiotic therapy (20 %). Recommendations based on this review were goal-directed antibiotic therapy for patients undergoing non-operative management of complicated appendicitis, tailoring antibiotic administration to clinical criteria of fever, abdominal pain, and resolution of ileus. However, the optimal use of clinical, laboratory, and imaging endpoints to guide goal-directed therapy is unknown, which may underlie the variation in treatment failure rates associated with this approach. In our own institution, we have found that neither the absolute value nor a change in post-operative WBC count is predictive of treatment failure.

Strategies to Improve Value

Current healthcare emphasis is on cost-containment and the provision of high-value care. Several centers have reported strategies to decrease treatment-related costs while maintaining a high quality of care. Standardization of operative technique and the use of cost-effective instrumentation have resulted in an approximately 60 % reduction in the cost of appendectomy for both uncomplicated and complicated appendicitis without an increase in complication rates. Fast-track discharge protocols are also effective at reducing costs by reducing the length of stay without increasing complication rates or revisit rates.

Clinical-Care Pathway

We advocate operating on all patients with confirmed or suspected appendicitis with the exception of patients who have a well-formed abscess on CT. Our practice is to operate as soon as possible following diagnosis. We have found this approach to be cost-effective at our institution where surgeons are in-house and operating rooms are readily available.

Cefoxitin is administered for all cases of uncomplicated appendicitis. Patients with imaging that demonstrates complicated appendicitis or have a perforation identified intra-operatively receive piperacillin-tazobactam for broader coverage. Patients with uncomplicated disease are treated with a single pre-operative dose of antibiotics, while those with complicated disease are treated routinely with a 7-day course. Patients initially receive piperacillin-tazobactam and are transitioned to amoxicillin-clavulanic acid when tolerating oral intake. Amoxicillin-clavulanic acid has become our institutional preference following a review of our patients that demonstrated nearly one-third of those discharged on ciprofloxacin-metronidazole (ISDA-recommended for complicated intra-abdominal infections) were unable to complete their course due to antibiotic intolerance.

Children with uncomplicated appendicitis are discharged the following day and parents are given the option of follow-up by phone or in clinic. Patients with complicated disease are discharged once they are tolerating a diet, require no intravenous pain medication, and experience 24 h free of symptoms suggestive of an evolving intra-abdominal abscess (fever, dysuria, worsening diarrhea, recurrent abdominal or pelvic pain). We do not routinely check post-operative laboratory tests in asymptomatic patients. For patients with persistent symptoms concerning for an intra-abdominal abscess and who are more than 4 days post-operation, we obtain a US. Further imaging by CT scan is at the discretion of our interventional radiology colleagues. Patients who are treated non-operatively for complicated disease are managed similarly following admission.

Interval appendectomy for patients treated non-operatively is offered on a case-by-case basis, and with shared decision-making on behalf of the parents and patient. The risks and benefits of both approaches are discussed in the context of the child's initial presentation, imaging findings (presence of a fecalith, which may increase the risk of recurrent appendicitis), and the family's overall preferences.

Summary

Treatment of pediatric appendicitis has evolved considerably over the past few decades. New data have emerged to challenge long-held surgical dogma and our understanding of how best to treat this disease continues to evolve. Further work is needed to explore how to most effectively employ the combined diagnostic value of the clinical presentation, laboratory data, and imaging results in order to minimize radiation exposure, resource utilization, and the risk of negative appendectomy. With regards to treatment, rigorous comparative effectiveness studies are needed to establish the efficacy and safety of non-operative treatment for both complicated and uncomplicated appendicitis, and to establish selection criteria for patients who could benefit from these non-traditional approaches. Finally, comparative effectiveness studies will be needed to establish the optimal endpoints surrounding goal-directed antibiotic therapy for patients with complicated disease, and to identify those patients who may benefit from interval appendectomy.

Editor's Comment

The diagnosis and management of appendicitis in children are active topics of research and debate. Efforts are focused on timely and cost-effective diagnosis while minimizing radiation risks and negative appendectomy rates. To this end, several scoring systems have been developed. The PAS scoring system is a good screening tool, with the main advantages of identification of patients who are at very low risk of appendicitis who can be discharged from the ED without imaging and those with an equivocal diagnosis who would benefit from imaging or close observation. While a repeat examination in the clinic or admission to an observation unit for serial examinations is acceptable for diagnosing appendicitis, they are perhaps not the most cost-effective or convenient for the family. Ultrasound is being used more frequently and accurately for diagnosis. Accuracy is highest at institutions committed to the use of US for diagnosing appendicitis, with a formal education process for ultrasonographers, standardized reporting techniques, and a regular quality review process.

Value-driven care is another area of interest with the goal of safely reducing costs without increasing morbidity. Decreased variability in care through the use of uniform equipment in the OR, standardized antibiotic protocols, and post-operative patient-care pathways have achieved this goal in several centers. Although care process models vary from center to center, the common theme is a clinical response-based protocol that minimizes antibiotic usage, laboratory evaluations, post-operative imaging, and length of hospital stay. This has not resulted in increased rates of post-operative infections or other morbidities. Each institution should evaluate their antibiograms in order to individualize the antibiotics of choice. Transitioning from intravenous antibiotics to oral antibiotics with similar bioavailability when the patient is ready for discharge is safe and effective for children who need additional antibiotics following surgery for perforated appendicitis.

Complicated appendicitis may be managed with initial surgery without increasing morbidity. However, in patients who present with a prolonged history of symptoms and imaging that demonstrates a well-formed abscess, percutaneous drainage of the abscess, and 10–14 days of antibiotics is reasonable. The decision to proceed with an interval appendectomy in 4–6 weeks after successful treatment is made on a case-by-case basis after discussion with the family. If an appendicolith is present in the abscess, the non-operative failure rate is increased and one should consider an early interval appendectomy with removal of the appendicolith.

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Ulcerative Colitis and Familial Polyposis

66

Inna N. Lobeck and Jason S. Frischer

Ulcerative Colitis

Ulcerative colitis is a chronic disease within the spectrum of inflammatory disorders of the gastrointestinal tract. Although the etiology of this disease has not yet been elucidated, it is likely a multifactorial interaction among the microbiome of the gastrointestinal tract, immunologic function, and genetic predisposition.

The incidence of UC ranges from 1 to 20 per 100,000 individuals per year with equal sex distribution. An inverse relationship has been described between age and presence of pancolonic disease, with younger children more commonly having a greater disease burden throughout the colon. Geographic location has been implicated in the incidence of disease with a preponderance of disease seen in North America, the United Kingdom, and northern Europe. Furthermore, a genetic component may exist—14 % of affected individuals have a first-degree relative with IBD. It has also been shown that mutations in nucleotide-binding oligomerization domain containing protein 2 (NOD2) and interleukin-23 receptor (IL23R) may play a role in disease development.

Diagnosis

UC is defined by rectal and colonic inflammation limited to the epithelium and lamina propria. Patients present with longstanding diarrhea associated with occasional hematochezia. UC is considered a chronic inflammatory disease but the disease spectrum ranges from mild colitis to acute severe UC and toxic megacolon. More than six bloody stools per day and either tachycardia, fever, anemia or erythrocyte sedimentation rate >30 mm/h are pathognomonic for acute severe UC based on the Truelove and Witt criteria. Extraintestinal manifestations of the disease include erythema nodosum, pyoderma gangrenosum, episcleritis, and primary sclerosing cholangitis. Arthralgias and joint effusions are the most common extraintestinal manifestations of UC.

The diagnosis of UC is made through a combination of clinical, radiographic, and endoscopic findings. In addition to the typical symptoms of UC, children with mild disease often present with pallor, poor growth, delayed maturation, and anemia. The severity of disease may be established radiographically. Double-contrast barium enema will typically show a shortened colon with pseudopolyps, collar button ulcers, and loss of haustra. In cases of toxic megacolon, an abdominal X-ray may show massive colonic dilatation associated with an abnormal mucosal contour that is most pronounced in the transverse colon. On colonoscopy, patients might have inflamed and edematous colonic mucosa if mild UC exists, or hemorrhagic mucosa with deep ulcers and mucosal detachment in severe acute disease. Contrary to Crohn's disease, UC is continuous in its distribution, always presenting with distal disease and variable proximal extent.

Treatment

Treatment for UC includes supportive medical management and occasionally definitive surgical treatment. The goals of medical management are induction and maintenance of remission and symptom relief. Systemic corticosteroids and aminosalicylic acid compounds are common first-line agents. Systemic corticosteroids, in particular, can induce remission in patients who have failed aminosalicylic acid treatment, though they should not be used for a prolonged period of time. Immunomodulators such as azathioprine and cyclosporine can induce remission in patients who do not respond to, or cannot be weaned from steroids. Likewise,

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Infliximab, a monoclonal anti-TNF antibody, is an effective treatment for patients refractory to or dependent on steroids despite treatment with azathioprine.

Acute, severe colitis is the most common indication for surgical management. Other indications include complications of medical treatment (lack of response, growth delay, poor skeletal development, sequelae from long-term steroid use), presence of colonic dysplasia, perforation, and severe hemorrhage. Toxic megacolon, characterized by systemic disease stemming from severe colonic inflammation, has also been established as an indication for definitive surgical management. In the emergency setting or with critically ill patients, a three-stage operation is the accepted standard of care. This commences with a subtotal colectomy and ileostomy with rectal preservation. Several months after initial surgery, completion proctocolectomy, ileal pouch-anal anastomosis (IPAA), and loop ileostomy are created. Finally, the protective ileostomy is closed to restore bowel continuity one month or so later.

Patients with persistent symptoms or who have potential for further growth generally undergo surgery on an elective basis. In the first 5 years after a diagnosis of UC, approximately 20 % of children will undergo colectomy. Several elective surgical options exist for treatment of UC. All variations, however, include the resection of the entire colon and rectum. Proctocolectomy may be performed either laparoscopically, laparoscopic-assisted or open. The historical operation for UC involves an open proctocolectomy and end-ileostomy. The advantages of this treatment are complete cancer risk elimination through the inclusion of the entire colon and rectum and the avoidance of fecal incontinence, relinquishing urgency, and frequency which may be seen with ileo-anal pouch or pull-through. However, complications associated with presence of an ileostomy including poor cosmesis, herniation, stenosis, or skin ulceration.

Permanent ileostomy is no longer essential in the management of UC. Colectomy with ileorectal anastomosis (IRA) has been reported for elective surgical treatment is not generally advisable. This procedure entails resecting the entire colon and anastomosis of the ileum to the rectum at the level of the sacral promontory. Through this abdominal approach, complications associated with pelvic dissection may be avoided. Although the colectomy with IRA has a low leak rate and technically less challenging than other options, the significant disadvantage of this procedure is the sparing of the rectum, allowing for long-term complications such as neoplastic change and proctitis. While the IRA may be a good temporizing solution that preserves continence, it is not optimal for permanent treatment of UC as the incidence of cancer in the rectal stump at 20 years is 5–17 %. The Kock pouch is an operative approach that creates an ileostomy with a reservoir that allows for patient control of stool emptying. Through catheter intubation of the pouch at the abdominal wall, patients empty the ileal contents electively, unlike a functioning ileostomy. Due to complications including difficulty with pouch intubation, valve failure requiring revision and fistulization, this procedure is rarely used.

The restorative proctocolectomy (RPC) for the treatment of UC was originally described by Utsonmiya and Park. The S-, J-, and W-pouch configurations have been used for the IPAA. This procedure attempts to maintain continence and retain anal tone. The J-pouch is the most popular of these configurations. This pouch is typically created with a stapling device and allows for a large reservoir. Whereas the Kock pouch is fixed to the abdominal wall, the RPC utilizes an IPAA. Due to its functionality and relatively low complication rate, this procedure has become the most widely practiced elective surgical treatment of UC. This operation is performed in either one or two stages in the elective setting. Occasionally, a subtotal colectomy with ileostomy in a significantly ill or malnourished child is required as the first step. In the elective setting, the first operation consists of a total or complete proctocolectomy, a pouch is formed, and an IPAA is created. If a two-stage procedure is to be performed, a protective loop ileostomy is created. The second operation entails ensuring proper healing of the IPAA and closure of the temporary ileostomy, regaining bowel continuity. In the primary surgery (laparoscopic or open), the colon and majority of the rectum are resected, leaving a short rectal cuff for anastomosis to the pouch.

We prefer a laparoscopic approach, placing 5-mm ports in the umbilicus and left lower quadrant. The right lower quadrant port is a gel port, allowing for multiple port placement, and is located at the site where colon extraction will be performed and diverting ileostomy created, if required. The operation commences with an examination of the small bowel, seeking signs of possible Crohn's disease. After examination, the entirety of the colon is mobilized from its retroperitoneal attachments, including the takedown of the hepatic and splenic flexures. Next, the omental attachments are removed from the transverse colon. We then make an opening in the very distal sigmoid colon mesentery and divide the colonic mesentery proximally towards the cecum. The distal sigmoid colon and terminal ileum are divided and the colon is extracted through the right lower quadrant port site.

The rectum is then mobilized to the pelvic floor. The dissection is performed immediately adjacent to the rectal wall in order to avoid ureteral or nerve injury. Once dissection has reached the level of the anal canal, the mobilized distal colon and rectum are delivered transanally (Fig. 66.1) and the rectum is divided with a cutting-stapler proximal to the dentate line in an extracorporeal fashion (Fig. 66.2). Attention is then directed towards creation of an ileal J-pouch. The small bowel mesentery is mobilized to the duodenum and all peritoneal attachments are divided to ensure appropriate length for the pouch to reach the anal canal. The peritoneum overlying the mesentery is scored on either side if necessary to gain

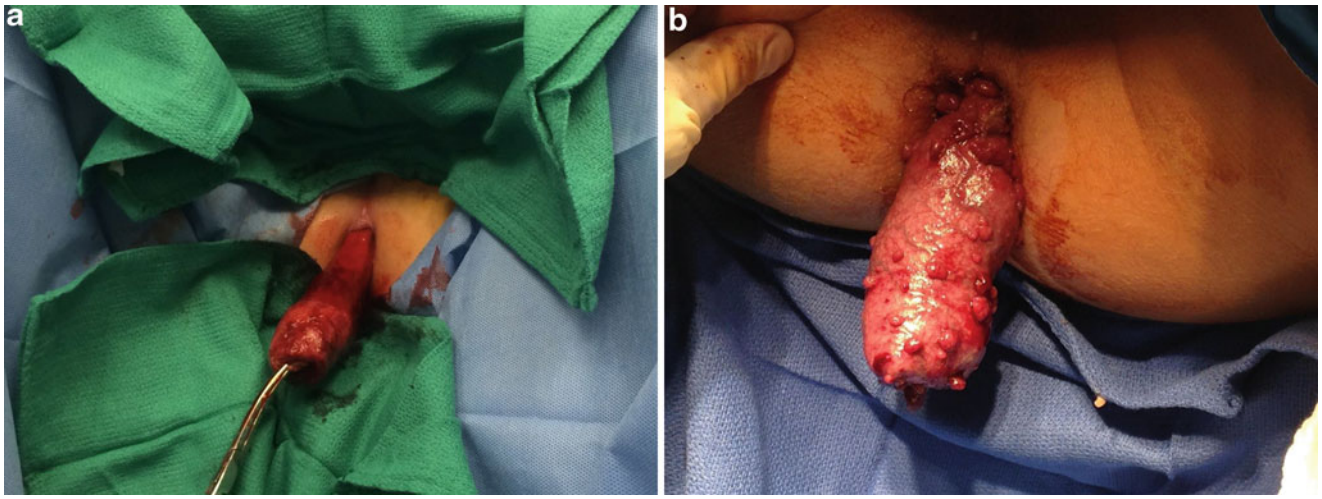

Fig. 66.1 Delivery of the colon and rectum transanally. (**a**) Eversion of the rectum through the anus. (**b**) FAP patient with significant polyp burden in an everted rectum

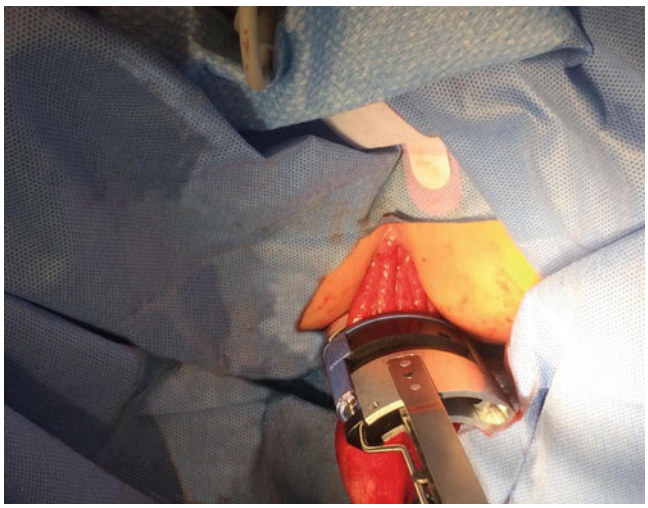

Fig. 66.2 Division of the rectum with cutting stapler

additional length. The J-pouch is created at a site that results in the least amount of tension. A blood vessel may be taken if needed for length after applying a non-crushing clamp and ensuring viability of bowel. The pouch is created through two 7–15 cm limbs of terminal ileum folded into a J shape. The pouch length is based on age (in a 9 year old we create a 9-cm pouch). A cutting stapler is fired longitudinally with each arm of the stapler in one limb of ileum on the antimesenteric border via a common enterotomy at the apex of the future pouch. We use an endovascular staple due to size considerations. A circular stapling device is then used to create the IPAA anastomosis. A closed-suction drain is placed next to the pouch and left in place until ready for discharge.

To complete the operation, a protective loop ileostomy is created proximal to the pouch. However, in selected cases, a one-stage procedure may be performed safely. The RPC may be done with or without mucosectomy, although if mucosectomy is performed, the ileo-anal anastomosis is hand-sewn at the dentate line. Using the Lone Star retractor for exposure will minimize stretching of the anal sphincters. The mucosectomy is facilitated by the injection of lidocaine with epinephrine into the sub-mucosal plane. The dissection is continued proximally to the level of the upper aspect of the puborectalis. The disadvantage of omitting mucosectomy is the possible risk of future neoplastic change in the retained rectum.

Outcomes

The most common complications of IPAA are anastomotic stricture (10–20 %), anastomotic leak (5–13 %), and pouchitis (10–60 %). Additional complications include infertility in girls (22 %), sexual dysfunction (2–15 %), and malignancy in the retained rectal mucosa. A small amount of narrowing at the IPAA anastomosis may not cause significant problems and typically resolves following gentle dilation prior to the final operation (ileostomy closure). Severe strictures, however, may require pouch revision. In a recent review of our experience at Cincinnati Children's Hospital Medical Center, 14 % of our patients had an anastomotic stricture, 9 % experienced an anastomotic leak, and 23 % developed pouchitis.

When pouchitis occurs, inflammation of the pouch may result in fecal incontinence, bleeding, and abdominal pain whereas in cuffitis, the remaining rectal cuff has inflammatory changes. Continued screening of the remaining rectal cuff through proctoscopy every 3 years is essential to satisfactory outcomes, ensuring absence of malignant changes. Patients will have on average 3–10 stools per day postoperatively. Daytime soiling occurs in 22 % and nighttime soiling in 56 %, with only 44 % of patients totally continent. In our review, 5 % of patients experienced daytime soiling and 24 % involuntary nocturnal leakage. Despite these complications, our data has revealed an improvement in overall quality of life after surgery.

Familial Polyposis

The diagnosis, treatment, and surveillance of patients with familial polyposis syndromes are all integral to achieving excellent patient outcomes. Development of numerous adenomas in the colon and extra-colonic abnormalities at a young age is pathognomonic of these syndromes. Thus, a family history evaluating for polyps or colorectal cancers is crucial to early detection.

Familial adenomatous polyposis (FAP) syndrome is an autosomal dominant disease with an incidence of one in 7000 to one in 22,000 live births. This genetic disease is caused by mutations in the adenomatous polyposis coli (APC) gene on the long arm of chromosome 5. Familial adenomatous polyposis is defined as the presence of more than 100 adenomatous polyps in the colon. However, many patients have thousands of polyps at time of diagnosis (Fig. 66.3). Half of individuals with the APC gene will have polyps by 15 years of age.

Diagnosis

Most adolescents with FAP are diagnosed while asymptomatic through routine colonoscopic screening due to a family history of adenomatous polyposis. When adenomas grow in size and number, however, symptoms including rectal bleeding, anemia, abdominal pain, and diarrhea may be exhibited. Symptomatic anemia in childhood should heighten suspicion for malignancy in patients at risk for FAP. Diagnosis of FAP is established through colonoscopy, revealing hundreds to thousands of adenomas throughout the colon. A biopsy of at least ten polyps is required for confirmatory diagnosis of FAP. Extra-colonic polyps, such as those in the stomach may be found in up to 90 % of patients, though only 6 % are adenomatous. Duodenal polyps are also frequently visualized through endoscopy. These are commonly located in the periampullary region and are more likely to have malignant transformation.

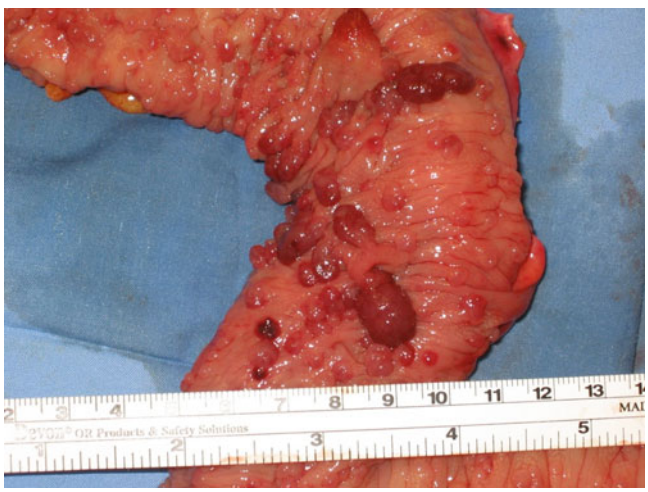

Fig. 66.3 Colon specimen of a patient with familial adenomatous polyposis demonstrating multiple polyps of variable sizes and different stages of development

Treatment

If left untreated, all patients with FAP will develop colorectal cancer by 40 years of age. Although trials are underway for selective cyclooxygenase inhibitor treatment for reduction of colonic polyps in the pediatric population, it has not yet been determined if the risk of malignancy can be eliminated with non-operative management. Thus prophylactic colectomy is standard and has been shown to improve life expectancy.

Surgical options for FAP include total colectomy with IRA, total proctocolectomy with ileostomy (TPI), and RPC with or without mucosectomy and IPAA. The optimal timing of surgery is unknown, but is typically performed between 15 and 25 years of age. Presence of symptoms and polyps with high-grade dysplasia necessitate more expedient resection. Likewise, patients with severe disease at colonoscopy or severe family history of disease at any age warrant earlier intervention. Attenuated APC is characterized by fewer polyps (average 30) and commonly involves the proximal colon. Asymptomatic patients with attenuated polyposis may delay surgery until 21–25 years of age.

Operative decision making is guided by patient factors including age, gender, prior surgical interventions, number and location of polyps, genetic history, compliance and follow-up, acceptance of temporary ostomy, and presence of malignancy or desmoid disease. Although curative in cases of low rectal cancer or sphincter dysfunction, proctocolectomy with end-ileostomy is a less common choice of operation due to the desire to avoid the psychosocial effects of a permanent stoma. Controversy surrounds total abdominal colectomy with IRA versus RPC with IPAA. Ileorectal anastomosis is considered in cases with a mild phenotype with few rectal polyps, attenuated FAP, absence of colorectal carcinoma, or metastatic colorectal carcinoma. This technique results in a good functional outcome without need for pelvic dissection. Long-term follow-up with surveillance of the retained rectum is absolutely mandatory with this technique. Complications include prolonged ileus (7 %), anastomotic breakdown (2 %), and bleeding (<1 %). Traditionally, IRA has involved the creation of a temporary diverting ileostomy,

though recent studies have demonstrated satisfactory results and low morbidity without fecal diversion. In the last several decades, IPAA has become a more commonly practiced treatment for FAP, especially in younger patients. While more technically difficult, it is indicated for patients with severe FAP, colorectal carcinoma, or mesenteric desmoid. Complications of RPC with IPAA include urinary and sexual dysfunction, as well as fertility issues, presumably due to the extensive pelvic dissection. Poor functional outcomes including increased stool frequency, nighttime defecation, and incontinence have been noted more following RPC with IPAA than IRA.

Historically IPAA was believed to eradicate the risk of future colorectal cancer. However, malignancies have been observed to develop within the anal transition zone, retained mucosa, the retained rectal cuff, or within the pouch. Controversy exists regarding the risk of malignancy after mucosectomy with hand-sewn anastomosis versus double-stapled anastomosis and further outcome studies are needed.

Laparoscopic colon resection has become increasingly popular over the last decade for the operative management of FAP. Although technically challenging, this technique may improve cosmetic result, reduce operative blood loss, and result in lower postoperative infertility.

Surveillance

In addition to surgery, patients with polyposis syndromes must undergo surveillance for malignant transformation in retained rectal tissue or the ileal pouch as well as extracolonic polyps. Surveillance includes EGD every 1–3 years and proctoscopy every 1–2 years for those with IRA or RPC with ileal pouch-anal anastamosis (RPC-IPAA). Also, a thyroid ultrasound should be done annually for all patients with FAP. Other polyposis syndromes should be considered when evaluating intestinal polyps (Table 66.1).

Editor's Comment

Urgent surgical intervention is indicated in patients with severe or fulminant colitis. Severe colitis is defined as more than six bloody stools per day along with fever, tachycardia, anemia, and elevated ESR while fulminant colitis is defined as more than ten bloody stools per day along with these systemic signs. A transverse colon diameter greater than 6 cm is generally considered diagnostic of toxic megacolon. Twenty to 30 % of these patients will require urgent or emergent subtotal colectomy with end-ileostomy.

Intractability is one of the most common indications for surgery in UC. Severe extraintestinal manifestations may prompt resection. Not all of these comorbidities are improved with resection, specifically primary sclerosing cholangitis. Surgery should be considered if growth failure persists despite maximal nutritional and medical therapy.

Up to 25 % of patients will have inadequate diagnostic criteria to make a distinction between UC and Crohn's disease preoperatively. This group is considered to have indeterminate colitis. Available long-term outcome data suggests that IPAA in this group is similar to that of UC. However, when counseling the family, one must consider that approximately 15 % of these children will subsequently be diagnosed with Crohn's disease.

Mucosectomy and double-stapled procedures are both acceptable techniques for RPC with IPAA. The advantages of the double-stapled approach include enhanced technical ease, less tension on the anastomotic suture line, and possibly improved functional results. Potential sphincter injury is minimized and anal canal transition zone is preserved. Despite these theoretical advantages, no significant functional difference between the two techniques has been demonstrated in available prospective randomized trials. The major disadvantages to the stapled technique are the required routine surveillance of the retained rectal mucosa for malignancy and the potential for inflammation of the rectal mucosa. Although IPAA without protective ileostomy has been advocated, most patients will benefit from a protective ileostomy especially if they are on high-dose steroids, are malnourished, or have received recent anti-TNF therapy.

The presence of extraintestinal manifestations of UC before colectomy especially primary sclerosing cholangitis has been associated with an increased risk of pouchitis. Presenting symptoms of pouchitis include abdominal cramps, fever, pelvic pain, and increase in stool frequency. The clinical diagnosis may require confirmation by endoscopy and pouch mucosal biopsy. Treatment is primarily antibiotics such as metronidazole and ciprofloxacin. In antibiotic-refractory cases, budesonide enemas may be useful. There are limited data that suggest that probiotics may have prophylactic effect. *C. difficile* infection should be considered in cases of recurrent or refractory pouchitis. Patients with chronic pouchitis should be assessed for Crohn's disease. Inflammation of the retained rectal mucosa ("cuffitis") can occur if the double-staple technique is used for IPAA. This usually responds to topical hydrocortisone or mesalamine.

Patients and parents should be counseled preoperatively about anticipated post-operative stooling patterns. Up to 50 % of children will suffer from nocturnal incontinence in the first 6 months following surgery. Daytime incontinence is much less frequent. Patients can expect 6–15 stools per day post op but this decreases over 1–3 years to around 4–6 stools per day. Fiber supplements and loperamide may help manage stool output and prevent dehydration.

Table 66.1 Familial polyposis syndromes summary with suggested surveillance recommendations

Condition	Incidence	DX	Symptoms	Associated malignancy	Surveillance	Start age (years)	Interval (years)
Familial adenomatous polyposis (FAP)	1:8000–10,000	>100 colonic polyps of various size and stages	–Rectal bleeding –Abdominal pain –Anemia –Diarrhea	Colon Duodenum Desmoid Liver (HB) Pancreas Thyroid Stomach CNS	Colonoscopy	10–12	1–2
					Upper endoscopy	20–30	1–3
					Abdominal ultrasound	10–12	1
					Thyroid ultrasound	10–12	1
					Abdominopelvic CT/MRI	[a]	[a]
Juvenile polyposis syndrome	1:16,000–100,000	≥3–5 colorectal polyps Multiple polyps throughout GI tract Polyps + family history of JPS	–Rectal prolapse –Anemia –GI bleed –Intussusception –Hypoproteinemia –Electrolyte imbalance –Failure to thrive	Colon Stomach Small intestine Pancreas	Colonoscopy	10–15	1–3
					Upper endoscopy	10–15	1–3
Attenuated FAP	n/a	10–100 colonic polyps	–Rectal bleeding –Abdominal pain –Anemia –Diarrhea –Later onset than FAP (avg.: 50 years old)	Colon Duodenum Thyroid	Colonoscopy	16–20	1–2
					Upper endoscopy	25–30	3
					Abdominal ultrasound	10–12	1
					Thyroid ultrasound	18–20	1
Peutz–Jeghers syndrome	1:8300–280,000	≥2 of the following: ≥2 Peutz–Jeghers polyps of small bowel, mucocutaneous hyperpigmentation of mouth, lips, nose, eyes, fingers, genitals, or family history of PJS	–Abdominal pain –GI bleeding –Anemia –Intussusception –Small bowel obstruction –Mucocutaneous pigmented lesions	Breast Colon Pancreas Stomach Ovary Lung Small intestine Uterine Cervix Testicle	Colonoscopy	8 50	3 years until 50 1–2
					Video capsule endoscopy/MRE	8	3
					Upper endoscopy	8	3 years until 50
					Clinical breast exam	25	0.5
					Mammogram/breast MRI	25	1
					Testicular exam	Birth–12	1
					Cervical smear	18–20	1
					Transvaginal ultrasound	18	1
					MRCP/EUS	30	1–2
Gardner syndrome	1:14,000	>100 colonic polyps of various size and stages	–Bone abnormalities –Skin abnormalities –Osteomas, fibromas, lipomas, epidermoid cysts –Supranumerary teeth –Symptoms 2 months–20 years	Colon Desmoid Duodenum Thyroid Brain Pancreas Hepatoblastoma Stomach	Colonoscopy	10–12	1–2
					Upper Endoscopy	20–30	1–3
					Abdominal ultrasound	10–12	1
					Thyroid ultrasound	10–12	1
					Abdominopelvic CT/MRI	[a]	[a]

[a]One to 3 years status post colectomy, 5–10 years afterwards. Immediate if symptoms

Suggested Reading

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Anorectal Malformations

67

Michael D. Rollins II and Marc A. Levitt

Current terminology in anorectal malformations (ARMs) is based on the location of the distal rectum and rectal fistula, which has both prognostic and therapeutic implications (Table 67.1). Inaccurate terms such as *high*, *intermediate*, and *low* are confusing and should no longer be used.

Over half of male patients with imperforate anus will have a fistulous connection between the rectum and the urinary tract (*rectobladderneck fistula*, *rectoprostatic urethral fistula*, or *rectobulbar urethral fistula*) and about one-third have a *rectoperineal fistula*, in which the rectal opening is on the perineal skin anterior to the anal dimple. Rarer malformations include *imperforate anus without fistula* and *rectal atresia*. *Imperforate anus without fistula* is more commonly found in patients with trisomy 21 and the rectum ends blindly in the pelvis, almost always at the level of the bulbar urethra. In patients with *rectal atresia*, there is a normal appearing anus with the rectum ending blindly at 2–3 cm. Many cases of rectal atresia are also associated with a presacral mass.

In females, there are three main types of malformations: *rectoperineal fistula, rectovestibular fistula*, and *cloaca*. A *perineal fistula* opens on the perineal skin, anterior to the sphincter complex and anal dimple, similar to males. In the case of a *vestibular fistula*, the opening lies within the introitus, but distal to the hymen (Fig. 67.1). A *cloaca* is a malformation in which the rectum, vagina, and urethra all open into a single channel, which subsequently opens onto the perineum usually just below the clitoris (Fig. 67.2). True *rectovaginal fistulas* are extremely rare.

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Prenatal Imaging

Parental prenatal counseling may be requested after fetal imaging suggests an ARM. The muscular components of the anal sphincter can be confidently visualized using ultrasound after approximately 23 weeks gestation. Ultrasound findings that increase suspicion of an ARM include dilation of the distal bowel, intraluminal calcified meconium or enterolithiasis. Presence of a cystic pelvic mass in a female fetus may suggest a cloacal malformation. Absence of the perianal muscular complex on 3D ultrasonography has also been shown to have a high sensitivity and specificity for identifying anorectal atresia. MRI is useful after 20 weeks gestation in fetuses suspected of having an ARM and can routinely delineate the musculature of the levator ani and external anal sphincter complex. Additionally, MRI can characterize abnormalities of the urinary tract, Mullerian abnormalities, limb anomalies, absent sacrum, and a presacral mass if present.

Diagnosis

The initial diagnosis of imperforate anus is almost always made during the first newborn physical examination, although a rectoperineal fistula is sometimes missed. Two important questions must be answered in the first 24 h of life: (1) should a colostomy be opened, deferring the repair of the defect until later in life, and (2) does the patient need urgent treatment for an associated defect (Figs. 67.3 and 67.4).

Males

The presence of a well-developed midline groove between the buttocks, a prominent anal dimple and meconium exiting through a small orifice located anterior to the sphincter in the midline of the perineum is evidence that the patient has a rectoperineal fistula. Occasionally one may see a prominent skin bridge over a tiny opening, giving the appearance of a

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Table 67.1 Classification of anorectal malformations and prognostic factors of bowel control

a. Anatomic classification of anorectal malformations	
Male	Female
Rectoperineal fistula	Rectoperineal fistula
Rectourethral fistula	Rectovestibular fistula
Bulbar	Imperforate anus without fistula
Prostatic	Cloaca
Rectobladder neck fistula	Rectal atresia
Imperforate anus without fistula	Rectal stenosis
Rectal atresia	Complex malformations
Rectal stenosis	
b. Prognosis for bowel control	
Good	Poor
Normal sacrum	Abnormal sacrum
Normal appearing bottom (good muscle)	Flat perineum (poor muscle)
Obvious anal dimple	*Types of anorectal malformations*
Types of anorectal malformations	Bladder neck fistula
Rectal atresia	Prostatic fistula
Perineal fistula	Cloaca with >3 cm common channel
Imperforate anus without fistula	Complex malformations
Bulbar fistula	
Vestibular fistula	
Cloaca with <3 cm common channel	

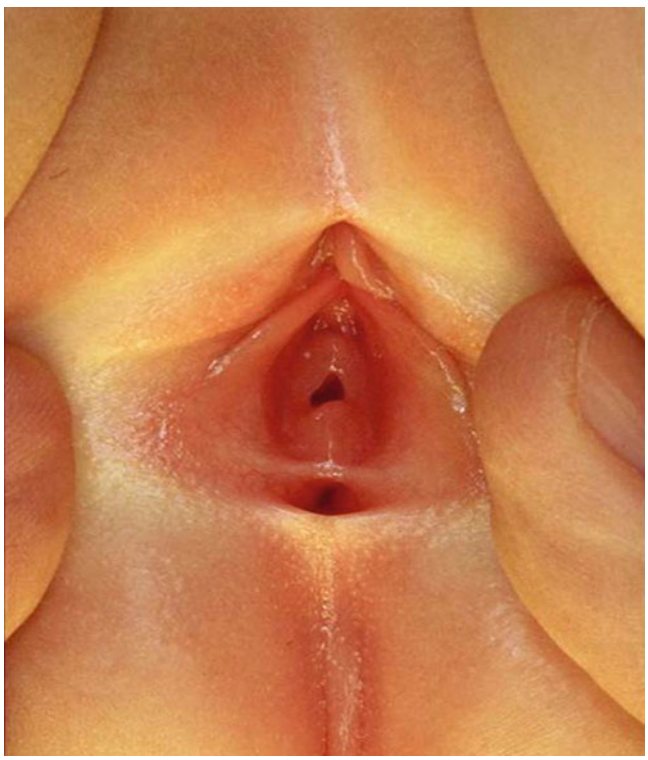

Fig. 67.1 Classic appearance of imperforate anus with rectovestibular fistula (supine position). Note that the fistula is located within the introitus but outside of the hymenal ring

bucket handle (Fig. 67.5), or a midline raphe, which can appear as a white or black ribbon of subepithelial meconium. These malformations can all be repaired via a perineal approach without a diverting colostomy. If a rectoperineal fistula is present, it may be technically advantageous to dilate the fistula to allow passage of stool until he is 3–4 months of age then perform a limited posterior sagittal anorectoplasty (PSARP). On the other hand, a flat bottom, with no evidence of a perineal opening and the presence of meconium in the urine are indications of a rectourethral fistula. A colostomy should be opened in these patients and the repair deferred.

If meconium is definitely seen on the perineum or in the urine, a conclusion as to the presence or absence of a fistula can be made with certainty. However, it may take some time for the intraluminal pressure to force the meconium past the pelvic musculature and out through a perineal or urinary fistula. This usually does not occur until after the first 24 h of life. A cross-table lateral radiograph of the abdomen and pelvis with the infant in prone position can be obtained to allow one to estimate the distance between the end of the dilated bowel and the skin. If this distance is <1 cm, a primary repair can be considered if the surgeon is experienced. If the distance is >1 cm, a colostomy should be performed.

Rarely, the anus may have a funnel-shaped appearance with a long skin-lined channel and a narrow opening (Fig. 67.6). This should prompt one to consider the diagnosis of Currarino syndrome with rectal atresia or stenosis and an associated hemisacrum and presacral mass.

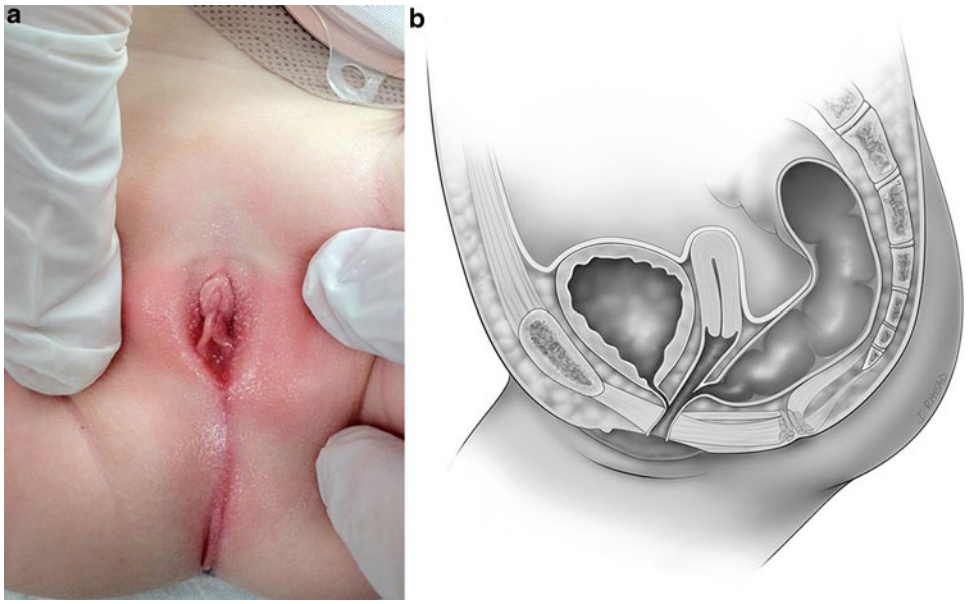

Fig. 67.2 Cloacal malformation. The urethra, vagina, and rectum meet to form a single common channel. (**a**) External appearance demonstrating underdeveloped labia and single orifice. (**b**) Illustration of short common channel

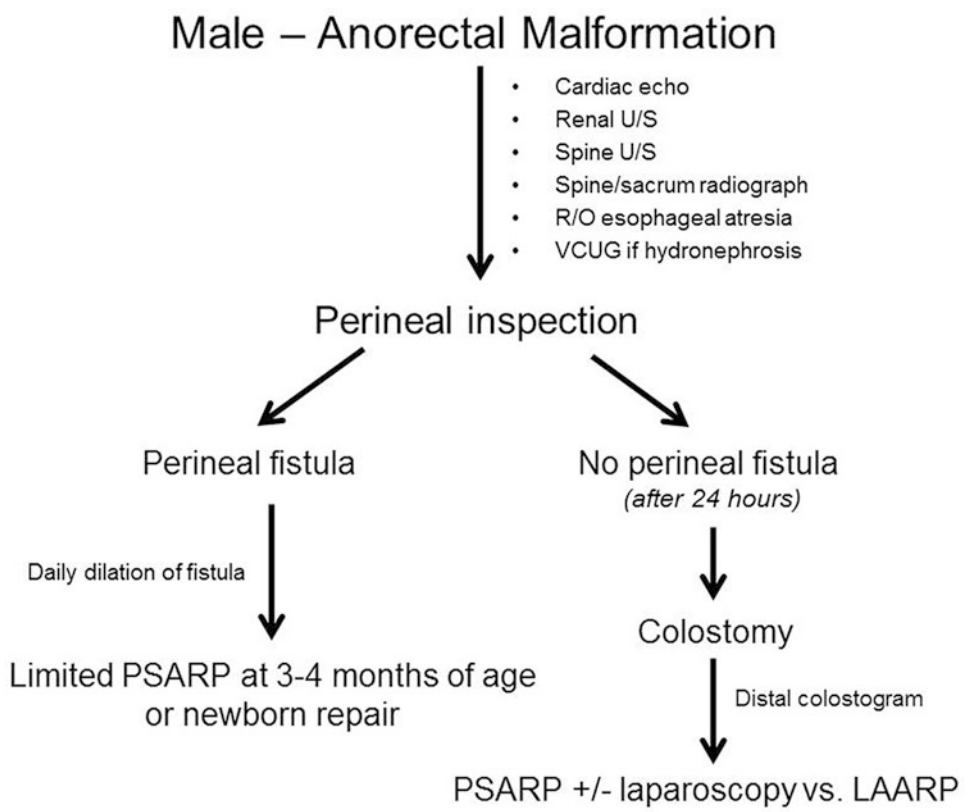

Fig. 67.3 Clinical algorithm for a male with anorectal malformation. *VCUG* voiding cystourethrogram, *PSARP* posterior sagittal anorectoplasty, *U/S* ultrasound, and *LAARP* laparoscopic assisted anorectoplasty

Females

The presence of a single perineal orifice in a newborn female establishes the diagnosis of a cloaca. All infants with cloaca require a colostomy and some also require a vaginostomy to drain a hydrocolpos.

In a female with a normal urethra, the presence of a rectal orifice located within the vestibule of the female genitalia but outside of the hymen confirms the diagnosis of a rectovestibular fistula. In these cases, some surgeons dilate the fistula to allow stool to pass and alleviate abdominal distention and defer the definitive repair until 3–4 months of age. Other surgeons prefer to open a colostomy and perform the repair at a later date. Surgeons who are experienced in the treatment of this abnormality may choose to do a primary repair in the newborn period with or without a protective colostomy.

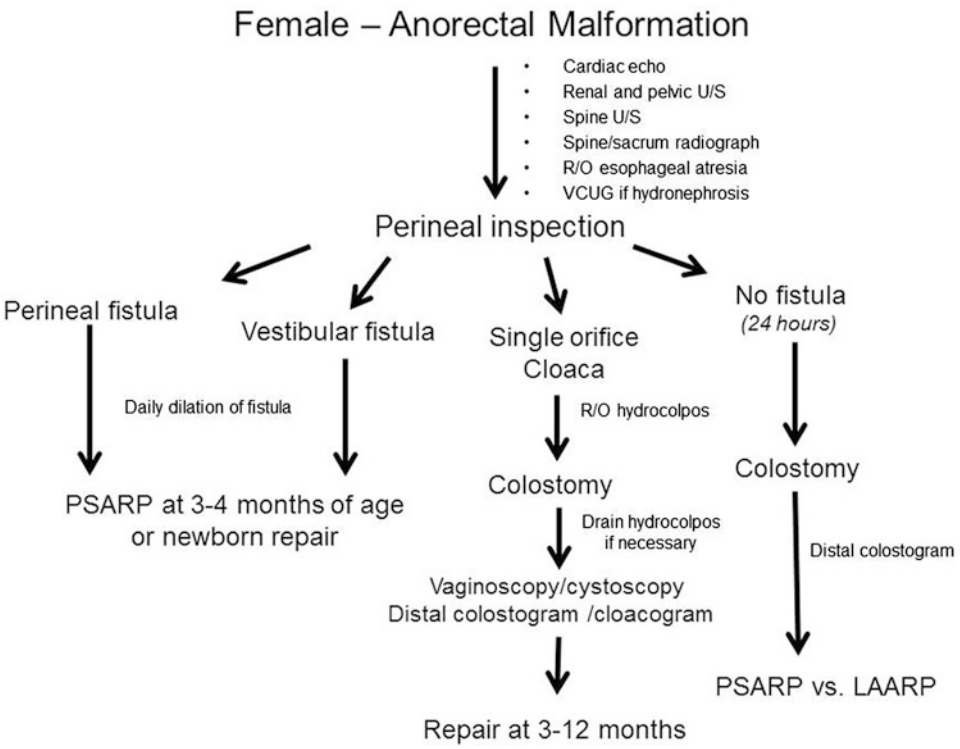

Fig. 67.4 Clinical algorithm for a female with anorectal malformation. *VCUG* voiding cystourethrogram, *PSARP* posterior sagittal anorectoplasty, *U/S* ultrasound, and *LAARP* laparoscopic assisted anorectoplasty

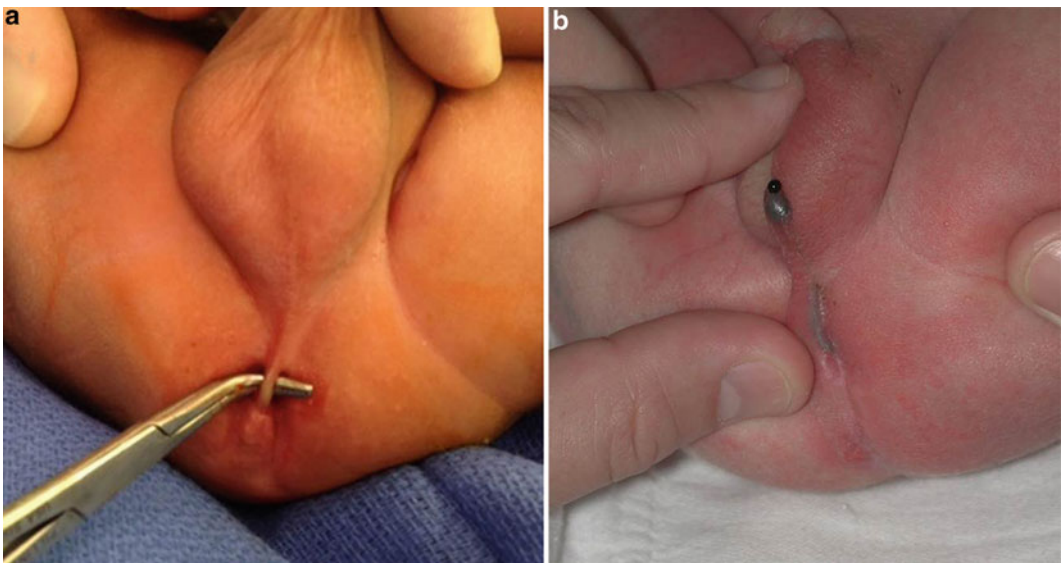

Fig. 67.5 Rectoperineal fistula in a boy. (**a**) Skin bridge referred to as a "bucket handle" deformity. (**b**) Subepithelial midline meconium

When the rectal orifice is located anterior to the center of the sphincter but posterior to the vestibule of the genitalia (in the perineal body), the diagnosis of rectoperineal fistula is established. These babies can undergo a primary anoplasty without a protective colostomy in the newborn period or after a period of dilating the fistula, similar to males. A common confusion is a female with a normal urethra and vagina and an anal opening that appears slightly anterior. If this opening is of normal caliber (Hagar 11 or 12 in the newborn), is within the sphincter, is supple (not fistulous tissue) and an adequate perineal body is present, then this is a normal variant and no surgery is indicated.

The absence of any of the above findings and the lack of meconium coming out through the genitalia after 24 h of life indicate that the patient most likely has imperforate anus without a fistula (more common in patients with trisomy 21).

Additional rare anomalies include: (1) *H-type rectovaginal* fistula where on inspection of the perineum, the patient may have a normal appearing anus (Fig. 67.7), (2) true *rectovaginal* fistula with the fistula located above the hymenal ring, a normal urethra and vaginal introitus, and no anal opening (Figs. 67.7), and *rectovestibular fistula with absent vagina*, in which there is a normal urethra, a rectal fistula in the vestibule, and no vaginal opening.

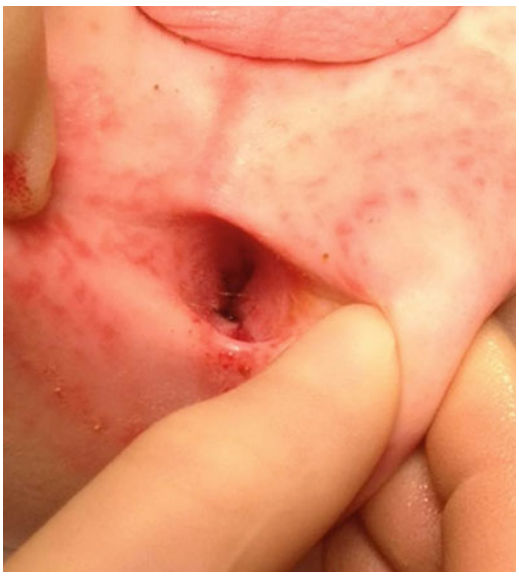

Fig. 67.6 Skin-lined funnel appearance of the anus in a patient with rectal stenosis and Currarino syndrome

Associated Anomalies

The waiting period of 16 to 24 h can be used to answer the second question concerning associated defects (Table 67.2) the majority of which are of the genitourinary system. In general, the more severe the anorectal anomaly, the more likely an associated defect will be present. However, even patients with the most benign malformation (rectoperineal fistula) should be completely evaluated, as up to one-third will have at least one associated malformation. In patients recognized to have a rectoperineal fistula outside the newborn period, a Cardiology consult to determine the need for an echocardiogram and Neurosurgery consult to determine the need for MRI of the spine is useful. The patient with a cloaca has a significant risk of an associated urologic defect as does the patient with a vestibular fistula, although the risk is less than cloacas.

The incidence of associated defects in males with imperforate anus varies based on the level of the defect, with a rectobladder neck fistula having the highest incidence and a rectoprostatic fistula or rectobulbar fistula being lower. All patients must have an ultrasound study of the kidneys to rule out hydronephrosis, the most common cause of which is vesicoureteral reflux. If hydronephrosis is identified, a voiding cystourethrogram should be obtained. In girls with a cloaca, the abdominal ultrasound must include the pelvis to rule out the presence of hydrocolpos or a distended bladder.

A nasogastric tube should be passed to rule out esophageal atresia and decompress the stomach while waiting for clinical evidence of a rectourethral or perineal fistula. All patients

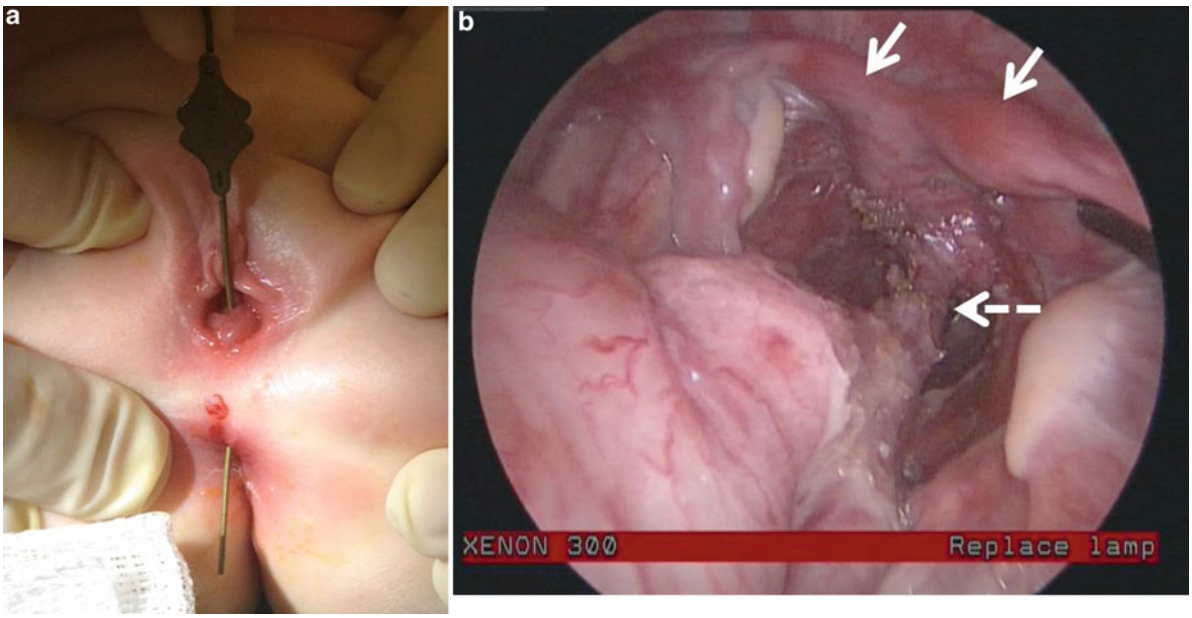

Fig. 67.7 Rectovaginal fistula. (**a**) H-type fistula. (**b**) Laparoscopic appearance of a rectal fistula entering into the posterior vagina. *Broken white arrow* showing rectovaginal fistula; *white arrows* identifying hemiuteri

Table 67.2 Associated anomalies

Cardiovascular	*Genitourinary*
Atrial septal defect	Vesicoureteral reflux
Patent ductus arteriosus	Renal agenesis and dysplasia
Tetralogy of Fallot	Cryptorchidism
Ventricular septal defect	Hypospadias
Transposition of great vessels	*Gastrointestinal*
Hypoplastic left heart	Tracheoesophageal fistula
Spine, sacrum, vertebrae	Duodenal atresia
Lumbosacral: hemivertebrae, scoliosis, hemisacrum, butterfly vertebrae	Malrotation
Tethered cord	*Gynecologic*
Spinal lipomas	Vaginal septum
Syringomyelia	Vaginal atresia
Myelomeningocele	Bicornuate uterus
	Uterine didelphys

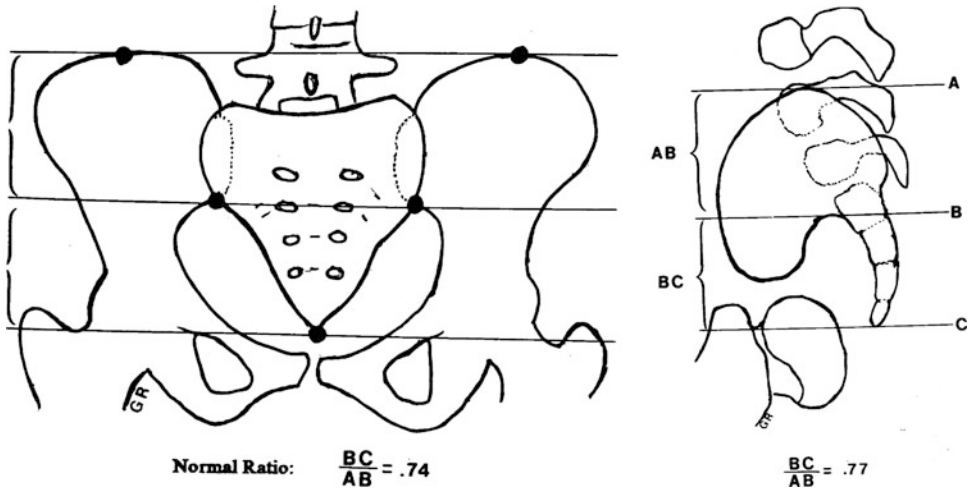

Fig. 67.8 Sacral ratio. *Line A* is drawn across the uppermost aspect of the iliac crests. *Line B* is drawn across the lowest point of sacro-iliac joints. *Line C* is drawn parallel to *line B* at the tip of the coccyx. The ratio is calculated by dividing the distance between *lines B* and *C* by the distance between *lines A* and *B*. (Pena A. Anorectal malformations. Semin Pediatr Surg. 1995;41(1):35–47. Reprinted with permission from Elsevier)

with imperforate anus should have an echocardiogram, as about 10 % of patients are found to have patent ductus arteriosus or a more serious structural cardiac defect such as tetralogy of Fallot or ventricular septal defect.

An ultrasound of the spine is also important to rule out the presence of a tethered cord, which occurs in about 25 % of all patients with ARMs. Although US remains the recommended screening modality to evaluate the spinal cord, recent studies have questioned its utility due to its poor sensitivity in detecting occult spinal dysraphism; it also can only be performed in the first 3 months of life, before sacral ossification. A radiograph of the spine must also be obtained. The presence of hemivertebra of the spine or sacrum indicates an increased risk of associated urologic defects and has negative prognostic implications in terms of bowel control. AP and lateral radiographs of the sacrum allow calculation of the *sacral ratio* (Fig. 67.8). Sacral ratios obtained during the newborn period may be misleading due to incomplete ossification. However, the accuracy of this ratio is improved at 5–6 months of age. A poorly formed sacrum (ratio <0.4) is associated with more severe malformations and carries with it a poor prognosis for bowel control. Evidence suggests that a lumbosacral MRI should be performed in patients with a sacral ratio <0.6 due to the tests ability to detect clinically significant spinal lesions. The presence of a hemisacrum might indicate the presence of a presacral mass, such as a teratoma, lipoma, or anterior meningocele, which can be confirmed with spinal ultrasound or pelvic MRI.

Initial Surgical Management

The ideal colostomy is created at the junction of the descending and sigmoid colon. Making the stoma more proximal ensures that the distal colon will be long enough to allow a tension-free pull-through later. In addition, stomas fashioned from the proximal sigmoid colon are less likely to prolapse because the colon is tethered by retroperitoneal attachments. To prevent prolapse of the more mobile distal stoma, the mucous fistula should be made with a very small external opening. The stomas should be far enough apart on the abdomen that the ostomy appliance can be placed comfortably over the functional stoma without covering the mucous fistula.

Loop colostomies have been discouraged in patients with imperforate anus because in theory they are incompletely diverting, which can allow overflow of stool into the distal

limb exposing the patient to fecal contamination of the genitourinary tract. While loop colostomies do have a higher rate of prolapse, the risk of urinary tract infection, development of megarectum, and need for stoma revision does not seem to be significantly different than in patients with a divided stoma provided the repair is performed early in life.

Under no circumstances should the distal stoma be closed as a Hartmann's pouch, as this will result in a mucocele and make it impossible to perform a contrast study of the distal rectum. A transverse colostomy is not recommended for several reasons: it makes it very difficult to clear inspissated meconium from the distal colon, it does not allow an adequate distal colostogram to be performed, and, in the presence of a fistula to the urinary tract, it can result in the resorption of urine, which can cause significant acidosis. At the time of the colostomy, use a soft rubber catheter to gently irrigate the distal limb with warm saline to remove all of the meconium from the lumen; this will prevent significant problems with inspissated meconium later on.

If the baby has *hydrocolpos*, it must be drained during the initial operation. Usually the hydrocolpos can be drained by tube vaginostomy. If there is bilateral hydrocolpos, two vaginostomy tubes can be placed or the vaginal dome can be opened and a window created between the hemivaginas. An undrained hydrocolpos will often cause hydronephrosis due to ureteral compression at the trigone. No treatment for the hydronephrosis should be considered until the hydrocolpos has been addressed. Once the vagina has been drained, the hydronephrosis should disappear. Even in the absence of hydronephrosis, it is important to decompress a hydrocolpos as the undrained vagina can become infected (pyocolpos), which can then lead to perforation or sepsis and may result in loss of the vagina.

Anoplasty

In infants with a perineal fistula, a formal anoplasty can be performed during the first several days of life without the need for a protective colostomy if the surgeon is experienced. The fistula can be dilated until the child is several months of age, at which time an anoplasty can be performed. This is technically easier in an older infant but requires a full preoperative bowel prep. The operation utilizes a minimal posterior sagittal incision from the fistula to the anal dimple. Multiple fine silk sutures are placed circumferentially around the rectal opening for uniform traction and to facilitate dissection. Circumferential full-thickness dissection of the rectum is performed until enough length is gained for the rectum to be placed accurately within the limits of the sphincter. In boys, the rectum and urethra are closely associated and special care is needed to avoid urethral injury. A Foley catheter should always be placed prior to anoplasty in a boy. In a girl, the posterior vaginal wall is adherent to the rectal fistula but there is a plane of separation. One should mobilize the rectum from the vagina to a point where the fistula can be placed within the limits of the sphincter without tension.

Almost all infants with a perineal fistula eventually have excellent bowel control although constipation is common and requires early management to achieve a good outcome. In addition to giving the child the best chance for normal bowel function, girls with perineal fistulas should be repaired to increase the size of the perineal body for future obstetric reasons.

Definitive Operative Repair

The PSARP remains the operation to which all technical modifications are compared. Laparoscopic assisted anorectoplasty has become increasingly popular for the management of ARMs. Proponents of this technique argue that functional outcomes will be better because a large posterior sagittal incision may be avoided and that the rectum is more accurately placed within the center of the sphincter muscle complex. However, studies examining long-term function after PSARP versus laparoscopic repair of ARMs have been inconclusive. We advocate the use of laparoscopy when it can replace laparotomy or an extensive posterior sagittal dissection. Thus it seems ideal for use in the treatment of rectobladder neck fistulas, in which the fistula is above the peritoneal reflection, and in repair of high rectoprostatic fistulas. In females, it might be useful to visualize the internal gynecologic anatomy and divide the fistula when the rectum inserts high on the posterior vagina in patients with or without a cloaca (a rare occurrence). Laparoscopy is not recommended for patients with rectobulbar fistula or no fistula as the fistula is well below the peritoneal reflection and shares a long common wall with the urethra.

Distal Colostogram

It is extremely important that the surgeon know the location of the distal rectum prior to the definitive repair. An augmented-pressure distal colostogram should be performed in all male patients who undergo a colostomy and all females with a cloaca. Information obtained from the study includes the location of the fistula between the rectum and the genitourinary tract, the length of available colon from the colostomy to the fistula site, the distance between the rectum and the anal dimple, and the relationship of the rectum to the sacrum. It may also demonstrate the characteristics of the vagina in females.

The study should be performed in the fluoroscopy suite using a balloon-tipped catheter to create a seal with the fascia

occluding the lumen of the colon. Hand controlled injection of contrast material is performed under pressure. It is begun with the patient in the supine position. Water-soluble contrast material should be used as barium is contraindicated in the presence of a recto-urinary tract fistula. A radiopaque marker is placed at the anal dimple. With the patient in the supine position, the surgeon can see the length of bowel available for the pull-through. The patient is then turned onto his or her side. As the injection is performed, contrast material will usually stop progressing at the pubo-coccygeal line. This line represents the upper limit of the levator muscles. It requires a significant increase in hydrostatic pressure for the contrast material to progress beyond this point.

In a male, the injection continues until the contrast material passes into the urethra. Usually the contrast goes up into the bladder rather than toward the penis and the injection should continue until the bladder is full and the baby starts to void. Films are taken during the entire sequence, particularly during voiding. The surgeon should be able to see the location of the fistula and its relationship to the bladder, bladder neck, and urethra (Fig. 67.9). If the study shows a bladder neck fistula, the surgeon knows that the rectum cannot be reached through a posterior sagittal incision and must be approached by laparoscopy or laparotomy. With a prostatic fistula on distal colostogram, the surgeon can anticipate locating the rectum in the soft tissue 1–2 cm deep to the coccyx during the posterior sagittal approach or just below the peritoneal reflection at laparoscopy. The presence of a bulbar urethral fistula indicates that the rectum will easily be found just deep to the levator muscles within 3–4 cm of the perineal skin. In the case of an imperforate anus with no fistula, the surgeon will not need to spend time looking for the fistula site and knows that the distal rectum is located adjacent to the bulbar urethra.

A distal colostogram is not necessary in patients who have a vestibular fistula. In patients with cloaca, one can complement the study by inserting a catheter into the perineal orifice and injecting contrast to delineate the bladder and vagina. A cystoscopy with catheter insertion into the bladder may also be done. Injection via a vesicostomy or vaginostomy, if present, delineates the anatomy. The goal of the study in patients with cloaca is to have images of all three crucial structures, bladder, vagina, and rectum, in AP and lateral projections and, if possible, in three dimensions. A three-dimensional cloacogram using a rotating c-arm in the fluoroscopy suite may provide additional useful information for operative planning.

Males

Patients with a rectobulbar or rectoprostatic fistula can be repaired using the posterior sagittal approach. It is mandatory that a Foley catheter be placed prior to commencing the operation. The patient is placed in the prone position with the pelvis elevated. The incision is made in the midline from above the coccyx to below the anal dimple. One must stay exactly in the midline, leaving an equal amount of muscle on each side of the incision. The posterior wall of the rectum is located and then opened in the midline. The incision in the rectal wall is continued distally up to the fistula site. The rectum is then separated from the urinary tract. A submucosal dissection is performed for about 3–5 mm above the fistula until a more obvious plane of separation is reached. This is facilitated by first delineating the lateral planes of the rectum. Once the rectum is fully mobilized, the urinary fistula is closed with long-term absorbable sutures.

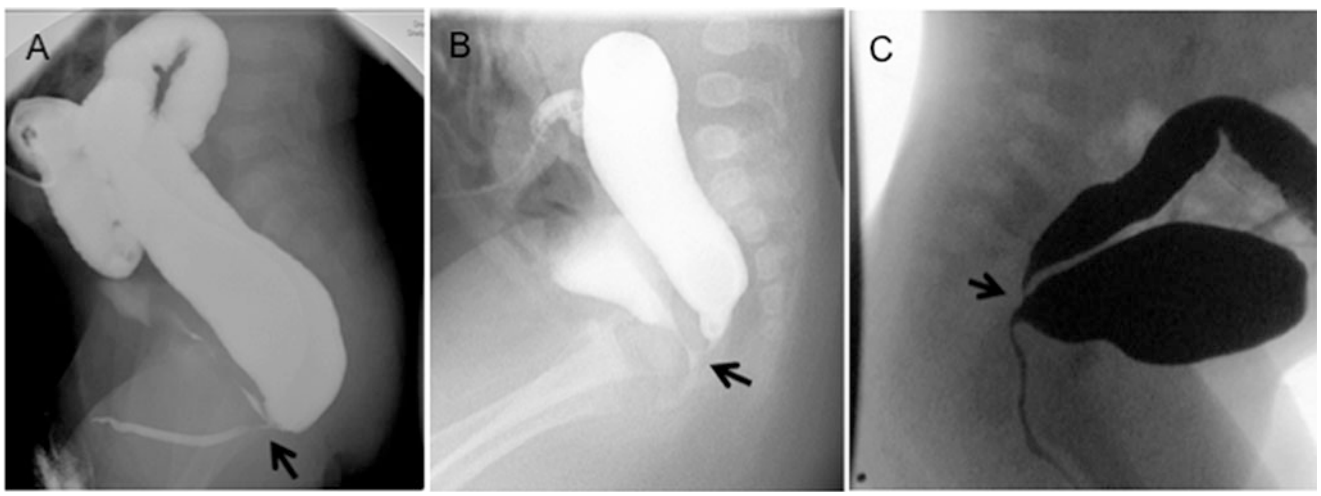

Fig. 67.9 Distal colostogram in the male with imperforate anus. (**a**) Rectobulbar urethral fistula. (**b**) Rectoprostatic fistula. (**c**) Rectobladder neck fistula. *Black arrow* indicates fistula location

The dissection should be performed as close to the rectal wall as possible while keeping the wall intact to preserve the intramural blood supply. The dissection continues until enough rectal length has been gained that an anastomosis between the rectum and the skin of the perineum can be created without tension. The electrical stimulator is used to determine the anterior and posterior limits of the sphincter mechanism. The anterior portion of the incision is closed, and the rectum is placed within the sphincter. The posterior edges of the levators are reapproximated behind the rectum. The posterior aspect of the muscle complex is also sutured together in the midline, incorporating the seromuscular layer of the posterior rectal wall in order to anchor the rectum. Finally, the anoplasty is performed by creating an anastomosis between the rectum and skin with interrupted long-term absorbable sutures. The rectum is occasionally very dilated, in which case the posterior wall should be excised and the rectum tapered in order to allow it to fit more easily within the sphincter mechanism.

Laparoscopic Assisted Anorectoplasty

Approximately 25 % of boys with an ARM have a rectoprostatic fistula and approximately 10 % have a bladder neck fistula. These patients are well suited for a laparoscopic approach to repair. A total body prep from the costal margins inferiorly is performed so that the entire lower half of the child may be included in the surgical field allowing access to both the perineum and abdomen. The operation begins with a laparoscopic approach, in which the distal rectum is dissected and the fistula is ligated. We typically use an absorbable endoloop for ligating the fistula. Further dissection is then performed to allow for the rectum to comfortably reach the perineum. The dissection is performed as close as possible to the rectal wall to avoid injury to nerves, reproductive structures, and the ureters. If getting the distal rectum to reach is difficult because the colostomy has been placed too distal in the sigmoid, it may be necessary to take down the mucous fistula. It is sometimes necessary to ligate one or more distal branches of the inferior mesenteric vessels in order to allow adequate mobilization of the rectum. The vascular arcades might have been disrupted when creating the colostomy, therefore one must be careful to ligate these distal inferior mesenteric artery branches close to the rectal wall, relying on its excellent intramural blood supply.

Once adequate length has been achieved, the rectum is ready to be pulled through. This can be done with the child in the lithotomy position after identifying the limits of the sphincter complex. The anorectoplasty may be performed using the technique of sequential placement of trocars or using a limited posterior sagittal incision. The latter technique allows for tacking of the rectum to the posterior edge of the muscle complex in order to prevent prolapse.

Females

All girls should undergo visual inspection of the introitus to identify a vaginal septum, which should be resected at the time of repair and to be certain there is not a distal vaginal atresia. Vestibular fistulae are repaired using a posterior sagittal incision with the patient in prone position. These defects may be repaired in a single stage using a preoperative bowel prep and a period of NPO and antibiotics postoperatively. Multiple silk sutures are placed circumferentially in the external orifice of the fistula, as uniform traction on the rectum facilitates the creation of a dissection plane. The posterior rectal wall is identified and the dissection continued between the rectal fascia and the rectal wall, staying as close as possible to the rectal wall.

The dissection progresses laterally on both sides until a point is reached where the distal rectum and fistula must be separated from the vagina. These two structures have a very thin common wall with no true plane of separation. A submucosal plane on the rectal side must be developed for the first 3–5 mm or so, until eventually a full-thickness plane can be developed. Circumferential dissection of the rectum is performed until adequate length is achieved for the anastomosis to be performed under mild tension preventing rectal prolapse. If defects were made in the posterior vagina or anterior rectum during the dissection, the rectum is mobilized further until it can be positioned such that the two suture lines are not adjacent to each other in order to avoid a rectovaginal fistula. The perineal body is reconstructed using interrupted long-term absorbable sutures, bringing together the anterior limits of the sphincter, and the rectum is placed within the limits of the sphincter. The remainder of the operation is as previously described.

Rectovaginal fistulas are uncommon. Repair may be performed using a posterior sagittal approach or laparoscopically if the fistula connects to the proximal vagina. In patients with an H-type rectovaginal or rectovestibular fistula where the anus is normally positioned within the sphincter and a fistula is present between the vestibule, vagina, or labia and the rectum at the level of the dentate line, a transanal Swenson-like repair similar to Hirschsprung disease may be performed.

Posterior Sagittal Anorectovaginourethroplasty (PSARVUP) for the Repair of Cloaca

Cloacal malformations represent a wide spectrum of defects. A major determinate of the technical approach to repair and prognosis is the length of the common channel. Cloacas with a common channel <3 cm may be repaired by general pediatric surgeons who have had adequate training in this procedure with acceptable outcomes expected. In defects with a

common channel >3 cm in length or more complex defects, the repair is often challenging and better outcomes may be achieved when the repair is performed by an experienced surgeon. In these more complex patients, urinary and fecal continence is often poor and requires artificial methods of keeping patients dry (intermittent catheterization) and clean (bowel management program).

Vaginoscopy and cystoscopy are performed as a separate procedure *after* the newborn period. This will provide useful information for surgical planning and prognosis. This should not be performed at the time of colostomy as visualization is difficult and it will often result in significant distension of the bladder or vagina, making the colostomy more difficult. With the scope positioned at the confluence of the urethra and vagina, the length of the common channel, also known as the *urogenital sinus*, is measured from the tip of the endoscope to the perineal skin. Also, the distance from the urethral take off and the bladder neck is determined. When the common channel is <3 cm, it should be possible to repair the entire malformation from a posterior sagittal approach. If the common channel is >3 cm, it is better to prepare the patient with a total body prep in order to be able to turn the patient and open the abdomen if necessary.

There are several key steps in repairing a cloaca with a common channel <3 cm. The posterior sagittal incision is continued anteriorly until the surgeon reaches the single perineal orifice and the common channel is opened in the midline. Total urogenital mobilization can be done in the majority of cases and significantly reduces the future risk of a urethro-vaginal fistula, vaginal stricture, or acquired vaginal atresia. The rectum needs to be dissected off the posterior aspect of the vagina. If a vaginal septum is present, the rectal fistula is usually located within the proximal aspect of the septum. The vagina and urethra are then mobilized as a single unit. The common channel is then split in the midline and secured to the skin becoming the edges of the labia. The urethral orifice is sutured approximately 5 mm behind the clitoris and the vaginal edges are sutured to the introitus. If the patient has two hemivaginas, the vaginal septum should be excised. The perineal body is reconstructed and the rectal component of the malformation is repaired as in a typical PSARP.

When dealing with a longer common channel, total urogenital mobilization may still be utilized but additional length is frequently needed requiring a laparotomy. If the length is still not adequate, then the urinary tract and vagina must be separated. Alternatively, the decision to separate the vagina from the common channel is made at the beginning of the case. Creation of a neovagina with colon or small bowel, or a vaginal switch maneuver should be in the armamentarium of a surgeon repairing these defects if the vagina does not easily reach the perineum.

If a laparotomy is needed during the main repair or at the time of colostomy closure, the Müllerian structures should be inspected and the presence of normal structures and patent fallopian tubes documented. In patients with the more complex malformations described above, a suprapubic cystostomy tube or vesicostomy is needed until intermittent catheterization can be started. The reconstructed urethra may need long-term stenting with a Foley catheter or circle stent.

Postoperative Care

Recovery after a PSARP is usually rapid and generally straightforward. The children seem to have surprisingly little pain. Patients with a colostomy can eat the same day of surgery. When a single-stage operation is performed in an infant or child who is passing stool, we withhold oral nutrition for 5–7 days after surgery, during which time they are maintained on parenteral nutrition. Broad-spectrum intravenous antibiotics are continued for 24 h. In boys who have had a rectourethral fistula repaired, the Foley catheter is left in place for 7 days. The catheter is removed and the parents are instructed to return if the child is unable to void within 6 h. If the Foley catheter is accidentally removed before the recommended time, it need not be replaced since the majority of patients will be able to void and the potential for urethral injury during recatheterization is significant.

Two weeks after surgery, the anus is calibrated in the clinic with Hegar cervical dilators and the parents are then taught how to dilate the neoanus. The dilator is lubricated and then passed through the anus into the rectum, held in place for 30 s, removed, and then passed again. The anus must be dilated twice per day. Every week the size is increased until the appropriate size for the patient's age is reached (Table 67.3). Once the desired size is reached, the colostomy can be closed and the frequency of dilations tapered.

After the colostomy is closed, patients often initially have very frequent bowel movements that can produce a severe perianal rash. It may take some time for this to heal. A variety of creams and ointments are available that attempt to create a barrier, usually with variable success. The best treatment for the severe diaper rash is to avoid prolonged contact between stool and the skin. We instruct parents to wash the perineum with mild soap and water every time stool appears. Soon the number of bowel movements will decrease and the patients typically develop constipation. Parents should be forewarned of this change so that they are ready to treat it. At this point, laxatives often need to be added. The family should then work toward a good bowel movement pattern, meaning 1–3 well formed stools per day. This is achieved with the right combination of diet, laxatives, and water-soluble fiber. This is the best scenario leading up to the time for the child to attempt toilet training.

Table 67.3 Anal dilation and tapering schedule following anorectoplasty

Dilation		Tapering	
Age of child	Dilator size	Frequency	Duration (months)
1–4 months	#12	Daily	1
4–8 months	#13	Every third day	1
8–12 months	#14	Twice per week	1
1–3 years	#15	Once per week	1
3–12 years	#16	Once per month	3
>12 years	#17		

Bowel Management

Constipation is the most common problem seen in patients with ARMs. It is more severe in less complex malformations. The more complex malformations have a poorer prognosis in terms of bowel control, but a lower incidence of constipation. It is extremely important that constipation be treated aggressively. Complications from prolonged constipation include soiling, overflow pseudoincontinence, and megarectum. Megarectum, in turn, provokes more constipation, which worsens the dilation, creating a vicious cycle. In order to avoid this, the child should empty the rectum every day, which is best achieved with a high-fiber diet and laxatives as needed. When properly treated, the majority of patients with ARMs will have voluntary bowel movements by the age of 3 years. However, about half still soil their underwear intermittently. This is usually due to constipation. If the soiling does not improve by the age of toilet training, a bowel management and enema program should be initiated. Parents should be informed that children born with ARMs will typically toilet train about a year later than normal but that the goal is to have the child clean and in normal underwear by the time they enter kindergarten.

Patients with ARMs may still suffer from fecal incontinence despite an adequate anatomic repair. However, these patients should be able to remain clean and completely free of accidents without having to wear diapers. An aggressive bowel management program that includes the use of enemas allows them to achieve this goal. Fecally incontinent patients may also have a tendency toward constipation. These patients typically still have their entire colon but have a megarectum. Most of these patients can be successfully managed with a large volume (500–1000 mL) saline enema with additives such as glycerin.

Once it is demonstrated that the bowel management has been successful, patients with severe constipation can be offered a Malone procedure, also known as a continent appendicostomy or antegrade continent enema (ACE) procedure (Fig. 67.10). An appendicostomy is created, in the umbilicus or right lower quadrant. This allows the enemas to be given in an antegrade fashion. The cecum is plicated around the base of the appendix to create a valve that prevents stool from leaking back through the umbilicus. Another option for antegrade enemas is a cecostomy tube. Procedures to create conduits for antegrade enemas are usually recommended when the patient wants to become more independent, as it allows the administration of the enema without parental assistance. It may also be indicated if the patient is becoming resistant to retrograde enemas. The Malone procedure is essentially just another way to administer an enema; therefore, it should in general only be performed in patients for whom bowel management has been successful. The urologic status of the patient should be known prior to surgery, as a Mitrofanoff, if needed, could be performed in conjunction with the Malone and the appendix potentially split for the two procedures. Also, any urologic reconstruction could be done at this time.

Outcomes and Quality of Life

In patients with perineal fistula, approximately 90 % experience fecal continence although around 20 % require laxative treatment for constipation (Table 67.4). Approximately 70 % of patients with vestibular and 50 % of patients with rectobulbar urethral fistulas are totally continent of stool. However, approximately 60 % of vestibular and rectobulbar urethral patients suffer from constipation.

Fecal incontinence has been shown to have significant negative impact on QoL in terms of social and emotional functioning, body image, and physical symptoms in children and adolescents as well as adults. However, QoL is significantly improved in about half of patients who follow a bowel management program. Patients with associated congenital anomalies and those with more severe ARMs have significantly poorer QoL.

With the exception of an occasional patient with myelomeningocele, a severe sacral abnormality or tethered cord, boys with imperforate anus usually have good urinary control. In the absence of a predisposing condition, we believe that most cases of urinary incontinence in male patients are due to injury during the peri-bladderneck dissection. This is also true of girls, with the exception of those with cloaca. Although the majority of patients with a common channel

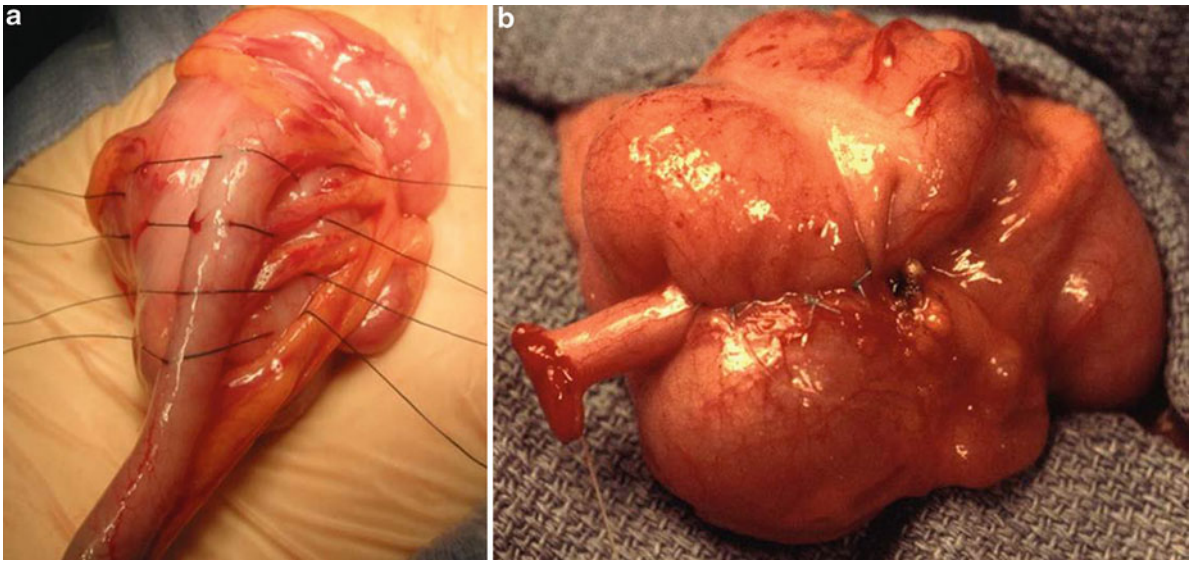

Fig. 67.10 Malone procedure. The cecum is plicated around the base of the appendix to create a valve, which prevents escape of gas or liquid through the appendix. (**a**) Non-absorbable suture placed in seromuscular layer of cecum and appendix. (**b**) Completed cecal plication

Table 67.4 Functional outcomes

	Voluntary bowel movement (%)	Totally continent[a] (%)	Constipated (%)	Soiling (%)
Perineal fistula	97	83	58	16
Rectal atresia or stenosis	100	56	70	40
Vestibular fistula	90	64	55	36
Imperforate anus without fistula	78	50	49	51
Bulbar fistula	79	46	59	49
Prostatic fistula	65	18	42	78
Cloaca: <3 cm common channel	66	35	39	63
Cloaca: >3 cm common channel	35	12	28	84
Vaginal fistula	60	20	20	80
Bladder neck fistula	20	7	14	90

Source: Data from Coran AG, et al, eds. Pediatric Surgery, 7th ed., Levitt MA, Pena A. Chapter 103: Anorectal Malformations, p. 1309, Copyright (2012)

[a]Voluntary bowel movements and no soiling

<3 cm have normal urinary control, approximately 20 % may require intermittent catheterization for a flaccid bladder. With a common channel >3 cm, approximately 80 % will have difficulty with urinary continence requiring intermittent catheterization or some form of continent diversion. An ARM index, comprised of the (1) type of malformation, (2) quality of the sacrum, and (3) quality of the spine, takes into account anatomical aspects predictive of continence. These three things should be known for all ARM patients.

Complications

Posterior urethral diverticulum (PUD) is a common complication that may occur following repair of a rectourethral fistula. It has been speculated that this may be more common following laparoscopic assisted anorectoplasty (LAARP) but is also a known complication following PSARP. In patients with a rectoprostatic fistula who had an LAARP, MRI may identify PUD in a third of patients. In the majority of these patients the diverticulum is asymptomatic and requires no intervention. A technique described to reduce the risk of a PUD during LAARP is sharp division of the fistula flush with the urethra without the use of clips or ties. We make sure to dissect the distal rectum low enough so that a three-millimeter grasper fits across at the level of the fistula. Also, by only using laparoscopy for bladder neck and prostatic fistulas and not for lower fistulas where the rectum is below the peritoneal reflection with a long common wall, this complication can be avoided. A PUD should be suspected in patients who report daytime dribbling, recurrent UTI, or passage of mucus through the urethra. If these symptoms are present, an MRI performed with a

20–24 Fr Foley placed in the rectum without inflating the balloon is accurate in detecting a PUD. Whether or not a PUD may be observed in an asymptomatic patient remains an area of debate. However, we recommend surgical excision of the diverticulum as malignant degeneration into a mucinous adenocarcinoma has been reported.

Colostomy complications include prolapse, stricture, retraction, and peristomal wound infections and are reported in 15–30 % of patients with divided colostomies and 25–30 % in those with loop colostomies. Although a divided colostomy has been traditionally recommended in patients with ARMs to avoid these complications and the risk of UTI, this has not been clearly demonstrated in the literature. One should follow the principles of creating the colostomy close to the retroperitoneal attachments of the proximal sigmoid colon to reduce the risk of prolapse which is the most common stoma-related complication and to leave the mucous fistula as long as possible for the future pull-through.

Wound infections are often superficial, limited, and healed by secondary intention. *Anal strictures* may result from ischemia or excessive tension of the pull-through segment or noncompliance with the dilation schedule. Options for management of anal strictures include resuming dilations, redo anoplasty in which the rectum is mobilized circumferentially to bring down a healthy segment of bowel, or stricturoplasty using a V-Y or skin flap advancement technique.

The incidence of *rectal prolapse* ranges from 6 to 30 % following LAARP and approximately 4 % following PSARP. Low gluteal and sphincter muscle quality, vertebral anomalies, tethered cord, and LAARP are risk factors for developing rectal prolapse. Rectal prolapse may be mild and asymptomatic or may be significant enough to warrant redo anoplasty. It can interfere with a bowel control and can also cause bleeding and mucous production.

Future Considerations

The management of patients with ARMs is complex and requires an understanding of the multiple problems that these children can have. Although it is extremely important for the surgeon to be able perform the operations without causing injury, technical mastery alone is clearly not sufficient. A multidisciplinary team approach including the pediatric surgeon, pediatric urologist, gynecologist, neurosurgeon, gastroenterologist, radiologist, and others when associated anomalies are identified is critical to achieve optimal outcomes. As these patients become older, bowel management and urologic and gynecologic function become critical aspects to their care. If these patients are not followed closely, and bowel, renal, and bladder function issues are not addressed early, adverse health related issues will occur. Accurate long-term assessment of outcomes regarding overall function and quality of life as well as burden of treatment is lacking and represents an area for improvement in the care of patients with ARMs. It is essential that the surgeon be able to manage the significant postoperative functional sequelae that many of these patients have and recognize that these are patients for life.

Editor's Comment

Imperforate anus is one of the more common congenital anomalies requiring surgical correction and pediatric surgeons should be well versed in the correction of its more common varieties. One of these is the perineal fistula in girls, commonly referred to as the "anterior displaced anus." Some controversy exists over the best way to correct these seemingly benign lesions. Regardless of the technique used, the functional result is the same: moderate to severe constipation. In the past, the fistula was often simply dilated, which allows meconium to pass; however, patients were often incontinent and needed extraneous methods to evacuate. Similarly, for a time it was popular to use the "cutback anoplasty," in which the fistula is opened in the midline posteriorly to the center of the anal sphincter and the rectal mucosa is anastomosed to the perianal skin. The result is a keyhole-shaped anal opening that is only partially surrounded by sphincter musculature. A better anatomic and functional result is achieved when the rectum is brought up through the anal sphincter with either a "mini-PSARP" procedure or anal transposition.

Girls with cloaca are treated in many children's centers by a team of surgeons that includes a pediatric surgeon, a pediatric urologist, and sometimes an expert in pediatric gynecologic anomalies. Pediatric urologic consultation can also be useful when searching for a high rectum in boys, who are at risk for injury to the urethra, bladder neck, seminal vesicles, and vasa deferentia during the very difficult and tedious dissection that is often required in these cases. One can also be lulled into a false sense of security by the rare male infant with an apparent perineal fistula, classically thought to be associated with a low lesion and straightforward repair, but who instead has a rectum that ends at the level of the prostate and a long, narrow fistula that opens on the perineum. These infants often need to have a laparotomy for proper mobilization of the rectum.

In boys with no apparent fistula, it might be difficult to see evidence of urethral passage of meconium as it is diluted by urine and soaks into the diaper. It is useful in these cases to place a cotton gauze pad over the penis within the diaper. The urine passes through the gauze while the meconium is trapped in the interstices of the cotton mesh.

Finally, although it is certainly better to make a decision regarding repair or colostomy within 48 h of birth, there are rare situations in which an infant with a severe cardiac anomaly and no apparent fistula is felt to be too unstable even for a bedside colostomy or is thought to be unlikely to survive

for long with or without cardiac reconstruction. With adequate gastric decompression, these children can sometimes be maintained for a surprising length of time and, in very rare cases, will begin to pass meconium through the perineal dimple a few weeks after birth, at which point they are often amenable to dilation.

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Part IX

Abdominal Wall, Peritoneum, and Diaphragm

Gastroschisis

68

Saleem Islam

Gastroschisis and omphalocele are the two most common congenital abdominal wall defects. Gastroschisis is the more common of the two with an increasing incidence worldwide. Embryologically, the intestine herniates into the umbilical cord region from the sixth to the tenth week of gestation due to rapid elongation and growth of the abdominal viscera. The etiology of gastroschisis is not entirely clear; however the most accepted theory suggests that there is failure of migration of the lateral embryonic folds, which is more common on the right side, resulting in a defect to the right of the umbilical cord. This implies that the defect occurs early during gestation.

The incidence is increasing worldwide and is approximately 1:4000 live births. In the USA the incidence increased from 2.3 per 10,000 live births in 1995 to 4.4 per 10,000 in 2005. Tobacco use during pregnancy, a variety of common medications (aspirin), and insecticide contamination of the soil have all been implicated but without conclusive evidence. There is a strong association with young maternal age. Almost 40 % of gastroschisis cases occur in mothers less than 21 years age. Low socioeconomic status, illicit drug use, and low body mass index have also been suggested as contributory. Race may also play a role, as the incidence is lower in African Americans while a higher incidence is seen in Hispanics.

Prenatal and Perinatal Management

Prenatal diagnosis for gastroschisis occurs in the majority of cases. An elevated maternal serum alpha-fetoprotein (AFP) may be the earliest sign. Up to 90 % of the defects are picked up on prenatal ultrasonography by the mid second trimester. Detection of free-floating loops of intestine in the amniotic fluid to the right of the umbilical cord is pathognomonic. Prenatal detection of an abdominal wall defect typically leads to a transfer in care of the pregnant patient to a high-risk center. Amniocentesis is not considered to be of benefit in isolated gastroschisis, but is used if additional defects are present.

Intestinal damage is seen in many cases of gastroschisis. This ranges from an inflammatory peel or serositis to intestinal necrosis or perforation. The inflammatory injury to the bowel does not occur in all cases and the severity is variable. The etiology is unknown but is thought to be the result of exposure to the amniotic fluid and constriction of the bowel with lymphatic obstruction at the abdominal wall. Waste products including urea, cytokines, meconium, and other substances have been implicated in the inflammatory response resulting in deposition of type IV collagen, bowel wall thickening, and intestinal dysmotility. Animal research in which amniotic fluid is exchanged for lactated ringers has resulted in improvement in the inflammatory response and decreased thickening of the bowel. Human trials with amniotic fluid exchange have been inconclusive.

Bowel diameter on prenatal ultrasonography has been evaluated as a potential marker for complex gastroschisis. The average bowel diameter prior to 30 weeks gestation is <2 mm. Bowel dilation >10 mm prior to 30 weeks gestational age has been predictive of atresia while intestinal damage may be seen in 35–40 % of neonates with bowel dilation ≥6 mm. Attempts have been made to correlate fetal US findings with postnatal outcomes. Intra-abdominal bowel dilation is significantly associated with bowel compromise, while bowel wall thickening, extra-abdominal dilation, or gastric dilation is not. Overall, fetal US measurements of bowel diameter and thickness are inconsistent predictors of clinical outcome and need further refinement.

Preterm delivery to limit intestinal exposure to the amniotic fluid has been proposed for gastroschisis. In theory, limited exposure would result in less injury thereby increasing the chance of early abdominal wall closure, improving intestinal motility, and decreasing the time to initiate feeds.

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Fetuses with gastroschisis are delivered prematurely more often (25–30 %) than those without abdominal wall defects (~6 %). Management protocols that include planned cesarean section between 36 and 38 weeks and as early as 34 weeks have resulted in high rates of primary repair. However, delivery before 37 weeks is associated with increased time to full enteral feedings and increased length of stay compared to term delivery. Furthermore, infants with gastroschisis who weigh <2 kg experience prolonged hospitalization, more ventilator days and increased time to full feeds. Given the added risks to the neonate and mother with planned preterm cesarean section, the evidence favors term delivery.

The mode of delivery for the fetus with gastroschisis is often a point of discussion. Some advocate routine cesarean section in order to avoid trauma to the exposed bowel from vaginal delivery and avoid exposure of the bowel to the vaginal flora. However, no clear benefit to cesarean delivery has been demonstrated. Therefore, a vaginal delivery at term is generally recommended unless contraindicated secondary to maternal or fetal issues. Many advocate delivery of the fetus with gastroschisis at a specialty center with full-time pediatric surgical and neonatal capabilities.

Neonatal Resuscitation

Newborns with gastroschisis experience considerable evaporative fluid loss. Immediately following delivery the patient's airway, breathing and circulation should be evaluated then attention turned toward management of the gastroschisis. Endotracheal intubation is used only if indicated for respiratory distress. Orogastric or nasogastric decompression is performed. Vascular access is obtained and intravenous fluids and antibiotics started. An initial isotonic fluid bolus of 20 mL/kg is given. In the past, 1.5–2× "maintenance" fluids have been recommended for the initial resuscitation. Cautious preclosure fluid resuscitation is now encouraged as excessive fluid may result in adverse outcomes such as increased ventilator days, days of parenteral nutrition, length of stay, and occurrence of bacteremia. The bowel is quickly inspected for signs of ischemia or a tight fascial ring then covered with a plastic bag over the torso ("bowel bag") to reduce fluid losses for transport to the NICU. After the bowel is covered, the baby is placed right side down and the gastroschisis stabilized to avoid kinking of the vascular pedicle. The use of narcotic pain medication at this stage is not required, however, some neonatal units prefer to use a short acting drug such as Fentanyl. Emergent surgical evaluation is necessary. If this is not available, transfer to a facility with surgical expertise must be arranged.

Surgical Care

Surgical evaluation of the bowel is rapidly performed to ensure there is no kinking of the blood supply related to patient position or constriction of the blood supply related to a small fascial defect. If a constricting defect is identified, the defect is opened at the fascial level, usually on the right lateral position. In addition to the intestine and stomach, care must be taken to look for intestinal atresia or other herniated structures. The gonads (ovary or testicle) may be herniated through the defect, and should be carefully placed into the abdominal cavity. Occasionally, the top of the bladder is noted to be protruding from the bottom of the defect. While an atresia may be suspected on initial inspection, it is often unclear in cases with extensive peel (Fig. 68.1). Similarly, the intestine may appear to have inadequate length initially due to the inflammation. Any bands crossing the bowel loops should be divided prior to placing a silo or primary abdominal wall closure.

Controversy exists over the closure technique for gastroschisis. Before the early 1990s, the standard was to attempt primary closure in all cases, and then construct a silo if closure was not possible. The introduction of the preformed silastic silo with a spring-loaded ring changed the paradigm, as it could be placed at the bedside with minimal sedation and avoids intubation. This technique was rapidly adopted across the USA and throughout the world.

Primary Closure

This technique involves immediate reduction of the herniated viscera to the abdominal cavity and closure of the defect.

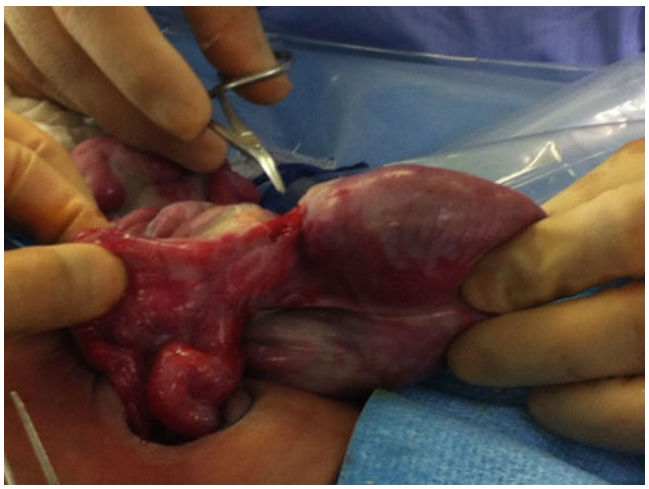

Fig. 68.1 Gastroschsis initial evaluation. Note the extensive inflammatory peel and foreshortened mesentery

Success rates for primary closure as high as 80 % have been reported. The procedure has been performed at the bedside, but more often is done in the OR under general anesthesia. The first step involves assessing the degree of inflammation and edema and searching for an atresia. A vigorous effort is then made to empty the large intestine and rectum of meconium performing irrigations with a catheter placed through the anus if necessary. Care must be taken to ensure there is no serosal injury. The abdomen is then stretched manually with the surgeon's fingers to create additional room, and the intestine then returned into the abdomen.

Various methods have been described to measure the abdominal pressure during this part of the procedure; including intra-gastric pressure, urinary bladder pressure, and peak inspiratory pressure on the ventilator. Intra-abdominal pressures >20 mmHg are associated with decreased visceral perfusion and an increase in peak inspiratory pressure >10 mmHg suggests a significant increase in intra-abdominal pressure. Once the contents are returned to the peritoneal cavity, the defect itself can be closed in a variety of ways. Fascial closure may be performed followed by skin closure and umbilical reconstruction by preserving the base of the cord. This technique results in a higher intra-abdominal pressure; so if there is concern about the pressure, skin closure alone can be performed. Subsequent spontaneous closure of the fascial defect similar to an umbilical hernia is anticipated in many of cases following skin closure alone. Finally, bedside reduction followed by "sutureless" repair using part of the umbilical cord to plug the defect has been successful.

Silo and Delayed Closure

Schuster first described the use of a silastic sheet sewn to the skin and fascia to create a silo in a neonate with gastroschisis. The preformed silo was introduced in the 1990s and became rapidly accepted, consisting of a spring-loaded silastic covered ring that was inserted into the abdominal cavity beneath the fascia with a transparent external silo (Fig. 68.2). The device comes in a number of sizes based on the diameter of the ring (3–10 cm). The ring is pinched and inserted into the abdominal cavity after the intestines have been gently placed into the silo (Fig. 68.3). The bowel is then serially reduced over the next 2–5 days using clamps or twisting and ligating the silo with an umbilical tie. Some authors advocate allowing the bowel to spontaneously reduce into the abdominal cavity and once a plateau is reached then perform definitive closure.

A major advantage of the silo technique is the gentle reduction of the viscera over time in order to decrease the effects of increased abdominal pressure. Reduced need for mechanical ventilation, reoperation for intra-abdominal hypertension, and incidence of necrotizing enterocolitis have been reported with silo use. In addition, silo placement allows for an elective procedure to achieve definitive closure. Disadvantages include increased incidence of sepsis, delay in closure, and increased time to initiation of feeds.

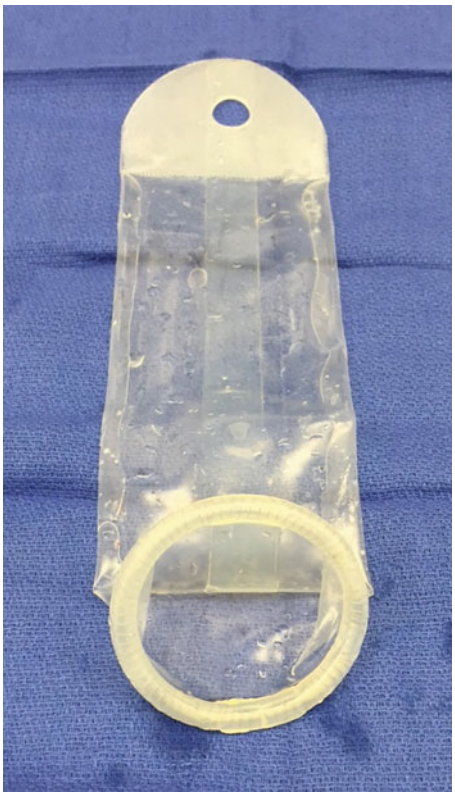

Fig. 68.2 Preformed spring-loaded silastic silo

Complicated Gastroschisis

Some newborns with gastroschisis will have associated intestinal atresia, intestinal perforation, prenatal loss of intestine with resultant short bowel (vanishing midgut), or bowel ischemia. These patients have overall worse outcomes and risk adjustment models have noted that long-term morbidity and complications are almost entirely in this group. Complex defects account for 5–15 % of cases in most reported series and result in a longer hospital length of stay, increased use of parenteral nutrition and parenteral nutrition associated cholestasis, higher readmission rates, increased total cost, and higher mortality rates compared to the simple gastroschisis cohort.

Intestinal atresia is noted in approximately 10–15 % of gastroschisis patients and management of these cases is individualized according to the location of the atresia and severity of the peel and inflammation (Fig. 68.4). If there is minimal bowel matting and thickening, an atresia may be safely primarily repaired at the time of abdominal wall

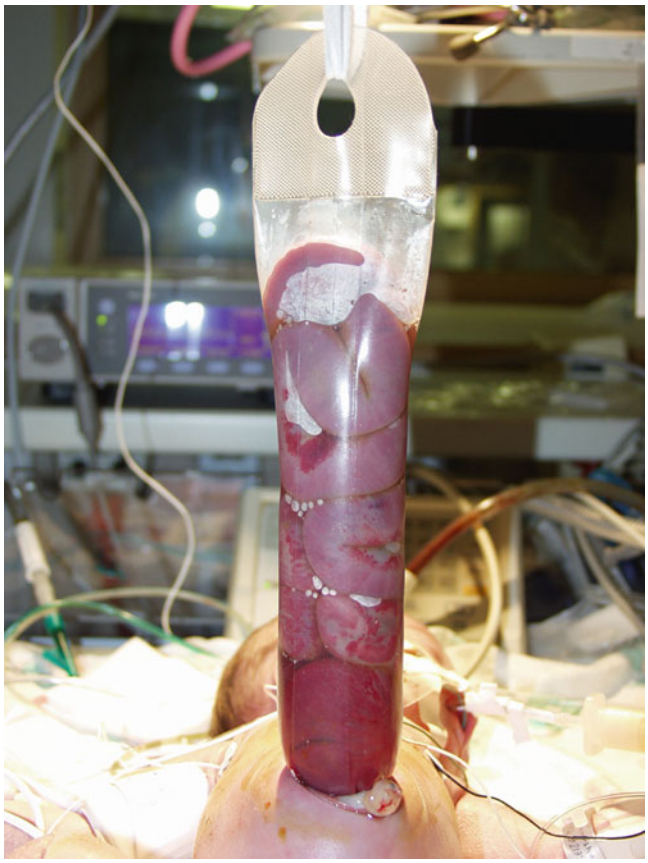

Fig. 68.3 Appropriate placement of silo. Bowel is placed in the smallest size silo that will accommodate it. Viable and well-perfused bowel visible within silo without much bottle-necking at level of defect

closure. However, if there is significant inflammation of the bowel wall, reduction of the bowel and defect closure can be performed and repair of the atresia delayed 4–6 weeks when the inflammatory peel has resolved. In cases of a distal intestinal atresia, the creation of a stoma is preferred to allow early enteral feeding and prevent continued distention of the proximal segment.

Special Considerations

Closed or vanishing gastroschisis is a rare condition in which the defect either completely or partially closes in utero, resulting in strangulation of the herniated bowel. This may present as a newborn with necrotic herniated midgut or as a newborn with a closed abdominal wall and limited intestinal length. These patients have short bowel syndrome requiring long-term parenteral nutrition and possibly bowel lengthening procedures or small intestine transplantation.

Ruptured omphalocele is another rare scenario that bears mentioning as it may be confused as a gastroschisis. In these cases, liver is included in the herniated viscera and the defect is much larger than the usual gastroschisis opening (Fig. 68.5). Management of these neonates is complex and requires staged closure, with outcomes much worse than a standard gastroschisis.

Outcomes

Gastroschisis outcomes have dramatically improved over the past four decades. Mortality was close to 50 % in the 1960s and currently is less than 10 %. Survival in simple gastroschisis is over 95 %, while 80–90 % survival is noted in complex cases.

Morbidity has also similarly improved with time. Most of the morbidity in gastroschisis is associated with dysmotility of the gastrointestinal tract. This is significantly worse in complex cases. Prolonged use of parenteral nutrition in patients who are unable to feed may result in cholestasis, and in some cases liver failure. The use of motility agents has not been beneficial in improving bowel function. However, clinical management pathways have resulted in decreased time to full enteral feeds. In patients who do not have bowel function or who are unable to tolerate enteral feeds within 3–4 weeks after closure, an intestinal atresia should be sought. Pneumatosis intestinalis and necrotizing enterocolitis occur in up to 10 % of neonates with gastroschisis but most will respond to non-operative management. Length of stay is close to 4 weeks on average and is generally longer in complex cases.

All patients with gastroschisis have malrotation. A Ladd procedure is usually not performed, as adhesions from the repair are presumed to likely prevent a future volvulus. The family should be alerted to the significance of bilious emesis and encouraged to seek prompt intervention. Other anomalies such as undescended testes are noted in 35–40 % of boys. In cases where the testicle is herniated through the defect, initial management consists of simple reduction of the gonad. Approximately half of patients with cryptorchidism will experience testicular descent. At a year of age, those with an undescended testicle should undergo an orchiopexy. If the testicle is non-palpable, it is reasonable to attempt diagnostic laparoscopy to evaluate the testicular position.

Children with gastroschisis are typically small for gestational age but will usually catch up to their peers by 12–24 months of age. However, outcomes data suggests that long-term neurodevelopmental outcomes are lower than age-matched cohorts. Additionally, roughly 60 % of patients report being dissatisfied with the appearance of their umbilicus, which can also result in psychosocial stress.

Care Management Pathway

The mother of a fetus with gastroschisis is referred for prenatal consultation. The anticipated prenatal, perinatal and postnatal course as well as potential complications and surgical management are discussed. The prospective parents also tour

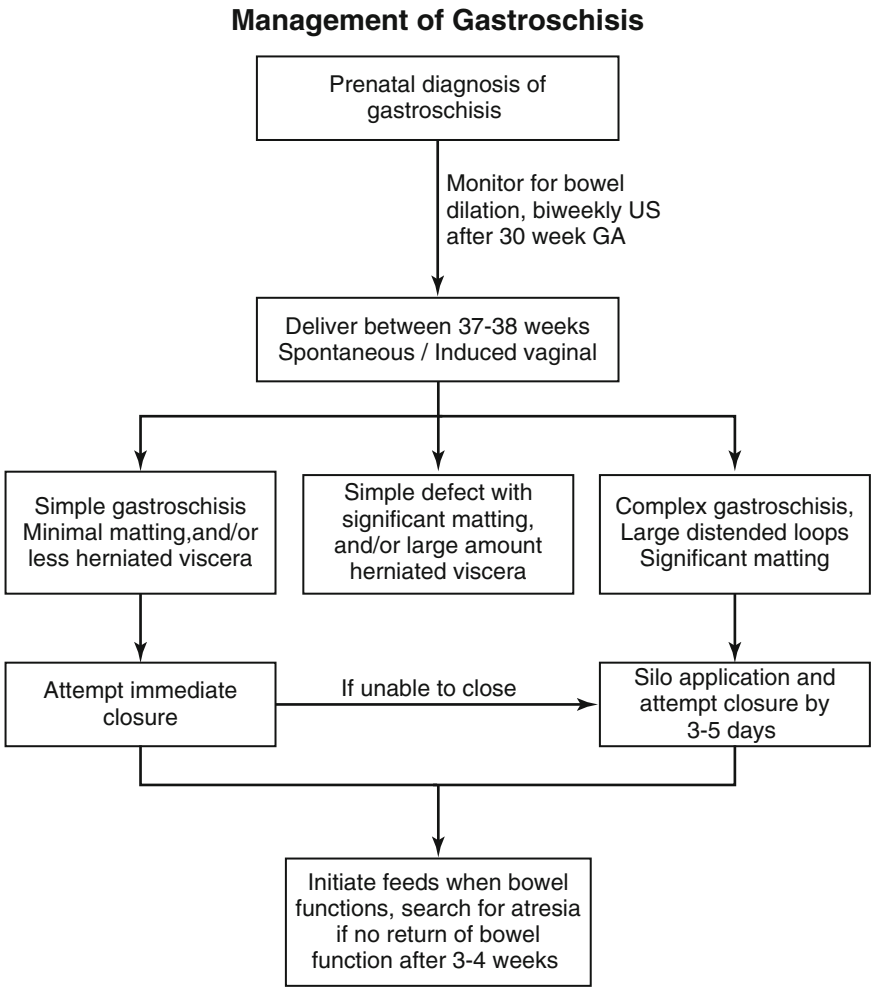

Fig. 68.4 Suggested algorithm for gastroschisis management

the NICU and discuss issues with the nurses and social workers. This helps to alleviate many concerns and prepare them for the postnatal care.

Communication with the high-risk maternal fetal medicine specialists allows for a coordinated delivery with pediatric surgical presence in the NICU to immediately receive the neonate. As resuscitation is proceeding, the gastroschisis defect and intestine are examined. I prefer to place a spring-loaded silo at the bedside for most cases and reserve immediate closure for cases with relatively little herniated and inflamed viscera. Twice-a-day reductions are started 12–24 h after placement of the silo and a PICC line placed for parenteral nutrition. The goal in all cases is to have the viscera reduced by 3–5 days and perform a final closure in the operating room. I prefer to close the skin only and have had good cosmetic results. Most of the fascial defects will spontaneously close by 3 years of age. Antibiotics are administered while the silo is in place and continued for 24 h after closure. If an atresia is identified, I perform an ostomy at the umbilicus.

An orogastric tube is kept on suction until the volume diminishes to less than 15–20 cc per day and then the tube is taken off suction and removed if tolerated. Feeding is initiated via continuous feeds through a small bore feeding tube to allow for gut priming and then advanced if tolerated and bowel function begins. For simple gastroschisis a hospital stay of 3–4 weeks is expected. Patients are followed for at least 2 years after discharge to ensure adequate weight gain and that there are no feeding issues.

Editor's Comment

The delivery of a fetus with gastroschisis should be performed at a center all the resources needed for definitive care. Labor may be spontaneous or induced as close to term as possible. Cesarean section delivery should be reserved for the usual maternal and fetal indications.

Following delivery, the intestines should be covered with a bowel bag and the patient placed in a right lateral position to avoid kinking of the mesentery during transport. Although no closure technique is clearly superior, bedside placement of a spring-loaded silo allows for rapid coverage of almost all defects in order to prevent insensible water losses and protect the bowel. Serial reduction of

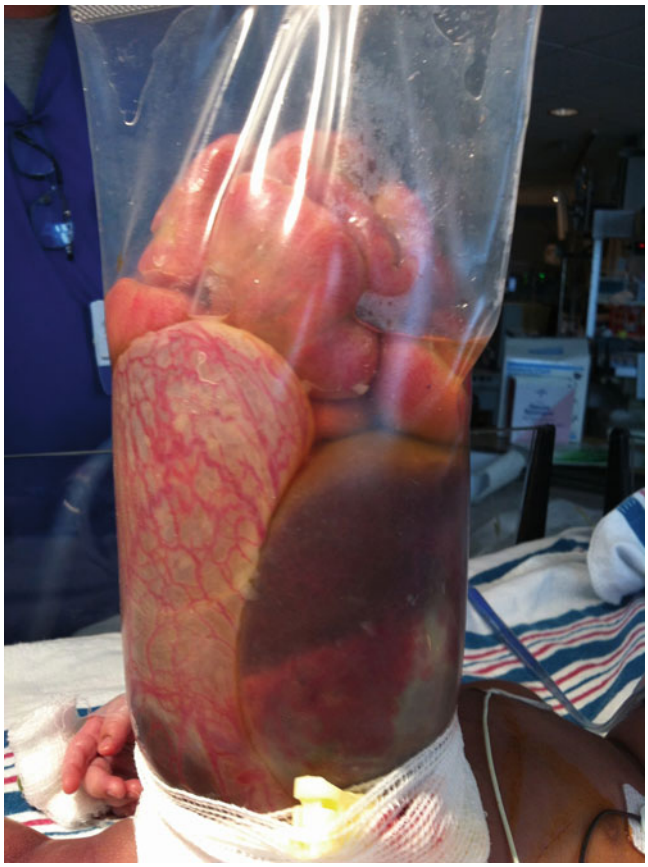

Fig. 68.5 Ruptured omphalocele. Note the large amount of herniated liver in the silo. Closure was eventually performed with a skin graft covering the bowel and the ventral hernia later repaired

the gastroschisis should be performed one or two times a day with a goal of complete reduction within 3–5 days. If the silo is left in place for longer periods of time, the fascial edges have a tendency to recede making the definitive fascial closure more difficult or a prosthetic patch necessary to avoid intra-abdominal hypertension with closure. The best intra-operative sign of excessive pressure is the peak inspiratory pressure. A number of techniques for fascial and skin closure have been described. A vertical midline closure of the fascia after creation of generous skin and subcutaneous flaps and creation of a neoumbilicus by marsupializing the skin edges to the fascia at the desired location and appropriate size for an umbilicus provides good cosmesis.

Antibiotics are usually continued postoperatively for 48 h and the patient maintained on parenteral nutrition until non-bilious, low-volume gastric output, and bowel function. Feedings are then slowly advanced. It is not uncommon for patients to become intolerant of feeds after several days of advancement. The feeds can be held briefly or decreased and then advancement resumed as long as there are no signs of sepsis and an abdominal radiograph shows no pneumotosis intestinalis. If the patient did not pass meconium preoperatively and has not had bowel function within 4 weeks following closure, an atresia or stricture should be ruled out. A contrast enema is obtained initially and if normal an upper GI performed after the contrast from the enema has cleared.

Management of an atresia diagnosed on initial inspection includes closure of the defect with repair of the atresia in 4–6 weeks or creation of a stoma. Rarely is the condition of the bowel amenable to primary anastomosis at the time of initial closure. If the atresia is distal, a stoma created at the umbilicus effectively decompresses the bowel and allows for early feeding. Proximal atresias may be adequately decompressed by nasogastric decompression.

Suggested Reading

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Omphalocele

69

Amita A. Desai and Corey W. Iqbal

Omphalocele is best described as a congenital abdominal wall defect through the umbilicus that can be variable in terms of its size and contents (Fig. 69.1). It is often confused with gastroschisis, but omphalocele differs significantly in that it includes a sac consisting of amnion, Wharton's jelly, and peritoneum, involves the umbilicus, oftentimes contains the liver, and has a high association with other anomalies.

Ambrose Pare first described omphalocele in 1634. The first successful surgical repair of an omphalocele is attributed to Hey in 1802. However, it was not until the 1940s, after Dr. Gross's introduction of a staged procedure utilizing skin flaps followed by ventral hernia repair, that infants with larger omphaloceles began surviving. In 1967 Schuster began repairing giant omphaloceles with a staged approach using prosthetic materials. Today multiple operative techniques are utilized to close omphalocele based on the size of the defect, associated anomalies, and overall clinical condition of the child.

The antenatal diagnosis of omphalocele can be made as early as 11–14 weeks gestation. In fact, the incidence of omphalocele this early in gestation has been reported to be as frequent as 1 in 1100 pregnancies. However, the prevalence at birth is between 1 in 4000–6000 live births, indicating a hidden mortality most likely due to in utero fetal demise from associated chromosomal anomalies as well as elective pregnancy termination after the diagnosis of omphalocele is made. Unlike gastroschisis, omphalocele is more common with advanced maternal age and the incidence does not seem to be changing.

Multiple theories have been proposed for the development of omphalocele. Perhaps the most commonly accepted theory is failure of the lateral embryonic folds to migrate medially. The failure of these lateral folds to meet in the midline results in a central defect that is covered by peritoneum, amnion, and Wharton's jelly. This theory is further supported by findings in other conditions associated with omphalocele. In normal embryogenesis, folding along the longitudinal axis by the cephalic and caudal folds takes place to create the cranial and caudal regions of the embryo. Failure of cephalic folding can lead to an anterior diaphragmatic hernia, sternal cleft, pericardial defect, cardiac anomalies such as a ventricular septal defect of left ventricular diverticulum, and ectopia cordis—a constellation of anomalies is known as pentalogy of Cantrell. Failure of caudal folding can lead to cloacal exstrophy, characterized by an omphalocele, bladder exstrophy, epispadias, diastasis of the pubic rami, and imperforate anus.

Another theory, gaining more acceptance, does not center on arrest of the lateral folds, but rather attributes the defect to abnormal rotation of the midgut. In normal development the intestines form outside of the fetus followed by rotation in a counter-clockwise direction forming the duodenal C-loop and fixing the cecum in the right lower quadrant. Failure of this reduction could result in a spectrum of disease including omphalocele.

Prenatal Management

Diagnosis of omphalocele can be made in the prenatal period with routine ultrasonography and is most commonly identified during the second trimester at the 18-week ultrasound. The omphalocele is identified as a ventral abdominal wall defect and is distinguished from gastroschisis by the presence of a sac, herniation through the umbilical cord, identification of the umbilical cord insertion on the hernia sac, and the presence of liver in the hernia (Fig. 69.2). Elevated maternal serum alpha fetoprotein may be seen but is not specific for omphalocele as it is also seen with neural tube defects and gastroschisis.

Given the high incidence of associated congenital anomalies, ultrasonography should include a detailed anatomic assessment of the entire fetus (Table 69.1). Additional workup should include chromosomal studies and a dedicated fetal

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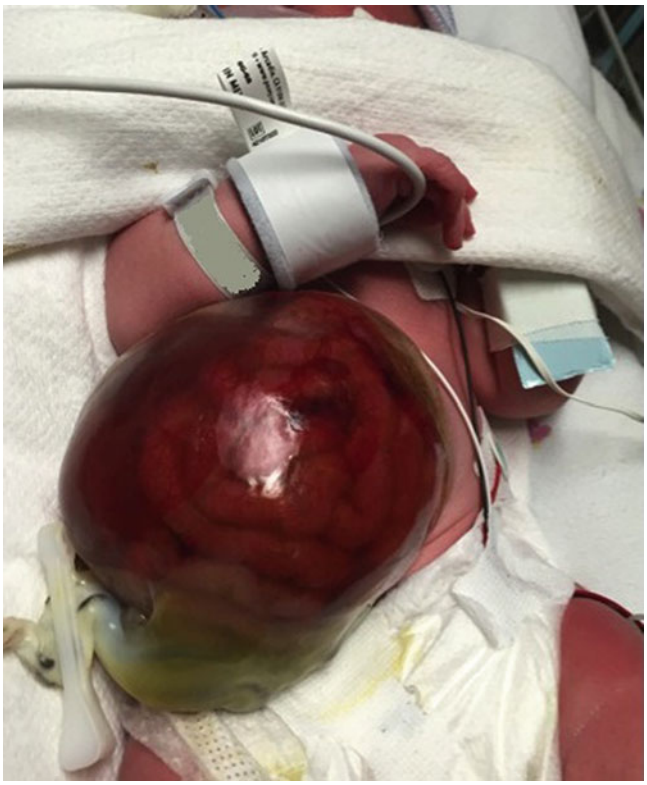

Fig. 69.1 Giant omphalocele shortly after birth with minimal abdominal domain. The liver and most of the midgut can be seen through the transparent omphalocele sac

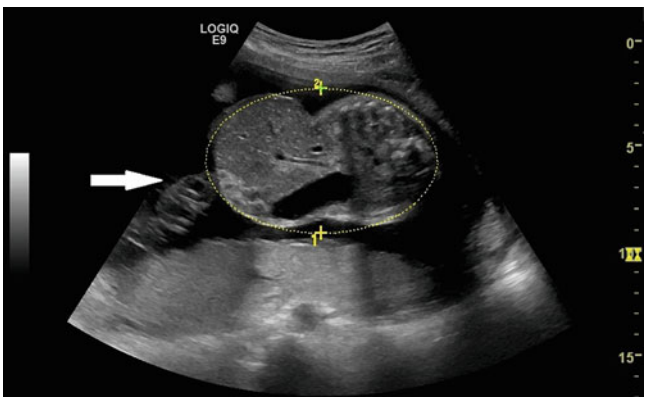

Fig. 69.2 Prenatal ultrasound showing an axial view of the fetal abdomen with a large, liver-containing omphalocele at 29 weeks gestation. The *arrow* indicates the umbilical cord inserting onto the sack

echocardiogram to rule out a structural cardiac defect. Fetal MRI is gaining popularity in the work-up of many prenatally diagnosed congenital anomalies, however its role in omphalocele is limited. We do not routinely obtain a fetal MRI for prenatally diagnosed omphalocele.

Identification of associated congenital anomalies is paramount for prenatal counseling as fetal mortality is highly dependent on the presence of anomalies which can be lethal independently or as part of a sequence of anomalies that portends a worse prognosis (Table 69.2). Currently, fetal intervention is not offered for omphalocele.

Multiple prenatal measures have been described to facilitate prediction of worse postnatal outcomes. In these measurements, the omphalocele diameter is compared to the abdominal circumference (OD/AC), head circumference (OD/HC), and femur length (OD/FL). A lower likelihood of primary closure and a higher risk for postnatal morbidity have been reported when the OD/HC ratio is $\geq$0.21. An OD/AC ratio $\geq$0.26 has also been shown to carry a higher risk of both postnatal morbidity and mortality. Available studies are limited by their small sample size and lack validation from other centers. Consequently, these parameters are not widely accepted or utilized. Ultimately, the presence of other congenital malformations or chromosomal anomalies is the most important prognostic factor.

Pediatric surgeons have a critical role in the prenatal counseling process, especially in the fetus with a giant omphalocele (defect >10 cm). In our center, these consultations take place with a team that includes pediatric surgery, maternal-fetal medicine, neonatology, genetics, palliative care, fetal health nursing coordinators, and social work. If a cardiac anomaly has been identified, then pediatric cardiology is involved as well. From the surgical standpoint, it is important to emphasize that in the case of a large omphalocele or in the setting of multiple other anomalies, surgical repair is often delayed and complete closure might require multiple operations. In this scenario, parents should expect a prolonged hospitalization.

If the decision is made to continue the pregnancy, patients should be seen regularly by an obstetrician or perinatologist given the increased risk for fetal demise, preterm labor, and growth restriction. Vaginal or Cesarean delivery remains controversial for small omphaloceles. In those with a giant omphalocele, birth dystocia, rupture of the omphalocele, and trauma to the herniated liver are concerns. We recommend Cesarean section if the omphalocele diameter exceeds 5 cm or if a significant portion of liver is within the omphalocele. Delivery should be as close to term as possible and performed at a tertiary care center with pediatric surgery available.

Treatment

The initial resuscitation should involve immediate placement of an orogastric or nasogastric tube to decompress the intestinal tract and prevent intestinal distension. Normothermia should be maintained and the sac itself should be covered with warm saline-soaked gauze immediately after birth to minimize insensible fluid losses. Venous access should be obtained for any immediate resuscitative needs. All attempts should be made to prevent rupture of the sac, which necessitates urgent bowel coverage and represents a significant problem if the omphalocele is too large for primary closure. Some infants will require intubation due to associated pulmonary hypoplasia.

Table 69.1 Incidence of associated congenital anomalies by system

System	Incidence (%)
Cardiac	7–47
Central nervous system	4–30
Musculoskeletal	4–25
Genitourinary	6–20
Gastrointestinal	3–20
Chromosomal	3–20
Facial	1–14
Respiratory	1–4

Source: Adapted from Klein MD. Congenital defects of the abdominal wall. In: Coran AG, Adzick NS, Krummel TM, editors. Pediatric Surgery 7th ed. Philadelphia: Saunders; 2012

Table 69.2 Syndromes associated with omphalocele

Lethal omphalocele-cleft palate syndrome
Beckwith–Wiedemann syndrome
Fibrochondrogenesis
Meckel–Gruber syndrome
Marshall–Smith syndrome
Cloacal exstrophy
Fryns syndrome
Thoracoabdominal syndrome
Triploidy
Trisomy 13, 18

Once stabilized, the neonate should be thoroughly evaluated for any other anomalies. In addition to a thorough physical examination, imaging with abdominal ultrasound and echocardiogram should be obtained in all neonates with omphalocele. Blood glucose should also be assessed given the association with Beckwith–Wiedemann and possible neonatal hypoglycemia. A genetic work-up should be initiated as well as any other additional diagnostic tests that may be indicated based on physical examination findings.

Operative Repair

A single approach does not apply to the surgical management of omphalocele. Surgical options are dependent on the size of the defect, the presence and severity of other associated congenital anomalies, gestational age, the status of the sac (ruptured or not), and surgeon preference. We consider closure as immediate or delayed. Options available for either early or delayed closures can be categorized as temporary abdominal closure, autologous tissue repair, or prosthetic mesh closure (permanent, bioprosthetic, absorbable).

Immediate Closure

We reserve immediate or early closure for small omphaloceles in neonates who are clinically stable and acceptable surgical candidates. No evidence-based size criteria exist to guide attempts at immediate closure. An umbilical defect <1.5 cm in size is considered a hernia of the cord and is amenable to immediate closure, as are many defects that are larger than 1.5 cm. The surgeon must use good judgment when evaluating larger defects for primary closure. Immediate closure of large omphaloceles can lead to abdominal compartment syndrome, cardiovascular collapse from kinking of the hepatic veins, hemorrhage from liver injury during dissection of the sac, and respiratory compromise.

If immediate closure is undertaken, the omphalocele sac is typically dissected free from the abdominal wall to mobilize the fascial edges for closure. Care must be taken when dissecting the membrane adjacent to the liver because violation of Glissen's capsule can lead to uncontrollable hemorrhage in the neonate. For this reason, we leave a portion of the membrane adherent to the liver. Once the sac has been excised, the surgeon must decide whether an autologous tissue repair or mesh repair is appropriate.

During closure, communication with the anesthesia team is paramount. Elevated airway pressures indicate the closure is too tight and will result in abdominal compartment syndrome. Hypotension typically indicates kinking of the hepatic veins. If primary closure appears to be too tight, then it should be abandoned in favor of a mesh closure that will permit more laxity of the abdominal wall. In certain situations in which the neonate is not tolerating closure, definitive closure may need to be abandoned altogether in favor of a temporary abdominal closure either with a prosthetic mesh or skin flaps.

The amnion-inversion technique is used for newborns without significant comorbidities who have a large omphalocele that is not amenable to primary closure. Advantages of this technique are that the membrane remains intact and the dissection is extraperitoneal. The skin and subcutaneous tissue are mobilized off of the amnion circumferentially to identify the fascia and polytetrafluoroethylene mesh is sutured to the fascial edges. The mesh is tightened over time by reefing up the mesh with horizontal mattress sutures. Once the omphalo-

cele contents are reduced and the fascial edges approximated, definitive closure can be performed.

Ruptured Omphalocele

Neonates with a ruptured omphalocele pose a unique challenge for the surgeon. Ruptured omphalocele is often large and delayed therapy is not an option once the sack is ruptured because the viscera must be protected. The defect is rarely amenable to primary closure and these neonates tend to be critically ill. In this circumstance, we prefer to use a prosthetic silo sutured to the abdominal wall as a temporizing measure. We have used both PTFE and silastic material. If the baby is physiologically stable, gradual reduction of the prosthesis is performed. In many cases, the abdominal domain cannot be re-established for primary closure and eventual closure with skin flaps or a bioprosthetic mesh is performed.

In some cases, skin cannot be used to get complete coverage, in which case we place a bioprosthetic mesh, close as much of the skin as possible and manage the exposed mesh with a negative pressure device. If the wound does not completely epithelialize, split-thickness skin grafting can be utilized to complete coverage.

Delayed Closure

We favor initial escharotic therapy with delayed repair in neonates with large, liver-containing defects and neonates with multiple other anomalies who are critically ill. In these babies, we utilize the "paint and wait" method using povidone iodine application twice daily, which results in formation of an eschar and eventual epithelialization of the omphalocele sac (Figs. 69.3 and 69.4). These children are left with a large ventral hernia defect that can be closed later in life.

Silver sulfadiazine and dilute betadine are the two most common agents used to induce scarring and eventual epithelialization of the sac. Silver sulfadiazine has been shown to be safe and effective but is not easy to apply. Iodine absorbed through the sac can result in hypothyroidism. Thyroid hormone levels must be monitored during the early treatment period; however, once an eschar begins to form, the risk for hypothyroidism is reduced.

Autologous Tissue Repair

Primary closure is the simplest method of closing an omphalocele and should be attempted when the fascial edges can be approximated in the midline with minimal tension. Typically only defects less than 5 cm are amenable to primary closure, although primary closure for defects >5 cm has been described. Once the fascia has been adequately mobilized, we use interrupted polydioxanone (PDS) sutures to close the

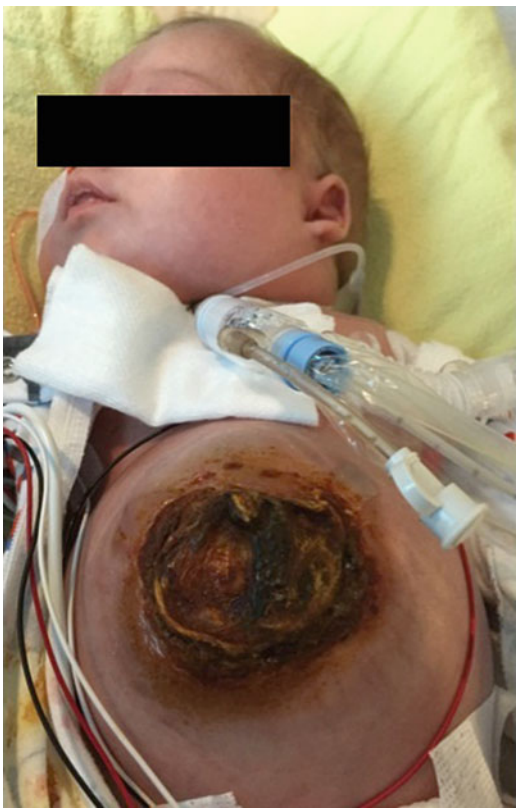

Fig. 69.3 Well-developed eschar following twice daily application of betadine

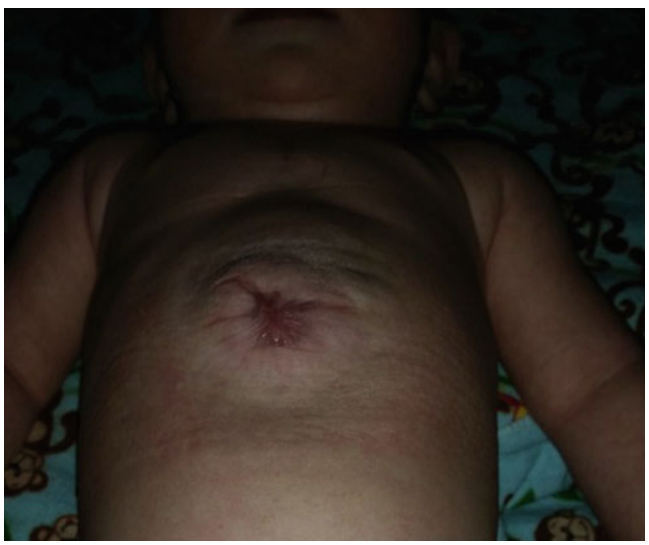

Fig. 69.4 Giant omphalocele with complete epithelialization over amnion sac after non-operative escharification with twice daily application of betadine

defect. The surgeon should not be reluctant to raise large skin flaps laterally to adequately mobilize the fascia for closure.

If the fascial closure is under significant tension, lateral relaxing incisions in the external oblique fascia can allow for additional mobilization of the rectus fascia to the midline. Also, a component separation can be performed incising the anterior rectus fascia laterally and folding the fascia to the midline. Unfortunately, for large omphaloceles, the rectus muscles are small and retracted to an extent that these methods are not useful and mesh repair is necessary.

More recently musculofascial flaps have been described by reconstructive surgeons and are an attractive method of autologous tissue repair for large defects. Others have described the placement of tissue expanders that gradually stretch autologous tissue and create excess tissue that can be used to fill the defect as a local flap. Mesh may also be used to achieve autologous repair. The mesh is secured to the fascial edge and serially tightened either by excision of the central portion of the mesh or reefing up the mesh with suture. This technique will gradually stretch the lateral abdominal wall until the two edges of fascia are approximated in the midline.

Mesh Repair

A mesh repair should be used if there is excessive tension when attempting to close a large defect primarily. Positioning the mesh behind the abdominal wall (sublay) is associated with the most durable repair. One should try to close as much autologous tissue as possible over the mesh. Large skin flaps should be raised to expose as much of the fascia as possible. This allows greater overlap of the mesh and the abdominal wall and results in a more durable repair.

We secure the mesh using interrupted non-absorbable polypropylene sutures. Sutures are passed through the anterior abdominal wall, through the mesh and then back up through the abdominal wall so that the knot is on the anterior abdominal wall. The sutures should be placed close enough to prevent any bowel from herniating between the mesh and the abdominal wall. Superiorly, if there is insufficient fascia, the mesh can be secured to the costal margin. Inferiorly, the mesh can be attached to the pubic bone if the fascia is absent. Care should be taken to avoid injury to the bladder in this scenario. Significant dead space is usually present after the extensive mobilization of skin and subcutaneous tissue which we manage with closed-suction drainage.

The advent of bioprosthetic materials has revolutionized the management of large hernias. Contrary to permanent meshes, bioprosthetic materials resist infection. Moreover, they allow for tissue in-growth and the creation of a neofascia which will grow with the child unlike a permanent mesh. While the long-term durability of bioprosthetic meshes does not seem to be as great as initially expected, these advantages make them appealing when compared to permanent meshes. We have transitioned away from permanent mesh in favor of bioprosthetic mesh. Multiple bioprosthetics are currently available but we have had the best results with acellular dermal matrices.

Post-Operative Care

In the early post-operative period, the baby should be monitored for signs of abdominal compartment syndrome. Refractory hypotension should raise the suspicion of decreased preload from kinking of the hepatic veins. In these cases, emergent decompressive laparotomy with temporary abdominal closure can be lifesaving.

Enteral feeds can be started when bowel function has returned. Parenteral nutrition is typically required while awaiting return of bowel function and during advancement of feeds. Careful attention should be given to the surgical site as up to 25 % of patients will develop wound complications following omphalocele closure.

Long-term survival in these patients is largely determined by associated congenital anomalies. Those with giant omphaloceles have been noted to have pulmonary insufficiency related to pulmonary hypoplasia. This might result in chronic lung disease, prolonged mechanical ventilation, need for supplemental oxygen, recurrent lung infections, and/or asthma.

Chronic feeding difficulties are common in babies with large defects secondary to oropharyngeal dysmotility, feeding aversion, and gastroesophageal reflux (GER). Significant GER may be present in up to 43 % of omphalocele patients. Failure to thrive can be a significant challenge because their abdominal domain may not be suitable for a gastrostomy tube. If a gastrostomy tube cannot be placed through the abdominal wall musculature, then orogastric or nasogastric tubes should be utilized for enteral nutrition.

Long-term outcomes are favorable for those who survive beyond infancy. The majority of adults with a history of a congenital abdominal wall defect report good psychosocial function. Furthermore, there is no significant difference in mean body height or body mass index compared to controls, and most do not complain of GER symptoms. However, large series with follow-up data of adults born with omphalocele are lacking.

Editor's Comment

Omphalocele differs from gastroschisis in that the herniated abdominal viscera are covered by a membrane, herniation is through the umbilical ring, the size of the defect is variable,

herniated viscera frequently include the liver, and it is more commonly associated with other anomalies and syndromes. Outcomes in babies born with omphalocele are largely related to the associated anomalies. Although the intestines are non-rotated, the risk of volvulus is extremely low. Patients can also have significant pulmonary hypoplasia that results in chronic lung disease.

Most defects <5 cm can be primarily closed provided the patient does not have comorbidities that preclude repair. For larger defects, the amnioinversion technique is an excellent alternative in the stable patient. Component separation is usually not practical with large omphalocele as little normal abdominal wall musculature is present.

When the clinical condition prevents surgical closure of the defect or the defect is too large, escharotic treatment with silver sulfadiazine is effective. This provides excellent antimicrobial activity although the therapy can cause leukopenia. Maximal WBC depression generally occurs within 2–4 days of initiation of therapy. Rebound to normal leukocyte levels follows onset within 2–3 days. Povidone iodine (betadine) treatment can result in hypothyroidism. Iodine is eliminated by the kidneys thus renal insufficiency increases the risk of toxicity, as does metabolic acidosis. The resultant ventral hernia can then be addressed at 1–2 years of age after improvement or resolution of comorbidities. Tissue expanders placed intramuscularly, intra-abdominally, or subcutaneously have been used to achieve primary closure of large defects during infancy as well as ventral hernias in older children.

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Eventration of the Diaphragm

70

Melvin S. Dassinger III and Lori A. Gurien

Eventration of the diaphragm is an abnormal elevation of one or both hemidiaphragms into the thorax. This rare disorder results when normal diaphragmatic muscle is replaced with diffuse fibro-elastic tissue, causing partial or complete thinning of the diaphragm. This condition can be congenital or acquired, and has a variety of presentations, ranging from an incidental finding on imaging to severe respiratory impairment with difficulty weaning from the ventilator. The true incidence of eventration is unknown, as many patients are asymptomatic and remain undiagnosed.

Congenital eventration is thought to be caused by failure of the muscular fibers to develop normally in the fetus, or from lack of muscle innervation due to absence of the phrenic nerve. Unilateral congenital eventration occurs more commonly than bilateral congenital eventration, with the left hemidiaphragm affected more often than the right. While the etiology remains uncertain, infectious causes such as cytomegalovirus and rubella during pregnancy have been proposed as possible causes. There is no evidence that individuals with a family history of eventration are predisposed to the condition. Acquired eventration results from a phrenic nerve injury, usually following thoracic surgery or birth trauma (associated with Erb's palsy). While the muscle appears to be normal, it is dysfunctional and loses contractility, eventually resulting in atrophy.

Neonates with eventration may present with symptoms of respiratory distress and require support with mechanical ventilation. This presentation sometimes makes it difficult for the clinician to differentiate eventration from a congenital diaphragmatic hernia with an associated hernia sac. Older infants and children are often present with milder symptoms such as exercise intolerance or recurrent respiratory infections. However, the majority of patients are asymptomatic and the diagnosis is an incidental finding on radiographs of the chest.

Diagnosis

Physical examination will sometimes demonstrate decreased breath sounds on the affected side. Subsequent 2-view chest radiograph will show elevation of the diaphragm (Fig. 70.1). The normal anatomic height of the right hemidiaphragm is slightly above the left. The diagnosis of a right-sided eventration is made when the right hemidiaphragm is elevated 2 rib levels or more above the left side. If a left-sided eventration is present, the left hemidiaphragm will be one or more rib levels above the right. Other static imaging studies such as CT or MRI can also be used to look for the presence of a completely intact diaphragm. Alternatively, these modalities might demonstrate a sharp transition from the weakened, thin central diaphragm to the normal muscular rim.

Dynamic imaging is typically needed to confirm the diagnosis. Traditionally, fluoroscopy was performed to evaluate for paradoxical movement of the diaphragm during respiration. A positive "sniff test" is described as downward movement of the unaffected hemidiaphragm with simultaneous upward movement of the affected hemidiaphragm when the patient inhales forcefully through the nose. Recently, ultrasound has replaced fluoroscopy as the imaging test of choice, as it provides an accurate assessment of diaphragmatic motion without radiation (Fig. 70.2). This motion is measured both in the direction of diaphragm movement as well as the amplitude of excursion. Normal diaphragmatic movement should be toward the transducer at inspiration with excursion of >4 mm. Additionally, ultrasound can visualize viscera both above and below the diaphragm. Even with these multiple imaging options, eventration can be difficult to differentiate from congenital diaphragmatic hernia; laparoscopy or thoracoscopy is sometimes needed to reach a definitive diagnosis.

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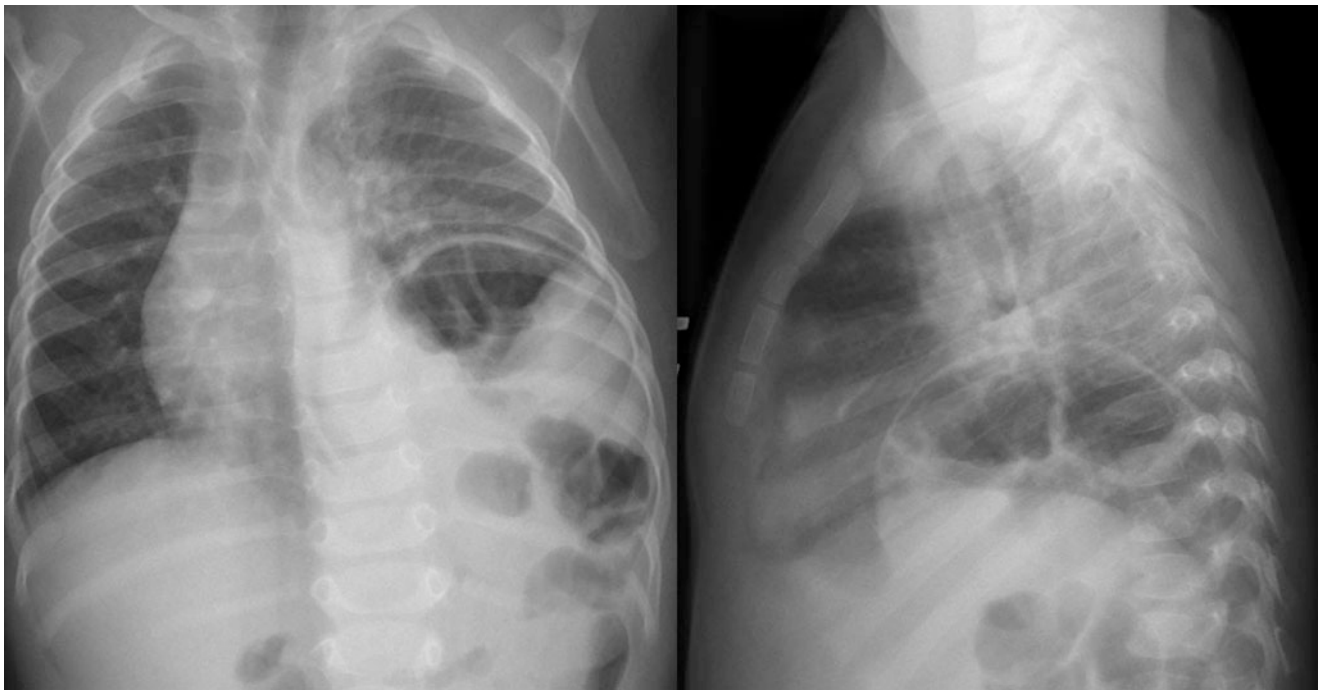

Fig. 70.1 Left-sided eventration incidentally found in a 1-year-old

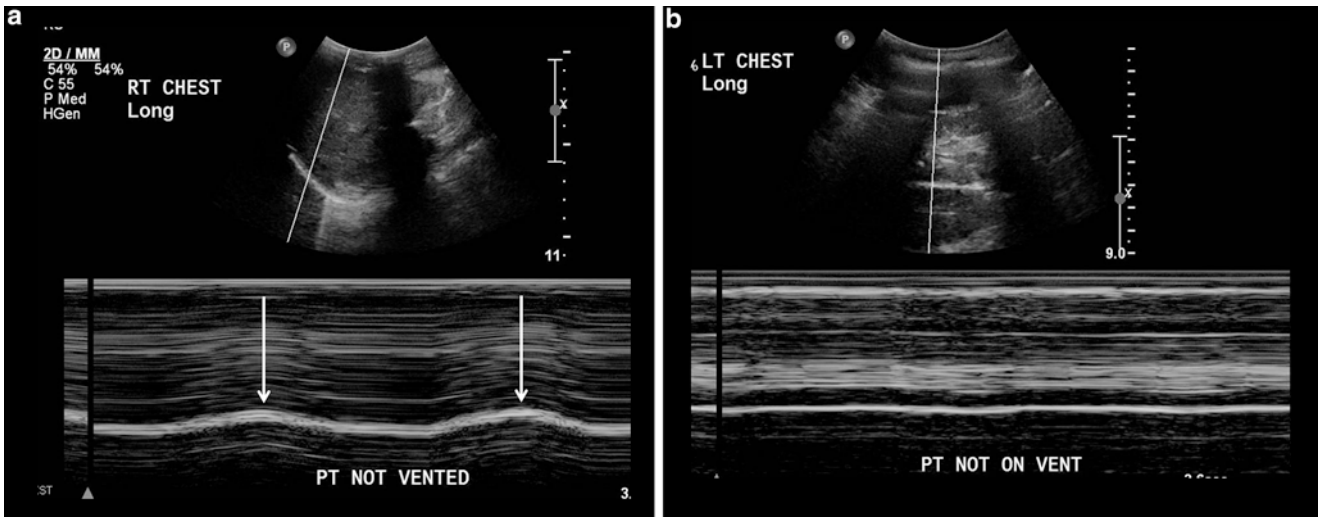

Fig. 70.2 Acquired left eventration in a 1-year-old girl following thoracic surgery. (**a**) Right hemidiaphragm longitudinal ultrasound with M-mode tracing showing normal excursion and movement toward the transducer (*arrows*) on inspiration, indicating inferior movement of the diaphragm. (**b**) Left hemidiaphragm longitudinal ultrasound with M-mode tracing demonstrating significantly decreased motion as compared to the right hemidiaphragm

Treatment

Patients with small, asymptomatic congenital eventrations can be managed without an operation. Large eventrations, in which the diaphragm is elevated above the fourth intercostal space, should be repaired even in asymptomatic patients due to the risk of subsequent hypoplasia of the ipsilateral lung. Symptomatic eventrations should also be repaired. For neonates with respiratory failure requiring mechanical ventilation, an echocardiogram is warranted to rule out a structural cardiac defect that could account for their symptoms. Acquired eventrations are initially managed with supportive care and observed to assess for spontaneous return of phrenic nerve and diaphragmatic function. However, if the patient's

condition worsens or fails to improve over time, operative repair is indicated.

Repair of the eventration can be approached either through the abdomen or thoracic cavity and can be performed using open or minimally invasive techniques. Regardless of the approach, the desired outcome is the same: to remove or strengthen the redundant, thin portion of diaphragm and obtain the optimal amount of tension to flatten out the muscle. For unilateral eventration, a muscle-sparing thoracotomy through the seventh intercostal space is chosen to best visualize the phrenic nerve and prevent injury during the procedure. Plication is then achieved by either diaphragmatic imbrication or excision of the central, weakened diaphragm. Imbrication involves eliminating diaphragmatic redundancy by placing multiple rows of non-absorbable suture, typically in an anteromedial to posterolateral fashion. Care must be taken to avoid the branches of the phrenic nerve and overly aggressive bites should be avoided to prevent injury to intra-abdominal viscera. Excision of the redundant diaphragm can be performed via a traditional technique with suture closure or using a stapling device. As loosening of the plication over time is expected, a taut repair without undue tension is essential at the time of operation to prevent recurrence.

A minimally invasive approach to diaphragmatic plication has gained acceptance. For the thoracoscopic approach, single-lung ventilation is recommended. The patient is positioned in the lateral decubitus position and three ports are placed in the seventh and eighth intercostal spaces. Carbon dioxide insufflation to 4–6 mm Hg allows for adequate visualization. The plication is performed with non-absorbable, braided suture. The restricted working space in the chest can make intracorporeal suturing a challenge. The pneumothorax is generally evacuated via one of the ports; a chest tube is not placed if the lung parenchyma was not damaged.

Laparoscopy is another, possibly more appealing, method of minimally invasive repair. This approach avoids the need for single-lung ventilation and allows the abdominal contents to be visualized and evaluated. Furthermore, the abdominal cavity affords more working room for either intracorporeal suturing or the use of a stapling device. The patient is placed in the supine position and pneumoperitoneum is established through a 5-mm port at the umbilicus. Additional ports are placed in the right and left upper quadrants. When repairing a right-sided eventration, a fourth port or instrument is introduced to provide retraction of the dome of the liver. The initial imbricating stitch serves to break the surface tension of the diaphragm, easing the remainder of the repair. As with the open repair, multiple sutures are placed in a medial to lateral fashion. A second row can be placed if the diaphragm is not taut.

Diaphragmatic pacing has been evaluated as the initial surgical therapy to regain muscle function in acquired diaphragmatic eventration secondary to phrenic nerve injury. The majority of work evaluating diaphragm pacing has been done in patients with spinal cord injury, central hypoventilation syndrome, and amyotrophic lateral sclerosis. Thus, additional research is needed to determine the optimal candidates with eventration of the diaphragm for implantation of pacers.

Postoperative Care

A chest radiograph performed in the recovery room should show flattening of the diaphragm. Small residual pneumothoraces will spontaneously resorb. Patients who were not ventilator dependent pre-operatively can usually be extubated in the operating room. Patients requiring mechanical ventilation pre-operatively often remain on the ventilator following the operation but can be rapidly weaned. These patients should be followed long-term with serial chest films to look for loosening of the plication and recurrence of the eventration.

Editor's Comment

Many children with unilateral eventration of the diaphragm are asymptomatic. Symptoms, including tachypnea, recurrent respiratory infections, failure to thrive, or inability to wean from mechanical ventilation, are an indication for surgical intervention. In cases where the eventration is related to phrenic nerve injury from birth trauma or chest surgery, spontaneous recovery often occurs. Partial or complete resolution of the elevated diaphragm is usually seen within 1–3 months. Early surgical intervention should be considered in asymptomatic infants with severe eventration, as this can affect subsequent lung development. Recovery of diaphragmatic function following phrenic nerve injury is possible following plication. Although recurrence is uncommon, it is usually best to follow these patients post-operatively with yearly chest radiographs for several years.

The thoracoscopic approach is straightforward and should allow a repair that is equivalent to that performed through a thoracotomy. Although excision of the redundant portion of the diaphragm is probably the best way to prevent a recurrence, especially in infants, if breakdown of the suture line occurs, the result is a diaphragmatic hernia. It is recommended to use non-absorbable interrupted sutures, placed in a way that distributes the tension evenly across the entire repair. Extracorporeal knots (Roeder or square) seem

to work best, but one must frequently check the status of the repair and have a low threshold to cut and replace any and all sutures that are under too much tension. It is also probably best to use pledgets, as the sutures tend to cut through the diaphragm over time. The laparoscopic approach is useful when a fundoplication or gastrostomy tube is needed and can be done concomitantly. The principles of the actual repair are essentially the same as for the thoracoscopic approach, though an extra port is often needed for bowel or liver retraction.

Congenital or acquired, the common etiology in the vast majority of cases is phrenic nerve injury or dysfunction, with subsequent paralysis of the diaphragm. Plication does not address the underlying condition but prevents the eventual displacement and restriction of the lung as the paralyzed diaphragm as it stretches and billows upward. By flattening the diaphragm, the lung is allowed to expand and most individuals can breathe normally with a single normally functioning diaphragm. An injured or stretched but physically intact phrenic nerve can recover but axonal regrowth can take months. A patient whose phrenic nerve was severed or crushed traumatically or by a surgeon should be considered a candidate for nerve repair or sural nerve interposition grafting, a procedure available at some centers.

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Congenital Diaphragmatic Hernia

71

Matthew T. Harting and KuoJen Tsao

Congenital diaphragmatic hernia (CDH) is a developmental anomaly that results from failure of complete formation of the diaphragm and is associated with subsequent abnormal development of the pulmonary parenchyma and pulmonary vasculature. CDH occurs in an estimated 1 in 2500 births and all aspects of this disease, including diaphragmatic defect size, degree of pulmonary hypoplasia, degree of pulmonary hypertension, occurrence of associated anomalies, and clinical course, highlight the profound heterogeneity of these patients. While a growing proportion of cases are diagnosed prenatally, some are diagnosed at birth due to respiratory distress within minutes or hours of birth. A small cohort are asymptomatic, eluding diagnosis for months, years, or, occasionally, a lifetime.

Concomitant pulmonary and diaphragmatic embryogenesis occur starting in the 3rd to 4th weeks of gestation. Abnormal pleuro-peritoneal membrane formation or altered post-hepatic mesenchymal plate development are proposed foundations for the diaphragmatic defect. The underlying origin of the pathophysiologic constellation of CDH is genetic, developmental, physical, or, most likely, some combination of these. Vincent Bochdalek, a mid-nineteenth century Czech anatomist, was one of the first to describe the anatomy of the posterior diaphragm and diaphragmatic herniation, a defect now known by his name.

Although the first English descriptions of this disease occurred in the mid-eighteenth century, the first attempts at repair occurred nearly 150 years later, and the first documented successful surgical repairs occurred in the early twentieth century. Emergent neonatal surgery, pioneered by Ladd and Gross, remained the standard of care from 1940 through the early 1990s. This approach was replaced by a strategy of initial resuscitation and stabilization, centered on low-pressure ventilatory support, followed by operative repair, which remains the current management paradigm.

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Prenatal Diagnosis

The initial recognition of a CDH may occur during the early second trimester by routine screening ultrasound (US). The absence of an intra-abdominal stomach or the presence of abdominal contents in the thorax suggests the diagnosis. Differential diagnoses include congenital pulmonary airway malformation (CPAM), pulmonary sequestration, diaphragmatic eventration, bronchogenic/enteric duplication cysts, or an intrathoracic mass. In our fetal center, a fetus with a presumed diagnosis of a CDH undergoes additional evaluation with a higher-level ultrasound, fetal echocardiography, and amniocentesis. Fetal magnetic resonance imaging (MRI) is also performed. Prenatal imaging provides accurate diagnosis as well as calculation of prognostic parameters (Fig. 71.1).

Many prenatal imaging characteristics have been used to predict the severity of the disease. The location of the liver, LHR, and observed-to-expected (O/E) ratio for lung volumes are most commonly utilized for prenatal counseling. An LHR >1.35 has been associated with 100 % survival, LHR 1.35–0.6 associated with 60% survival, and LHR <0.6 associated with zero survival. Unfortunately, gestational age alters LHR due to a growth differential between the lungs and the head, though comparing the observed to an expected LHR normalizes for gestational age. Severe CDH is defined by some as O/E LHR <25%, in which survival is approximately 10% with liver up and 25% with liver down. There are generally no survivors when O/E LHR is <15% with the liver up. Fetal MRI is used to further delineate the anatomy and calculate lung volumes. MRI calculations of O/E total lung volume as well as the percent predicted lung volume are useful prognostic indicators for the severity of disease.

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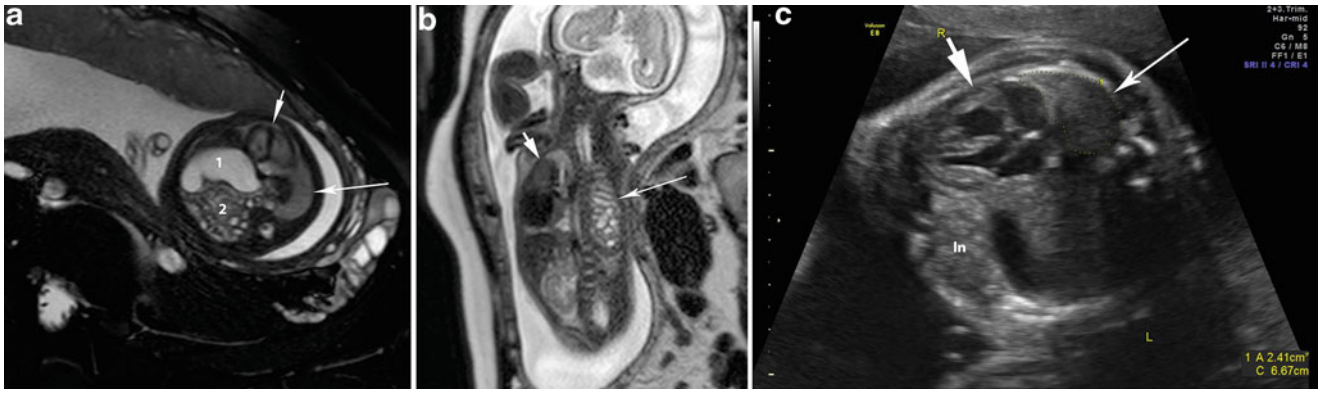


Fig. 71.1 Prenatal imaging of a patient with a left CDH. (**a**) Prenatal MRI showing an axial image of the fetal thorax including the right lung (*arrow*), heart (*arrowhead*), intrathoracic stomach (*1*), and intrathoracic bowel (*2*). (**b**) Prenatal MRI showing a coronal image of the fetus including bowel in the left thorax (*arrow*) and the right thorax (*arrowhead*), including lung and heart. (**c**) Prenatal ultrasound showing the tracing method for determining the lung-to-head ratio (LHR) (*yellow dotted line*) around the right lung (*arrow*) at the level of the four chamber view of the heart (*arrowhead*). Intestine (In) is identified in the left thorax

Patients should also undergo echocardiography, as congenital heart disease occurs in 15% of cases. Severe CHD (single ventricle, anomalous pulmonary veins) portends a poor outcome. Given the increased risk associated with certain genetic abnormalities, fetal karyotype assessment is strongly recommended.

Prenatal management begins with counseling by an experienced multidisciplinary team consisting of pediatric surgeons, neonatologists, and maternal-fetal specialists. Expectant management is routine, with monthly US surveillance to monitor for polyhydramnios, fetal hydrops, and other prenatal complications. The majority of patients with CDH will deliver at or near 37 weeks estimated gestational age. Steroids are only indicated in premature labor if the fetus is at risk of preterm delivery (24–34 weeks EGA). It is strongly recommended that these babies be delivered at a facility that has all of the necessary resources immediately available to provide the highest level of care. Data do not support recommendations for a specific method of delivery, though scheduled cesarean section for high-risk CDH fetuses may optimize the team coordination and postnatal management.

Although fetal surgery for CDH, including fetoscopic temporary tracheal occlusion, has demonstrated some promise, it has not been proven to be superior to optimal postnatal management. Identifying the appropriate candidate for fetal intervention has been a major challenge. The Tracheal Occlusion To Accelerate Lung Growth (TOTAL) trial currently being conducted in Europe and Canada hopes to identify which patients will benefit the most from fetal intervention. Fetoscopic Endoluminal Tracheal Occlusion (FETO) is the technique being used in the TOTAL trial. With this technique, a balloon is deployed in the fetal trachea in an effort to increase pulmonary pressure, therefore reducing pulmonary hypoplasia. There are two arms of the TOTAL study: (1) moderate lung hypoplasia (O/E LHR 25–34.9% or 35–44.9% + liver up) and (2) severe lung hypoplasia (O/E LHR <25%). Participation in this trial may be considered if patients have access to a participating institution and the fetus has O/E LHR measurements that meet inclusion criteria.

Treatment

Initial postnatal care requires rapid assessment and coordinated intervention. Infants with sufficient respiratory effort and independence may be monitored closely and respiratory effort assisted with supplemental, blow-by or nasal cannula-delivered oxygen. Those who experience rapid and significant respiratory distress (poor respiratory effort, sternal retractions, cyanosis, gasping, and tachypnea) require immediate intubation *without* bag-mask ventilation. Respiratory care strategies are aimed at preventing pulmonary overdistension and barotrauma. Initial conventional ventilation settings include pressure-controlled, pressure-limited mode with positive inspiratory pressure of 22 cm H_2O, positive end expiratory pressure of 5 cm H_2O, respiratory rate of 40 breaths per minute, fraction of inspired oxygen (FiO_2) of 100%, and an I-time of 0.35 (note: assist-control mode). Intravenous access, arterial access, urinary catheter placement, and gastric decompression are established. Preductal oxygen saturation (SaO_2) is monitored. Approximately 30 min are allowed to reach a relative level of stability prior to obtaining the first arterial blood gas. Chest radiography should confirm tube positioning and the presumed diagnosis (Fig. 71.2). An ECHO should be obtained within the first few hours to assess cardiac anatomy and pulmonary hypertension. Additionally, intracranial US should be obtained as a baseline prior to the initiation of ECMO. Efforts are made to minimize environmental and physical stimulation of the newborn as this can exacerbate pulmonary hypertension.

Established therapeutic targets and treatment limitations are paramount to balancing optimal tissue and cellular physiology

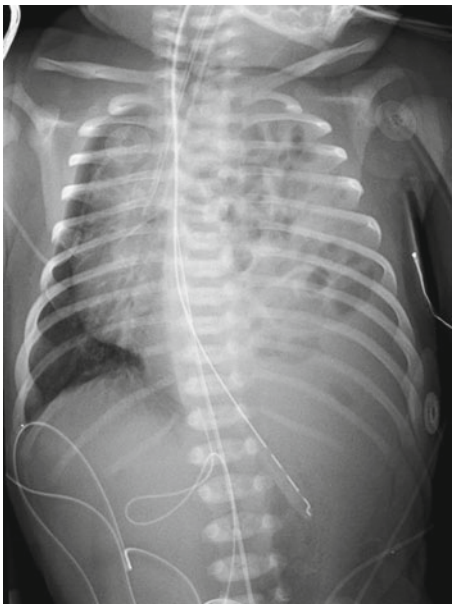


Fig. 71.2 Chest radiograph of an infant with a left CDH

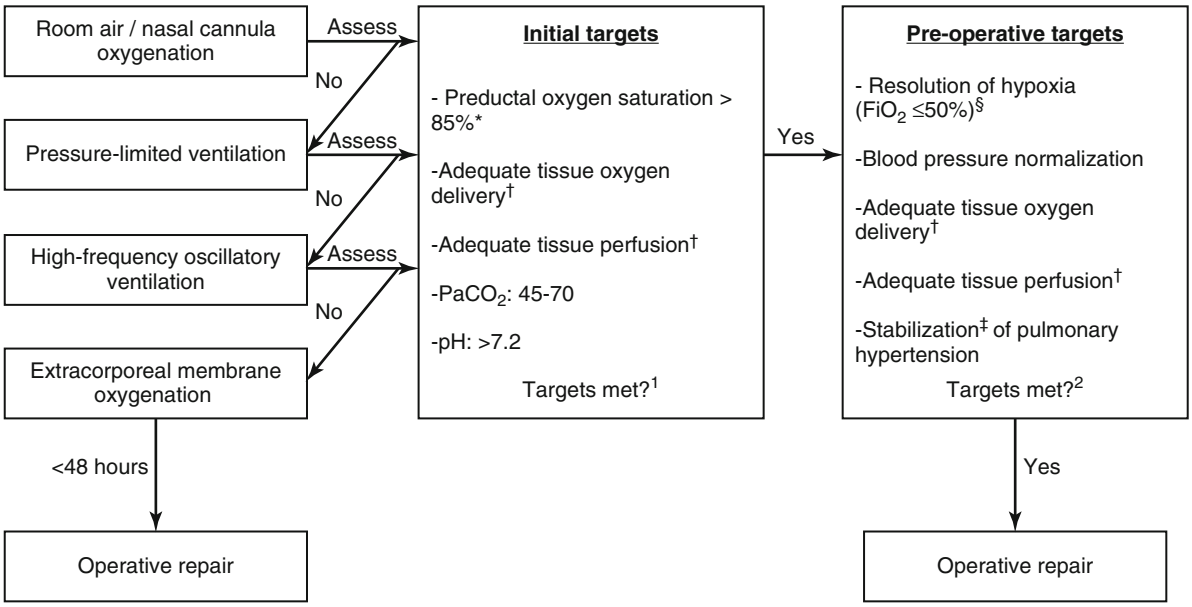
while minimizing iatrogenic lung injury. Initial targets include preductal SaO_2>85% (an initial, transient SaO_2>70% may be tolerated for ~2 h, as long as it is improving), adequate tissue oxygen delivery and perfusion (assessed by physical exam, urine output >2 mL/kg/h and lactate <3 mmol/L), $PaCO_2$ 45–70 mmHg, and pH 7.2–7.4. These parameters are continually monitored, with an arterial blod gas (ABG) obtained every 1–4 h, based on patient status. Hypercarbia is managed with increasing peak inspiratory pressure (PIP) (by 1–2 cm H_2O, max of 26) or ventilator rate (increments of 5 BPM, max of 60). The I-time should be adjusted to the rate as needed. Hypoxia is addressed by leaving the FiO_2 at 100% and adding inhaled nitric oxide (iNO) to a max of 20 ppm. Preductal saturations can fluctuate rapidly and dramatically, and may be affected by numerous factors (patient position, fluid status, ventilator settings, pulmonary hypertension, blood pressure, and gastric decompression).

Inability to maintain oxygenation or ventilation generally signals failure of conventional ventilation and the need for alternative support. We transition to high-frequency oscillatory ventilation (HFOV) if $PaCO_2$ consistently exceeds 70 mmHg with a PIP of 26 and an RR of 60, or if preductal oxygen saturation is consistently below 85% with a PIP of 26, a peak end expiratory pressure (PEEP) of 5, and iNO of 20 PPM. Our initial HFOV settings are MAP 2 above that of the conventional ventilator (*not* greater than 15), amplitude twice that of MAP or higher to achieve optimal chest movement (up to the level of the umbilicus), and frequency of 8–10 Hz (optimized to the last CO_2). Goal lung expansion is 8–9 ribs on CXR.

Extracorporeal membrane oxygenation (ECMO) is initiated if HFOV fails to maintain the goal physiologic parameters. Specific indications for initiation of ECMO include preductal saturations consistently below 85%, persistent metabolic acidosis (lactate >5 mmol/L or pH <7.20), $PaCO_2$ consistently exceeding 70 mmHg with resulting respiratory acidosis (pH <7.20), or hypotension resistant to intravenous fluid therapy and inotropic support with inadequate end organ perfusion (urine output <0.5 mL/kg/h). Relative contraindications include significant congenital anomalies, lethal chromosomal anomalies, intracranial hemorrhage, weight <2 kg, and gestational age <34 weeks. The optimal mode of ECMO for CDH patients, veno-venous (VV) or veno-arterial (VA), remains unclear. VV ECMO provides oxygenated blood to the pulmonary vasculature and preserves the carotid artery but does not necessarily stabilize hemodynamic compromise and can be cumbersome, depending on the degree of anatomic variability. Alternatively, VA ECMO allows for hemodynamic control, reduces right heart strain, and is less vulnerable to anatomic variability. We use a step-wise protocolized approach to pulmonary support (Fig. 71.3).

There are a few additional factors important to the optimal medical management of CDH. Intravenous fluid management includes initiation of maintenance fluid (containing dextrose) at 40–60 mL/kg/day and this should be adjusted based on blood glucose, fluid balance, and patient weight. It is critically important to avoid generalized edema from fluid overload. In the edematous patient who is hemodynamically stable with oliguria, diuresis (furosemide) should be considered, particularly prior to operative repair. Hemodynamic management starts with a mean arterial blood pressure (MABP) appropriate to gestational age. Term or near-term infants should have a MABP of 40–50 mmHg. If the patient is persistently hypotensive, a normal saline bolus (10 mL/kg) is given and may be repeated within the first 4 h of life. If hypotension persists, we initiate dopamine or dobutamine infusion and titrate to a MABP of 40 mmHg. Epinephrine may subsequently be added (not to exceed 0.3 μg/kg/min). Refractory hypotension should prompt hydrocortisone treatment, echocardiography, and consideration of ECMO. Targeting a supra-normal blood pressure is appropriate if the preductal oxygen saturation target (85 %) is not achieved.

The hematocrit is usually within normal limits in these patients without additional transfusion of blood, though patients with marginal tissue perfusion should have the hematocrit maintained around 40%. There are no data to support prophylactic antibiotic administration. Sedation and analgesia should be used as clinically indicated, but minimized as tolerated. Paralysis is generally avoided, given the potential for rapid intrathoracic pressure change, atelectasis, ventilation–perfusion mismatch, and chest wall compliance alterations with the loss of the patient's own contribution to minute ventilation.



* may allow 70-85% briefly

§ FiO_2 should not be weaned below 40%

† assessed by physical exam,UOP, & lactate

‡ defined by repeated echocardiography and unchanged pharmacotherapy

1. Each mode of ventilatory support should be slowly optimized within designated limitations to prevent iatrogenic injury. Once the settings reach these limitations, and initial targets are not met, the mode ofsupport should be changed.

2. Support should be decreased in a *gradual, methodical* manner to reach the pre-operative targets. In addition, pre-operative ventilatory and hemodynamic support should allow for a potential post-operative deterioration.

Fig. 71.3 Pulmonary support algorithm for newborn infants with CDH

Identification and management of pulmonary hypertension (pHTN) is critically important in the newborn with CDH. Echocardiography should be performed in the early postnatal period. Infants with right ventricular pressures greater than systemic systolic blood pressures ("suprasystemic" pressures), significant tricuspid valve regurgitation (regurgitation jet) or right ventricular enlargement with ventricular septal deviation toward the left ventricle (septal "bowing") are diagnosed with CDH-associated pHTN. Oxygen is an excellent pulmonary vasodilator and FiO_2 should be at 100%. Appropriate management of hypotension can also minimize pHTN. Inhaled nitric oxide(iNO) is a selective vasodilator of the pulmonary vasculature and is often used for the treatment of pHTN although studies have not conclusively demonstrated a benefit. Phosphodiesterase-3 inhibition (milrinone) can improve right ventricular function and relax the pulmonary arteries (0.25–0.5 μg/kg/min). When acute pHTN is unresponsive to these treatments, ECMO is considered. Additional pharmacologic agents used to treat less severe or chronic pHTN are sildenafil (0.5–2.0 mg/kg/dose every 6 h), inhaled or intravenous prostacyclins, prostaglandin E1 (PGE1), or endothelin-receptor antagonists (bosentan).

Surgical Approach

Surgical repair of the diaphragmatic defect should be undertaken following physiologic stabilization (with or without ECMO support). Therapeutic goals include $FiO_2 \leq 50$ %, normalization of blood pressure, lactate <3 mmol/L, UOP >2 mL/kg/h, and resolution of pHTN (systolic pulmonary pressures less than systemic pressures). This process usually takes between 2 and 10 days.

CDH may be repaired by laparotomy, laparoscopy, thoracotomy, or thoracoscopy (Table 71.1). The operative steps include: reduction of the herniated abdominal contents, assessment of the size of the defect, dissection of the posterior rim of diaphragm, closure of the defect (primary, patch, or tissue repair), and closure of the laparotomy (patch closure if inadequate abdominal domain) or thoracic incision. The CDH Study Group has developed a classification schema for the defect size in order to risk stratify patients. Defect size is reported in a standardized "A-D" classification (Fig. 71.4). All A and most B defects can be closed primarily (2-0 braided nylon +/- pledgets). Large B and all C or D defects require a patch. We use a 1 mm polytetrafluoroethyl-

Table 71.1 Advantages and disadvantages (known and theoretical) of the common approaches to CDH repair

	Operative approaches		
	Laparotomy	Thoracotomy	Thoracoscopy
Advantages	Common approach (~90 %)	Minimizes abdominal organ contact	Cosmetically optimal
	Abdominal patch if domain insufficient		Decreased pain
	Access to manage abdominal abnormalities		
	Facilitates reduction of abdominal viscera		
Disadvantages	Incisional hernia risk	More limited access space	Challenging for large defects
	Increased pain	Musculoskeletal sequelae	Increased recurrence rate?
	May reduce abdominal compliance	Increased pain	May increase end-tidal CO_2
		Reduced thoracic compliance	Insufflation alters intrathoracic pressure

ene (Goretex) or polytetrafluoroethylene/polypropylene patch to close the defect. The patch is shaped like a cone or dome to allow for optimal intra-abdominal space and maximal patient growth in a way that prevents creating excessive tension. Choosing between primary repair and patch repair must be centered on the idea of minimizing tension and generating an optimal anatomic repair at the gastroesophageal junction. Tube thoracostomy is not routinely employed. If the abdominal domain is inadequate after viscera reduction, a temporary abdominal wall closure with polytetrafluoroethylene patch is performed.

Patients who progress to preoperative ECMO support require additional considerations. Although no consensus exists regarding timing of repair while on ECMO, our center has chosen to operate early—usually within 48 hours of going on ECMO. We minimize anticoagulation, targeting lower anti-Xa levels of 0.2–0.4 IU/mL with lower ACT goals. A 100 mg/kg IV bolus of aminocaproic acid is given approximately 6 hours prior to operation, then as a continuous infusion of 30 mg/kg/h for 48–72 hours. Platelets should be maintained around 80–100/mm^3. In patients on ECMO, we use the abdominal approach, minimize dissection of the posterior rim of diaphragm, generously utilize electrocautery, are liberal in using a patch for abdominal closure and leave a chest tube. Hemostatic agents are used for hemostasis. Early, moderate, and late post-operative complications are relatively common (Table 71.2). Re-operation is particularly challenging in these patients, given the development of significant peritoneal adhesions.

Post-operative Care

Patients often experience at least a modest destabilization in the immediate post-operative period, requiring escalation of therapy. Achievement of the preoperative physiologic goals will allow latitude to manage the patient in this circumstance. The general approach to post-operative ventilator management is gradual and methodical (1–2 total ventilator changes per day, no drastic changes). HFOV can be managed by weaning the frequency, then the amplitude to maintain $PaCO_2$. The FiO_2 should be weaned (5–20 % per day) to achieve goal preductal oxygen saturations. The MAP is weaned once the $FiO_2 \leq 60$ % and lung expansion is adequate (approximately 8 ribs). In patients on conventional ventilation, PIP should be weaned, followed by the back-up rate while maintaining similar tidal volumes to achieve goal $PaCO_2$ levels. Inhaled nitric oxide should be decreased when the $FiO_2 \leq 60\%$ and the pHTN is stable or improving. Although there are no consistent guidelines for weaning iNO, decreases of 5 PPM/day until the dose is 5, then 1 PPM/day until off, with close attention to oxygenation and pHTN, is a conservative protocol.

Patients requiring ECMO support have several additional challenges. Anticoagulation is maintained, but minimized. The risk of hemorrhage remains high, mandating routine brain US and frequent lab monitoring. The chest tube should be removed once ECMO is discontinued.

Nutrition is provided initially with parental nutrition and subsequently advanced to enteral feeds when appropriate. Patients usually tolerate gastric feeds but may require post-pyloric feeds. Diuresis is usually necessary to optimize fluid balance and gas exchange.

Long-term Follow-up

CDH survivors often suffer from associated morbidities. In addition to ongoing pulmonary impairment, patients may experience nutritional challenges related to foregut dysfunction and gastroesophageal reflux (GER), neurocognitive delay, behavioral disorders, auditory loss, and other less common morbidities. Comprehensive, multidisciplinary follow-up will allow early identification and management of these problems (Table 71.3). Long-term respiratory issues range from mild bronchospasm to pulmonary hypertension, intermittent aspiration, or recurrent pneumonia, which can ultimately result in chronic lung disease. Supplemental oxygen is commonly required at discharge. Bronchodilators and inhaled steroids are used to minimize inflammatory exacerbations and bronchospasm.

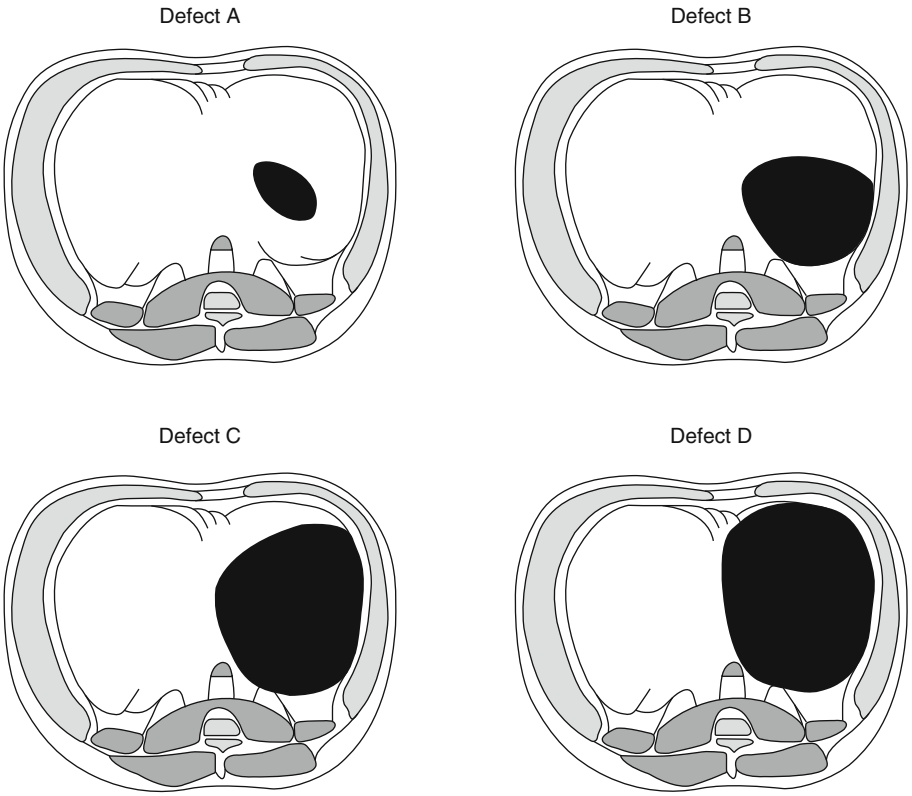


Fig. 71.4 Classification of CDH based on diaphragmatic defect size at operation. Orientation: the defect is on the patient's left side and the surgeon is looking up from the abdomen toward the chest. (Reprinted from the Journal of Pediatric Surgery, Standardized reporting for congenital diaphragmatic hernia – an international consensus, Vol 48, Issue 12, Lally KP, Lasky RE, Lally PA, et al., Congenital Diaphragmatic Hernia Study Group, pp. 2408-15, Copyright 2013, with permission from Elsevier)

Table 71.2 Complications after CDH repair

Acute/early	Moderate	Long-term
Hemorrhage	Infection	Adhesions
Abdominal compartment syndrome	Re-herniation/patch failure	Re-herniation/patch failure
Re-herniation/patch failure		Bowel obstruction
Pleural effusion		

Aspiration leading to recurrent pulmonary infections should be recognized early and managed by minimizing secretions. In some cases, aspiration precludes oral feeding. Sildenafil is a common pharmacologic agent used for management of chronic pHTN. History and physical examination, intermittent chest radiography, and pulmonary function testing are used to guide progress.

The gastroesophageal junction and diaphragmatic hiatus are either directly involved or in very close proximity to the diaphragmatic defect and are often distorted during surgical repair. This likely contributes to the high rate of foregut dysfunction and frequent GER. Any child with CDH, particularly with frequent emesis, difficulty with oral intake, or recurrent pulmonary infections, should be screened for GER. Gastric acid suppression using proton pump inhibitors or histamine-receptor antagonists is initiated on every patient with CDH. A subset of patients will have severe ongoing symptoms related to GER ultimately requiring fundoplication. Additionally, these patients may be treated with gastrostomy/jejunostomy tube placement.

Neurologic abnormalities, developmental delay, and behavioral disorders are being increasingly recognized as a chronic morbidity associated with CDH. These morbidities are best managed by pediatric subspecialists (neurology, psychiatry, neurodevelopmental, and behavioral), dedicated therapists, social workers, counselors, and special school programs.

Table 71.3 Components of a multidisciplinary CDH team

Multidisciplinary CDH team
Pediatric surgery
Pulmonology
Nutrition
Developmental medicine
Cardiology
Gastroenterology
Audiology
Orthopedic surgery
Neurology
Genetic counselors
Ophthalmology
Neonatology
Maternal-fetal specialists

Long-term survivors frequently require additional surgical intervention including orchiopexy, inguinal hernia repair, or correction of pectus excavatum. Repair of recurrent diaphragmatic herniation may be through the previous surgical site or through alternative approaches to avoid dense adhesions. Bowel obstruction can occur from adhesions or recurrent herniation. The laparoscopic approach for gastrostomy placement, fundoplication, or the management of an adhesive obstruction is reasonable although conversion to an open approach is not uncommon.

Morgagni Hernia

Failure of formation of the anterior-medial portion of the diaphragm, where the septum transversum and inferior-anterior thoracic wall intersect, results in a CDH of Morgagni. This less common diaphragmatic defect is distinct from the classic variety in nearly every way. Although it can be diagnosed in the early postnatal period, it is usually diagnosed serendipitously in older children by chest radiograph (Fig. 71.5). The diagnosis, if in question, can be confirmed by CT or MRI. Although most children are asymptomatic, clinical presentation can occasionally be in the form of a bowel obstruction. Operative repair may be performed using open or minimally invasive techniques. Rarely, a patch may be required to achieve closure of the hernia.

Future Studies

CDH remains the focus of intense basic science, translational, and clinical investigation. Using the nitrofen rodent model and genetic models, the molecular biology of CDH is being revealed. Roles of specific proteins (caveolin, endothelin, bone morphogenetic protein (BMP), and vascular endothelial growth factor), receptors (VEGF receptors, BMP receptors, and apelin receptor), genes, and gene activators (FREM1, Slit3, Gli2/3, Wt1, Six1, and Eya) in the development of CDH have been identified.

Collaborative institutional effort led to the formation of a CDH registry nearly 20 years ago. Given the limitations of single institution studies, multi-institutional efforts through the CDH Study Group are expanding clinical research opportunities and providing generalizable conclusions. Nearly every facet of CDH management lacks high-quality evidence to guide therapy although numerous retrospective and prospective studies are currently underway in an attempt to study important clinical questions in as rigorous a fashion as possible. Identification of the appropriate candidate for fetal intervention is also an area of active investigation.

Editor's Comment

CDH results in variable degrees of lung and pulmonary vasculature hypoplasia. While many high-volume centers have reported increased survival rates, this has not been the collective trend. One potential explanation for this is inconsistent perinatal care among centers. When CDH is diagnosed antenatally, early referral to a tertiary center is recommended. Centers that routinely use postnatal management protocols have demonstrated improved overall survival rates including increased survival in high-risk CDH patients.

Significant efforts have been made to identify prenatally those fetuses that will be most severely affected. A number of radiographic features have shown promise for achieving this goal as well as identifying fetuses that may benefit from prenatal intervention. Lung area-to-head circumference ratio (LHR), O/E LHR, MRI determined fetal lung volume, O/E FLV, and MRI determined percent liver herniation into the thorax have all been used to predict the severity of disease. While O/E LHR is very good at predicting early mortality, MRI derived measurements appear to be slightly better. Fetal MRI also predicts the need for ECMO and development of chronic lung disease more accurately than ultrasound.

Infants with CDH should be intubated immediately after birth and a naso- or orogastric tube placed to suction in order to avoid gastric distension and compression of the lung. Permissive hypercapnia and gentle-ventilation strategies to avoid barotrauma have become the mainstay of treatment in CDH. Inhaled nitric oxide is the most commonly used therapy for pulmonary hypertension although its effect is inconsistent. The use of iNO varies among high-volume centers and currently there is no conclusive evidence that it reduces mortality or the need for ECMO. The decision to use ECMO has shifted toward earlier use for preoperative stabilization to achieve lung preservation when medical therapy has failed. The timing of repair in patients who require ECMO remains an area of debate.

Stable CDH patients are candidates for a minimally invasive approach to repair although the recurrence rate appears

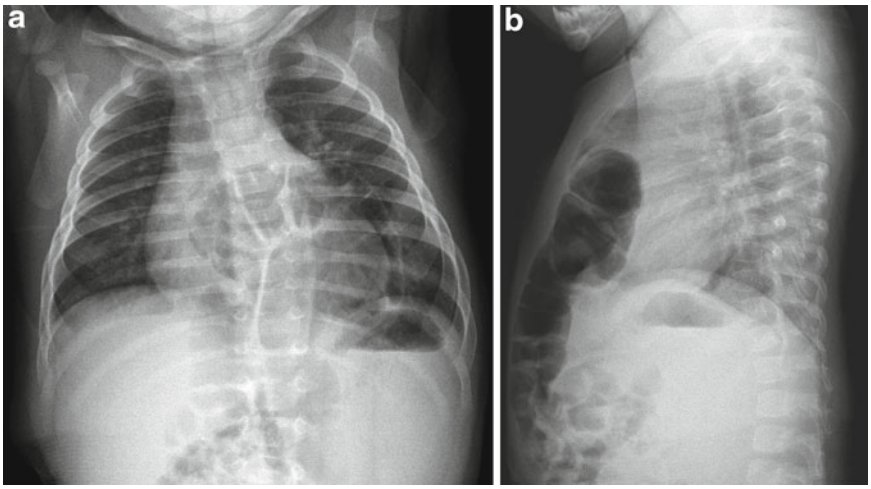


Fig. 71.5 (**a**) Antero-posterior and (**b**) lateral chest radiographs of an infant with CDH—Morgagni type (5-year-old). Note the bowel in the chest and the anterior location of the defect

to be higher than with open techniques. Large CDH defects can be repaired using a synthetic or biologic patch or autologous tissue. The split abdominal wall muscle flap technique for closure of large defects (type C and D) is an excellent option. This provides a durable closure with autologous tissue that can grow with the child. Recurrence rates are much lower than with patch repairs. This technique can also be used in patients on ECMO with minimal risk of bleeding.

Follow-up and management of CDH-associated morbidities are critical and a follow-up schedule has been recommended by the American Academy of Pediatrics Section on Surgery. Chronic lung disease, gastroesophageal reflux, and hernia recurrences are well-documented morbidities. Long-term follow-up data have recently highlighted the adverse effects of CDH on subsequent neurodevelopment. Furthermore, scoliosis and pectus deformity are more common in children with large CDH who require a patch or muscle flap repair.

Suggested Reading

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Uncommon Hernias

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Justin Lee and Douglas C. Barnhart

Unusual Inguinal Hernias

The classic indirect inguinal hernia that occurs in children is almost invariably due to a congenital failure of normal closure of the processus vaginalis, which allows a loop of bowel or occasionally an ovary to herniate into the inguinal canal. Numerous unusual anatomic structures herniating through a patent processus vaginalis have also been described and are usually known eponymously by the person who originally described or treated it.

Littre Hernia

Littre's hernia is a hernia that involves a Meckel's diverticulum. This may occur through either an inguinal, umbilical or femoral defect. It can present with incarceration, obstruction, bleeding, or perforation. It may also present as an acute scrotum. Typically the distinction between a Littre hernia and hernia with incarcerated small bowel is made at exploration. Preoperative distinction is not important. Presentation may occur at any age with cases reports involving infants and the elderly. Surgical treatment is based on the principles of resection of the Meckel's diverticulum and anatomic repair of the hernia. This could be done either open or laparoscopically.

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Amyand Hernia

Amyand's hernia is an inguinal hernia with appendix as the prolapsing component. Typically this is right-sided but left-sided presentations are also reported. The appendix may appear inflamed due to the incarceration or even develop acute appendicitis due to appendiceal obstruction within the hernia sac. An incarcerated Amyand hernia can present as an acute scrotum resembling a testicular torsion or it can mimic an edematous spermatic cord. Ultrasound distinguishes this scenario from a testicular torsion. The treatment of Amyand's hernias should include hernia repair and appendectomy if the appendix appears to be inflamed. If distinguished from an acute scrotum preoperatively, a laparoscopic repair is possible.

Richter Hernia

When only the antimesenteric portion of the bowel wall protrudes through a hernia defect, it is referred to as a Richter hernia. If this becomes incarcerated and strangulated, perforation can occur in the absence of an intestinal obstruction. A Richter hernia can occur within any part of the abdominal wall, but the most common location is at the site of a femoral hernia. Other reported sites include the inguinal ring, Spigelian fascia, obturator canal, and previous abdominal incisions. In the era of laparoscopy, a Richter hernia may occur at laparoscopic trocar sites, which are often not large enough to allow protrusion of the entire circumference of the bowel. In addition to the standard hernia repair, the involved bowel must be carefully inspected. In questionable cases, it is recommended that the bowel be fully reduced and re-examined after a period of re-perfusion prior to a definitive decision regarding viability.

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Femoral Hernia

Femoral hernias are rare in children, difficult to diagnose, and require a different operative approach than a standard indirect inguinal hernia repair. The diagnosis is often a clinical one based on physical examination when a bulge is identified in the upper thigh below the inguinal ligament and within the femoral canal. Given the prevalence of indirect inguinal hernias and the infrequency of femoral hernias, femoral hernias are uncommonly distinguished preoperatively. The absence of an expected indirect inguinal hernia sac or hernia recurrence should lead one to consider the possibility of a femoral hernia. In obese patients, radiological evaluation using ultrasound, CT, or MRI may be helpful for the diagnosis. Furthermore, diagnostic laparoscopy will clearly demonstrate the presence of a femoral hernia.

Data comparing various surgical techniques for repair of this infrequent hernia are limited. The principles of repair include reduction of the hernia, excision of the hernia sac, and closure of the femoral canal defect. This can be done open using either a preperitoneal approach from above the inguinal ligament, a limited anterior approach from below the inguinal ligament, or laparoscopically. Both primary tissue and mesh herniorrhaphies have been described in children. Primary tissue repair is accomplished by suturing Cooper's ligament (pectineal ligament) to the inguinal ligament. Mesh may be used as an on-lay patch or as a plug placed within the femoral ring. With any operative approach care must be taken to avoid injury to the femoral vein which is lateral to the hernia sac. Additionally, closure of the defect must avoid narrowing the femoral canal to the extent that there is venous compression.

Given the infrequency of these hernias, our experience is limited but we would share the following anecdotal observations. The cases of femoral hernia which we have diagnosed have been in school-age children and have been distinct from inguinal hernias on physical examination. Primary tissue repair using a Cooper ligament (McVay repair) has been easily accomplished and has not required the use of mesh in any child as the defect is small. In one case the femoral canal was narrowed, resulting in significant venous congestion that required revision. One child with cystic fibrosis presented with synchronous bilateral femoral hernias. One side recurred after primary tissue repair, requiring revision using mesh. This child was likely at increased risk due to malnutrition and chronic cough. Our current practice would be to use mesh only in very select cases and place it in the preperitoneal space.

Spigelian Hernia

A Spigelian hernia protrudes through an area of weakness in the abdominal wall between the rectus abdominis muscle medially and the semilunar line laterally. These hernias occur most commonly below the arcuate line, which is the lower limit of the posterior layer of the rectus sheath, but they can also occur above this site. The hernia is usually intraparietal (between muscle layers), rarely penetrating the external oblique fascia, and therefore can be difficult to appreciate on physical examination. The defect is usually only about 1–2 cm in diameter. Omentum and small or large bowel may be contained within the sac. Incarceration and strangulation are common complications of this hernia. Because the hernia is deep to the external oblique fascia, pain and tenderness may be the only signs. Diagnosis is therefore often made with either imaging or laparoscopy. US, CT, or MRI can be used to make the diagnosis of a Spigelian hernia although CT and MRI have the highest sensitivity and specificity. Spigelian hernias have been associated with ipsilateral undescended testicles. In these cases the testicle is often found in the Spigelian hernia sac without a gubernaculum in the inguinal canal. The embryology underlying this association is not clear but the association should be considered in boys with nonpalpable testes.

The operative approach involves a transverse incision centered over the mass and opening of the external oblique aponeurosis along its fibers to expose the peritoneal sac. If a large sac is present, the redundant peritoneum is excised and the edges sutured together. The defect is closed by approximating the separated transversus and internal oblique layers. Minimally invasive repair can be performed using either an intra-abdominal or preperitoneal approach. Recurrence is uncommon with either approach. Therefore mesh reinforcement should be used only in selected patients in whom the tissues seem extremely attenuated or in the presence of an unusually large defect.

Laparoscopy is an effective means to diagnose and repair Spigelian hernias. One compelling reason to use laparoscopy is that despite imaging there are times when the diagnosis remains uncertain preoperatively. The characteristic defect is identified laparoscopically. The fascia can then be closed either laparoscopically or through a limited anterior incision using laparoscopic guidance.

Lumbar Hernias

In adults and older children, two types of lumbar hernias are anatomically defined. A *Grynfelt* hernia occurs in the superior lumbar triangle between the inferior aspect of the 12th rib the internal oblique muscle laterally and the quadratus lumborum medially. A *Petit* hernia is a defect in the inferior lumbar triangle between the latissimus dorsi posteriorly, the iliac crest inferiorly, and the posterior border of the external oblique muscle anteriorly. A Grynfelt hernia is a deep hernia whereas a Petit hernia lies superficially. Congenital hernias account for approximately 20 % of lumbar hernias and often have associated

regional anomalies. Specific associated anomalies include diaphragmatic hernia and lumbocostovertebral syndrome. Lumbocostovertebral syndrome is characterized by genitourinary anomalies, lumbar abdominal wall defects, vertebral defects, and rib hypoplasia. Congenital lumbar hernias can also occur with spinal dysraphism.

Large or symptomatic lumbar hernias should be repaired. Prosthesis and tissue flap repairs have both been reported with success. Primary repair is the preferred method in children but may be precluded by a very large lateral abdominal wall defect. An iatrogenic lumbar hernia most commonly occurs following an open nephrectomy. In some cases, when there is a history of postoperative infection, this finding may not necessarily be an open defect but rather a weakness of the fascia. Conservative observation is recommended since the natural history is more consistent with a diastasis recti rather than a true hernia. Management of lumbar hernias associated with lumbocostovertebral syndrome should be individualized based on the unique anatomy of the affected child.

The decision to proceed with operative repair of these hernias should be individualized. If the hernia defect is large, there is little risk of incarceration and the hernia is often asymptomatic. In our opinion, the potential risk of postoperative mesh related causalgia and other complications outweigh the potential benefit of repairing an asymptomatic hernia for many children. This is particularly the case for children who have other anomalies that limit activities. In contrast, we repaired a very large flank hernia in a child who had a preceding diaphragmatic hernia repair because the hernia was interfering with his ability to roll over. While lumbar hernias are rare, we have seen several children who have flank eventrations after repair of congenital diaphragmatic hernias. These are likely a consequence of denervation and are not true hernias. None of these have required repair.

Epigastric Hernias

Small fascial defects in the linea alba are common and frequently present in young children as a non-reducible subcutaneous mass. These small epigastric hernias (epiploceles) typically occur in the supra-umbilical midline. Commonly these hernias are identified when the parent notes a small (approximately 1 cm) spherical mass in the subcutaneous tissue. It would be unusual for these to be symptomatic but if they are, it is intermittent mild tenderness of the mass. They may be mistaken for a subcutaneous soft tissue tumor on ultrasound as the fascial defect is often too small to be identified. The location and appearance are pathognomonic, and imaging studies only confuse the diagnosis.

Anatomically these hernias have a very small fascial defect in the decussation of the linea alba. Typically the defect contains preperitoneal fat or less commonly incarcerated omentum. This tissue is generally viable and does not become strangulated. The defect in the fascia is usually less than 5 mm in diameter. Epigastric hernias can occur in the presence of an associated diastasis recti which does not require treatment.

Data regarding the natural history of these very small hernias is limited. Intuitively it seems that these defects are too small for bowel to herniate through. Therefore the risk of complications with observation is very low. Our practice is to repair them only if the subcutaneous lesion is tender or if the child is having an anesthetic for another procedure. It is critical to precisely mark the hernia preoperatively as it is very challenging to identify it after the child is anesthetized. A small (1 cm) incision in the skin crease directly over the mass allows identification of the incarcerated adipose tissue which can be reduced or amputated. The small fascial defect is closed with one or two sutures. Laparoscopic repairs are described but unmerited in our opinion given the small skin crease incision used in the open approach.

Laparoscopic Trocar Site Hernias

Laparoscopic trocar site hernias and the associated risk factors are well-described in the adult literature with the dominant risk factors being trocar size, obesity, and postoperative infection. Given the popularity of laparoscopic surgery in children, there is surprisingly little literature on this complication; but what exists suggests different risk factors than in adults. Laparoscopic port site hernias are more common in infants and younger children than older children. This is likely due to the thinner abdominal wall musculature. We have observed omental extrusion from 3-mm stab incisions, and there are reports of this occurring with 2-mm access sites as well. The risk may be increased if the trocar displaces during the case and requires replacement resulting in an increase in the size of the muscular defect beyond the described diameter. Small bowel obstruction due to intestinal herniation through 5-mm trocar sites has been reported in infants and toddlers.

The critical aspect in treatment of these iatrogenic hernias is prevention by secure fascial closure of the defect. This can be challenging through 2–3 mm stab incisions. We therefore close these smaller sites selectively. For 2–3 mm sites, we close any site in which multiple trocar replacements occurred or the fascia is visible through the skin incision. We close all sites >3 mm using a figure-of-eight suture. Other surgeons advocate fascial closure of all 3 mm sites because these defects can be closed under laparoscopic visualization with minimal disruption of the skin incision. There are insufficient data about the incidence of these hernias to strongly support one view over the other. In either case, avoiding the need for trocar replacement by securing them at initial placement should help to decrease the risk of subsequent hernia formation.

Repair of trocar site hernias can be performed laparoscopically through prior trocar sites. Laparoscopy assures complete reduction and provides clear visualization to assure adequate fascial closure. This is done with a figure-of-eight suture either directly or using specially designed fascial closure devices. Recurrence is rare.

Traumatic Abdominal Wall Hernias

Disruption of the abdominal wall musculature can occur with a variety of blunt force traumas. The most commonly described injury mechanisms are bicycle handlebar and seatbelt injuries. The rectus muscle is often involved in seatbelt injuries due to it being the initial point of contact with the belt. Typically the skin is not disrupted but there may be an associated area of ecchymosis or hematoma. Given the force required to disrupt the musculature, associated injuries are common and should be sought. Small bowel perforation is the most common associated injury. Traumatic hernias are typically diagnosed by CT as they can be difficult to distinguish from a simple abdominal wall hematoma acutely. In reviewing the CT scan, particular attention should be paid to the coronal and sagittal views as muscular disruption may be unrecognized on axial views if the defect is limited to a single slice.

Due to the high rate of associated small bowel injury, these hernias should be repaired acutely. We have repaired these through a midline laparotomy during repair of the

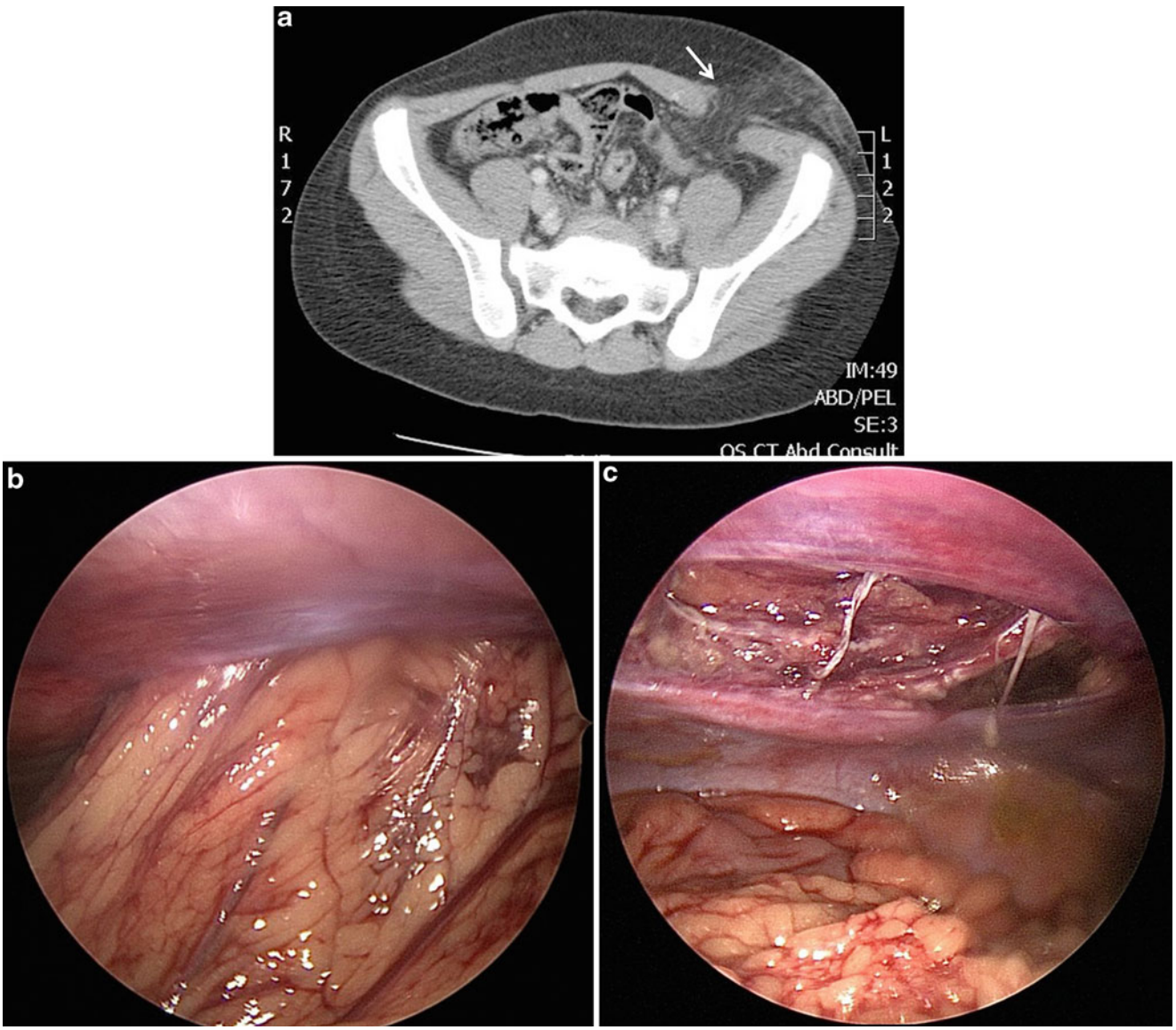

Fig. 72.1 (**a**) Axial CT scan of child who suffered blunt abdominal trauma due to handlebar injury. Note the omental herniation through all layers of the abdominal wall musculature. (**b**) Laparoscopic view of hernia with omentum in defect. (**c**) Laparoscopic view of muscular defect after reduction of the omentum. This was repaired primarily and an associated small bowel injury was identified and repaired

small bowel injury. This approach allows debridement of compromised muscle and a multilayer closure without disrupting the injured skin overlying the hernia. Mesh is not required and should be avoided due to the risk of infection from the associated bowel injury. It is unusual for a traumatic hernia to present in delayed fashion but in these cases it can be repaired using either a laparoscopic or direct anterior approach. With either approach the requirement for mesh should be rare as there are healthy fascia edges which can be reapproximated without tension (Fig. 72.1).

Diastasis Recti

Diastasis recti is a separation of the rectus abdominis muscle with a characteristic bulging of the abdominal wall in the epigastrium and is not a hernia. The bulging is due to laxity of the linea alba, however the midline aponeurosis is intact without an abdominal wall defect. This condition may be congenital due to a more lateral insertion of the rectus muscles on the costochondral junctions and is more common in premature infants and African-Americans. The bulge extends from the xiphoid to the umbilicus and can be consistently demonstrated by having the child sit up from a supine position or when the child is crying. Given this pathognomonic examination, diagnostic imaging is rarely indicated. Since the fascia is intact, there is no associated risk of incarceration. Management consists of parental education and reassurance that this will improve significantly if not resolved completely with time. Plication of the broad midline aponeurosis has been described for cosmetic indications but would rarely be indicated in a child (Fig. 72.2).

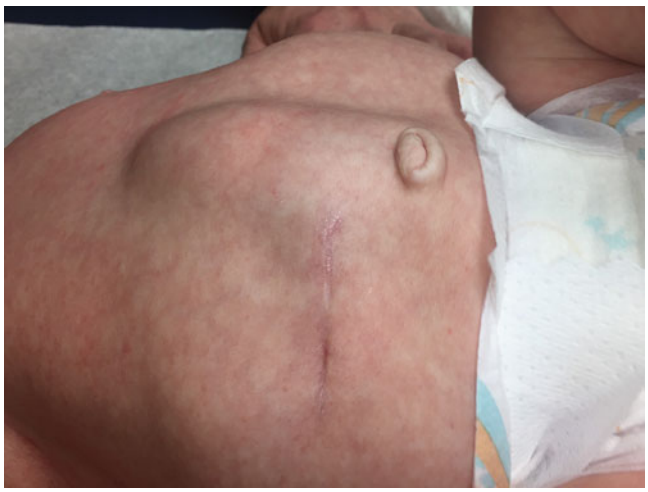

Fig. 72.2 Characteristic appearance of diastasis recti in an infant. Note the symmetric cylindrical appearance extending the full length of the linea alba. This is most prominent when the infant contracts abdominal muscles

Editor's Comment

The eponymous inguinal hernias are interesting but can usually be repaired with typical operative techniques. If a Richter's is identified, one must carefully separate the bowel wall from the hernia sac in order to achieve a complete reduction and secure closure of the defect. Direct inguinal hernias are rare in children but should be repaired using a traditional technique such as the Cooper ligament (McVay) repair. Mesh repair of inguinal hernias in children is not recommended.

A Spigelian hernia is rare even when the caregiver provides a clinical history consistent with the diagnosis. If the clinical examination is unrevealing, an US, CT, or MRI is a reasonable next step. If the radiographic imaging is negative, observation or diagnostic laparoscopy is recommended using an individualized approach. If a defect is identified, a straightforward primary tissue repair through an incision directly over the defect is performed.

Fascial defects from trocars should be closed in infants and young children with a thin abdominal wall. If the umbilicus has been used as one of the port sites, the other sites can be closed under laparoscopic visualization with minimal skin disruption and the umbilical fascial defect closed under direct vision to complete the case. Trocar site hernias can be closed laparoscopically, but a direct approach by slightly enlarging the previous incision is effective with acceptable cosmesis.

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Umbilical Disorders

73

Stephen J. Fenton

The umbilical cord originates from a connecting stalk that attaches the early embryo to the developing placenta. During the 4th week of gestation, the embryo begins to fold, from the cranial and caudal regions as well as laterally. The coalescence of these four folds (cranial, caudal, lateral) transforms the flat trilaminar embryonic disc into a cylindrical C-shaped fetus with body cavities. As a result of the folding process, the connecting stalk develops into the umbilical cord, containing the umbilical arteries (normally two), umbilical vein and the allantois and arises from the central portion of the anterior embryonic abdominal wall.

The allantois is a diverticulum from the caudal end of the yolk sac. It remains very small and is involved with early embryonic exchange of waste and is associated with bladder development. As the bladder enlarges, the allantois becomes the urachus, a tube between the umbilicus and the bladder. It usually obliterates but maintains a connection to the umbilicus seen as the median umbilical ligament. For a brief period of time, the omphalomesenteric (vitelline) duct, a connection between the yolk sac and the terminal ileum of the midgut also traverses through the umbilical cord. This usually involutes during the 5th to 7th weeks of gestation.

The abdominal wall at the umbilical cord is not closed, but forms the umbilical ring. This opening in the linea alba serves as a passageway for the umbilical vessels. It also accommodates physiologic umbilical herniation of the midgut that occurs between the 6th and 10th gestational weeks. This allows room for the midgut to elongate and upon reduction back into the abdominal cavity at the 10th week of gestation the midgut should have rotated a total of 270°.

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Umbilical Masses

It is relatively common for parents to bring their child to pediatric surgeon because of a visible or palpable mass within the umbilicus. Like any new or unusual finding in a newborn or small child, there is often significant anxiety on their part.

Umbilical Granuloma

Separation of the dry umbilical cord stump should occur within the first week of life and is considered delayed when it persists for longer than 3 weeks. Delayed separation can be associated with an underlying immunodeficiency disorder, infection, or urachal abnormality and should prompt further evaluation. Once the cord has separated, there is generally a base of granulation tissue that will undergo epithelialization within several days. When new skin growth fails to occur, the result is a small mass of granulation tissue, often referred to as a granuloma, typically a soft, reddish-pink, friable mass 1–10 mm in size. It can be sessile, but is often pedunculated (Fig. 73.1). After a urachal or vitelline duct remnant has been ruled out by a detailed history (drainage of urine or succus?) and examination (complex, mucosa-like structure?) most granulomas can be treated with application of silver nitrate. Care should be taken to apply the silver nitrate very precisely on the granulation tissue and to protect the skin with petrolatum jelly so as to avoid burning or staining the surrounding healthy skin.

If after several treatments the granuloma persists, one should consider the possibility of an umbilical polyp. If after further investigation the diagnosis remains an umbilical granuloma, we will usually remove it using a fine hemostat in the office followed by silver nitrate cauterization of the base and gentle pressure. The parents should be informed that this will not be painful to the infant, however, some bleeding might occur and will require some time and pressure to resolve. If it is truly pedunculated, suture ligation can also be performed.

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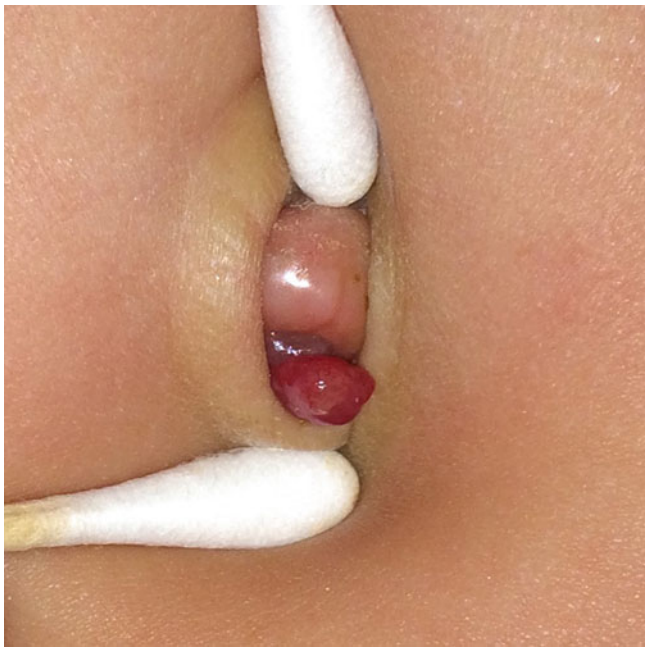

Fig. 73.1 Umbilical granuloma. A soft, pink, friable pedunculated mass typical of an umbilical granuloma

After ligation, the parents should be instructed to wash and dry the umbilicus over the course of the next several days and expect the granuloma to dry up and fall off within that period of time (Fig. 73.1).

Umbilical Polyp

An umbilical polyp is a retained remnant of the omphalomesenteric duct or allantois and is comprised of either intestinal or urogenital mucosa, respectively. The polyp is distinguishable from a granuloma by its appearance, which is shiny, red, and smooth. They are not responsive to cauterization and require surgical excision.

Epidermal Inclusion Cyst

Like any healing scar, skin cells can become trapped below skin level and the buildup of dead skin cells, keratin, and sebum results in an epidermal inclusion cyst (formerly but erroneously known as sebaceous cysts). These start quite small and eventually become clinically apparent in the toddler or school-age child. The appearance of a smooth, painless 1–2 cm round, or ovoid mass covered with thin taut skin filled with an opalescent semi-solid material is distinctive and pathognomonic. They can occasionally become infected but usually become evident abruptly seemingly overnight when they pop out from the depths of the umbilicus onto the outer skin.

No work up or imaging is needed. These can be excised quite easily with a single suture or even cyanoacrylate skin adhesive to close the small elliptical incision made at the base. This could be done in the office with local anesthesia but it is the rare child who does not require deep sedation or a general anesthetic. The risks are minimal and recurrence is extremely rare.

Umbilical Hernia

The fascial opening that is the umbilical ring should spontaneously close over time, with the majority of children having complete closure by 5 years of age. Incomplete closure results in an umbilical hernia with protrusion of the peritoneum through the ring as the hernia sac. Umbilical hernias are most commonly found on initial examination of the newborn and it is common for parents to state that their child has had the hernia since birth. It becomes more apparent with increased abdominal pressure and is a case where a crying child will actually assist with the examination. Most reduce with very little pressure and the fascial edges can be easily palpated deep to the skin. The size of the fascial defect is what determines the likelihood of spontaneous closure. A hernia with a fascial defect larger than 1.5 cm or excessive overlying skin (proboscis) is less likely to close without intervention (Fig. 73.2).

The great majority of umbilical hernias are asymptomatic and because most will close spontaneously, it is standard practice to wait until the child is at least 3 or 4 years old

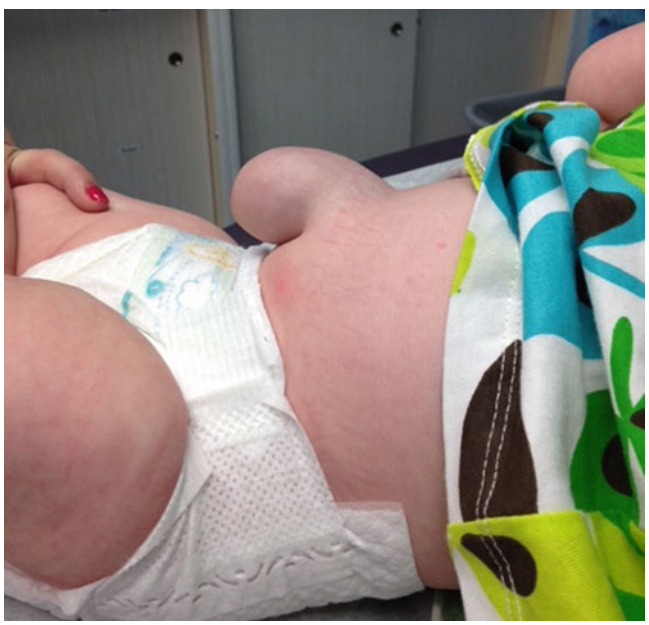

Fig. 73.2 Proboscis umbilical hernia. Large proboscis umbilical hernia (courtesy of Michael D. Rollins)

before recommending surgical repair. Some surgeons insist on waiting until age 5, which is reasonable if the defect is <1 cm and therefore still likely to close on its own. Some parents and referring pediatricians will need reassurance that delaying repair will cause no harm to the child. Occasionally parents will describe episodes of incarceration requiring manual reduction, either by them or by a physician. These children should be considered for early repair. Although true incarceration is extraordinarily rare, the parents should be informed of the signs and symptoms and recommended to seek immediate medical attention should this occur.

Umbilical hernia repair is a very safe and generally straightforward operation. It is always done under general anesthesia and though some surgeons feel it is important to have good muscle relaxation, others feel it is reasonable to forego paralysis and even feel comfortable with anesthesia delivered by laryngeal mask. Most prefer an infra-umbilical incision but a supra-umbilical incision is preferred by some and is useful when there is the need to repair a second defect such as an epigastric hernia or epiplocele just superior to the umbilicus. The hernia sac should be dissected circumferentially and either carefully separated from the dermis or amputated, leaving a disk of sac on the skin. The sac can then be oversewn if it is large enough to invert into the abdomen and left intact, though most surgeons prefer to excise the sac at the fascial edge. The fascia can then be closed transversely or longitudinally according to surgeon's preference. All sutures are placed first, being careful to visualize the needle tip and avoid injury to underlying bowel. They are then tied in succession. Most favor interrupted heavy absorbable sutures, monofilament or braided, though some have confidence in a running or locking stitch or use a permanent suture material.

Hemostasis must be meticulous. After fascial repair, the umbilicus needs to be reconstructed. A small or moderate amount of redundant skin should be left intact, though a truly excessive amount of skin, especially the classic proboscis of skin, may be excised, though a careful umbilicoplasty will need to be performed. If the skin is left intact, the base of the umbilicus should be tacked to the fascia at or just below the fascial repair. It is best to do this at two points, ensuring both a good bite of fascia and umbilical dermis, taking care to not buttonhole the skin. The skin can then be closed in layers as any incision. Some surgeons still prefer to place a pressure dressing while many simply use skin glue, which allows the child to bathe almost immediately and the parents will not have to worry about dressing care.

Umbilicoplasty

Children who have a large hernia with redundant overlying skin (large proboscoid hernia) may also require an umbilicoplasty. A variety of techniques exist to recreate the umbilicus and one should utilize the technique with which they feel most comfortable, as none has been shown to be superior to the other. Our preferred technique is to trim some of the excess skin. An absorbable braided stitch is then placed through the fascia in what will be the center of the umbilicus. It is then sewn intradermally around the edges of the wound in a running purse-string fashion. Once around the entire wound, the suture is then placed back through the fascia next to the first fascial bite. Carefully, the suture is tightened and then tied, resulting in an inversion of the skin edges around the center of the neo-umbilicus.

Umbilical Drainage

The persistence of a patent omphalomesenteric duct or urachus causes drainage from the umbilicus, typically evident in the newborn period. It is important to identify these problems and not treat them like simple granulation tissue, which they resemble.

Omphalomesenteric Duct Remnant

Incomplete involution of the omphalomesenteric (vitelline) duct can lead to a variety of disorders (umbilical polyp, omphalomesenteric duct, omphalomesenteric duct cyst, Meckel's diverticulum, omphalomesenteric fibrous band). Complete patency of the omphalomesenteric duct results in communication between the terminal ileum and the umbilicus. After separation of the umbilical cord, a stoma-like lesion appears with intermittent drainage of succus entericus.

Further evaluation with ultrasound imaging is reasonable to look for a connection with underlying bowel. Surgical excision of the duct with closure of the enteric defect and repair of the umbilical hernia is required. The fistula tract should be cored out and traced back to the terminal ileum. There the tract is divided and the ileum closed in two layers with absorbable suture. Occasionally, a segmental resection of small bowel will be required.

Patent Urachus

Failure of the urachus to completely obliterate will result in a urachal anomaly such as an umbilical polyp, patent urachus, urachal cyst, or bladder diverticulum. A patent urachus results in communication between the bladder and the umbilicus and for some reason is three times more likely to occur in boys. Drainage of urine is the most common symptom, but recurrent urinary tract infections can also be seen. The persistent drainage of urine can result in an erythematous rash of the surrounding skin, which is sometimes mistaken for omphalitis.

Ultrasound imaging is helpful in demonstrating the urachal remnant and should be obtained whenever a urachal anomaly is suspected. A patent urachus can result from distal urinary obstruction (posterior urethral valves). Therefore a voiding cystourethrogram (VCUG) should be obtained prior to surgical repair. Complete surgical excision including a cuff of bladder is recommended for repair and to prevent the risk of future urachal adenocarcinoma (Fig. 73.3). Most will close the bladder in two layers with absorbable suture, which can usually be done completely extraperitoneally. Some prefer to leave a Foley catheter in the bladder for short a period of time. Bladder spasms sometimes occur following repair and can be treated with oxybutynin.

The laparoscopic resection of a urachal remnant is well described. Three access sites are typically required, one in the epigastrium for visualization and two additional incisions on either side of the umbilicus for working instruments. We usually start with a 5-mm trochar in the epigastrium and two additional incisions for 3-mm trochars or instruments can be placed directly through them based on the size of the child. The higher camera placement will allow for complete visualization of the abdominal side of the umbilicus as well as the entire urachal remnant to the bladder. This is the greatest benefit of the laparoscopic approach, especially in the setting of a questionable diagnosis. Electrocautery is used to completely mobilize the remnant. An endoloop is used to ligate it as close to the bladder as possible. The remnant is then divided and removed from the abdomen (Fig. 73.4). This approach remains somewhat controversial, as the dictum has been to include a cuff of bladder along with the remnant to prevent future development of adenocarcinoma. The true risk of developing a malignancy in a urachal remnant is unknown. Given that spontaneous resolution of these remnants has been reported, a laparoscopic resection is a reasonable approach.

Umbilical Infection

Umbilical infections are rare but can be very serious, even life-threatening. In very rare cases, they can be the nidus for a necrotizing process.

Infected Urachal Cyst

Urachal cysts are subfascial, located in the properitoneal space superior to the bladder and inferior to the umbilicus. They often remain asymptomatic and undiagnosed until infected. They present as a tender, erythematous mass in the midline just inferior to the umbilicus. Parents will often deny ever having seen umbilical drainage and the child will be otherwise healthy. An US study is adequate for diagnosis and should be obtained. If the US is unclear, CT or MRI can be obtained, especially if an omphalomesenteric duct cyst is suspected.

The initial treatment should be antibiotic therapy with incision and drainage as indicated. Complete surgical excision should be undertaken 4–6 weeks later to allow for adequate resolution of the inflammation surrounding the cyst. Like any true cyst, it is important to remove the inner secretory lining of the cyst to prevent recurrence.

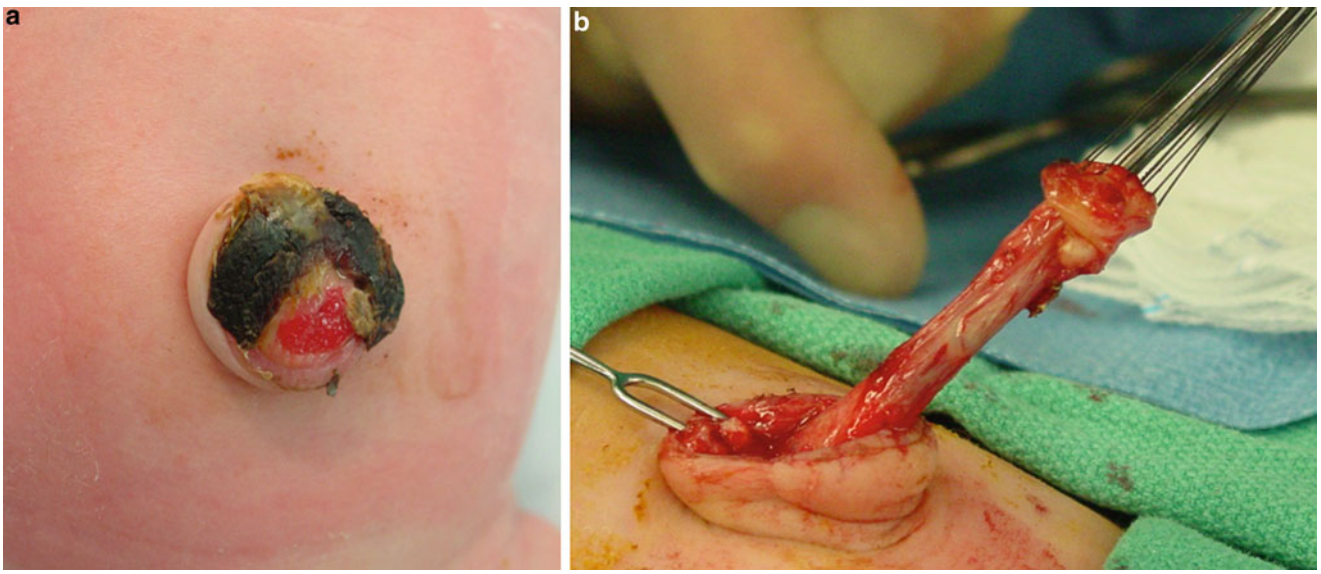

Fig. 73.3 Urachal remnant. (**A**) Umbilical opening of a patent urachus. (**B**) Removal of the urachal remnant through an infra-umbilical incision (courtesy of Earl C. Downey)

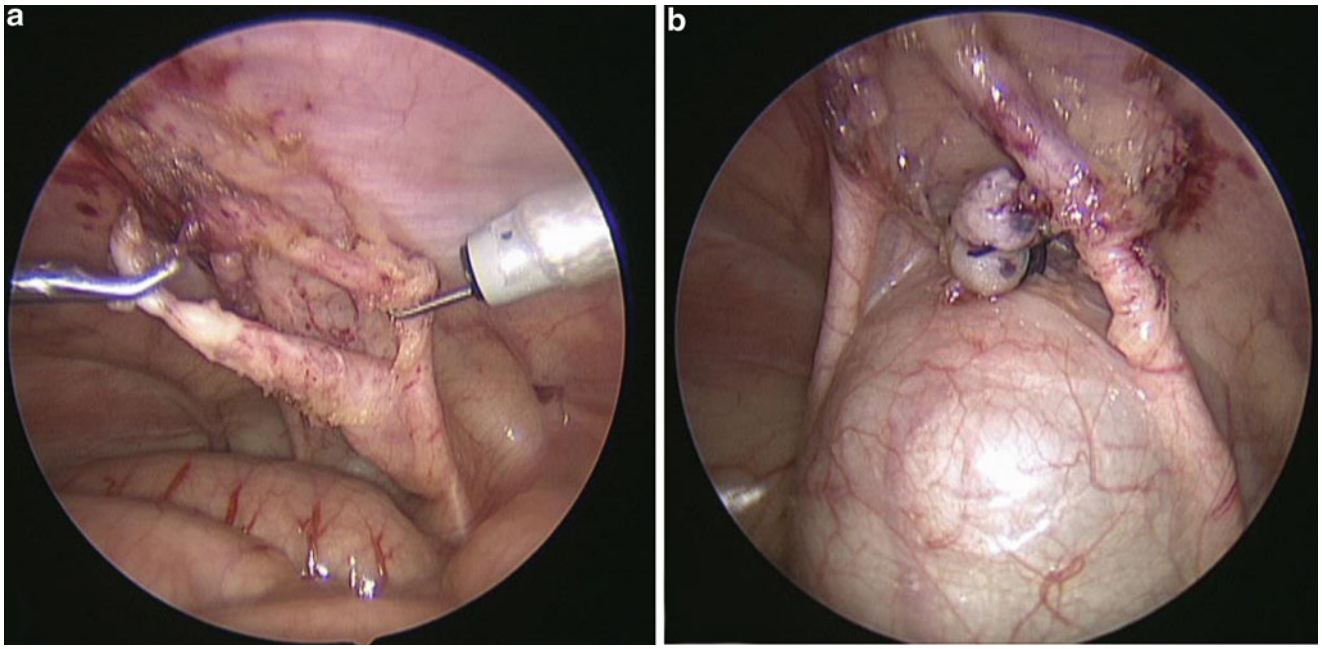

Fig. 73.4 Laparoscopic resection of urachal remnant. (**A**) Laparoscopic mobilization of the urachal remnant. (**B**) Ligation of the remnant along with a small cuff of bladder using an absorbable endoloop (courtesy of Michael D. Rollins)

Infected Omphalomesenteric Cyst

Infected omphalomesenteric cysts are much less common than urachal cysts. Like Meckel's diverticulitis (they are on the same spectrum of anatomic variation) the diagnosis is rarely made except at exploratory laparotomy or laparoscopy. They are more likely to be intra-abdominal and present more like appendicitis or other infectious intra-abdominal processes. If the cyst is just posterior to the umbilicus, it can present like a urachal cyst, in which case antibiotics with or without incision and drainage is the best initial strategy, followed by delayed excision after complete resolution of the inflammatory process. Formal resection might require a minilaparotomy or periumbilical incision and attachments to the ileum need to be dissected out and excised.

Omphalitis

Omphalitis is an infection of the umbilicus and surrounding tissues and is primarily a disease of the newborn. It occurs in less than 1 % of neonates in developed countries due to infection control techniques. It should be suspected when there is purulent drainage from the umbilical cord stump with surrounding erythema, induration, and tenderness. Risk factors include low birth weight, prolonged labor, prolonged rupture of membranes, and umbilical catheterization. The most common complication is sepsis, and the most feared complication is necrotizing fasciitis. Portal vein thrombosis and liver abscesses can also occur following treatment.

Most often the infection is polymicrobial; however, *Streptococcus*, *Staphylococcus*, and *Escherichia coli* are common pathogens. Broad-spectrum intravenous antibiotics are the primary treatment but these infants need to be very closely observed. Mortality rates are reported to be as high as 15 %. In the rare instance that this infection progresses to necrotizing fasciitis, prompt and aggressive surgical debridement of all necrotic tissue should be undertaken. Due to progression of disease, this usually entails several procedures and can result in devastating wounds. This type of infection spreads rapidly with a mortality rate as high as 85 %.

Editor's Comment

New attending pediatric surgeons are often astonished by the number and variety of umbilical disorders that present almost daily in outpatient practice. Umbilical granulomas can usually be treated with silver nitrate, but the pediatrician will have tried two or three times already. Pedunculated granulomas can be ligated after application of alcohol using a 000 braided absorbable suture. The granuloma usually falls off within 2 weeks. Surgical excision should rarely be necessary and sometimes means you are dealing with a duct remnant.

Infants are frequently referred for evaluation of an umbilical hernia. Parents will often report that the patient is constipated and that the hernia seems to cause pain with bowel movements. Parents can be reassured that this is most likely not the case and that the majority of umbilical hernias with a fascial defect less than 1.5 cm will spontaneously close by the age of 4–5 years. It

is helpful to have the parents feel the size of the fascial defect as the hernia may appear larger when the child is crying.

It is better to decide whether the child will need an umbilicoplasty before you begin the operation, so that the proper incision can be made (infra-umbilical or through the central portion). There are several different ways to perform an umbilicoplasty but regardless of the technique used, it is important to leave some excess skin to prevent effacement in adolescence. We occasionally use a purse-string technique, but also find the technique of marsupializing the skin edges to the fascia in multiple locations while leaving a small central defect to have an excellent cosmetic result. An alternative is to excise three inverted triangles of skin around the edge of the skin defect before placing the pursestring.

Initial management of an infected urachal cyst should include antibiotics with or without incision and drainage, followed by delayed surgical resection. If incision and drainage is required, one must be careful not to penetrate the posterior wall of the cyst as this will result in intraperitoneal contamination. Delayed resection of the remnant is much less morbid than attempting to resect a large, acutely inflamed cyst with abscess. Resection of the remnant using either laparoscopy or a periumbilical incision in 4–6 weeks can be safely performed as an outpatient with minimal morbidity. When using laparoscopy, avoid placing a trocar at the umbilicus and instead place the camera port in the right upper quadrant. A second trocar is placed in the right lower quadrant as a working port and for removal of the remnant and a stab incision created for retraction in the left upper quadrant. The remnant is double ligated with a PDS endoloop, incorporating a small cuff of bladder. A Foley catheter can be placed preoperatively so the bladder can be distended after resection of the remnant to evaluate for a leak.

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Peritoneal Dialysis

74

David E. Skarda

Over the past half-century children have benefited from major improvements in both dialysis technology and clinical management of renal failure. The first reports of the use of peritoneal dialysis to treat children with renal failure were published in the 1940s. However, the practicality of widespread use of PD was limited until the development of a more durable catheter followed by modification several years later. Additionally, the use of PD in children increased with two important innovations: continuous ambulatory peritoneal dialysis and continuous cycling peritoneal dialysis. Today, PD is an integral component for treatment of both acute kidney injury (AKI) and advanced chronic kidney disease (CKD) in children and adolescents.

Indications

Dialysis is often necessary for the treatment of AKI, CKD, and in certain cases of toxic ingestions and inborn errors of metabolism. Currently, there is no consensus for the definition of AKI in children and adolescents. To date, it has generally been accepted that AKI is characterized by the failure of the kidneys to regulate electrolyte, acid–base and fluid homeostasis adequately, often with a concomitant reduction in glomerular filtration rate. The current standard of care is to define AKI based on a combination of changes in serum creatinine and alterations in urine output. Generally, dialysis should be initiated when the measured or calculated glomerular filtration rate is between 10 and 15 mL/min/1.73 m^2, unless the child remains asymptomatic and growth is well maintained.

Criteria for initializing dialysis in children include: (1) the treatment of metabolic disturbances unresponsive to conservative treatment, such as hyperkalemia (serum $K^+ > 7.9$ mmol/L), unrelenting metabolic acidosis and hyperphosphatemia; (2) fluid overload, with or without severe hypertension or congestive heart failure, not controlled with fluid restriction and diuretics; (3) symptomatic uremia with encephalopathy and pericarditis, though the rate of increase in both urea nitrogen and creatinine levels is also considered; (4) AKI associated with poisoning due to dialyzable compounds; and (5) inborn errors of metabolism such as ornithine transcarbamylase deficiency with hyperammonemia.

Hemodialysis vs. Peritoneal Dialysis

The mode of dialysis may be age and center dependent. In some pediatric hospitals HD is preferred for children over the age of 5 years whereas PD is offered to younger children. PD is often preferred for children under the age of 2 years or weighing less than 10 kg.

Selection of dialysis mode also requires consideration of the impact on the maintenance of residual renal function. Although there is no consensus, peritoneal dialysis has been associated with less risk of residual renal function loss. The choice of the mode of dialysis is part of the integrated care model within a dialysis-transplantation program.

The patient and family must be actively involved in the choice of therapy. This decision must take into account the difficulties of vascular access in small children, large distances from the care facility, comorbid conditions, and the psychosocial situation. An increasing number of units are offering pre-emptive transplantation for children in whom the progressive decline in renal function is anticipated as this allows patients, family, and providers sufficient preparation time for the transplantation.

Peritoneal Dialysis Catheter Insertion Options

There are four methods for PD catheter placement: (1) blind percutaneous insertion, (2) open surgical insertion, (3) laparoscopic insertion, and (4) image-guided insertion. One advantage

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of both the open and laparoscopic insertion techniques is that an omentectomy can be performed. This decreases the risk of early catheter malfunction. The role of the surgeon in choice of dialysis modality and the timing of catheter placement are crucial to the successful treatment of children with AKI and CKD who require renal replacement therapies.

Preoperative Preparation

Children with AKI and CKD are at increased risk for pneumonia, pulmonary effusions, and congestive heart failure. A nutritional assessment prior to placement of a PD catheter is critical as these patients often require gastrostomy tube placement in addition to the PD catheter. In general, the gastrostomy should be created prior to placement of the PD catheter to minimize the risk of PD catheter contamination. However, some authors have reported successful combined gastrostomy and PD catheter placement under the same anesthetic.

A thorough history and physical examination should include a detailed evaluation for the presence of a hernia (umbilical, inguinal, or other rare hernias) or communicating hydrocele. Identification of a hernia, either during the preoperative evaluation or during PD catheter placement should prompt repair during the same anesthetic as these will likely become problematic when PD is initiated.

Preoperatively, both a CXR and electrocardiogram should be obtained as well as a renal function panel, hemoglobin level, platelet count, and blood gas. Many of these patients will have severe hypertension, hyperkalemia, anemia, platelet dysfunction, and acidosis. All of these conditions should be managed prior to the induction of general anesthesia. This may require a short hospital stay prior to the procedure.

Catheter characteristics should be considered prior to placement including the catheter type and size, catheter exit site, peritoneal insertion site, subcutaneous course of the catheter, and desired intraperitoneal location of the catheter. Dynamic changes in the patient's size due to fluid shifts and habitus are also considered.

Catheter Type and Size

A 2-cuff catheter is appropriate in nearly all patients including small newborns as there is a lower risk of peritonitis compared to single-cuff catheters. For adolescents and children older than 1 year, a standard 2-cuff silastic catheter with an outside diameter of 5.3 mm and an inside diameter of 3.5 mm is the best option. The distance between cuffs should be individualized according to patient's size and body habitus. For infants less than 1 year of age a standard 2-cuff catheter may still be appropriate. However, a smaller catheter with an outside diameter of 3.7 mm and an inner diameter of 2.5 mm with a shorter distance between cuffs may be necessary. A coiled catheter with side holes is preferred over straight catheters. This coiled configuration allows the functioning portion of the catheter (where the holes are) to rest in the pelvis in a tension free, dependent position. In general, the distance between inner cuff and the beginning of the coiled portion of the catheter should be the same length as the distance between the umbilicus and pubic symphysis. The use of a catheter with 150° flex between the cuffs (flex-neck or swan-neck catheter) is preferred as it allows for a lateral and caudally directed skin exit site that decreases the incidence of infection.

Catheter Exit Site

The catheter exit site on the skin is critical in reducing infectious complications. The exit site must not be in a skin crease. Selecting a catheter exit site is best performed prior to the induction of general anesthesia when the patient's movement can reveal skin folds that may not be visible during the procedure. The exit site is generally just medial to the anterior axillary line and should not be at the level of the belt line or in any location that may interfere with movement or bending. Care must be taken to avoid placing the exit site in a location included within the diapers of infants or fecally incontinent patients. Presternal catheter exit site has been recommended for patients with limited space on the abdominal wall. Consideration should be given to the location of a future renal transplant incision and this site avoided if possible.

Right or left abdominal catheter placement is often a matter of patient and surgeon preference. However, some have suggested that the downward peristaltic movement of the descending colon may help keep the coiled (functioning) portion of the catheter in the true pelvis. The skin opening at the skin penetrance site should be no larger than the diameter of the PD catheter. Use of a skin stitch to secure the catheter to the skin is discouraged as this is thought to increase the risk of infection.

Catheter Position

The functional portion of the catheter should be in the pelvis but not resting on the pelvic floor. This dictates the length of the catheter from the inner cuff to the first side hole. This is generally the same length as the distance from the umbilicus to symphysis pubis. For modern catheters with a coil configuration the first side hole coincides with the beginning of the curve of the coil. The coil should lie horizontally in the pelvis with the patient in supine position.

The catheter should be oriented so that it penetrates the peritoneum slightly inferior to the posterior rectus fascia and then passes through the rectus muscle and anterior rectus fascia in a superior trajectory. This creates a tension-free position for the catheter to rest such that the functioning coiled portion of the catheter rest in the true pelvis. Excessive dissection of subcutaneous planes should be avoided to reduce leaking around the catheter. Closing the peritoneum in a purse-string fashion around the catheter may also help reduce leakage. The subcutaneous tunnel course must allow for a gradual passage of the catheter from the anterior rectus sheath to the skin without any kinks in the catheter. There must be adequate distance (at least 2 cm) between the subcutaneous (outer) cuff and the skin site.

Other Considerations

Many patients are relatively hypervolemic at the time of PD catheter placement. This results in edema of the body wall. After PD catheter placement, much of this edema may resolve altering the subcutaneous course of the PD catheter. In general, this has the effect of inferiorly displacing the skin exit site and increasing the flex in the catheter to a more acute angle. This has the potential of kinking the catheter and limiting flow. In patients with massive subcutaneous edema at the time of PD catheter placement it is reasonable to have the skin exit site located such that the catheter is relatively even with the anterior fascia penetrance site. Thus as the edema resolves and the skin shifts interiorly the catheter will continue to function well.

An issue unique to PD catheter placement in children and infants is the consideration of normal growth. Although the recommended diameter of the PD catheter changes only once as the patient transitions from an infant to a toddler, the appropriate length of the catheter changes dramatically. A catheter placed into perfect position in a 4-year-old will likely not be in perfect position when the patient is 6 years old. As the patient grows, the inner catheter cuff remains in position between the posterior and anterior rectus fascia and the functional portion of the catheter slowly pulls out of the pelvis. This may affect the function of the catheter and require replacement. However, removal of a functional PD catheter simply to reposition it into the pelvis is not recommended.

Surgical Technique

The decision between using an open versus laparoscopic approach for PD catheter placement is dependent on many factors including the surgeon's preference and experience. Laparoscopy offers several advantages such as improved peritoneal visualization for positioning the PD catheter, thorough adhesiolysis, easier subtotal omentectomy or omentopexy, and the ability to limit the abdominal wall dissection which may decrease the risk of subsequent leakage of dialysate fluid. Patient-related factors may also influence the approach. Children less than 10 kg are more suitable for the open approach whereas those with a BMI greater than 30 will benefit from laparoscopic placement. If significant intraperitoneal adhesions are anticipated, laparoscopy affords the opportunity to increase the intraperitoneal space for the catheter with a more thorough adhesiolysis direct placement of the catheter into the free space. When using the laparoscopic approach a mechanical bowel preparation is often helpful to reduce the stool burden and improve visualization.

Open Approach

Evaluate the patient preoperatively to identify the proposed catheter penetrance site and exit site as previously mentioned. As a general guide, the length of the catheter between the inner cuff and the beginning of the coil should approximate the distance between the patient's umbilicus and symphysis pubis. Following induction of anesthesia give a first generation cephalosporin and prep the skin with chlorhexidine. Create a small (usually less than 2–3 cm) transverse incision over either the right or left rectus. This incision is often 1–2 cm superior to the level of the umbilicus. A small transverse defect is created in the anterior rectus fascia. Bluntly separate the rectus muscle fibers and identify the posterior rectus fascia. Grasp the posterior rectus fascia 1–2 cm inferior to the incision through the anterior rectus fascia with a clamp and retract it ventrally. This angled pathway through the abdominal wall will ensure proper positioning of the PD in the pelvis. Place two 3-0 absorbable monofilament (PDS) stay sutures 1 cm apart using a taper needle on the posterior fascia.

Open the posterior rectus fascia between the stay sutures and perform the subtotal omentectomy. Place a stylet through the catheter stopping about 2 cm proximal to the tip so that the tip of the PD catheter is flexible. Remove the stylet while advancing the new PD catheter into the pelvis. Place a 3-0 absorbable monofilament purse-string suture to secure the peritoneum and posterior rectus fascia. Secure the inner edge of the internal cuff to the posterior rectus fascia using the two stay sutures. Close the anterior rectus fascia using interrupted size-appropriate absorbable monofilament suture on a taper needle around the new PD catheter. In small infants the superior edge of the inner cuff is often very close to the anterior rectus fascia. In this setting

the new PD catheter inner cuff can be secured to the anterior rectus fascia using the same monofilament suture used to close the anterior rectus fascia.

Create the skin exit site at the location identified prior to the induction of anesthesia. The skin exit site should be no larger than the diameter of the PD catheter and should be at or below the previously made transverse skin incision. The skin exit site should not lie in the belt line or in an area covered by a diaper. Use a tunneler to create a gentle arc through the subcutaneous tissue to avoid kinking the catheter. The outer cuff will be in this subcutaneous space and should be at least 2 cm away from the skin exit site. Do not place a suture on the catheter at the skin penetration site. Place the desired adapter onto the catheter. In our institution the dialysis team prefers a titanium adapter. Test the new PD catheter by instilling 30 mL of warm saline into the peritoneal cavity and then disconnect the syringe and lift the catheter up vertically. The saline should freely flow into the abdomen. Angle the opening of the catheter down and the fluid should immediately drain. Simply lifting and dropping the catheter is enough to determine functionality. Allow the new PD catheter to completely drain then flush the catheter with heparin (500 IU/L) and apply the sterile transfer cap system. Close the remainder of the abdominal wall in layers with long-term absorbable suture. Dress the new PD catheter and skin exit site using a sterile dressing that immobilizes the entire length of the PD catheter.

Laparoscopic Approach

The preoperative patient evaluation, catheter sizing, perioperative antibiotics, and skin preparation are identical to the open approach. We prefer to access the peritoneal cavity through a 5-mm skin incision at the inferior ridge of the umbilicus. Grasp the umbilical stalk, retract it ventrally, and place a Veress needle through the fascia and peritoneum. In the setting of morbid obesity a left upper quadrant Veress needle technique might be safer and simpler. Insufflate with carbon dioxide at a pressure appropriate for age and physiologic response: 6–8 mm Hg on infants less than 1 year of age, 8–10 mm Hg in children 1–3 years of age, and 10–12 mm Hg in children >3 years of age. Place a 5-mm port through the infra-umbilical incision.

Perform a partial (or near complete) omentectomy. This can be accomplished in several ways dependent upon patient size and habitus. In larger children, second and third ports may be needed to perform the omentectomy. Place a 5-mm port at the skin incision for the fascia penetrance site and a 10–12-mm port in the lateral abdominal wall opposite to the eventual placement site of the PD catheter. The larger port is used to facilitate the omentectomy with a sealing heat source and for removal of the omentum in a specimen retrieval bag. Reestablish pneumoperitoneum, remove the 5-mm port which was placed at the future catheter fascia penetrance site (placed through the rectus abdominis just superior and lateral to the umbilicus), and place an appropriately sized introducer with peel-away sheath angled towards the coccyx. Place the stylet into the PD catheter, mark the surface of the catheter with a marker just internal to the inner cuff, and lubricate the catheter to minimize friction. Place the catheter through the peel-away sheath into the pelvis and confirm appropriate position of the inner cuff by retracting the peel-away sheath and laparoscopically visualizing the mark on the catheter just internal to the inner cuff. Note that with insufflation and desufflation the position of the PD catheter will change. The coiled portion of the PD catheter should reside in the pelvis in the pouch of Douglass. All port site fascial defects and skin edges should be closed with long-term absorbable suture. Catheter function is assessed as previously described.

Postoperative Care

Ideally, the new PD catheter should not be used for dialysis for 2 weeks following placement. In the clinical setting where dialysis is necessary sooner than 2 weeks the volume should be minimized if possible (10 mL/kg/cycle). The catheter should remain completely immobilized.

The European Pediatric Peritoneal Dialysis Working Group has made specific recommendations for PD catheter care based on available evidence:

- Use gauze or a non-occlusive dressing that absorbs any moisture. Avoid using an occlusive dressings without gauze.
- Keep the catheter immobilized. Avoid excessive movement at the exit site.
- The patient may be mobilized gently on the next day. The child should not return to school for at least 1 week.
- It should be 6 weeks post-implantation before the child engages in heavy exercise.
- Do not redress the catheter for 1 week unless a dressing change is necessary. Evaluate the exit site weekly throughout the 6-week healing period.
- If there is any hematoma in the catheter tract, treat with 2 weeks of oral antibiotics.
- There is to be no showering or swimming during the initial 6-week period.
- Dressing changes at the exit site should be avoided in the first week. If required, a strict aseptic technique should be used. After the first week, use a strict hand-washing regime, sterile solutions, sterile dressing, and restricted staff. Gloves or masks are not advocated.
- The frequency of exit-site care has not been established but should be a minimum of twice weekly. Wet or dirty

dressings require change; the frequency should be a minimum of daily during exit-site infections.
- Sterile saline from single-use sachets or diluted cleansing agent is recommended. The cleansing agent may need to be individualized because of skin sensitivities.
- Povidone iodine and hydrogen peroxide should be avoided: they are toxic to skin cells. Crusts or scabs should not be forcibly removed during cleansing.
- Do not use tap water for exit-site cleansing. Due to danger of pseudomonas infection, there should be no prolonged immersion of the exit site in the bath, but showering before the exit-site change is suggested.
- Swimming is not encouraged, especially in public pools, lakes or rivers, whirlpools or hot tubs. It can take place with good supervision and with occlusive dressings covering the exit site and catheter after the 6-week healing period. An immediate dressing change should take place after swimming.
- If trauma to the exit site occurs, contact the center. If any hematoma is present then prompt administration of an antibiotic chosen on past history of skin colonization is recommended for 7 days.
- There are no convincing data to suggest screening children or caregivers for *Staphylococcus aureus* nasal carriage or on the use of mupirocin cream around the exit site on a regular basis. However, this is recommended for those requiring a second catheter due to *S. aureus* infection, when both child and family should be screened and treated.

Troubleshooting a Malfunctioning PD Catheter

PD catheter failure occurs when dialysate can no longer be effectively introduced or removed from the peritoneal cavity. Initial evaluation of the malfunctioning catheter is often with an abdominal X-ray with or without soluble contrast infused through the failing PD catheter. This can reveal malposition, kinking or obstruction of the catheter, and can help direct surgical intervention to correct the problem. The AXR may also show constipation, which can result in catheter malfunction from compression of the catheter in the pouch of Douglas and occlusion of the holes by a distended rectum. The catheter placed correctly should stay in the pelvis, however, they can flip up into the upper abdomen, where it will usually not function very well. If the source of catheter malfunction remains unclear, diagnostic laparoscopy is a reasonable next step. Diagnostic laparoscopy allows direct evaluation for intraperitoneal adhesions, omental attachment, or loculations that may limit catheter function. A catheter that will not stay in the pelvis most likely needs to be replaced so that it traverses the abdominal wall at a more acute caudad angle. This may also provide an opportunity for therapeutic correction of these problems. Initial insufflation of CO_2 through the PD catheter can facilitate peritoneal access.

Editor's Comment

A well-positioned and functional peritoneal dialysis catheter is critical to the management of children with renal failure. Although the pediatric surgeon's role in the care of the child with end-stage renal disease is primarily technical, it is extremely important that every detail of the operation be performed with the utmost care. These catheters are lifelines and any complication can have profoundly negative effects. The catheter must work reliably, without leakage, and the risk of infection must be minimized. There is little advantage to the laparoscopic approach except for some redo operations and to troubleshoot a malpositioned or poorly functioning catheter. Key steps to the procedure include: angling the catheter through the abdominal wall so that the catheter remains in the pelvis, selecting an appropriately sized catheter, partial omentectomy, purse-string closure of the peritoneum and posterior rectus fascia, placement of the inner cuff within the rectus muscle, running closure of the anterior rectus sheath, creating a subcutaneous tunnel that avoids kinking the catheter, and making the exit site lateral and slightly inferior to the fascial penetrance site. Intraoperative fluoroscopy is sometimes helpful to ensure appropriate positioning of the catheter coil. We infuse 20–30 mL/kg of saline by gravity through the catheter to confirm function. Most of the infused saline should then passively drain.

A PD catheter should be placed as though it were permanent—never cut corners so that it will be easier to remove someday. A catheter placed on the right side will usually find the right place in the pelvis more easily because the sigmoid colon is less likely to get in the way. The stylet used to place the catheter is usually very long and can easily become contaminated on the surgeons mask or an unsterile object outside the field, in which case it must be removed from the field and replaced with a new one. Place the purse string with small bites (and long gaps between stitches so that more tissue is snugged against the catheter) *before* entering the peritoneum and catch a tiny bite of cuff so that it stays snug against the posterior rectus sheath. The catheter should be brought out the lateral aspect of the rectus sheath so that the anterior sheath can be closed water-tight. A second cuff is generally superfluous. Finally, we do not leave the operating room until the catheter functions perfectly and there is zero leakage; otherwise, we will be sure to return in the near future to repair or replace it. One should have the confidence to let the nephrologists use it the night of surgery if this is felt to be necessary.

Children who are about to undergo placement of a PD catheter often require correction of platelet dysfunction. Desmopressin (dDAVP) is rapid acting and is effective for the treatment of platelet dysfunction in about half of patients. Patients with renal failure may also be anemic due to decreased erythropoietin production. Recommendations have been made to treat anemia preoperatively raising hemoglobin levels to approximately 10 g/dL to reduce bleeding time.

Inguinal hernias are not caused by the dialysis but it is more likely that a pre-existing hernia or small patent processus vaginalis becomes clinically apparent sooner due to the increased intra-abdominal pressure created by the infusion of dialysate. Repair of these hernias can be challenging and they are prone to recurrence. Removal of a PD catheter can be difficult due to the adhesions at the cuff. It is not usually necessary to close the peritoneum – most catheters can be removed through the skin exit site only. A rare but devastating complication of PD is sclerosing encapsulating peritonitis (SEP), which causes recurrent bowel obstruction and chronic bowel dysfunction. The cause is unknown but it seems to be associated with immunosuppression and the use of chlorhexidine-based antiseptics (formerly used to clean the tubing and equipment used for peritoneal dialysis). Treatment includes radical excision of the extensive fibrotic peel that envelops the bowel but the recurrence rate and mortality are high.

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Ventricular Shunts for Hydrocephalus

75

Heather S. Spader and Jay Riva-Cambrin

The Hydrocephalus Working Group defines hydrocephalus as "active distension of the ventricular system of the brain resulting from inadequate passage of CSF (cerebrospinal fluid) from its point of production within the cerebral ventricles to its point of absorption into the systemic circulation." The annual incidence of congenital hydrocephalus has remained steady over the last few decades at 0.4–0.8 per 10,000 births per year in the USA, however the prevalence of hydrocephalus seems to be increasing likely due to acquired hydrocephalus associated with prematurity and the increasing survival seen in this population. Successful management of premature infants with acquired hydrocephalus comes at a price, estimated at $1.4–2.0 billion annually. In 2003, children with hydrocephalus represented 0.6 % of all pediatric admissions with nearly 40,000 annual admissions. Furthermore, these admissions account for 3 % of all pediatric hospital charges.

Diagnosis

Patients with hydrocephalus fall into two categories: (1) the initial diagnosis of infants with hydrocephalus and (2) failure of a CSF diversion procedure, which includes endoscopic third ventriculostomy (ETV) failure, shunt malfunction, and shunt infection.

The clinical diagnosis is based on a constellation of symptoms that principally result from increased intracranial pressure and which vary depending on the age of the child. The median age at initial diagnosis is less than 3 months; therefore, the majority of new diagnoses of hydrocephalus in children occur in the infants. Infants present with symptoms such as failure to thrive, irritability, lethargy, vomiting, and loss or delay of developmental milestones. Clinical signs include a full fontanelle, splaying of the cranial sutures, head circumference crossing percentile lines, and, rarely, sun-setting eyes. Older and more communicative children complain of headache, vomiting, blurred vision, worsening school performance and present with signs such as papilledema, stupor, ataxia, and occasionally sixth nerve palsies.

Once the diagnosis is suspected, imaging is performed. Cerebral ultrasounds can be useful to screen infants with open fontanelles but CT and MRI are frequently used to rule out other intracranial diagnoses such as tumors and cysts and to confirm the diagnosis. Specifically, these modalities are used by neurosurgeons to examine and measure ventricular size, identify specific patterns of ventriculomegaly (determining where the blockage of CSF is arising), and assess whether the patient is a candidate for non-shunting interventions such as endoscopic third ventriculostomy.

ETV is a procedure in which the floor of the third ventricle is perforated (ostomy) endoscopically to bypass the pathologic obstruction of CSF without the use of implanted hardware. Overall, it is an effective procedure in select patients but about two thirds are patent at one year and only about a half remain functional at 5 years. Success depends on the child's age, the etiology of the hydrocephalus, and the presence of a previous shunt. Neurosurgeons use a validated tool called the ETV Success Score (ETVSS) to predict and counsel families prior to treatment (Fig. 75.1).

The vast majority of ETV failures occur within the first month. When an ETV fails, the patient will once again present with any of the age-related signs and symptoms of raised ICP and increased ventricular size on serial imaging. A CSF leak and an enlarging pseudomeningocele (subcutaneous accumulation of CSF) are early signs.

The CSF shunt malfunction rate is 40 % within the first 2 years of implantation. Those at the highest risk of shunt failure are infants under the age of 6 months, children with a pre-existing cardiac comorbidity, and those in whom an endoscope was utilized to place the initial shunt. The most common causes of shunt malfunction are obstruction (30 %), infection (8–10 %), loculated ventricles (5–7 %), and

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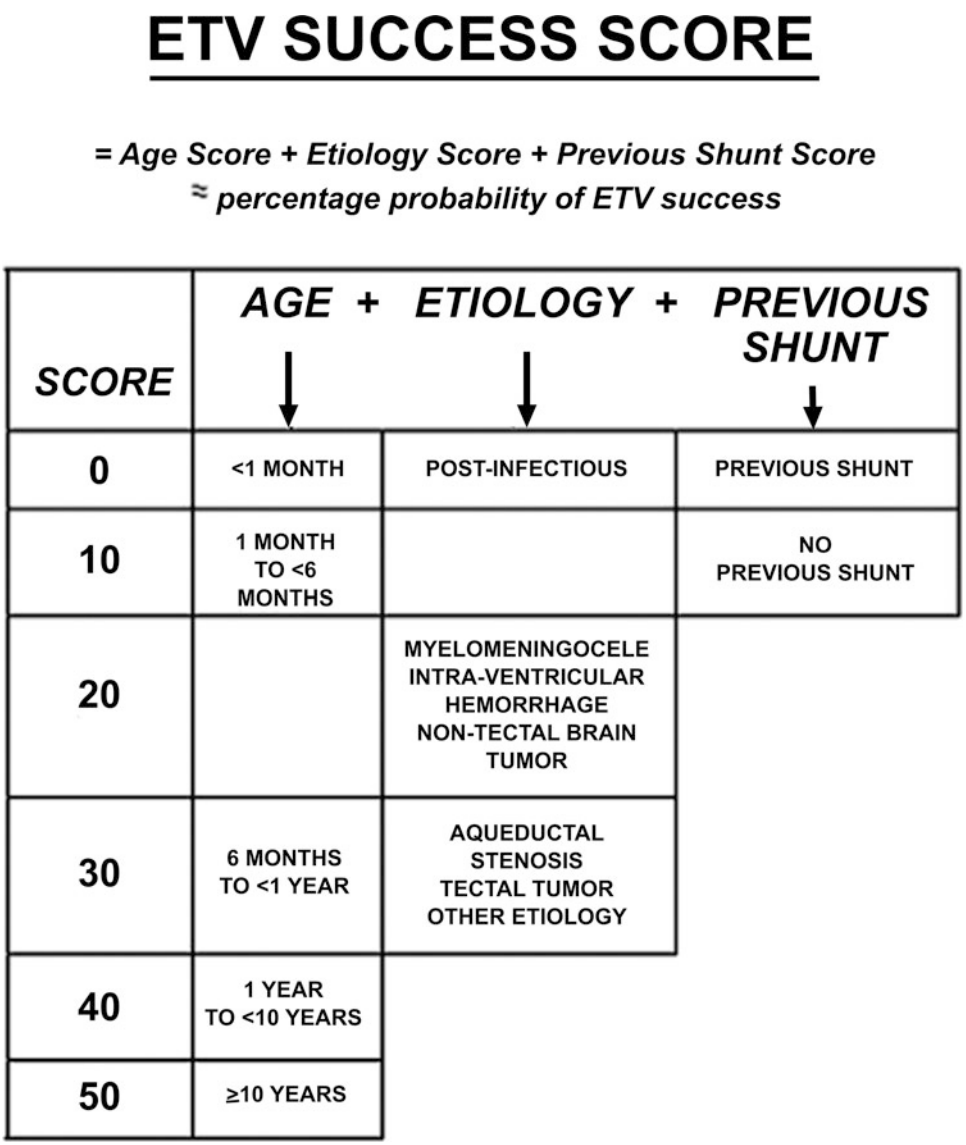

Fig. 75.1 ETV success score. (Reprinted from J Pediatr 155, Kulkarni et al. Endoscopic third ventriculostomy in the treatment of childhood hydrocephalus, 254-9 e1, Copyright 2009, with permission from Elsevier.)

overdrainage (3–5 %). In general, signs and symptoms of shunt malfunction are those associated with elevated ICP. The exception is shunt failure due to CSF overdrainage. In this case, the shunt is functioning but results in *lower* than physiological intracranial pressures. These patients present with vomiting and severe headaches while upright, both of which improve with recumbency. Suspicion of CSF shunt malfunction is confirmed with a shunt series, which is a series of plain X-rays of the skull, neck, chest, and abdomen to visualize a fracture or dislocation of the catheter, and with CT or fast MRI to compare ventricle size with previous scans.

Patients without clear indications for shunt revision are observed. Close observation is superior to operative intervention in these patients because infectious complications increase with each shunt surgery. The use of diuretics and acetazolamide (to decrease CSF production), are of limited benefit and are not employed in our practice.

Shunt Infection

CSF shunt infection occurs in 4–11 % of cases after either initial implantation or shunt revision and is directly correlated with the number of previous shunt revisions. Shunt infection can lead to ventriculitis, which promotes the development of loculated compartments of CSF. This results in cognitive decline and further shunt malfunction. Presentation of CSF shunt infections can be similar to that of CSF shunt malfunctions; however, infections are also associated with fever, erythema along the shunt tract, abdominal pain, exudate or pus from the shunt wounds, or exposed shunt hardware. The laboratory evaluation includes serum white blood cell count, serum erythrocyte sedimentation rate, serum C-reactive protein, blood cultures (if a ventriculoatrial shunt is in place), and, most importantly, CSF cell count and culture obtained

from the shunt ("shunt tap"). A CT or fast MRI along with a shunt series is also recommended. Rarely, CSF shunt infections can present with an abdominal pseudocyst where the patient has only a low-grade fever and nonacute generalized abdominal pain. In these cases, an abdominal US or CT with contrast is diagnostic and can rule out other abdominal causes such as appendicitis or bowel obstruction.

Treatment

Insofar as most of the underlying causes of hydrocephalus are not amenable to direct therapy, lasting treatment almost always involves a surgical intervention that results in relief of elevated ICP, usually by providing an alternate route of absorption of CSF.

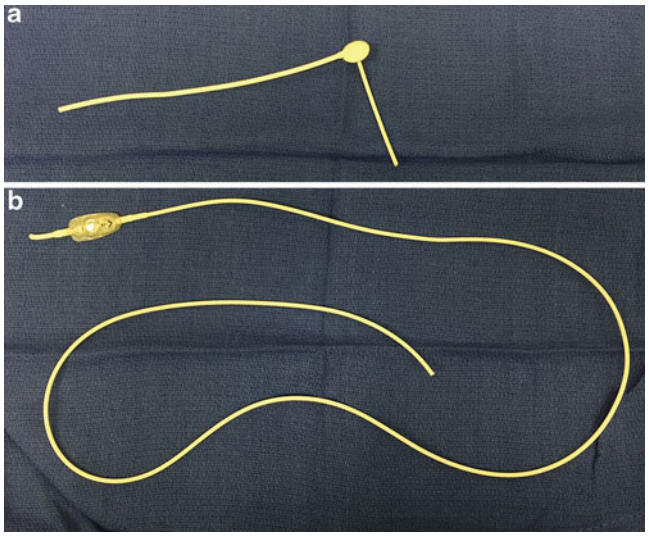

Fig. 75.2 Shunt components. (**A**) Proximal ventricular catheter; snap top, (**B**) valve, and distal catheter

Endoscopic Third Ventriculostomy

An ETV is performed through a single burr hole in older children or through the lateral edge of the fontanelle in infants. An endoscope, rigid or flexible, is passed through the brain parenchyma into the lateral ventricle. The endoscope is then navigated through the foramen of Monro into the third ventricle, where a perforation is made in the floor between the pituitary stalk and the basilar artery.

The ventriculostomy bypasses the CSF obstruction by creating a direct communication from the ventricular space to the subarachnoid space, mimicking the natural model. The principal advantage is a more natural CSF circulation without implanted hardware (no risk of shunt infection or obstruction), but the procedure is associated with a higher risk of diabetes insipidus due to injury to the pituitary stalk (1–2 %), meningitis (3 %), or, rarely, a catastrophic injury to the basilar artery (<1 %).

CSF Shunts

The principle of ventricular shunting is to establish communication between the ventricular system and an alternate CSF drainage cavity or site such as the peritoneum, right atrium, or pleura. Ventricular catheters are most often placed in either the frontal or occipital horn of the ventricle, preferably on the right side. The components of a shunt include the proximal ventricular catheter, a valve, and the distal catheter leading to the abdomen, heart, or pleural space (Fig. 75.2).

Ventriculoperitoneal (VP) shunts are the most common type, but the distal catheter may be placed in the heart, pleura, and even the gallbladder if the abdominal cavity has significant adhesions from previous surgery. There have been many developments in valves, but the main feature of most placed today is a differential pressure valve that opens when the pressure gradient exceeds a certain threshold and closes when the pressure drops to prevent back flow. Features such as antisiphon devices and externally adjustable valves have not been shown to be superior to a non-programmable differential pressure valve in children; nor have any specific valve design.

In premature infants, a ventricular access device (reservoir) or ventricular subgaleal shunt is used until the infant outgrows the need for CSF diversion or is large enough (>2 kg) for placement of a more permanent CSF shunt. The ventricular access device consists only of a reservoir and a ventricular catheter and is implanted under the scalp to be tapped with a small needle and syringe when necessary. Some neurosurgeons prefer implanting a ventricular subgaleal shunt, which consists of a catheter that connects the ventricle to a subgaleal scalp pocket, obviating the need for external tapping.

Shunt placement surgery starts with the patient positioned so that the entire tract for the shunt is visualized from the head and neck to the site of the distal catheter (abdomen, heart, pleural space) (Fig. 75.3). We minimize hair clipping and use chlorhexidine preparation for the skin after giving a prophylactic dose of antibiotic (usually cefazolin). Adherence to a standardized shunt procedure protocol decreases variability and shunt infection rates.

For frontal shunts, a curvilinear incision is made in the mid-pupillary line just anterior to the coronal suture. Frontal shunts also require a small intermediary linear incision behind the ear through which the subcutaneous tunneler is passed. For occipital shunts, a curvilinear incision 4 cm lateral to midline and 6 cm above the inion is made without the need for an intermediary incision.

Fig. 75.3 Patient positioning and draping

For ventriculoperitoneal (VP) shunts, after making incisions on the head, a 1-cm incision is made lateral and superior to the umbilicus over the rectus abdominis muscle. The shunt tunneler is used to subcutaneously communicate the cranial incisions with the abdominal incision through which the shunt tubing is passed. The abdomen can be entered in one of three ways: with a trochar, laparoscopically with the assistance of a pediatric surgeon, or by mini-laparotomy, usually done by the neurosurgeon, to gain access to the peritoneal cavity. The ventricular catheter is placed, with or without image guidance, into the lateral ventricle of the brain and connected with the unitized valve and distal catheter.

For ventriculoatrial shunts, central venous access is normally obtained through the internal jugular or subclavian vein by a pediatric surgeon. The scalp incisions are the same as for a VP shunt. Once the vein is accessed, the distal catheter is placed into the vein and an intra-operative X-ray is used to confirm placement of the catheter tip at the junction of the superior vena cava and the right atrium.

For ventriculopleural shunts, a 3-cm linear incision is made at the third rib (or the most prominent rib) in the mid-clavicular line. Dissection is carried down to the superior aspect of the rib and through the muscle until the pleura is visualized. Respiration is then stopped by the anesthesiologist while the pleura is punctured and the distal catheter placed into the thorax under constant irrigation. The anesthesiologist then performs a Valsalva maneuver, and the pleura is closed while constantly irrigating the catheter. A postoperative chest X-ray is performed in the recovery room to rule out a significant pneumothorax.

Postoperative Care

All patients are administered a dose of antibiotics 8 h after the operation. They also undergo a non-contrast CT or MRI of the brain with limited sequences as a baseline reference. In addition, they undergo a shunt series. Most patients go home the day after shunt surgery and can return to school a few days later.

Future Directions

ETV, while an excellent alternative to shunts in older children, has a poor chance of success in infants (<40 %). In an effort to improve the success rate, some perform bilateral choroid plexus cauterization (CPC) during ETV in infants. This was born of necessity by neurosurgeons in Uganda because CSF shunts and replacement parts are expensive and not readily available in the developing world. CPC is performed after successful ventriculostomy using a flexible endoscope by cauterizing the choroid plexus on the floor of the right ventricle using a Bugbee wire then accessing and cauterizing the left lateral ventricle choroid plexus through a septostomy. ETV + CPC can increase success rates from 40 % to 66 %. This technique is now being utilized at certain North American centers and confirmed to have a 50–80 % success rate in infants with some etiologies of hydrocephalus. This technique is currently under investigation for the treatment of infant hydrocephalus by the Hydrocephalus Clinical Research Network (HCRN).

Editor's Comment

Pediatric surgeons are frequently asked to participate in VP shunt placement when the patient has presumed intra-abdominal adhesions from previous abdominal surgery or when central venous access is required for placement of a ventriculoatrial shunt. Laparoscopic insertion of the distal shunt tubing into the peritoneal cavity should be used when possible. The incidence of distal shunt obstruction is lower when laparoscopy is used compared to the open technique of a mini-laparotomy and recovery is faster.

Children with VP shunt infections and meningitis sometimes present with abdominal pain. Primary peritonitis occurs in approximately 10 % of patients with VP shunts. US or CT is useful in these situations to evaluate for an intra-abdominal source of infection such as appendicitis or pseudocyst related to the shunt. Differentiating pseudocysts from lymphatic malformations, abscesses, cerebrospinal fluid collection, or urinomas is sometimes difficult with imaging alone and often requires aspiration of the fluid for diagnosis. They can also cause a small bowel obstruction. Pseudocysts are sometimes infected and the pathogens are usually skin flora, such as *Staphylococcus aureus* or *Staphylococcus epidermidis*. Externalization of the shunt and percutaneous drainage of the infected pseudocyst is usually curative. The need for cyst drainage by laparoscopic or open surgery is uncommon. In cases with uninfected cysts, removal of the tube tip from the cyst is effective treatment.

Children with VP shunts may safely undergo elective gastrointestinal surgical procedures including fundoplication and gastrostomy tube. Also, a VP shunt may be placed simultaneously with these procedures without a significant risk of shunt infection. Perioperative antibiotics should be given. If a patient with a VP shunt undergoes appendectomy for non-ruptured appendicitis, the shunt may be left in place and the patient closely monitored for signs of infection. If perforated appendicitis is encountered, the shunt tubing should be externalized. During inguinal herniorrhaphy, catheters have been known to sometimes protrude into the inguinal hernia sac, where they can be damaged or caught up in the ligation of the hernia sac.

The intraperitoneal portion of the shunt can erode into the intestine and will sometimes even project through the anus after having eroded into the colon. This almost always creates more drama than danger and the treatment is nearly always simply the removal of the catheter (through the anus) and allowing the small opening in the bowel to heal itself. In infants with a patent processus, placement of a VP shunt will often lead to the formation of a large hydrocele or inguinal hernia. These should be repaired in the usual fashion before they become symptomatic or excessively large.

The child with infected ventricular shunts usually presents with classic signs and symptoms of meningitis, but young children with meningitis sometimes present with what appears to be an acute abdominal process. Distinguishing the two can be difficult although imaging will usually help identify a source of pain in the abdomen such as appendicitis or pancreatitis. Shunt infection is an emergency and cannot be ruled out on clinical grounds alone, especially by inexperienced personnel in the middle of the night—the shunt must be interrogated immediately and the fluid sent for gram stain and culture without delay.

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Disorders of the Abdominal Aorta and Major Branches

76

Davis B. Horkan and Omaida C. Velazquez

Children with abdominal aortic diseases are likely to come under the care of a pediatric surgeon and will invariably require a multidisciplinary surgical and medical team during the entire spectrum of care from preoperative planning through long-term follow-up. This group of disorders is rare and heterogeneous in nature, and as such the incidence and etiologies have not been thoroughly defined. Clearly, these diseases can be classified broadly into those that are congenitally present and those acquired during childhood. The more useful clinical dichotomy, however, is in separating these diseases into those of the aneurysmal variety and those of the stenotic or occlusive variety. From a technical perspective, pediatric vascular reconstruction must account for the small vessel lumen and associated restrictions to laminar flow, the diseased biology of the vascular wall, limited availability of conduit for reconstruction, and the potential for both longitudinal and circumferential growth. These issues can only be addressed in the context of a multidisciplinary team of surgeons and physicians with systemic support for the family and patient.

Diagnosis

Aneurysmal disease in children is defined as aortic diameter greater than 30 mm or, more usefully, a dilatation may be compared to another site along the aorta with aneurysm defined as a greater than 50 % enlargement. Approximately 60 % of congenital abdominal aortic aneurysms will be diagnosed before the age of 3 years, while age of presentation for acquired aneurysm is more variable dependent on etiology. A classification scheme for childhood arterial aneurysms was proposed in the early 1990s and remains useful (Table 76.1). Acquired aneurysms are more common than congenital, and the incidence of congenital aneurysm appears to be greater in males. Clinical presentation is variable, with diagnosis most often occurring in the asymptomatic patient with a pulsatile abdominal mass on exam. Presentation may also occur during syndromic evaluation or following rupture.

Doppler US imaging is the method of choice to confirm the diagnosis of abdominal aortic aneurysm and may provide information regarding pathology of the main aortic branches. Approximately 70 % of these aneurysms are found in an infrarenal location, but juxtarenal, suprarenal, and thoracoabdominal aneurysms are not uncommon. Doppler US is also used for serial follow-up imaging of aneurysmal disease due to its convenience and favorable risk profile. After confirming the diagnosis, complete body imaging is necessary to evaluate for systemic disease. Gadolinium-enhanced MR angiography is the preferred modality for imaging of the head and neck. Children with concurrent aortic and intracranial aneurysms typically have a poor prognosis.

CT angiography provides excellent resolution of the thoracic, abdominal, and extremity vessels with high sensitivity and specificity for aneurysmal disease. CTA also allows assessment for arterial wall inflammation and intramural thrombus. Digital subtraction angiography (DSA) is associated with an increased risk of complications due to the necessity for intra-arterial access and is therefore reserved for cases in which other diagnostic imaging has been inconclusive or when endovascular intervention is being considered. Preoperatively, CTA or MRA is almost always required to provide the best anatomical definition for reconstructive planning.

Stenotic aortic disease is similar to aneurysmal disease in the wide variation seen in pathogenesis of the disorders including congenital genetic, embryologic, or metabolic dysfunctions or acquired inflammatory, autoimmune, or infectious etiologies. A significant number will remain idiopathic even after an

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Table 76.1 Classification of childhood arterial aneurysms

Class	Principal artery affected	Clinical characteristics and risk factors
Arterial infection	Aorta (particularly thoracic), iliac	Cardiovascular anomalies
		Umbilical catheterization
		Dyspnea
		Cough
		Chest pain
		Progression to rupture
		Death if untreated
Giant cell aortoarteritis	Aorta	Signs and symptoms vary from
		Absent to shock
	Peripheral arteries (rare)	Untreated aortic lesions progress to rupture
Autoimmune vasculitis	Renal, hepatic, and splenic arterial branches	Usually asymptomatic but may cause hematuria
		Perirenal hematomas, or
		Death with rupture
Kawasaki disease	Coronary (20–30 %)	Often asymptomatic
	Axillobrachial	Myocardial infarction or tamponade (coronary)
	Iliofemoral	Limb ischemia (extremity)
	Hepatic	Obstructive jaundice (hepatic)
Medial degeneration, Marfan, and Ehlers–Danlos syndromes	Aorta	Aortic rupture or dissection common
		Arteriography and vascular reconstruction hazardous in type IV Ehlers–Danlos syndrome
Medial degeneration—other forms	Aorta	Associated with cardiac and aortic anomalies
	Peripheral arteries (rare)	Often present with aortic dissection or rupture
Arterial dysplasia	Renal	Usually asymptomatic
		Detected during arteriography for renovascular hypertension
Idiopathic, congenital	Iliofemoral, brachial, aorta	Often asymptomatic
		May cause limb ischemia
		Rupture not reported
Extravascular causes	Aorta, visceral, and extremity arteries	Aortic aneurysms often rupture
		Peripheral lesions asymptomatic
		Visceral lesions can cause GI bleeding

Source: Modified from Sarkar R, Coran A, Cilley R, et al. Arterial aneurysms in children: clinicopathologic classification. J Vasc Surg. 1991;13:47–56, with permission from Elsevier

extensive work-up. The extent of stenosis may be localized or include long segments of the aorta. Other arteries will be affected in more than 70 % of children, with aortic stenotic disease showing concurrent stenosis of at least one other artery including the renal artery, celiac trunk, or superior mesenteric artery. Renal artery involvement is most common and is bilateral in the majority of children. The celiac trunk is involved in approximately 30 % of cases with another 20–25 % showing SMA involvement.

Children with stenotic disease tend to present at an older age compared to aneurysmal diseases with diagnosis at a mean of 9 years of age and with complications related directly to the site and extent of stenotic disease. Almost 90 % present with renovascular hypertension often associated with left ventricular hypertrophy (30 %), headache (12–15 %), renal failure, congestive heart failure, or stroke. Other common presentations include claudication in 10 % of cases, limb-length discrepancy, and intestinal ischemia.

Physical examination reveals absent or diminished femoral and distal pulses and in most cases an abdominal bruit. While no formalized classification has been proposed, the differential diagnosis includes: fibromuscular dysplasia (FMD), middle aortic syndrome (MAS), tuberous sclerosis, neurofibromatosis type I, Alagille's syndrome, Williams' syndrome, Takayasu's arteritis, and other vasculitides. As with aneurysmal diseases, aortic stenosis can be sporadic or it can be a harbinger of systemic disease; therefore, it should prompt complete body vascular imaging. Doppler US, CTA, or MRA are the initial imaging modalities of choice, but are sometimes limited due to the small diameter of the affected vessels and diminished flow. When these initial imaging methods do not provide satisfactory images, DSA will usually prove useful for diagnosis and characterization of the lesions.

For all children diagnosed with large vessel disease, thorough assessment includes cardiac evaluation with ECG and echocardiogram to delineate congenital anomaly, heart

failure, or left ventricular hypertrophy. In cases involving systemic vasculitides, coronary artery angiography may be indicated. Laboratory evaluation to evaluate renal function is indicated for every patient. Genetics evaluation, inflammatory and autoimmune panels, and infectious disease work-up should be obtained in a multidisciplinary manner.

Preoperative Preparation

Optimal medical therapy must be based on definitive diagnosis of the underlying disorder. As such, the evaluation is performed in consultation with genetics, rheumatology, and infectious disease with inclusion of nephrology and cardiology often indicated by renal or cardiac end-organ damage. In cases involving inflammatory or autoimmune vasculitis, medical therapy must be initiated and reconstruction delayed if possible until disease remission or control has been achieved. Similarly, in the minority of cases involving an infectious etiology, proper antimicrobial therapy should be started prior to any reconstruction involving graft placement.

Control or improvement of hypertension is desirable, is performed in coordination with a nephrologist, and usually requires the use of multiple antihypertensive medications including beta-blockers, angiotensin-converting enzyme inhibitors, calcium channel blockers, diuretics, and alpha-blockers. Control or improvement by conservative means is least likely in cases that are idiopathic. In some cases of severe hypertension refractory to medical management, percutaneous transluminal balloon angioplasty of stenotic renal arteries might be considered as a temporizing maneuver prior to operative reconstruction. As always, close attention to renal and cardiac function is of paramount importance in the preoperative period.

Operative planning must include particular attention to the timing of intervention and to the choice of conduit for reconstruction. Reconstruction for both aneurysm and stenosis is associated with lower mortality in older children. Additionally, allowing the child to age and grow improves the availability of adequate autogenous conduit choices, improves the size match between the conduit and the growing native vessel, and has been associated with increased graft patency rates and decreased necessity for revision. Autogenous venous conduits should be assessed formally prior to operation by Doppler US vein mapping. Saphenous vein grafts are the most commonly used native vessel and often provide an appropriate size match, but must be followed closely for dilation as a consequence of being exposed to arterial pressures. Internal jugular vein and internal iliac artery grafts are also suitable.

Synthetic grafts including expanded polytetrafluoroethylene and polyethylene terephthalate are widely used with the advantages of having ready availability, low immunogenicity, and a wide size availability, but are limited by lower patency rates and the expected need for replacement as size mismatch between the inert graft and the growing native artery increases. Blood type-matched cryopreserved arterial allografts provide another means of readily available conduit, and are especially attractive in younger children without size-appropriate natural conduits and can be ordered with additional length to accommodate for growth. However these have also been associated with immunogenic fibrosis, which complicates later revision. Newer options include the already available decellularized cryopreserved arterial allografts, which avoid the immunogenicity of standard cryopreserved grafts, and soon vascular smooth muscle cell or mesenchymal stem cell-based tissue-engineered vascular patches should become available, promise to more closely mimic natural conduits and will be grown to order. Autogenous conduits 3 mm and greater in diameter are suitable for use, but synthetic and allograft conduits should be 6 mm or greater to decrease risk of early thrombosis.

Regardless of technical approach or conduit choice, all patients should undergo preoperative lower extremity pulse volume recordings, arterial Doppler ultrasound study, and ankle-brachial index measurements as a baseline for comparison to post-operative and long-term follow-up values.

Surgical Technique

The approach for open vascular reconstruction is most commonly a full midline laparotomy incision for wide exposure (Fig. 76.1). Left medial visceral rotation is performed with the descending and transverse colon, spleen, tail of the pancreas, and stomach mobilized medially to expose the subdiaphragmatic aorta and its branches. Less often, right medial visceral rotation or mobilization of the kidney or ureter may be required for adequate exposure. The left diaphragmatic crus is divided to expose the proximal abdominal aorta. Full dose heparinization (50–70 units/kg) is administered intravenously 3–5 min prior to clamping for proximal and distal control of the vessels to be reconstructed. Grafts should be placed with longitudinal redundancy to accommodate for somatic growth. When using venous autografts, a synthetic tubular mesh such as 4–6 mm Dacron tubular graft should be placed to reinforce the vein graft and mitigate aneurysmal dilation under arterial pressure. Anastomoses should be performed in a fully or partially interrupted fashion to allow circumferential growth of the anastomosis with the native vessel. Recently, interrupted vascular anastomosis has been performed for pediatric reconstruction using nitinol-alloy U-clip devices, which have had reported success in pediatric cardiac uses.

In post-pubertal patients with aneurysmal disease, endovascular repair may provide a suitable and inviting option for

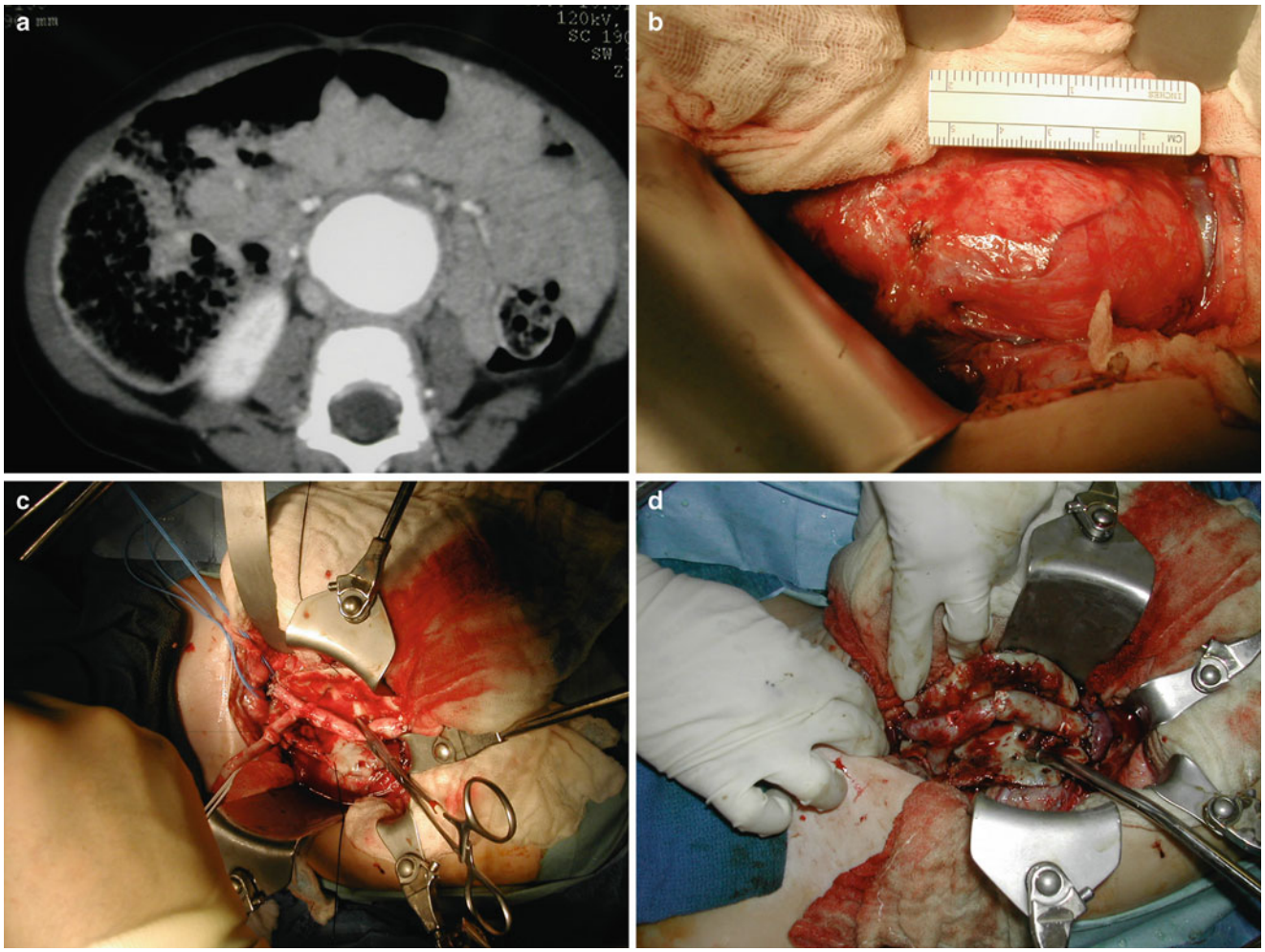

Fig. 76.1 (**a**) CTA abdomen of a 14-month-old child with abdominal aortic aneurysm. (**b–d**) Intraoperative photographs of aneurysm repair with cryopreserved aorto-iliac arterial allograft. (**b**) Exposed infrarenal AAA; (**c**) Proximal anastomosis is completed; and (**d**) Completed reconstruction

intervention. However, in most children presenting with congenital and acquired forms of aneurysmal disease, open repair remains the option of choice and allows flexibility in treating all sizes of children and extents of disease. Aneurysmorrhaphy should not be performed for pediatric aneurysmal disease due to the abnormal vessel wall, and instead complete resection and reconstruction are indicated. Aneurysmal disease reconstruction is performed by end-to-end anastomosis. Aneurysms of the internal iliac artery can be embolized or resected without reconstruction, but all other named branches require reconstruction.

Stenotic disease is more amenable to less invasive options of intervention than aneurysmal disease. The applicability and effectiveness of endovascular options including balloon angioplasty and stenting is dictated by the underlying pathogenesis, location, and extent of stenosis. Significant risks include occlusive dissection during the procedure or high-grade restenosis as a late complication. For stenosis arising from fibromuscular dysplasia, angioplasty may provide benefit but restenosis is likely and requires repeated treatments.

Vascular reconstruction for stenotic disease is performed by end-to-side anastomosis. Aorto-aortic bypass or aorto-iliac bypass are the reconstruction options of choice for long-segment aortic involvement or for involvement of multiple visceral arteries. When renal artery stenosis is a factor, renal artery re-implantation into the graft or renal autotransplantation to the native or reconstructed iliac artery are common treatment options. As the majority of renal artery stenoses are focal ostial lesions, patch angioplasty may be useful when the aorta itself is not involved. Treatment for celiac or SMA stenosis will more often require use of a branched synthetic graft. In those undergoing endovascular treatments, technical failure or need for re-intervention complicates 25–30 % of cases. Mortality is similar for endovascular and open repairs ranging from 2 % to 3 %.

Outcomes

Early complications including bleeding, infection, end-organ ischemia or failure, injury to adjacent organs, and need for reoperation are all known complications for complex vascular reconstructions in children. As expected, emergent interventions are associated with a higher risk of complications than planned reconstructions with mortality as high as 80 % for ruptured pediatric AAA. Little data exists regarding the need for reoperation of early aneurysm repairs. In reconstructions for aortic or renal artery stenosis with renovascular hypertension, outcomes have been favorable. Improvement of hypertension occurs in 50–60 % of patients treated primarily with renal artery angioplasty, with restenosis rates ranging from 25 % to 35 %. Improvement in hypertension with open reconstruction has been excellent in long-term follow-up: 50–60 % of patients are normotensive without antihypertensives and another 25 % of patients are normotensive on one medication.

Editor's Comment

There are few pediatric surgeons who have the training and expertise to perform complex reconstructive operations of the aorta and its major branches in infants and children on their own. Most institutions that care for these children use a multidisciplinary approach with a team that consists of an adult vascular surgeon, a pediatric general surgeon, and an experienced interventional radiologist. This approach combines the expertise of several skilled individuals who can work together to achieve excellent results in children with vascular problems that require major reconstruction. Complex reconstructive vascular operations in children are certainly challenging but surprisingly well tolerated. Patients with renovascular hypertension should have their blood pressure well controlled prior to a planned procedure. At least one lower extremity should be sterilely prepared during any operation that could require the use of autologous vein graft material.

Good surgical exposure is important and usually entails a long midline or left thoraco-abdominal incision. The spleen and left colon should be fully mobilized to expose the aorta and its major branches. If the right renal or iliac vessels need to be addressed, the right colon might need to be mobilized as well. Of course, proximal and distal vascular control is also very important. The thoracic aorta might need to be exposed by dividing the left crus to achieve proximal control. These exposures are generally more straightforward in children than they are in adults because of cleaner dissection planes, a paucity of fat and fibrosis, and generally pristine vessels free of atherosclerosis. The usual cardiac risks that are a major concern in adult vascular surgery are also rarely an issue in these children. Nevertheless, in these situations one can never afford to be cavalier.

Vascular anastomoses are performed with fine permanent monofilament sutures in the usual fashion, but in children one must always incorporate the potential for growth at the anastomosis itself as well as in the length of the graft. Anastomoses should be performed at least partly with interrupted sutures although some surgeons prefer instead to incorporate a "growth stitch" that can gradually loosen over time as the child grows. Grafts should be created with some degree of redundancy to account for linear growth. Autologous venous grafts are ideal conduits but tend to become aneurysmal over time. A way to avoid these aneurysms is to reinforce the grafts with an outer covering of polytetrafluoroethylene graft. Depending on the caliber of the graft, 4- or 6-mm conduits are cut along their length and placed around the grafts after the anastomoses have been completed. Complications include bleeding, thrombosis, ischemia, and embolism. Long-term results have been excellent but close follow-up with serial Doppler US or MR angiography are essential.

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Part X

Liver, Biliary Tree, Pancreas, and Spleen

Neonatal Hyperbilirubinemia

77

Clyde J. Wright and Michael A. Posencheg

Neonatal hyperbilirubinemia, or jaundice in the newborn, is caused by deposition of bilirubin in the skin. It manifests in over 50 % of newborns but relatively few require therapy. Bilirubin is a breakdown product of heme proteins, the most abundant of which is hemoglobin. The heme moiety is converted by heme oxygenase to biliverdin, which is reduced to unconjugated bilirubin by biliverdin reductase. Unconjugated bilirubin is bound to albumin in the blood and is taken up by the liver and conjugated by uridine diphosphate glucuronyl transferase (UDPGT). Conjugated bilirubin is excreted by the liver into the small intestine and eliminated in the stool. However, conjugated bilirubin can be deconjugated in the bowel, reabsorbed into the blood, and delivered again to the liver (enterohepatic circulation). Elevation of unconjugated bilirubin is the result of increased heme breakdown, decreased uptake of bilirubin by the liver, decreased bilirubin conjugation, or increased enterohepatic circulation. In contrast, elevation of conjugated bilirubin is primarily due to decreased liver excretion, bile duct abnormalities, or hepatocyte dysfunction.

Jaundice is the clinical manifestation of elevated unconjugated or conjugated bilirubin; however, the skin discoloration is somewhat different when comparing the two. Unconjugated hyperbilirubinemia produces a more yellow–orange hue, while conjugated hyperbilirubinemia produces a yellow–green hue. The initial challenge to the clinician is determining which form of jaundice is present and whether or not it is pathologic. Conjugated hyperbilirubinemia is always considered pathologic and is defined as a conjugated fraction of >1 mg/dL in the setting of a total serum bilirubin (TSB) <5 mg/dL, or more than 20 % of the TSB if it is >5 mg/dL. More than 70 % of cases are due to either idiopathic neonatal hepatitis or biliary atresia. In preterm or sick term infants, the most common cause is parenteral nutrition-associated cholestasis. The complete differential diagnosis for conjugated hyperbilirubinemia contains over 100 diagnoses. We will focus on the differential diagnosis and management of the more common condition of unconjugated hyperbilirubinemia.

Hyperbilirubinemia presents a challenge to the clinician due to the acute and chronic neurological sequelae that can occur in infants with markedly elevated levels. When unconjugated bilirubin concentrations exceed the infant's capacity to bind with albumin, either because of an exceedingly high bilirubin level or a low albumin level, there is an increased concentration of unbound bilirubin. This bilirubin freely crosses the blood–brain barrier and is toxic to neurons of the basal ganglia and brainstem nuclei. The clinical manifestation is termed acute bilirubin encephalopathy or bilirubin-induced neurological dysfunction (BIND). These symptoms are often confused with those of sepsis or asphyxia and initially include lethargy, poor feeding, and hypotonia. This can progress to stupor, irritability, fever, high-pitched cry, seizures, and hypertonia. The hypertonia associated with hyperbilirubinemia has been classically described as backward flexion of the neck (retrocollis) and trunk (opisthotonos). Lastly, if unchecked, acute bilirubin encephalopathy can progress to a shrill cry, loss of ability to feed orally, apnea, coma, and death. The long-term sequela of this brain injury is kernicterus, which can include choreoathetosis, sensorineural hearing loss, dental enamel dysplasia, paralysis of upward gaze, hypotonia, and delay in acquisition of motor skills. The goal in treating hyperbilirubinemia is to prevent both the acute and chronic sequelae.

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Diagnosis

The differential diagnosis of unconjugated hyperbilirubinemia in the newborn is extensive and includes physiologic jaundice, which is part of the normal transition from fetal to neonatal life. In utero, bilirubin produced by the breakdown of heme proteins easily crosses the placenta and is conjugated and excreted by the mother's liver and intestinal tract. Many factors make the newborn infant ill-equipped to deal with the loss of this route of excretion. Newborns have a larger mass of red blood cells, and therefore a higher hemoglobin load. Additionally, these cells have a shorter life span when compared to older children and adults. Furthermore, the newborn liver exhibits reduced UDPGT activity (<1 % of adult activity in the first few days of life), and delayed passage of meconium with a prolonged intestinal transit time increases enterohepatic circulation. The combination of these factors results in a physiologic hyperbilirubinemia that occurs in more than half of newborns, peaking around the fourth day of life. Average peak TSB is 5–6 mg/dL in formula-fed term newborns and approaches 9 mg/dL in breast-fed infants. While classically it has been taught that a TSB of 5 mg/dL approximates the minimum serum level required to detect clinical jaundice, it is important to remember that estimating bilirubin levels by clinical exam is unreliable. Any jaundice detected clinically, especially when detected in the first 24 h, requires prompt laboratory evaluation.

When the bilirubin level is elevated in the first 24 h of life, rapidly rising, or >17 mg/dL, further work-up is necessary. Any one of these conditions is likely to represent a process other than physiologic jaundice. The evaluation of such an infant begins with a review of the pertinent maternal and neonatal history. Maternal factors such as blood type, Rh status, and antibody profile might contribute to an increased risk of hyperbilirubinemia. Isoimmune hemolytic disease can manifest when maternal antibodies cross the placenta and bind to antigens present on newborn red blood cells including major blood group antigens (A and B), minor blood group antigens (Kell, Kidd, and Duffy), or Rh factor.

Regarding ABO incompatibility, infants born to mothers with type O blood are at risk for major blood group incompatibility, as their anti-A and anti-B antibodies are more likely to be IgG and cross the placenta. Mothers with type A or type B blood commonly develop anti-B and anti-A IgM antibodies, which cannot cross the placenta and therefore pose little risk to the newborn. Rhesus isoimmunization occurs in Rh positive infants born to Rh negative mothers who have developed anti-Rh IgG antibodies from previous exposure to Rh positive blood. While Rh isoimmunization requires prior sensitization and therefore does not occur in first pregnancies, ABO incompatibility can occur in the first child. This is an important history to establish as immune-mediated hemolysis can cause significantly elevated bilirubin levels and requires specific therapeutic interventions.

Other important maternal factors include TORCH infection, maternal diabetes, intra-uterine growth restriction, and the use of medications such as sulfonamides, nitrofurantoin, anti-malarials, or oxytocin. All of these can contribute to an increase in unconjugated bilirubin by different mechanisms.

Delivery and neonatal history are also important. Evidence of birth trauma such as ecchymosis and cephalohematomas increases the amount of hemoglobin that must be degraded. It is important to know the infant's gestational and postnatal age as this determines treatment thresholds. The infant's ethnicity increases the risk of certain disease processes. For example, G6PD deficiency is more common in infants of African, Mediterranean, Middle Eastern, or Southeast Asian descent. Some states test for this condition as part of the newborn screen. Breast-feeding is associated with higher bilirubin levels than formula feeding. Additionally, the infant's voiding and stooling pattern must be investigated as these represent the major routes of elimination.

Along with a thorough history, the physical exam can provide clues that impact the aggressiveness with which one evaluates the infant's hyperbilirubinemia. Jaundice becomes clinically apparent as yellow–orange skin discoloration at levels >5 mg/dL. Furthermore, it progresses in a cephalocaudal manner, from the face to the chest, trunk, and lower extremities. However, multiple studies have shown the clinicians' ability to predict bilirubin values on the basis of this progression to be poor. Jaundice is best evaluated by assessing the color of skin that has been blanched with light pressure in natural light.

Other physical exam findings are important to note and are sometimes associated with higher bilirubin levels. The infant with polycythemia often appears ruddy, in contrast to the pale infant undergoing hemolysis. Infants with long standing hemolysis in utero may have evidence of hydrops fetalis, such as pleural effusions or ascites. Microcephaly, petechiae, and hepatosplenomegaly suggest the possibility of a TORCH infection. Lastly, jaundiced infants should be monitored closely for signs and symptoms of acute bilirubin encephalopathy or BIND.

The laboratory evaluation of an infant with clinical jaundice should always include a fractionated bilirubin level, with total serum, unconjugated, and conjugated levels determined. These individual fractions must be determined as the diagnosis and subsequent therapeutic interventions depend on this information. A blood type, Coombs' test, and complete blood count with reticulocyte count can determine whether ongoing hemolysis is occurring. A G6PD level can be helpful in establishing the diagnosis in infants with the appropriate ethnic background. Serum albumin, the primary protein transporter for bilirubin in the blood, should be measured as low serum levels of albumin increase the risk of developing neurological sequelae due to the increased amount of free bilirubin crossing the blood–brain barrier. The newborn screen provides information regarding rarer conditions associated with increased total and conjugated bilirubin such as galactosemia, tyrosinemia,

and hypothyroidism. Lastly, if an infant demonstrates signs or symptoms of sepsis, the appropriate tests should be sent to establish this diagnosis, including a urine culture. Urinary tract infections have been associated with late-onset as well as conjugated hyperbilirubinemia.

Treatment

The primary reason to evaluate infants with hyperbilirubinemia is to prevent the neurological sequelae of markedly elevated bilirubin levels by instituting the appropriate therapies aimed at decreasing serum bilirubin levels. Phototherapy is the mainstay of treatment for the majority of infants with *un*conjugated hyperbilirubinemia. In 2004, the American Academy of Pediatrics published updated clinical practice guidelines for the management of hyperbilirubinemia, which provide clear guidelines regarding the prevention and evaluation of hyperbilirubinemia, as well as follow-up of infants with a gestational age of 35 weeks or greater with this condition. Also provided are nomograms with gestational age and postnatal age-specific recommendation for the use of phototherapy and, in more severe cases, double-volume exchange transfusion (DVET). These are still in use today.

Unconjugated bilirubin absorbs light maximally in the blue portion of the visible spectrum (approximately 450 nm). Phototherapy with a light source that approximates this wavelength results in the photoisomerization of unconjugated bilirubin into a polar, water-soluble, and more readily excreted form. Both configurational and structural isomers are formed, the most common of which is lumirubin. The efficacy of phototherapy is related to the wavelength and irradiance of the light, the surface area of exposed skin, and the distance between the light source and the skin. To ensure maximal effectiveness of phototherapy, the clinician should request maximal skin exposure of the infant including removal of any head covering, use of a fiberoptic pad (or bili blanket) under the infant, and use of an irradiance of >30 $\mu W/cm^2/nm$. Irradiance can be measured with a radiometer at the bedside.

The level of TSB that warrants the use of phototherapy in infants with a gestational age of 35 weeks or greater can be determined using the standard age-specific nomogram. Several items of clinical data must be applied when using this chart. The primary determinants include gestational age, actual age, and TSB concentration. Furthermore, a review of the infant's clinical condition will reveal if there are any risk factors for acute bilirubin encephalopathy. Increased hemolysis, increased permeability of the blood–brain barrier, and decreased binding to albumin are further risk factors that can be due to isoimmune hemolytic disease, G6PD deficiency, asphyxia, lethargy, sepsis, temperature instability, acidosis, or albumin <3.0 g/dL.

The guidelines for use of phototherapy in infants less than 35 weeks gestation are not well established. Studies have not determined a safe level of bilirubin for these infants, but there is a suggestion of improved neurological outcomes with a more aggressive approach to treatment with phototherapy in babies <1000 g. Some experts suggest starting phototherapy based on the infant's birth weight or gestational age. One method to approximate the level to start phototherapy involves dividing the first two digits of the infant's birth weight by two and adding one. For example, for a 1500 g infant, consider starting phototherapy at a total serum bilirubin of 8.5 mg/dL (15/2 + 1). For consideration of performing a DVET, the clinician would use the first two digits without adjustment (15 mg/dL). In 2012, Maisels et al. published consensus-based guidelines for management of jaundice in this population of infants. These guidelines are based on gestational age instead of weight, but do approximate the method outlined above.

In some instances, the total serum bilirubin continues to rise despite the appropriate use of phototherapy, in which case hemolysis should be strongly considered as a cause. In the setting of antibody-mediated isoimmune hemolytic disease, the use of intravenous γ-globulin (IVIG) has been shown to decrease the need for a DVET with less risk to the infant. The current recommendation from AAP is to administer IVIG 0.5–1 g/kg over 2 h if the TSB is rising despite phototherapy, or the TSB is within 2–3 mg/dL of the exchange transfusion level. This dose can be repeated in 12 h. One reported complication involving the use of IVIG is the development of necrotizing enterocolitis.

For some infants, the use of phototherapy and IVIG is not sufficient to control the rising bilirubin level. Alternatively, some infants may have neurological sequelae of bilirubin toxicity despite bilirubin levels below suggested therapeutic levels. In these instances, a DVET is indicated. This process is labor intensive and must be anticipated far in advance. Preparatory steps include acquiring a sufficient volume of blood, establishing adequate vascular access, and setting up the equipment, including a blood warmer. This often takes hours to complete. A DVET involves removing twice the infant's blood volume with simultaneous isovolemic replacement of reconstituted whole blood. This process achieves two separate but related goals: it removes bilirubin and, in the setting of isoimmune hemolytic disease, it removes the offending maternal antibodies. Some experts suggest performing a DVET at even lower levels than recommended in the guidelines when significant antibody-mediated hemolysis is occurring.

To calculate the amount of blood to order and exchange, estimate the infants blood volume (between 80 and 100 mL/kg based on level of prematurity and amount of perinatal blood loss) and multiply the result by two. In general, blood is ordered as reconstituted whole blood, using O-negative red blood cells and AB-positive plasma. Blood should be withdrawn at a rate of 1–2 mL/kg/min and simultaneously replaced at the same rate. Exchange of twice the infants

blood volume in this manner replaces approximately 86 % of the infant's own blood (a single volume exchange replaces approximately 63 %). The distribution of bilirubin in both the intravascular and extravascular spaces does not allow for the removal of an equivalent percentage. One can expect a bilirubin level of approximately 45 % of pre-exchange levels at the conclusion of the procedure and the eventual rebound to at least 60 % of pre-exchange levels. Some infants require more than one DVET.

The optimal method for performing a DVET involves two operators, one responsible for blood removal and the other for infusion. This continuous process is best done using an umbilical arterial catheter for withdrawal and umbilical venous catheter with the tip above the diaphragm for infusion. Other combinations are possible and include variations of umbilical and peripheral catheters. If only one line can be inserted, a push–pull technique can be employed to remove and then infuse blood in small aliquots. This technique is more time consuming and more prone to both error and complications.

There are many potential complications associated with the DVET. These include electrolyte disturbances, arrhythmias, cardiac arrest, thrombotic or embolic sequelae, metabolic acidosis, thrombocytopenia, DIC, infection, necrotizing enterocolitis, temperature instability, and blood-borne infection. Before, during, and after the procedure, attention should be paid to the following blood tests: serum electrolytes (especially calcium), blood glucose, bilirubin, CBC, and reticulocyte count. Some experts utilize a calcium infusion during the procedure, especially if the blood products contain citrate, which chelates calcium. Serial bilirubin levels should be followed after the procedure to ensure the rebound is not significant enough to warrant repeat DVET.

Editor's Comment

Depending on the admission standards at a given institution, infants in the neonatal intensive care unit who need surgery are often admitted to the Surgery service. Regardless of the arrangement, surgeons need to monitor their newborn patients for hyperbilirubinemia for several important reasons. The first is that any newborn can develop hyperbilirubinemia and might be at higher risk for brain injury due to their exposure to other potential neurotoxins in the form of drugs and anesthetics. Second, elevated levels of conjugated bilirubin can be a sign of parenteral nutrition-associated cholestasis and impending liver dysfunction, in which case measures must be taken to prevent progression of this disease process including cycling of the parenteral nutrition, advancing enteral feeds as tolerated, and considering supplements such as omega-3 fatty acids. Finally, infants with a persistent elevation of conjugated bilirubin must be considered to have biliary atresia until proven otherwise. The success rate of establishing biliary drainage and avoiding liver transplantation diminishes significantly the later infants with biliary atresia undergo Kasai portoenterostomy.

It is often surprisingly difficult to distinguish the infant with biliary atresia from the more common case of parenteral nutrition-induced cholestasis. It is reasonable to start with an ultrasound to confirm the presence of a gallbladder and then proceed with HIDA scan if there is still some question. It is not uncommon for there to remain some concern about the differential diagnosis, in which case some recommend liver biopsy, though even experienced pathologists can have difficulty distinguishing the two entities. It is occasionally necessary to proceed with an intra-operative cholangiogram to confirm the presence of patent bile ducts. The one consolation in the case of a negative study is that infants with cholestasis often appear to benefit from having their biliary tree flushed and cleared of inspissated bile. Many are also at risk for gallstones and therefore benefit from what is essentially a prophylactic cholecystectomy.

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Biliary Atresia

78

Joseph B. Lillegard, Avery C. Miller, and Alan W. Flake

Biliary atresia (BA) is an uncommon disease occurring in 1/10,000–15,000 live births worldwide. It is an obliterative cholangiopathy characterized by inflammation of the bile ducts leading to progressive fibro-proliferative obliteration of the extrahepatic biliary tree and, to a variable extent, the intrahepatic bile ducts. The progressive destruction of the intra- and extrahepatic bile ducts leads to cholestasis, liver fibrosis, and cirrhosis.

The etiology of biliary atresia remains unknown but is likely multi-factorial involving environmental, genetic, and immunologic factors. In the most common form, acquired BA (75–90 % of patients), infants develop jaundice within 3–4 weeks of birth. BA in this setting is not secondary to true agenesis of the bile ducts, but rather a progressive inflammatory process. One theory suggests that it is caused by an antecedent infection followed by a progressive autoimmune-mediated bile duct injury. This notion is supported by a clinically defined subgroup of infants with BA and positive cytomegalovirus (CMV) serology as well as an established murine model of BA, which is induced by neonatal infection with rhesus rotavirus (RRV). An autoimmune hypothesis is further supported by data demonstrating a strong predominance of lymphocytic cell infiltrate, in particular regulatory T-cells, at the level of the fibrous plate. Some have suggested that the extrahepatic bile ducts are the site of the autoimmune process and the consequences to the liver seen on biopsy are secondary to manifestations of outflow obstruction.

A second group of patients with BA will present with it at birth and the condition is associated with other congenital anomalies (Table 78.1). Syndromic, embryonal, or fetal biliary atresia occurs in 10–25 % of cases and these patients will not typically have a jaundice free period after birth. Approximately 25 % of patients with BA are syndromic, with about half of these patients having one anomaly and half with more than one. The most common anomalies are splenic malformations, interrupted IVC, cardiac malformation, and malrotation. Of the patients with more than one anomaly, some will have biliary atresia splenic malformation (BASM) syndrome. There have been a number of associated gene defects implicated in syndromic BA patients, in particular those genes associated with hepatic nuclear factor 3, the TGF-beta superfamily, and aneuploidy of chromosome 22; however, this represents an area where more research is required to determine the exact role these and other gene defects have on the development of BA.

Both anatomic and clinical classifications systems have been developed to characterize different types of biliary atresia. The anatomic systems are based on the patency of the extrahepatic biliary tree. One commonly used anatomic system describes three types of biliary atresia: type I is atresia of the common bile duct, type II atresia at the hepatic duct, and type III atresia at the porta hepatis, which is the most common. Types I and II have historically been referred to as "correctable" biliary atresia because it was once felt that when a patent extrahepatic bile duct exists it could be used for reconstruction. It is now recognized that even the "correctable" forms of biliary atresia should be treated by portoenterostomy.

Types I and II account for 10–15 % of all cases, and the majority (85–90 %) are type III. Recently an additional anatomic variant not previously included in the traditional anatomic BA classification scheme has been described. Cystic biliary atresia (CBA) is uncommon, but an increasingly recognized distinct variant of BA, currently accounting for

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Table 78.1 Anomalies associated with syndromic biliary atresia

Splenic malformations (asplenia and polysplenia)
Interrupted IVC (suprarenal) with azygous continuation
Cardiac malformations
Intestinal malrotation
Aberrant hepatic arterial supply (left hepatic from left gastric or SMA)
Situs inversus
Preduodenal portal vein
Annular pancreas
Duodenal, esophageal, or jejunal atresia

approximately 10 % of cases. CBA is the only variant of BA that can be diagnosed antenatally. Diagnosis has been made in as many as 50 % of patients using prenatal US. CBA has a more favorable prognosis than other forms of BA, but it can be confused with choledochal cysts thereby delaying definitive treatment affecting the long-term prognosis for these patients. CBA is best differentiated from choledochal malformations using cholangiography (Fig. 78.1). The presence of a normal intrahepatic ductal pattern rules out the presence of biliary atresia. Cysts within the hilum of the liver communicating multiple thin filmy "hairy" intrahepatic bile ducts should confirm the diagnosis of CBA. The improved prognosis seen in these patients appears to be related to their early diagnosis and improved bile drainage from these fine intrahepatic bile ducts.

Both the anatomic and clinical classification systems have prognostic value with higher rates of liver transplantation and higher mortality rates reported in patients with type III biliary atresia and in patients with syndromic biliary atresia.

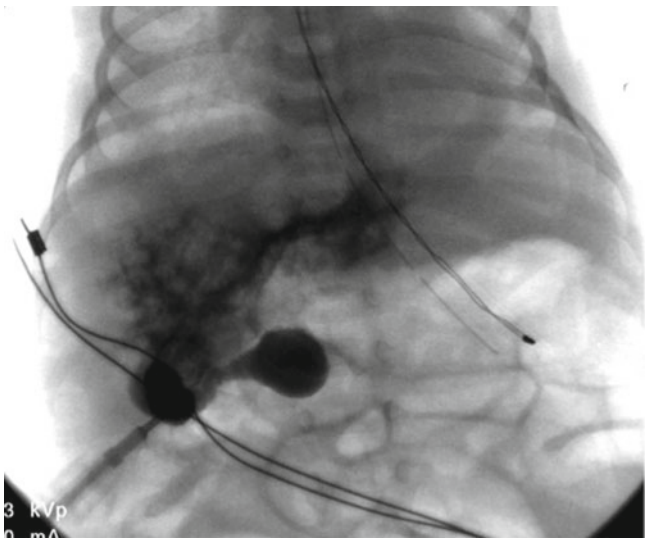

Fig. 78.1 Cholangiogram of cystic biliary atresia

Diagnostic Workup

The typical patient with biliary atresia is a full-term, normal birth weight, healthy appearing infant who develops persistent prolonged jaundice by weeks 4–6 of life with icteric sclera and skin, acholic stools, dark urine, and hepatomegaly. There is often a delay in the diagnosis of biliary atresia because up to 66 % of newborns develop jaundice with the overwhelming majority of cases due to either physiologic jaundice (usually lasts only 2–3 days) or breast milk jaundice (can last up to 4 weeks with >20 % of cases lasting at least 3 weeks) and only a minority of cases due to neonatal cholestasis (1/500 cases of jaundice in infants 2–4 weeks old).

Biliary atresia should be suspected and worked up in any infant who remains jaundiced for >2 weeks (3 weeks if breastfed) because earlier diagnosis and surgical intervention have been shown to lead to improved outcomes. It is recommended that total and direct bilirubin levels be checked in any infant who is jaundiced at 3 weeks. Physiologic and breast milk jaundice are related to liver immaturity with increased bilirubin production, decreased bilirubin clearance and excretion, and excessive enterohepatic recirculation; therefore, the total bilirubin level will be elevated but the direct or conjugated level should be low (<20 % of total). Neonatal cholestasis is due to intrinsic liver disease and dysfunction, therefore the total bilirubin will be elevated with >20 % being direct or conjugated bilirubin. In BA specifically, the conjugated bilirubin levels may comprise 50–80 % of the total bilirubin level.

An infant with evidence of neonatal cholestasis (elevated total bilirubin with >20 % direct bilirubin) must undergo a complete workup to rule out both extrahepatic and intrahepatic causes (Table 78.2). As surgeons we are most often involved in excluding the extrahepatic causes of neonatal cholestasis; however, this should be preceded by a thorough medical workup to exclude infectious, metabolic, genetic, and toxic causes of cholestasis.

The evaluation of extrahepatic causes of neonatal jaundice starts with laboratory tests demonstrating increased serum ALT, AST, alkaline phosphatase, and GGT (which are usually disproportionately elevated in biliary atresia), and an elevated total bilirubin with >20 % direct bilirubin. A fasting abdominal US should be obtained and will often demonstrate an enlarged liver and a contracted or absent gallbladder. Other findings that have been reported with a focused and detailed US include an abnormal gallbladder wall, shape or contractility, absence of the common bile duct, a triangular cord sign (a focal area of increased echogenicity anterior to the bifurcation of the portal vein representing the fibrotic remnant of the extrahepatic biliary tree in biliary atresia), and enlarged hepatic artery diameter. The results from US are both technician and center dependent and therefore highly variable in their diagnostic value. US

Table 78.2 Differential diagnosis

Extrahepatic causes:
Biliary atresia
Choledochal cyst
Inspissated bile plug (CF pts)
Gallstones
Bile duct stricture or stenosis
Spontaneous perforation of the CBD
Tumor
Intrahepatic causes: (abbreviated list
Toxic:
Total parenteral nutrition
Medications
Infectious:
Viral (hepatitis, herpes, adenovirus, enterovirus, and HIV)
Bacterial sepsis
Metabolic/genetic:
Alagille syndrome
Mitochondrial disorders
Cirhin deficiency
Alpha-1 antitrypsin deficiency
Cystic fibrosis
Hemochromatosis
Disorders of glucose, amino acid, lipid, or bile acid metabolism
Idiopathic neonatal hepatitis

cannot confirm the diagnosis, but it can exclude other extrahepatic causes of neonatal cholestasis (choledochal cyst).

Hepatobiliary scintigraphy is often obtained to assess the patency of the extrahepatic bile ducts. It can exclude the diagnosis of biliary atresia when bile flow into the duodenum is demonstrated. In cases of biliary atresia, hepatobiliary scintigraphy usually demonstrates good hepatic uptake with absent or reduced excretion at 24 h. The diagnostic value of hepatobiliary scintigraphy can be improved by using the isotope technetium-99 labeled diisopropyliminodiacetic acid (DISIDA scan) in conjunction with phenobarbital preconditioning (to increase biliary excretion) and obtaining 24 h images. The sensitivity of hepatobiliary scintigraphy approaches 100 %, but specificity ranges widely (40–100 %). The findings of hepatobiliary scintigraphy remain nonspecific and additional workup is required.

Percutaneous liver biopsy is often the next step in the diagnostic workup. In BA, the liver biopsy usually demonstrates expanded fibrous portal tracts with edema, fibrosis, and inflammation, bile ductule proliferation, and canalicular and bile duct plugs consistent with cholestasis (Fig. 78.2). Although these histologic findings are diagnostic of neonatal cholestasis, they are non-specific and the differential diagnosis can still include biliary atresia, choledochal cyst, bile duct stricture or stone, and other toxic, metabolic, or genetic causes depending on the results of the other diagnostic studies obtained. The final step and the standard study for the diagnosis of BA is abdominal exploration with cholangiogram, which will demonstrate an atretic biliary tree (Fig. 78.3).

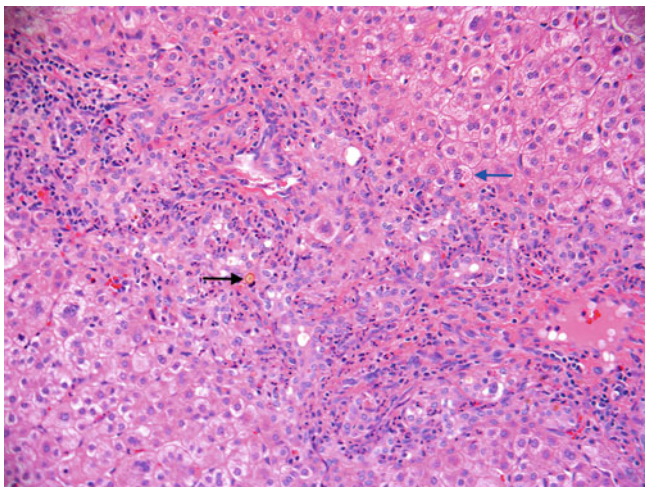

Fig. 78.2 Histologic section of liver demonstrating typical findings confirming the diagnosis of biliary atresia. Characteristic changes include portal tract expansion and fibrosis, bile ductular proliferation and periductular inflammation, bile pigment within bile duct lumina consistent with "plugging" (*solid arrow*), and enlarged surrounding hepatocytes with some showing multi-nucleation (*outlined arrow*) and intracellular cholestasis. H&E, 200x original magnification. (Photo courtesy of Dr. Tricia Bhatti, Faculty Director, Division of Anatomic Pathology, The Children's Hospital of Philadelphia.)

Newer modalities being used to evaluate patients with suspected biliary atresia include ERCP and MRCP. These are not routinely used because of limited availability and experience with these procedures in neonates. Both have theoretical value in the diagnostic workup of biliary atresia and may play a more prominent role in the future.

Preoperative Preparation

One of the most important aspects of preoperative care is a thorough and rapid workup with diagnosis and surgical treatment as quickly as possible. Earlier age at treatment has been consistently shown to lead to improved overall survival and survival without liver transplantation. In addition, adequate preoperative and postoperative nutrition has been shown to lead to improved outcomes, therefore periods without nutrition should be minimized and fat-soluble vitamins and supplemental enteral feedings may be necessary. Finally, family education is essential, with attention to the possible immediate complications in the perioperative period, the potential for the portoenterostomy not to provide adequate biliary drainage with the need for liver transplantation within the first year of life, and the progressive nature of the disease in some patients with development of liver fibrosis, cirrhosis,

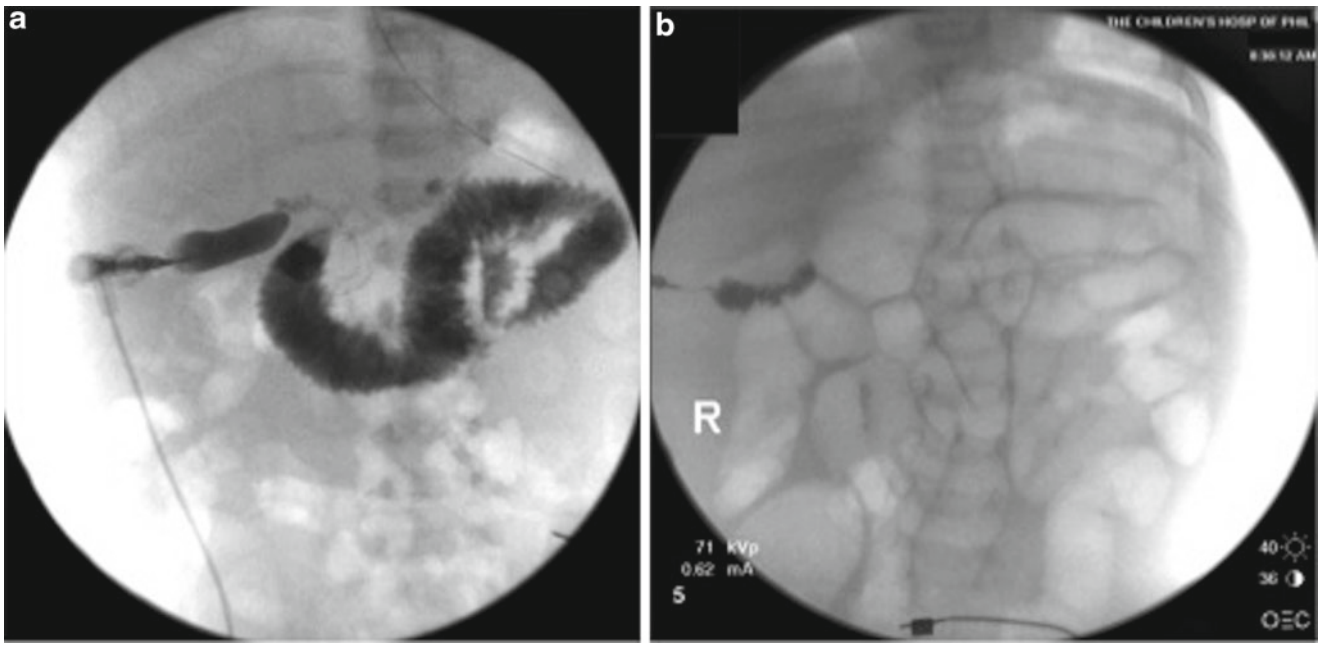

Fig. 78.3 Intraoperative cholangiogram. (**A**) Type II. (**B**) Type III

and the need for liver transplantation over time. In addition, families of patients with BASM or syndromic biliary atresia should be made aware of the worse outcomes in this patient subgroup.

Treatment

The treatment of biliary atresia is surgical, with hepatic portoenterostomy and liver transplantation (when necessary). Without definitive surgical therapy, the natural history of biliary atresia is marked by progressive liver fibrosis and cirrhosis with death due to end stage liver disease within 2 years. Most patients with biliary atresia should undergo a portoenterostomy except patients who present late (>120 days old) with signs of liver cirrhosis (significant ascites or variceal hemorrhage as a result of portal hypertension), who should be considered for primary liver transplantation.

The goal of the portoenterostomy (the Kasai procedure) is to relieve cholestasis by establishing bile flow from any remaining patent small bile ducts below the fibrous plate of the liver capsule. Portoenterostomy is performed under general endotracheal anesthesia with placement of upper extremity venous access and a nasogastric tube. We begin our procedures with a 2-cm subcostal incision over the position of the gallbladder. If the gallbladder is a fibrotic remnant without a lumen, then a cholangiogram can be omitted. Otherwise, the gallbladder is dissected out of its fossa and a cholangiogram is attempted by placing a purse-string suture in the dome of the gallbladder, excising the tip of the gallbladder, and inserting a small IV cannula (22–24 Fr). With the catheter secured in place, contrast material is injected under fluoroscopic guidance. Failure of flow of contrast material into the duodenum or liver confirms the diagnosis of biliary atresia.

If the cholangiogram confirms BA, the incision is extended to a full right subcostal incision. The liver is mobilized by taking down the falciform and triangular ligaments and the liver should be brought out of the incision exposing the area of the hilum. Next, we perform a meticulous dissection of the hilum and preparation of the fibrous plate for portoenterostomy (Fig. 78.4). The hepatic artery and its branches are identified and dissected. The underlying portal vein is identified and dissected free at its bifurcation, clearing its upper margin away from the fibrous plate and liver capsule to provide a rim of liver capsule for the portoenterostomy. This portal dissection is carried out to the first branches of the hepatic arteries bilaterally.

The cystic artery is ligated, the gallbladder is taken down off of the hepatic bed, and any common bile duct remnants are dissected and divided leaving the extrahepatic ductal remnants attached only at the fibrous plate. Next, fine monofilament traction sutures are placed circumferentially around the fibrous plate to the depth of the liver capsule. The fibrous plate is then placed on maximal traction and sharply divided with Metzenbaum scissors at the depth of the liver capsule. At the completion of this division, a smooth, glistening cut surface of the fibrous plate should be present without exposure of the liver parenchyma. Hemostasis is achieved by placing an epinephrine-soaked gauze over the fibrous plate. The specimen should be oriented and sent to pathology.

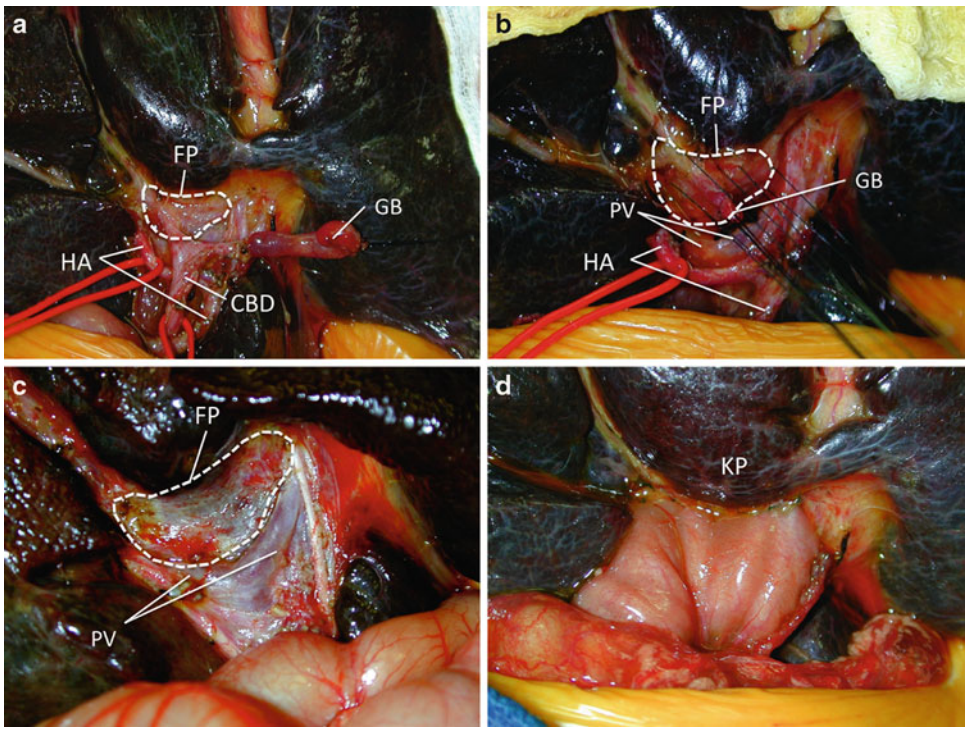

Fig. 78.4 The Kasai portoenterostomy. (**A**) Exposure of the area of the fibrous plate (FP—*dotted line*) prior to division of the common bile duct (CBD) remnant. The hepatic arteries (HA) have been dissected to their first hepatic branch and the gall bladder (GB) dissected off the liver. (**B**) The portal vein (PV) bifurcation has been dissected away from the FP and traction sutures placed around the margins of the plate. (**C**) The transected fibrous plate. Note the glistening fibrotic surface and the bile staining around the periphery of the plate. (**D**) The completed portoenterostomy

The liver is then placed back into the abdominal cavity and a Roux-en-Y jejunal limb is created. The proximal jejunum is divided 10–20 cm distal to the ligament of Treitz and a Roux limb (15 cm) is created by performing an end-to-side jejuno-jejunostomy with a single layer of interrupted absorbable sutures. The mesenteric defect is then closed and the Roux limb is passed through the transverse mesocolon for a retrocolic anastomosis. The liver is then re-eviscerated and the fibrous plate is examined for hemostasis. With adequate hemostasis, an enterotomy is made in the antimesenteric border of the Roux limb to approximate the size of the fibrous plate. A portoenterostomy is then performed using interrupted fine absorbable monofilament sutures. The posterior rim of the anastomosis between the area of the portal vein and the fibrous plate is performed with horizontal mattress sutures with the knots tied internally. The anterior half of the anastomosis is then completed with the knots tied externally. The viscera are then placed back into the abdominal cavity, hemostasis is confirmed, and the incision is closed in layers.

Laparoscopic portoenterostomy has also been described. Since its first description in the literature in 2002, only limited reports have been published and long-term results are still lacking. Proposed advantages of the laparoscopic approach include faster recovery, less postoperative pain, shorter hospital stay, better cosmesis, and reduced adhesion formation, which has implications for possible subsequent liver transplantation. The data suggest that there are no significant differences between the two groups with regard to operative time, hospital stay, intraoperative blood loss, early clearance of jaundice, cholangitis, or variceal bleeding; however, the rate of 2-year native liver survival appears to be significantly higher in the open group compared with the laparoscopic group, suggesting there might be a qualitative technical difference between the two approaches. Furthermore, though there are fewer adhesions noted after laparoscopic portoenterostomy, patients who have undergone liver transplantation after open or laparoscopic portoenterostomy show no significant difference in the need for blood transfusions, operative time, or the need for reoperation. Thus, despite the appeal of the laparoscopic Kasai, current literature does not support any major clinical advantages over the traditional open operation, with concerns lingering over the ability to perform the same quality operation with the laparoscopic approach.

Postoperative Care

Postoperative care after portoenterostomy is focused on determining if bile flow has been established, preventing postoperative complications and maintaining adequate nutrition. Patients with BA have ongoing issues with malnutrition from fat malabsorption leading to fat-soluble vitamin deficiencies and increased caloric needs. These patients require life-long nutritional support with oral fat-soluble vitamin supplementation and a high calorie, high protein diet with more than 125 % of the recommended daily allowance for calories. In some patients, supplemental nocturnal feedings

with semi-elemental formulas and medium chain triglycerides may be necessary to meet nutritional goals.

Immediate postoperative complications such as bleeding and anastomotic leak can occur and must always be considered in neonates doing poorly after portoenterostomy. In addition, ascites is sometimes exacerbated in the immediate postoperative period, particularly in patients with significant cirrhosis, and requires careful fluid management. Prophylactic antibiotics are administered before, during, and after the operation. These neonates are at especially high risk of cholangitis, with 45–60 % experiencing at least one episode, usually within the first year of life (>50 % of episodes occur within 6 months and 90 % within the first year). The incidence of cholangitis correlates inversely with bile flow. Many centers administer oral prophylactic antibiotics for 3–12 months postoperatively to prevent cholangitis, however there is no strong evidence to support this practice. We give trimethoprim-sulfamethoxazole prophylactically in the postoperative period at resumption of oral diet. Patients with acutely rising bilirubin levels, who initially achieved good drainage after a Kasai procedure, should be considered for revision of the portoenterostomy, but this is an uncommon circumstance and revision is generally discouraged.

In addition to preventing complications, medical therapies have been used in attempt to stimulate bile flow and reduce inflammation. Ursodeoxycholic acid has proven benefits in the treatment of adults with primary biliary cirrhosis, sclerosing cholangitis, and other cholestatic liver diseases. Studies examining the use of UDCA in children with biliary atresia are scarce, but there is some evidence that it can help certain children maintain a good flow of bile.

Corticosteroids are another therapy used at many centers. Proposed benefits include stimulation of choleresis by inducing canalicular electrolyte transport, limitation of the development of bile duct injury and fibrosis, and prevention of the closure of microscopic bile ducts in the postoperative period through their anti-inflammatory and immunosuppressive effects. There is a lack of consensus on the impact of steroids on outcomes in biliary atresia. Some retrospective studies have suggested an improved outcome however several multi-institutional studies performed around the world have produced mixed results. Most believe that the risks of corticosteroids outweigh the small potential benefit and so its routine use seems to be decreasing. With an autoimmune process as a dominant possible etiology for the development of acquired BA, research is underway to study the effects of intravenous immunoglobulin (IVIG). High-dose IVIG attenuates bile duct inflammation and injury in a mouse model of BA, while in humans studies are underway to determine if it might be useful in children with BA.

Several factors that influence the success rates of portoenterostomy have been identified in published series (Table 78.3). Age at treatment has been consistently associated with better long-term native liver survival. The best results are seen in patients who undergo the operation before age 30 days and then outcomes are less encouraging with increasing age thereafter. In most reports the best outcomes were reported when portoenterostomy is performed before 60 days; this relationship may be explained by age serving as a proxy for the extent of liver damage present at the time of the procedure. Histologic features of the excised biliary remnants, including a smaller number and cross-sectional area of residual biliary ductules, indicate a lower probability of successful restoration of bile flow with portoenterostomy. In the UK there appears to be an impact of surgeon and center expertise on outcome with centralization of care of biliary atresia leading to improved 5-year survival with native liver (pre-centralization: 40 %; after centralization: 60 %). To date, these findings have not been reported in centers in the USA. The presence of syndromic biliary atresia or BASM has been associated with lower overall survival and survival with native liver (4-year survival and survival with native liver: with BASM 75 % and 30 %; without BASM 90 % and 45 %); this worse outcome has been attributed in many series to the associated cardiac anomalies. The anatomy of the extrahepatic biliary remnant also affects outcome with improved 10-year survival with native liver reported in patients with "correctable" (Types I or II) biliary atresia (10-year survival with native liver: no patent ducts 20 %, patent gallbladder, cystic duct, and common bile duct 35 %, cyst at the liver hilum with communicating dystrophic intrahepatic ducts 50–60 %, and atresia of common bile duct only 85 %). In addition, the presence of cirrhosis or liver fibrosis at time of portoenterostomy indicates a higher risk of developing advanced liver disease and requiring liver transplantation in the future. The occurrence of postoperative cholangitis has also been considered a risk factor for progressive liver fibrosis and cirrhosis and a marker of poor bile drainage.

There are three important measures of outcome with regard to the surgical management of biliary atresia: percentage clearance of jaundice, native liver survival, and overall survival. Postoperative total bilirubin levels at 3 months strongly correlate with outcome of portoenterostomy: bilirubin levels <2 mg/dL are predictive of good outcomes while levels >6 mg/dL are predictive of poor outcomes at 2 years.

Table 78.3 Factors influencing outcomes after portoenterostomy

Age at treatment
Histologic characteristics of residual biliary ductules
Surgeon and center expertise
Syndromic biliary atresia or BASM
Anatomic pattern of biliary atresia
Episodes of cholangitis
Presence of cirrhosis at the time of surgery

Finally, hepatobiliary scans demonstrating bile flow at either 6 weeks or 6 months after portoenterostomy are predictive of longer-term survival with native liver.

Portoenterostomy adequately restores bile flow in 40–60 % of patients. Subsequently, the course of the disease is highly variable with many patients developing cirrhosis and complications of portal hypertension due to ongoing intrahepatic biliary injury. Overall, 20–30 % of patients have long-term stability of their disease with reported 10- and 20-year survival rates with native liver of 30–35 % and 15–25 %, respectively. Of patients with biliary atresia who survive more than 20 years with their native liver, just over 60 % develop liver-related complications such as cholangitis, portal hypertension, gastrointestinal bleeding, and hepatocellular carcinoma.

Transplantation

Biliary atresia is the leading indication for pediatric liver transplantation accounting for over 40 % of all pediatric liver transplants and >75 % of liver transplants in children <2 years old. Despite an adequately draining portoenterostomy, progressive fibro-proliferative obliteration of the intrahepatic biliary ducts leads to fibrosis, cirrhosis, and liver failure in many patients with 70–80 % of all patients undergoing portoenterostomy eventually developing a need for liver transplantation. Common indications for liver transplantation in biliary atresia patients include, in order of decreasing frequency: poor early response to portoenterostomy with persistently acholic stools, high bilirubin levels (>6 mg/dL at 3 months), and complications such as failure to thrive, ascites, or variceal hemorrhage; late-onset (adolescence) cholestasis with development of cirrhosis with hepatic dysfunction; primary treatment for neonates with a late presentation (>120 days old or with significant ascites or variceal hemorrhage as complications of portal hypertension); recurrent cholangitis; portal hypertensive bleeding in the setting of high total bilirubin levels or if refractory to endoscopic management; and refractory ascites with advanced liver disease.

Outcome after liver transplantation is excellent with 1-, 5-, and 10-year patient survival rates of 95 %, 90 %, and 88 % and graft survival rates of 87 %, 82 %, and 81 %, respectively. Furthermore, patients demonstrate a period of catch-up growth and normal development after liver transplantation. Malnutrition adversely affects both waiting list and post-transplantation mortality; therefore, aggressive use of fat-soluble vitamin supplementation, supplemental enteral feedings, and medium chain triglyceride enteral nutrition formulas should be considered in patients with progression of biliary atresia. Overall long-term patient survival rates greater than 90 % are now being achieved with portoenterostomy and liver transplantation options.

Future Directions

Biliary atresia is a rare disease that needs to be better understood. Ongoing efforts to characterize the etiology of this disease may lead to the development of new treatments. In the meantime, international initiatives between medical centers have been formed to facilitate studying the clinical aspects of this disease and to perform definitive clinical trials of treatments.

In addition to these research initiatives, new screening methods and physician education could potentially improve outcomes in biliary atresia by leading to earlier diagnosis and quicker portoenterostomy. One promising screening tool is a stool color card, which when given to parents prior to discharge from the hospital have led to an earlier diagnosis of biliary atresia with ~80 % of cases of biliary atresia diagnosed before 30 days of age and 90 % before 60 days of age. Large studies investigating the impact of stool cards are ongoing. Other screening modalities being investigated include measuring direct bilirubin levels in blood spots and blood specimens. Beyond screening, physician education and awareness may play a role in improving outcomes. This includes educational initiatives to increase awareness that infants with jaundice persisting into the 2nd and 3rd weeks of life need to be worked up for causes of neonatal cholestasis and potentially altering the routine follow-up visit schedule for newborns. (In the USA follow-up visits are at 2 and 8 weeks of age with the peak presentation of biliary atresia at 4–6 weeks of age). Finally, from a surgical perspective, advances in liver transplantation and immunosuppression could lead to improved outcomes in patients with biliary atresia.

Editor's Comment

Biliary atresia is a rare disease with an unknown etiology that generally occurs in a full-term infant who develops persistent jaundice and acholic stools within the first month of life. There is a typical delay in the diagnosis of biliary atresia due to the frequency with which newborns develop perinatal physiologic jaundice. However, biliary atresia should be suspected and worked up in an expeditious fashion in any infant who remains jaundiced after 2–3 weeks of life. This has to be the overwhelming take-home message because surgical intervention with Kasai portoenterostomy performed in a timely fashion is associated with much better outcomes. The principle behind Kasai portoenterostomy is to allow decompression of bile (lymph?) from the atretic bile ducts to pass through tiny canaliculi located at the fibrous portal plate, where normal bile ducts would converge to become the hepatic ducts. The critical maneuver therefore is meticulous technical dissection of the portal plate and establish-

ment of the proper excision plane of this fibrous plate to expose these microscopic ducts above the level of the bifurcation of the portal vein. This excision of the portal fibrous plate must be neither too superficial nor too deep into the liver parenchyma, as though shaving a thin slice of thickened capsule, and should be made with a fresh blade or very sharp tenotomy scissors—it needs to be at just the right level. Encouraging features of achieving a successful level include weeping of clear yellow biliary fluid and minimal bleeding. Should bleeding occur it should be controlled with pressure with warm gauze and avoidance of electrocautery to prevent further damage to these fragile ductules.

The standard diagnostic approach (US, DISIDA, percutaneous liver biopsy, intraoperative cholangiogram, in that order) is invasive but highly accurate. There are some children who undergo a laparotomy and cholangiogram and are found to not have biliary atresia; but even when biliary atresia has been ruled out, the diagnosis is usually cholestasis, in which case flushing the extrahepatic biliary tree of inspissated bile and sludge by performing a cholangiogram is often therapeutic.

Children with biliary atresia clearly have better outcomes when a meticulous portoenterostomy is performed early in the course of the disease by a surgeon with a great deal of experience. However, patients do best when they are cared for in a tertiary care center with expertise in gastroenterology, hepatology, nutrition, pathology, radiology, and nursing. In some centers pediatric transplant surgeons perform the portoenterostomy. Postoperative care is paramount and includes meticulous attention to nutrition particularly medium chain triglycerides, careful monitoring of weight gain and fat-soluble vitamins. The utility of ursodeoxycholic acid remains questionable. Corticosteroids have fallen out of favor given their lack of clear benefit and known risks; we no longer administer corticosteroids to our patients. The traditional approach is to revise the portoenterostomy if the child drains initially and then stops draining, and to proceed to liver transplantation if adequate drainage is never achieved.

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Congenital Intrahepatic Cholestasis

79

Marie V. Nguyen and Kasper S. Wang

Most children with congenital intrahepatic cholestasis disease, such as progressive familial intrahepatic cholestasis (PFIC) and Alagille disease (ALGS), develop some degree of pruritus, which in many children can be severe enough so as to Ileal exclusion (IE) impact all aspects of everyday life. Medications used to treat pruritus, including phenobarbital, rifampicin, ursodeoxycholic acid (UDCA), and orally administered bile acid-binding resins such as cholestyramine, can ameliorate symptoms. In the setting of intractable pruritus, surgical interventions should be considered. Amongst all the surgical options, partial external biliary diversion (PEBD), which involves surgically creating an enteric conduit between the gallbladder and skin, diverting approximately 50 % of bile flow away from the enterohepatic circulation, is the most established and commonly performed surgical intervention for the treatment of intractible pruritus. The postulated mechanism of action of all surgical options for the treatment of pruritus involves interruption of the enterohepatic circulation, which reduces the load of bile acids and thus the accumulation of bile acids and pruritogens. If surgical bypass procedures fails to reduce symptomatology, liver transplantation remains the only other treatment, particularly in the setting of cirrhosis.

Disorders of Intrahepatic Cholestasis

There are three subtypes of PFIC, each with a specific genetic mutation which leads to defective transport proteins. PFIC type 1, or Byler disease, now known as FIC1 syndrome, is a systemic disorder caused by mutations of the *ATP8B1* gene on chromosome 18q21-22, which encodes the FIC1 protein. Most patients with FIC1 disease experience episodes of severe cholestasis eventually progressing to liver failure by the second decade of life. On electron microscopy, coarse granular bile within dilated canaliculi ("Byler's bile") is pathognomonic for FIC1 disease. The mechanism is hypothesized to be phospholipid membrane instability leading to diminished bile acid transport. Some mutations in *ATP8B1* are associated phenotypically with somewhat milder disease known as Benign Recurrent Intrahepatic Cholestasis (BRIC) type 1. BRIC1 patients manifest many of the clinical features of FIC1 syndrome, including pancreatitis and diabetes, although the majority of BRIC1 patients do not progress to chronic liver disease despite recurrent attacks of cholestasis. Liver transplantation for FIC1 has been associated with worsening extrahepatic manifestations, and should only be considered if PEBD fails.

PFIC2 is caused by mutations in *ABCB11*, which encodes bile salt export pump (BSEP), the major canalicular bile acid pump. Loss of BSEP function results in severe hepatocellular cholestasis. Liver histology of PFIC2/BSEP patients reveals more inflammation than in FIC1, with amorphous or filamentous bile seen on EM. Although cirrhosis and liver failure often occur within the first decade, recurrent cholestasis following liver transplantation has been reported in children with BSEP disease and is associated with significant morbidity and mortality. The third subtype of PFIC is caused by mutations in the *ABCB4* gene, which encodes the MDR3 flippase required for biliary phosphatidylcholine secretion. Symptom onset and liver failure in patients with MDR3 disease typically occur later in life than the other PFIC types, ranging from 1 month to over 20 years, with earlier onset associated with protein-truncating mutations compared to patients with missense mutations.

Diagnostic criteria for PFIC include early onset of unremitting cholestasis and absence of anatomic obstruction. Serum gamma-glutamyltransferase (GGT) levels can be applied in the initial differentiation of the PFIC subtypes, with low levels seen in FIC1 and BSEP disease, and elevations up to ten times the normal level in PFIC3. Disorders of primary bile acid synthesis have presentation similar to PFIC, but are excluded by high serum bile concentration.

Alagille disease (ALGS) is caused by mutations in either *JAGGED1* or *NOTCH2*, genes encoding the essential ligand

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and receptor, respectively, for Notch signaling, which is critical for biliary organogenesis. Pathologically, the ALGS liver manifests the absence or paucity of bile ductules within portal triads secondary to functional loss of Notch signaling. ALGS patients with cholestasis may manifest disabling pruritus, and potentially xanthomata. The estimated prevalence is 1 in 70,000 live births, although this is likely an underestimate since the diagnosis is based on the presence of liver disease, which does not manifest in all patients with ALGS. Clinically, patients with ALGS may have distinctive facial features including a broad, prominent forehead, deep-set eyes, and a small, pointed chin. Alagille disease (ALGS) patients may have cardiac defects including tetralogy of Fallot and vascular abnormalities within the central nervous system and kidneys. Affected individuals may also have butterfly vertebrae. Genetic testing is performed if the diagnosis is suspected. An estimated 20–30 % of patients ultimately require liver transplantation.

Medical Management of Pruritus

Given the unclear pathogenesis of cholestatic pruritus, medical treatment remains largely empiric. Patients affected by cholestatic pruritus typically describe a circadian rhythm and characteristic pattern of itching, with most exacerbations occurring in the evenings, frequently localized to the palms and soles. However, the severity of cholestasis has never been correlated with the frequency or intensity of pruritus. Pruritogenic substances are thought to be synthesized by the liver, given the resolution of pruritus following liver transplantation. Anti-pruritic strategies, short of treating the underlying cholestatic disorder, include a range of pharmaceutical agents. These agents include those broadly aimed at removal of pruritogens from the enterohepatic circulation with non-absorbable exchange resins such as cholestyramine; metabolic modification of putative enzyme inducers of pruritogens with rifampin or phenobarbital; and attenuation of central or systemic pruritus with opioid antagonists such as naloxone or naltrexone. Systemic removal of potential pruritogens by anion absorption, plasmapheresis, or dialysis is a last-resort. Randomized, placebo-controlled trials are still needed to validate these treatments. Despite wide use, the therapeutic effect of UDCA in pruritus remains uncertain.

Surgery

The various surgical procedures, used to treat pruritus, deplete the bile salt pool by interruption of the enterohepatic bile salt circulation. However, relief of symptoms is not necessarily linked to depletion of serum bile salts and it is likely that it reduces levels of some undefined pruritogen. Lysophosphatidic acid (LPA) and autotaxin, the enzyme that produces LPA, have been implicated as a pruritogen associated with cholestatic diseases in adults. To date, neither has been implicated in pruritus associated with PFIC or ALGS. Despite lack of a clear understanding of how surgery can alleviate pruritus, surgery should be considered when pruritus cannot be adequately managed medically. Considerations for surgical intervention must take into account the specific disease process and its severity, along with the well-informed patient and family.

PEBD is a standard operation for the PFIC diseases and ALGS. The operation can be performed through a small right upper quadrant transverse incision or by a minimally invasive approach. The proximal jejunum is divided approximately 15 cm from the ligament of Treitz and a jejunal segment approximately 10–20 cm in length is isolated for use as the biliary conduit, taking care to preserve the mesenteric pedicle. Continuity of bowel is re-established by hand-sewn or stapled anastomosis. The dependent portion of the gallbladder is then anastomosed either end-to-end or end-to-side to the proximal end of the conduit using absorbable sutures to minimize subsequent stone formation. The distal end of the conduit is brought out to the skin as a matured ostomy in the right lower quadrant to prevent skin irritation. Preservation of flow through the common bile duct ensures only partial diversion of bile with the remainder of flow into the duodenum to enable normal digestion and absorption.

Laparoscopic approaches to PEBD have been described, with similar outcomes to the open approach in single-institution series. Externalization of bowel via an umbilical port allows for the isolation of the jejunal segment on its vascular pedicle with subsequent jejunojejunostomy. After bowel is returned to the abdominal cavity, the gallbladder is transfixed anteriorly through the abdominal wall with a suture, and an isoperistaltic side-to-end cholecystojejunostomy is then created laparoscopically. The distal end of the jejunal conduit is then externalized through the right abdominal trocar site and matured as an ostomy. In lieu of bowel as a conduit for drainage of the gallbladder, placement of a gastrostomy button device transabdominally into the gallbladder for intermittent biliary drainage has been reported in a small case series, although this is associated with gallstone formation.

Partial internal biliary diversion (PIBD), originally described in 2007, is an adaptation of PEBD for patients averse to a permanent stoma. The operation involves construction of an isolated jejunal segment greater than 15 cm, similarly anastomosed proximally to the gallbladder. However, the tapered distal end is anastomosed end-to-side to the mid-ascending colon, angulated acutely to minimize colonic reflux and potential cholangitis. The longer conduit is theorized to create resistance to bile flow to enable partial drainage of bile flow into the duodenum.

Ileal exclusion (IE) can be performed as a primary surgical option for esthetic reasons in lieu of PEBD or if the

patient has undergone a prior cholecystectomy. It can be performed as a rescue procedure for patients with post-PEBD electrolyte imbalances associated with excessive bile loss. IE reduces the bile salt load by excluding the terminal ileum, the site of bile salt reabsorption for recirculation to the liver. The operative technique entails diverting the distal 15 % of ileum proximal to the ileocecal valve by anastomosing the proximally divided ileum to the cecum or ascending colon. The total small bowel length is either measured or estimated using established nomograms of bowel length based on age.

Postoperative Care

Close medical follow-up is needed even with complete symptomatic resolution, given the possibility of remitting disease and nutritional problems related to deficiencies in vitamins A, D, E, and K. Patients should be monitored for complications of fat malabsorption, with particular attention to bleeding from vitamin K deficiency. Diet should be initiated early, and growth parameters tracked over time given that poor weight gain may persist despite adequate food intake.

Patients undergoing any of the surgical procedures for interruption of the enterohepatic circulation can experience a number of complications. Electrolyte abnormalities can occur with excessive loss of bile and bile salts from the enterohepatic circulation. Ischemia of the defunctionalized segment of jejunum is possible as is small bowel obstruction secondary to adhesions or volvulus around the jejunal conduit. Other potential complications include ascending cholangitis with PIBD and choleretic diarrhea with IE.

Outcomes

PEBD, PIBD, and IE have been shown to improve pruritus, xanthoma burden, and quality of life in some patients. More recently, the Childhood Liver Disease Research Network (ChiLDReN) reported the first-ever multi-institutional retrospective study tracking outcomes in 57 patients who underwent PEBD, IE, and PIBD. The analysis included 20 patients with ALGS, 16 with FIC1, 15 with BSEP, and 6 with gGT less than 100 U/L (diagnosis otherwise undetermined) over the course of 24 months. Findings were consistent with a number of small single-institutional series that hitherto describe more effective and durable clinical and biochemical improvements with PEBD compared to IE. PEBD has been shown to result in complete resolution of pruritus and reversal of histological abnormalities in up to 75 % of FIC1 patients as well as select patients with ALGS and BSEP, albeit in limited patient cohorts. The Childhood Liver Disease Research Network (ChiLDReN) study similarly reveals significant reduction of bilirubin levels in FIC1 and Bile salt export pump (BSEP) following PEBD. Additionally, improvements in cholesterol and xanthomata were experienced by ALGS patients following PEBD in comparison to IE.

Most patients with either FIC1 or BSEP disease are maintained on UDCA to suppress intrinsic synthesis of bile salts. All other anti-pruritic medications are generally tapered off based on symptomatology. Long-term outcomes determining whether PEBD can obviate the need for liver transplantation in FIC1 are currently lacking but there is some evidence that patients may experience resolution of liver disease post-diversion. Liver transplantation is indicated in the majority of patients with complete MDR3 defects who fail UDCA therapy, at which point liver histology reveals extensive bile duct proliferation and periportal fibrosis.

The mechanism by which PEBD may reverse hepatic injury in FIC1 but not ALGS or BSEP is unclear. Bile acid composition of patients with ALGS is unchanged following PEBD, whereas PEBD for FIC results in marked improvements in the phospholipid content of bile. Such differences in bile acid composition may reflect differences in the etiology of cholestasis, and furthermore predict clinical response to PEBD, although no causative relationship has been established.

Extent of fibrosis is perhaps the most important factor affecting success of PEBD. Biopsy is indicated in every patient with PFIC before proceeding with PEBD or liver transplantation. Early intervention with PEBD has been reported to interrupt hepatic injury and reverse histological abnormalities, including fibrosis, whereas cirrhosis is a poor prognostic indicator necessitating liver transplantation. Although PIBD is similar in principle to PEBD, with promising early results, long-term data is lacking regarding its durability.

Outcomes data following IE, similar to PIBD, is limited in comparison to PEBD. Single-institution, retrospective studies have shown promising early results with relief of pruritus and normalization of bilirubin levels over the course of several months. However, about 50 % of patients relapse over a variable time course, within the span of months to years. The timing of relapse is likely related to the extent of ileal resection as well as the adaptive capacity of the neo-terminal ileum and proximal colon for reabsorption of bile acids.

Editor's Comment

The outcomes in patients with intrahepatic cholestasis who undergo PEBD are generally quite good; most patients experience near-complete relief of pruritus and, for patients with Alagille disease, improvement in palmar hyperkeratosis and a decrease in subcutaneous xanthomas. Many patients with progressive familial intrahepatic cholestasis (PFIC) also experience improved growth and a slowing in the progression

of liver dysfunction. Some even demonstrate improvement in their liver histology. The results of ileal diversion are less consistent, less dramatic, and probably less durable. Some have reported excellent early results, though the immediate- and long-term results seem to be worse, presumably due to a gradual increase in more proximal ileal absorption of bile salts.

PIBD is an appealing concept in that it avoids an external ostomy and should accomplish the same degree of relief. A big concern is the risk of ascending infection when the colon is used as the drainage site. In addition, it is likely that patients will experience increased frequency and urgency of defecation when bile is allowed to drain directly into the colon.

We tried to create a reservoir using the jejunum in which a gastrostomy button is placed, with the idea that the patient could intermittently empty the bile without having to wear an external appliance. This did not work as planned, perhaps because the pouch was created in a dependent area (RLQ), but more likely because of the properties of bile—it tends to leak around the gastrostomy. Although PEBD works much better than ileal bypass, patients generally hate having an ostomy and seem to forget how miserable they were before the procedure. We have had several patients request to be converted to internal drainage. Though technically straightforward, this usually involves cholecystectomy, which precludes conversion back to PEBD should the procedure fail. We have in one instance preserved the jejunal conduit by creating an end-to-side anastomosis to the proximal jejunum, which would allow us to perform PEBD again in the future should the internal drainage procedure fail.

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Cholecystitis

80

John J. Tackett and Robert A. Cowles

Cholecystitis, usually recognized as a common adult surgical indication, has become a more frequent health problem in children. This Gallbladder wall inflammation often occurs secondary to irritation from stones or bile sludge within the gallbladder body with or without blockage of the cystic duct. While most cases of cholecystitis in children are acute, surgical pathology specimens can demonstrate chronic signs of long-standing inflammation and tissue fibrosis.

While there are only about 1.5 cases of pediatric gallbladder disease for every 1000 cases in adults, 4 % of all cholecystectomies are performed in children. Some of this increase is due to increasing obesity among children—one third of children in the USA are overweight or obese. This has led to an increase in the most common cause of cholecystitis in children, cholelithiasis. Cholelithiasis has an incidence of 0.15–0.22 % in healthy children, but increases in incidence in certain chronic diseases and predisposing conditions. Severe chronic illness can cause acute acalculous cholecystitis, the second most common cause of cholecystitis in children. Risk factors associated include mechanical ventilation, parenteral nutrition, and prolonged fasting. The third major type of gallbladder disease in children is biliary dyskinesia. This is a chronic acalculous cholecystitis defined by decreased emptying of the gallbladder often associated with histologic findings of chronic inflammation.

Cholelithiasis can begin in the prenatal period, but is most commonly found during the hormonal and dietary changes brought by puberty. Girls are at higher risk (4:1). Gallstones are thought to form secondary to bile supersaturation with cholesterol or bilirubin. These supersaturated crystals eventually aggregate to form gallstones. There are three major types of gallstones: cholesterol, black, and brown. Cholesterol stones are comprised of cholesterol, calcium salts, and glycoproteins, are generally radiolucent, and are the most common.

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Black gallstones, also known as pigment stones, are radiopaque and usually result from hemolytic disease, causing excess calcium bilirubinate to supersaturate the bile. In the past, stones associated with hemolytic disease represented up to a quarter of all stones in children. Least common are brown stones, usually formed in the ductal system due to bacterial infections and typically radiolucent.

Risk factors for gallstone formation are important and include genetic, life-event, and iatrogenic factors. Some ethnic groups have increased incidence of cholelithiasis: Pima Indians, Scandinavians, and Hispanics. Hemolytic diseases, like sickle cell disease, can predispose a child for pigment stones. As patients age, their risk of cholelithiasis increases, with 10 % of pediatric cases occurring within the first six months of life and nearly 70 % of cases occurring between adolescence and early college years. Becoming pregnant can increase the life-long risk of gallstone formation. Obesity is also a significant risk factor. Severe illness is a life-event risk factor that can also have associated iatrogenic risks. Severe sepsis, necrotizing enterocolitis, bronchopulmonary dysplasia, hepatobiliary disease, and cystic fibrosis have been associated with an increased risk of gallstones. Treatment during disease processes, such as ileal resection (bile-salt malabsorption), parenteral nutrition, chemotherapy, artificial heart valvuloplasty, and treatment with certain antibiotics (ceftriaxone) can iatrogenically increase risk. The most common iatrogenic risk factor is the prescribed use of oral contraceptives.

Diagnosis

When a patient arrives in our clinic or ED with complaints of abdominal pain, we should always consider gallbladder disease in the differential diagnosis. We begin every evaluation for abdominal pain and possible cholecystitis with a detailed history and physical examination. The history must focus on the timing of onset symptoms, specifically post-prandial relation. It is also important to understand the episodic nature of the symptoms as this will help in the interpretation of imaging studies and understanding the patient's disease natural history

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of acute versus chronic cholecystitis. Patients with acute cholecystitis will commonly present with nausea, vomiting, persistent right upper quadrant pain, and low-grade fever. While mild elevations in the transaminases and bilirubin may occur, frank jaundice is not a common finding in acute cholecystitis and when present suggests bile duct obstruction from gallstones.

During the physical examination, we perform a focused abdominal exam with special attention to localizing the focus of tenderness. We assess for the presence of a Murphy's sign by deeply palpating the right upper quadrant during inspiration; arrest of inspiration on deep palpation is suggestive of acute cholecystitis. As similar pain can also be associated with nephrolithiasis, we also percuss the patient's back to evaluate for costo-vertebral angle tenderness quite specific to pain from a kidney stone. As with any patient, the history of present illness and physical examination should be accompanied by a focused medical and surgical history. In this workup, we are looking for history of hemolytic disease or previous abdominal surgery.

Our patients undergo peripheral blood testing including: CBC with differential, chemistry panel including liver function tests and blood type and screen (while the risk of major intra-operative blood loss is low in the pediatric population, we perform this blood draw to limit blood draws prior to possible surgery). Our initial imaging study is a RUQ US. This imaging modality is the most sensitive for evaluation of the gallbladder. Ultrasound also has the utility of evaluating the common bile duct, including possible dilation or obstruction. While patients occasionally undergo plain film radiography of the abdomen prior to surgical consultation, we do not regularly order abdominal X-rays in the focused imaging evaluation of cholecystitis as only 15 % of gallstones are radiopaque. If the ultrasound demonstrates gallbladder wall thickening, pericholecystic fluid, and gallstones or sludge highly suggestive of cholecystitis, we stop imaging and proceed to treatment of acute cholecystitis (Fig. 80.1).

In rare cases where the clinical suspicion for cholecystitis is high but the US does not confirm it, we proceed with a hepatoiminodiacetic acid (HIDA) scan to evaluate for cystic duct obstruction. The HIDA is considered positive for cholecystitis if the gallbladder fails to fill (Fig. 80.2). A CCK-HIDA scan is especially useful in the diagnosis of biliary dyskinesia. In stable patients with chronic episodic RUQ or epigastric pain, a gallbladder ejection fraction of less than 35 % would be considered suspicious for biliary dyskinesia. In the appropriate clinical setting, either a US that is considered diagnostic for cholecystitis or a positive Hepatoiminodiacetic acid (HIDA) would result in a recommendation for cholecystectomy.

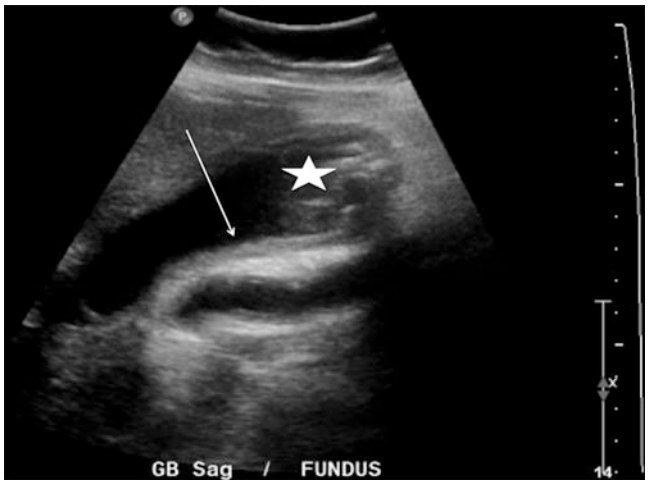

Fig. 80.1 Pediatric right upper quadrant ultrasound demonstrating thickened gallbladder wall (*arrow*) and gallstones with sludge (*star*)

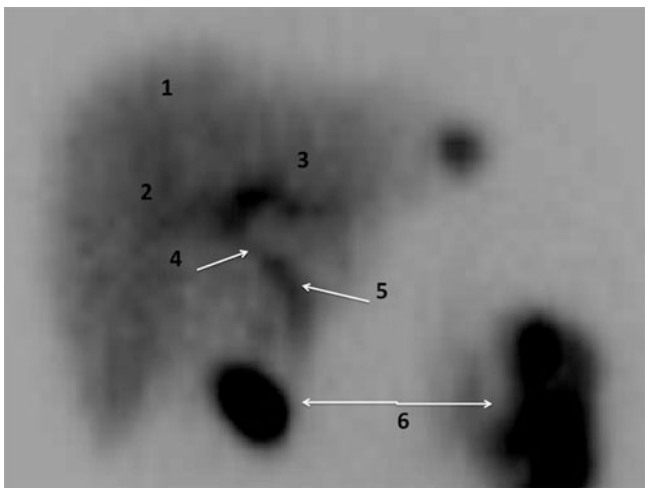

Fig. 80.2 Pediatric hepatoiminodiacetic acid (HIDA) scan without filling of the gallbladder. *1* = liver, *2* = right hepatic duct, *3* = left hepatic duct, *4* = common hepatic duct, *5* = common bile duct, *6* = duodenum

Treatment

Choledocholithiasis is relatively uncommon in children, and it is rare to find signs of both cholecystitis and choledocholithiasis in the same patient. In this more complicated scenario, however, an ERCP would be requested to clear stones from the bile duct prior to cholecystectomy.

After a diagnosis of cholecystitis is made, we prepare our patients for laparoscopic cholecystectomy. This preparation begins early during the initial evaluation with intravenous fluid resuscitation. We initiate ampicillin/sulbactam for broad-spectrum gram-negative and gram-positive coverage to include *Escherichia coli*, Enterococcus, and *Klebsiella*. In a vast majority of patients, we proceed with a laparoscopic cholecystectomy within 24 h of presentation. We always discuss the possible need for conversion to an open procedure in the event of poor visualization, bleeding, unclear anatomy or if we feel the laparoscopic dissection is unsafe. While our need to convert to open is very rare, it is nonetheless important to discuss this possible conversion and explain our want to avoid more serious complications, including bile duct or hepatic artery injury. The presence of dense adhesions blocking safe visualization might also be an indication to consider conversion.

Our approach to pediatric laparoscopic cholecystectomy differs from the adult approach. We are able to use a smaller laparoscope (and sometimes smaller instruments) when our patients are younger and thinner. We traditionally use a 5-mm, 30-degree scope. In our smallest children, we have used a 3-mm laparoscope to further minimize incisional morbidity. Depending on patient size, ports ranging from 3 to 12 mm in size are used. Regardless of port size, we rarely use fewer than four ports in order to maximize safe visualization.

We begin by placing our largest trocar at the umbilicus; this is typically placed after administration of local anesthetic in an open fashion. We bluntly dissect down to the fascia and open the peritoneum. We then place stay sutures that double as a purse-string closure at the end of the case. These 2-0 braided, absorbable sutures are placed through the fascia on both sides of the peritoneal defect. We then place the umbilical trocar under direct visualization and begin insufflation of the abdominal cavity. We again take size into consideration when choosing the insufflation pressure as a small, young child will require only 10 mmHg, while an obese teenager, often larger than an adult with a normal BMI, will require much higher pressure (15 mmHg) to allow for adequate space for visualization. After insufflation, we introduce the laparoscope to first check for any signs of injury from umbilical trocar placement. We then turn our attention to our instrument port placement. Each is placed under laparoscopic visualization after local anesthetic injection. The trocar that will hold the instrument responsible for retraction of the gallbladder fundus is typically placed first in the lateral right upper quadrant near the costal margin. This will allow for retraction and planning for the additional trocars that will be used to either manipulate the gallbladder neck or dissect the critical structures. The gallbladder fundus will be positioned cranially and laterally over the right lobe of the liver. The trocar for manipulation of the neck will be placed near the mid-clavicular line below the right costal margin. During instillation of anesthetic via a syringe, we are able to see the needle tip against the peritoneum to help plan the trajectory of the instrument trocars before any superficial skin incisions are made. The last trocar is usually placed a third of the way down between the xyphoid and umbilicus.

A surgeon and an assistant perform dissection and removal of the gallbladder. The assistant maintains cranial retraction of the gallbladder fundus with his or her left hand while manipulating the gallbladder neck with the right; the neck should be frequently moved in order to allow for constant exposure of the cystic duct and artery from multiple angles. The surgeon drives the laparoscope in his or her left hand while dissecting with the right. Alternatively, the laparoscope can be held and moved by a second assistant. We usually begin dissection with a Maryland dissector and then transition to hook electrocautery. We mobilize the gallbladder from any inflammatory adhesions and begin to dissect within the triangle of Calot, formed by the cystic duct, the common hepatic duct, and the cystic artery. We do not expose the common bile duct or common hepatic duct even if visible. We continue dissection to separate the lower one third of the gallbladder from the cystic plate—the liver bed of the gallbladder. At this point, we should have achieved the "critical view" of the cystic duct and artery as they directly enter the gallbladder. Two (and only two) structures should be seen entering the gallbladder. If at any time there appears to be evidence of aberrant anatomy or poor visualization, we take a surgical pause to determine whether we can achieve better mobilization and visualization of the biliary structures or if an intra-operative cholangiogram or conversion to an open procedure is safest. Rarely do we find cholangiography or conversion necessary in defining anatomy. With clear visualization of the cystic duct and cystic artery entering gallbladder, these structures can be clipped and divided.

We begin with the cystic duct placing a 5 mm clip at the proximal end abutting the gallbladder. We then place two additional clips slightly distal to the first. It is important to avoid clip placement along the distal cystic duct as it joins the common hepatic duct to form the common bile duct. We divide the cystic duct between the clips and inspect the lumen to ensure its singularity as a safety check for missing common bile duct injury. We then repeat the process with the cystic artery; to avoid small branch bleeding and right hepatic artery injury, we do not fully dissect the artery, and we do watch the back ends of the clips as they are placed.

With the gallbladder free of its vascular and draining structures, the surgeon is able to continue dissection of the visceral peritoneum between the gallbladder body and liver. We perform this with continuous motion of the gallbladder neck ensuring proper tension of the tissues to develop a plane of dissection. Moving the hook electrocautery through this plane, we take care to avoid dissecting too close to the liver bed or the gallbladder wall, which can cause thermal damage. If a hole is created in the gallbladder, it can be temporarily held closed with a grasper. Bile and any leaked stones are removed with a suction-irrigator. Once the gallbladder is completely freed from the liver, we move the laparoscope from the umbilical port to the lowest lateral port. The surgeon next introduces an endoscopic bag through the umbilical port. The assistant places the gallbladder within the bag under direct vision, and the bag is removed via the umbilical port incision. Occasionally, we have to use blunt stretch or further open the umbilical fascia to allow for the bag containing the gallbladder and stones to pass.

After removal of the gallbladder, the umbilical port is replaced and the laparoscope is moved back to that position. We inspect the gallbladder fossa of the liver to look for any bile leak from ducts of Luschka or bleeding from the hepatic parenchyma. We also look to ensure that our cystic duct and cystic artery clips are properly in place. While we do not routinely irrigate the dissection bed, we do irrigate with saline if

there has been bile spillage or bleeding. We also direct the laparoscope caudally to inspect the pelvis. We then remove three of the four trocars, leaving a lateral trocar in place. Tying down the previously placed stay sutures in a purse-string fashion closes the umbilical fascia. One final laparoscopic inspection is performed after umbilical fascial closure to confirm that no bowel or omentum has been entrapped in this closure and the last trocar is then removed. We close the umbilical skin with simple absorbable sutures and the other trocar incisions are closed with running subcuticular stitches. We then apply surgical glue across the incisions.

As mentioned, we rarely use intra-operative cholangiography, usually only in a patient with choledocholithiasis who was unable to undergo successful preoperative ERCP. During laparoscopic cholecystectomy, the cystic duct is exposed and a cystic ductotomy is created with endoscopic shears. A cholangiogram catheter is advanced and secured via this ductotomy. The cholangiogram is performed by introducing water-soluble dye diluted 1:1 with saline through the cholangiogram catheter into the gallbladder and flushing the system under fluoroscopy. Glucagon can be given to relax the sphincter of Oddi and allow for stones to pass. Filling defects are then assessed on the fluoroscopic images.

Common bile duct exploration is technically challenging in children and is seldom required. Most complications of this operation can be minimized or eliminated with proper exposure and visualization of the important structures. One of the most significant complications is injury to the common bile duct, which is best treated with a Roux-en-Y hepaticojejunostomy. In this rare event, discussion of the case with an experienced pediatric surgeon or pediatric transplant surgeon may be the most appropriate course of action before proceeding.

Postoperative Care

Postoperatively we do not continue antibiotics unless an abscess or clearly infected fluid is encountered. We allow our patients to have a meal of clear fluids after surgery followed by a diet low in fat. Our younger patients receive acetaminophen and ibuprofen for pain management. Our teenage patients are given low-dose narcotics only when the first regimen fails. We recognize that children with hemolytic cause of cholecystitis require more narcotic pain management. At discharge, we instruct our patients to shower in 24 h and transition to a regular diet as tolerated, with care to avoid fatty foods if diarrhea is encountered. We routinely have our patients follow-up in 14 days. This clinic visit allows for monitoring patient progress and identifying any short-term complications of the operation. Many short-term complications can be identified through US and treated with ERCP drainage or stenting. At this clinic visit, patients and their parents are re-educated about long-term risks of the operation, including bile duct stricture and adhesions.

Special Consideration

Nonoperative management of cholecystitis and symptomatic cholelithiasis has not been proven effective in pediatric patients, thus cholecystectomy is indicated. However, when a patient is critically ill, interval drainage through a percutaneous cholecystostomy tube placed by our interventional radiologist is a reasonable option. After recovery from the critical illness, an interval cholecystectomy should be performed. In our newborn ICU patient population, we treat infants with biliary stasis secondary to prolonged parenteral nutrition with ample hydration and observation.

In children with chronic hemolytic diseases who present with right upper quadrant pain, we work very closely with our pediatric hematology colleagues to coordinate pre- and postoperative care. We find this teamwork is imperative for ensuring smooth safe transition between phases of care while also alleviating additional anxiety among the patient and his or her parents. It is important to educate the entire care team about the plan that can involve preoperative transfusion or aggressive hydration that is outside of the normal routine care of pediatric gallbladder patients.

Editor's Comment

Indications for cholecystectomy in children include pigmented gallstones, symptomatic cholesterol stones, and biliary dyskinesia. Acalculous acute cholecystitis is also seen occasionally, especially in immunocompromised or critically ill patients. It is usually best to treat these children with percutaneous cholecystostomy, rather than attempt to remove the gallbladder. Children with incidental asymptomatic gallstones are usually recommended for cholecystectomy, though some are observed for months or years, and sometimes prescribed ursodiol, in the hope that the stones might resolve. They rarely, if ever, disappear.

Biliary dyskinesia is an increasingly common indication for cholecystectomy. The diagnosis is suggested by: (1) intermittent RUQ or epigastric pain precipitated by meals, (2) associated nausea, and (3) a positive CCK-HIDA scan (gallbladder ejection fraction <35 %). If all three criteria are met, cholecystectomy can be expected to relieve the pain in 85–90 % of the cases. With only two of three of these findings, the likelihood of success is probably closer to 60 or 70 %, and with only one, cholecystectomy should only be considered if the patient is truly debilitated, all other likely causes have been excluded, and the patient understands that there is at best a 50–50 chance that the operation will be a success.

Removal of the gallbladder is not entirely without risk. Besides operative risks, which are minimal, it can result in the unpleasant and often intractable problem of fecal urgency and loose stools.

In general, intra-operative cholangiogram is rarely indicated and really only necessary in the rare case of anatomic confusion. Most children with one of the traditional indications for intra-operative cholangiogram (jaundice, pancreatitis, and dilated CBD) and whose symptoms have resolved can safely undergo cholecystectomy without intra-operative cholangiogram. If the clinical impression is that they might actually have a stone in the CBD, they should undergo ERCP (or at least an MRCP) before undergoing cholecystectomy. Common duct exploration in children is technically difficult and potentially hazardous; it should almost never be necessary when therapeutic ERCP is available. Likewise, open cholecystectomy should rarely be necessary in children. The severe inflammation or fibrosis commonly seen in adults occurs rarely in children and the anatomy is rarely as confusing.

Three-trocar cholecystectomy is feasible but because it affords no significant advantage (it eliminates one small port) and the risks are almost certainly higher, it is difficult to justify. The single-port operation is used by some but whether it can be done with consistent safety remains to be seen. Robotic-assisted single-site cholecystectomy is promising as a useful and safe technique that could one day become standard.

Regardless of the technique, the operating surgeon should always control both the dissector and the assistant's grasper (rather than the camera). This is how all other operations are performed and is more natural. The dissection of the cystic duct should begin at the infundibulum of the gallbladder so that there is no question that it is the cystic duct that is being isolated and divided. The cautery hook should be used more like a spatula, dividing tissue that has been placed under tension by gentle traction, rather than using it as a hook every time.

As a complication of cholecystectomy in children, common bile duct injury appears to be exceedingly rare. Reconstruction is usually best accomplished with Roux-en-Y choledochojejunostomy, which can be prone to strictures due to the small caliber of the duct in children. Bile leak is also quite rare but is treated in the standard fashion (percutaneous drainage, ERCP with sphincterotomy and stent). Every attempt should be made to retrieve spilled stones, although retained intraperitoneal stones discovered incidentally months or years later are rarely cause for concern. In some cases, the cystic duct can be quite large and therefore not properly controlled with even the longest endoscopic hemoclip. In these situations, it is usually best to use an endoscopic linear stapling device.

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Choledochal Cysts

81

Inna N. Lobeck and Gregory M. Tiao

A choledochal cyst (CDC) is an uncommon but correctable cause of biliary obstruction. Patients often present with abdominal pain and jaundice. Some present with pancreatitis or, less commonly, cholangitis. Left untreated, chronic inflammation can result in biliary cirrhosis and a risk of malignancy. Cases of cholangiocarcinoma, adenocarcinoma, cystadenoma, and superficial spreading cancer of the bile duct have been reported in patients with a CDC. Operative intervention is warranted in all patients with choledochal cysts.

Choledochal cysts were first described by Vater and Elzer in 1723. Their anatomic variations were classified into three types by Alonso-Lej et al. This classification scheme was subsequently modified by Todani et al. into five subtypes (Fig. 81.1). The most common forms are type I and type IV CDC. In the case of a type I choledochal cyst, the dilatation is confined to the common bile duct, whereas the dilatation in patients with a type IV choledochal cyst either extends in continuity with the intrahepatic biliary tree or there is a short portion of normal-caliber common hepatic duct with isolated or multi-focal intrahepatic duct dilatation. In both type I and IV cysts, the dilated duct tapers to a normal diameter before it is joined by the pancreatic duct in the head of the pancreas.

Types II, III, and V choledochal cysts are rare variants, comprising less than 2 % of the cases. A type II choledochal cyst is a diverticulum arising from the wall of the bile duct, thought to occur due to a localized weakness in a segment of the common bile duct. A type III choledochal cyst, also known as a choledochocele, consists of a dilatation at the distal end of the common bile duct that protrudes into the lumen of the duodenum. Type V choledochal cyst, or Caroli's disease, consists of multiple cystic dilatations of the intrahepatic biliary tree, often with strictures between the cysts. The cysts can be confined to one lobe of the liver or found throughout the intrahepatic biliary tree. Recently, a sixth type of choledochal cyst has been described. This type of cyst is defined as a cystic dilation of the cystic duct and has only been described in case reports.

Choledochal cysts are believed to be congenital in origin. The most widely accepted theory as to their pathogenesis is an anomalous pancreaticobiliary ductal malunion (APBDU), in which the pancreatic duct joins the bile duct proximal to the sphincter complex, forming a long common channel that allows reflux of pancreatic enzymes into the common bile duct. This results in inflammation, ectasia, and ultimately dilation (Fig. 81.2). The damage to the bile duct is believed to occur in two ways: direct enzymatic injury to the biliary epithelium and damage caused by increased intraluminal pressure. Other, less accepted theories include embryologic proliferation of epithelial cells in the developing bile duct resulting in dilation and sphincter of Oddi spasm resulting in functional bile duct obstruction.

Diagnosis

Eighty percent of patients with choledochal cysts present before age 10. In clinical practice, the classic triad of abdominal pain, jaundice, and right upper quadrant mass occurs infrequently. Young children more commonly present with an abdominal mass or jaundice, whereas adults commonly present with biliary/pancreatic symptoms and abdominal pain. Some patients are diagnosed during an episode of cholangitis when they present with jaundice, fever, and right upper quadrant pain (Charcot's triad). Adults commonly present with symptomatic cholelithiasis (45–70 %) or acute cholecystitis as a result of biliary stasis. When a choledochal cyst goes undiagnosed and untreated for an extended period of time, recurrent bouts of cholangitis can result in a thickened and inflamed cyst wall. The biliary epithelium can be significantly damaged, resulting in marked metaplasia or malignancy. Although this is more common in adults, it should

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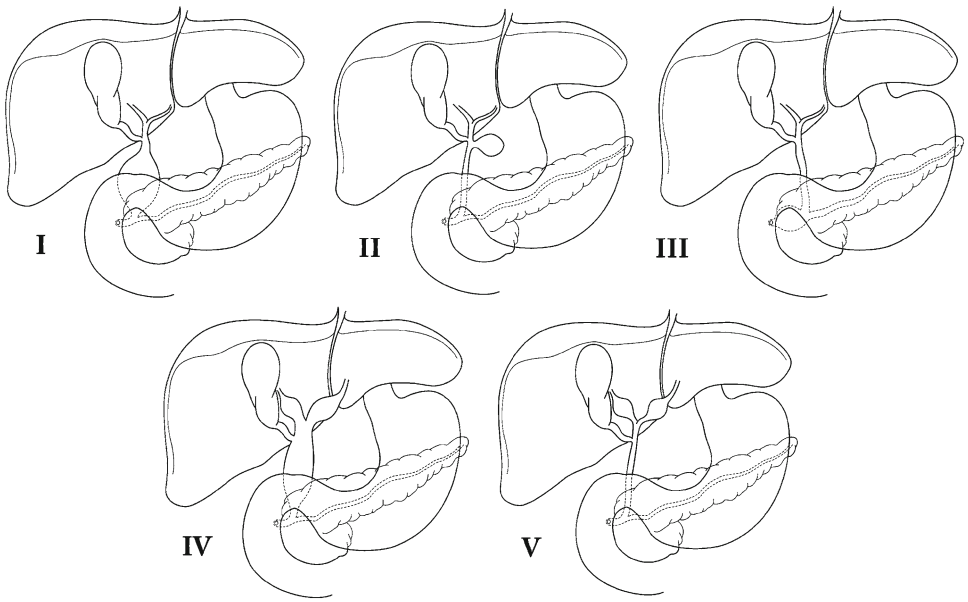

Fig. 81.1 Classification of choledochal cysts, according to Todani et al. (Modified with permission from Fischer JE, Bland KI, Callery MP, Clagett GP, Jones DB, editors. Mastery of surgery. 5th ed. Philadelphia, PA: Lippincott, Williams & Wilkins; 2006.)

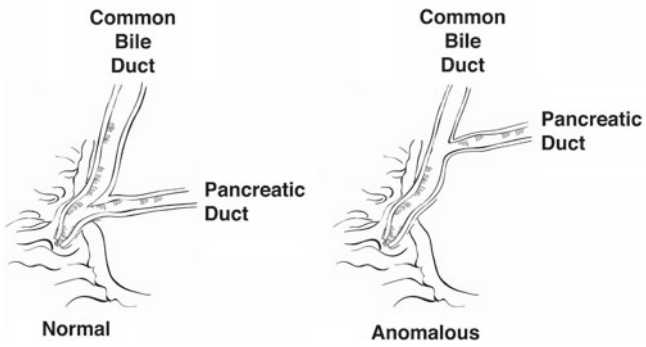

Fig. 81.2 Pancreaticobiliary malunion (PBMU): thought to be the pathologic basis for the development of a type I and IV choledochal cyst. (Modified with permission from Fischer JE, Bland KI, Callery MP, Clagett GP, Jones DB, editors. Mastery of surgery. 5th ed. Philadelphia, PA: Lippincott, Williams & Wilkins; 2006.)

also be taken into consideration in treatment of pediatric cases, as malignancies stemming from choledochal cysts carry a poor prognosis. In severe cases, the epithelium is replaced by granulation tissue and fibrosis, resulting in abnormalities of liver function, pancreatitis, and portal hypertension. A giant choledochal cyst can spontaneously perforate such that a patient presents with biliary ascites and sepsis. These patients have chemical peritonitis and require urgent care.

Due to the widespread application of ultrasound, the diagnosis of a cystic anomaly of the biliary tract may be made antenatally. For types I, II, and IV cysts, this is visualized as a cyst in the right upper quadrant. The diagnosis may be further delineated by presence of a communication between the cystic duct and biliary tree. The differential diagnosis for a cystic lesion arising in the hilum of the liver detected in utero includes choledochal cyst and a cystic variant of biliary atresia. These patients require assessment of the patency of the extra-hepatic biliary tract soon after birth. Patency can be established based on clinical criteria (pigmented stool) or by nuclear medicine scan. If the biliary tract is obstructed, biliary atresia is likely. If the biliary tract is patent, the cystic lesion is more likely a choledochal cyst. These patients are ideal, as operative repair can be performed prior to the onset of inflammatory changes that can make operative dissection more difficult and dangerous. Commonly used imaging modalities include MRCP, CT scan, and endoscopic ultrasound which generally define the anatomic configuration of a choledochal cyst. Although ultrasonography is usually the first study performed and will identify the abnormality in the bile duct, CT or MRI should be employed to define the anatomic extent of disease for surgical planning purposes. For type III choledochal cyst, the gold standard diagnostic modality is ERCP, which may also be therapeutic through use of endoscopic sphincterotomy.

Laboratory studies performed in patients with a choledochal cyst are usually unremarkable. Serum conjugated and unconjugated bilirubin and hepatocellular transaminase levels are normal unless the patient has active cholangitis or has developed cirrhosis. In patients who present with recurrent episodes of pancreatitis, serum amylase levels may be elevated.

Surgical Therapy

The first choledochal cyst excision with hepaticojejunostomy was performed by Mcwhorter in 1924. Since then, various procedures including external drainage or internal drainage through cystenterostomy were attempted, though with significant morbidity and mortality. Today, the treatment of a patient with a choledochal cyst depends on the subtype. The majority of patients with choledochal cysts undergo excision of the cyst and re-establishment of bile flow through biliary-enteric

anastomoses. For most, we perform definitive correction soon after diagnosis so as to limit the likelihood of progressive inflammatory changes within the CDC; however, patients with active cholangitis should be treated with an appropriate course of intravenous antibiotics before definitive repair is undertaken. Likewise, patients who present with acute pancreatitis should be treated to allow for resolution of pancreatic inflammation prior to definitive resection.

All patients receive preoperative intravenous vitamin K, as some are deficient due to underlying cholestasis. Perioperative antibiotics are administered before incision and continued for 24 hours.

The goal of surgical intervention should always be complete excision. For patients with a type I or IV cyst, we perform excision of the cyst and a retrocolic, isoperistaltic, Roux-en-Y hepaticojejunostomy (RYHJ). Treatment with hepaticoduodenostomy (HD) has been reported in the literature, but may not be optimal as HD has been associated with bile reflux resulting in gastric cancer and biliary cancer. RYHJ is our preferred approach due to its low morbidity, excellent clinical results with infrequent incidence of postoperative anastomotic strictures, cholangitis, malignancy, and stone formation. We use a right subcostal incision to enter the peritoneal cavity and, if necessary, extend the incision across the midline. In most instances, the choledochal cyst is readily apparent. Mobilization of the gallbladder will aid in the delineation of the anatomy. An intra-operative cholangiogram performed through the gallbladder is helpful to determine where the proper hepatic duct is of normal caliber and where the pancreatic duct joins the biliary tract. If possible, the common duct is circumferentially mobilized, allowing the application of traction to the choledochal cyst and a safer dissection of the hepatic artery and portal vein. In cases in which the size of the choledochal cyst distorts the hilar anatomy, decompression of the cyst will facilitate safer dissection.

Dissection should proceed distally until the duct narrows to normal caliber, which is where the cyst should be divided. The choledochal cyst will often extend behind the first portion of the duodenum into the head of the pancreas. Although it is rare for the choledochal cyst to extend to the pancreaticobiliary ductal junction, care must be taken to avoid injury to the pancreatic duct. Superiorly applied traction to the cyst and close adherence to the wall of the choledochal cyst allow for safer dissection. In patients who have had chronic pancreatitis and atrophy of the pancreatic head due to APBDU, the safest procedure may be a pancreaticoduodenectomy. Complete resection of the cyst is important. If remnant cyst is present, the risk of cancer may be as high as 50 %. Division at the superior edge of the duodenum may leave residual cyst wall in the head of the pancreas, which could lead to a recurrence or a future malignancy. Once the neck of the cyst is defined, it is ligated at its base using a non-absorbable suture.

In patients with a long-standing choledochal cyst, recurrent bouts of cholangitis may have resulted in significant inflammation throughout the hilum, fibrosis of the ducts and adhesions, making dissection around the choledochal cyst quite difficult and creating the potential for injury to the hepatic artery or the portal vein. In this circumstance, the choledochal cyst may be opened longitudinally and the mucosa of the cyst excised from within (Fig. 81.3). The posterior fibrous remnant of the cyst wall is left in place, minimizing the likelihood of injury to adjacent hilar structures. Here again, it is important to excise all of the cyst mucosa as there is a risk of developing cholangiocarcinoma in the abnormal biliary epithelium left behind. If the cyst cannot be excised in total, the mucosa should be stripped or fulgurated through abrasion and iodine or alcohol application. Patients with remnant cysts postoperatively require frequent surveillance through ultrasound and endoscopy.

Dissection is carried distally until the cyst narrows to normal caliber where it is oversewn. For a type I cyst, the proximal dissection in carried up the common hepatic duct to where its caliber appears normal and can be divided (Fig. 81.4). For a type IV cyst, we have found that the intrahepatic ductal dilatation usually resolves after the abnormal common bile duct has been removed. Due to this, we divide a type IV cyst just distal to the confluence of the right and left proper hepatic ducts. If the mucosa appears abnormal, we perform a frozen section biopsy at the line of division to ensure that the biliary epithelium is intact. If the mucosa appears histologically normal, hepaticojejunostomy is performed at this level. If the mucosa is abnormal, more proximal dissection must be undertaken, as malignancy has been reported to occur within intrahepatic cysts. When intrahepatic disease is localized, it may be judicious to perform a partial hepatectomy and eliminate risk of malignancy.

We re-establish biliary drainage by end-to-side hepaticojejunostomy into a 40-cm limb of a Roux-en-Y brought to the hilum in a retrocolic position, using a single-layer interrupted anastomosis with absorbable suture. A proper anastomosis with precise mucosal apposition is important, as this minimizes the likelihood of subsequent leak or stricture. Sutures are placed such that all the knots are outside the lumen, reducing the likelihood of choledocholithiasis. Anchoring sutures from the Roux limb to tissue around the bile duct are placed to decrease tension on the anastomosis. For the cyst that extends up to the confluence of the right and left hepatic duct, we spatulate the lateral wall of both ducts to create a larger opening and a wider anastomosis.

Patients who have had previous internal drainage procedures for choledochal cysts should undergo reoperation with cyst excision, even if they remain asymptomatic. This is due to the continued risk of malignancy and symptom recurrence.

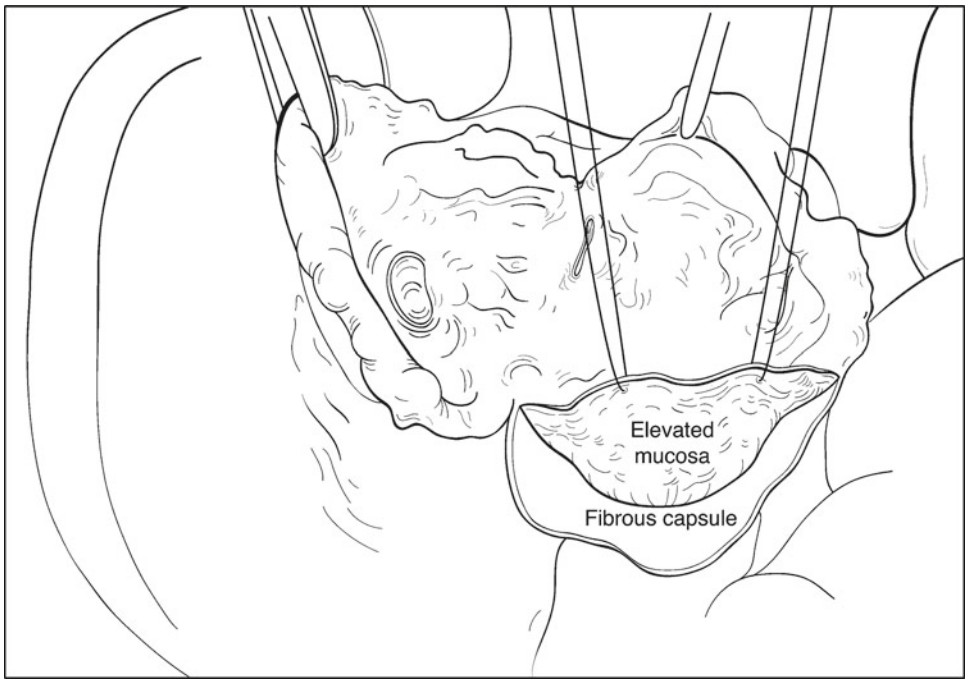

Fig. 81.3 Mucosectomy of the lining of a choledochal cyst. Recurrent bouts of cholangitis within a choledochal cyst will cause extensive inflammation and fibrosis within the hilum. The choledochal cyst can be opened longitudinally and the mucosa excised leaving the residual fibrous capsule. (Modified with permission from Fischer JE, Bland KI, Callery MP, Clagett GP, Jones DB, editors. Mastery of surgery. 5th ed. Philadelphia, PA: Lippincott, Williams & Wilkins; 2006.)

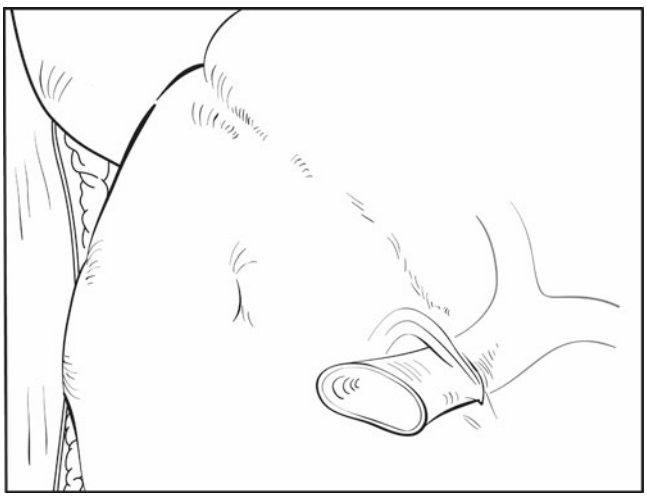

Fig. 81.4 Choledochal cyst divided. The proximal extent of dilation is identified and the choledochal cyst is divided. If the mucosa appears intact, a hepaticojejunostomy is performed to this level. If the mucosa is abnormal either at the gross or microscopic level, more proximal dissection must be performed. (Modified with permission from Fischer JE, Bland KI, Callery MP, Clagett GP, Jones DB, editors. Mastery of surgery. 5th ed. Philadelphia, PA: Lippincott, Williams & Wilkins; 2006.)

In patients who present with a perforated choledochal cyst, the first step is to control the biliary ascites. Suitable drainage can be achieved through operative placement or by interventional radiology. Percutaneous trans-hepatic biliary drainage assists in controlling the leak and defines the cyst anatomy. Only after suitable control of the biliary leak and the treatment of accompanying sepsis have been achieved should operative resection and reconstruction be undertaken.

Minimally invasive surgical techniques have been applied to the treatment of choledochal cysts. Multiple reports have demonstrated successful and safe excision with reconstruction using a laparoscopic approach. Complete cyst excision must still be achieved when utilizing this approach, otherwise residual cyst epithelium left within the head of the pancreas could lead to cyst recurrence or cholangiocarcinoma. In our experience, the dissection of the choledochal cyst into the head of the pancreas has been the most challenging aspect of the procedure. Advantages of laparoscopic management include quicker recovery, fewer adhesions, decreased postoperative pain, decreased postoperative ileus, and improved cosmesis. With addition of robot-assisted surgery, cyst excision and biliary reconstruction have resulted in improved dexterity and decreased operative time. These techniques, however, should be reserved for surgeons experienced in these minimally invasive techniques.

For patients with a type II choledochal cyst, excision of the diverticulum and the extra-hepatic biliary tract with a Roux-en-Y hepaticojejunostomy is our procedure of choice. Although simple excision of the diverticulum with ligation at its base can be performed, excision of the extra-hepatic biliary tract is recommended because of the risk of the development of a cholangiocarcinoma in the remaining extra-hepatic biliary tract. We have treated one patient in which it was difficult to define where the diverticulum arose from the biliary tract. In that case, we opened the cyst, excised all of its mucosa, and fulgurated the residual cyst wall.

For patients with a type III choledochal cyst, the recommendations for treatment vary according to the type of epithelium

found within the choledochal cyst. An ERCP should be performed prior to surgical intervention. At the time of ERCP, biopsy of the mucosa lining the cyst should be performed. If the biopsy reveals mucosa of duodenal origin, the lesion can be treated by a sphincterotomy or meatotomy to enlarge the opening and relieve the obstruction. This is most commonly performed endoscopically though may be done through an open transduodenal approach. In the rare cases where the epithelium lining the lesion appears to be of biliary tract origin, or the cyst is large and not amicable for endoscopic sphincterotomy, excision of the cyst with re-implantation of both the bile duct and the pancreatic duct has been recommended. Here again, it is essential to excise all of the biliary epithelium so as to minimize the likelihood of the development of malignancy.

In patients with Caroli's disease (type V choledochal cyst), the extent of disease dictates the type of surgical procedure performed. In patients with disease confined to one lobe of the liver, formal lobectomy is recommended. If a patient has bilobar or diffuse disease with recurrent cholangitis, liver failure, fibrosis, or malignancy, liver transplantation is the treatment of choice. The timing for transplantation has not been established but transplantation must take place prior to the development of a cholangiocarcinoma. Therefore, these patients require close long-term surveillance even if asymptomatic.

Postoperative Care

Cholangitis is a common and potentially serious postoperative complication and therefore patients are maintained on peri-operative intravenous antibiotics until they can tolerate enteral feeds, at which time suppressive antibiotics are started and maintained for at least 6 months. If no episodes of cholangitis occur during the 6-month period, antibiotics are discontinued. The use of ursodeoxycholic acid might be beneficial in the peri-operative period but can be discontinued if no complications arise.

Established complications following repair of a choledochal cyst include stenosis at the hepaticojejunostomy, intrahepatic lithiasis, and cholangiocarcinoma, any of which can occur years later. Although the 5-year survival is over 90 % and cyst excision carries an 89 % event-free rate, long-term follow-up must be performed as the risk of malignancy may be present years after treatment. We obtain an abdominal US every year for the first 2 years and thereafter if symptoms arise.

Editor's Comment

It is becoming increasingly clear that excision of the most common varieties of choledochal cyst can often be safely performed laparoscopically or robotically and that these will become the preferred approach in the near future. These are obviously advanced minimally invasive techniques that will not be available at every center but parents should be made aware that there are alternatives to the standard open approach, even if it means transferring the child to another institution. Some centers have also shown that hepaticoduodenostomy is a safe and effective alternative to Roux-en-Y hepaticojejunostomy.

The critical points are that the mucosa of the cyst must be completely excised and the mucosal edges must be carefully approximated at the hepaticojejunostomy. It is also important to trace the distal common bile duct into the pancreas while avoiding injury to the pancreatic duct. Stents and drains are not routinely necessary but patients should be closely monitored for signs of a bile leak, which usually resolves with percutaneous drainage and 1–2 weeks of parenteral nutrition. As with most anastomoses involving the GI tract, leaks are often followed by strictures, which sometimes respond to percutaneous balloon dilation or stent placement but more often require surgical revision of the anastomosis. Cholangitis is thought to be minimized by creating a relatively long Roux limb (20–30 cm) but always suggests the possibility of an obstruction, either in the biliary tree or the Roux limb (an argument against excessive length). Stones that form within the biliary tree can also cause obstruction and cholangitis.

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Hepatic Resection

82

Jennifer Minneman and Heung Bae Kim

Indications for hepatic resection in children include a variety of benign and malignant conditions. Benign lesions include mesenchymal hamartoma, adenoma, vascular malformation, focal nodular hyperplasia (FNH), and simple cysts. The most common malignant lesions requiring resection include hepatoblastoma and hepatocellular carcinoma (HCC), but angiosarcoma, rhabdomyosarcoma, rhabdoid tumors, and cholangiocarcinoma can also be seen in the pediatric population. Other lesions such as inflammatory myofibroblastic tumors (IMT) are considered benign but unfortunately have a propensity to be locally invasive, which usually mandates aggressive local resection.

When a small benign lesion is suspected, biopsy may be necessary in order to be comfortable recommending observation. In the case of a purely cystic lesion, a choledochal cyst may be ruled out through a combination of ERCP, MRCP, or HIDA scan. Unfortunately, expectant management can often be more anxiety-provoking for the parents and the surgeon than a definitive resection, and therefore sometimes resection is performed after a period of observation, after symptoms develop or if the lesion demonstrates interval growth. Indications for resection of a known benign lesion include symptoms related to mass effect, pain, demonstrated growth, or a well-defined natural history that includes growth, risk of malignancy, or risk of rupture or hemorrhage. Usually, mesenchymal hamartoma, adenoma, and biliary cysts require resection, but FNH and simple hepatic cysts that are not large or symptomatic can be safely observed.

Surgical resection is indicated as one part of the treatment for most malignant hepatic lesions. Hepatoblastoma is the most common hepatic malignancy in young children until adolescence, when hepatocellular carcinoma becomes more common. Therapy for hepatoblastoma usually includes a combination of surgical resection and chemotherapy. If the tumor is easily resectable with a straightforward lobectomy or segmentectomy, upfront resection should be performed with adjuvant chemotherapy administered subsequently. If there is concern for close margins (portal vein, IVC, and hepatic vein) or the lesion would require an extensive or non-anatomic resection, several rounds of neoadjuvant chemotherapy are recommended to reduce the size of the tumor, making subsequent surgical resection easier and safer.

Surgical resection is the mainstay of therapy for children with HCC since chemotherapy and radiation are largely ineffective. In addition, unlike adult HCC in which tumor usually develops in the setting of cirrhosis, the majority of children with HCC have an otherwise normal liver. Therefore, the risk of postoperative liver insufficiency following resection of even very large lesions is minimal. The fibrolamellar variant of HCC is commonly seen in adolescents and may have a better overall prognosis but is unfortunately even less chemoresponsive than standard HCC. Some conditions such as tyrosinemia are known to result in early cirrhosis with a high risk of the development of HCC and in these cases liver transplant is indicated for known HCC but has also been recommended prophylactically prior to the development of HCC.

Diagnosis

The initial presentation of a liver tumor in a child can vary from an incidental finding on prenatal ultrasound to a large visible or palpable abdominal mass. Since the liver is well protected behind the lower ribs, a tumor must become very large before it is palpable unless it is an exophytic lesion arising from the anterior-inferior portion of the liver. Unfortunately, the palpation of a very large mass is the most common presentation of malignant tumors. Rarely, a child may initially present with life-threatening hemorrhage or tumor rupture.

Initial diagnostic imaging is usually with US, but delineation of anatomy and operative planning requires cross-sectional imaging with either CT or MRI. Although we prefer CT-angiogram with arterial and venous phases—it provides higher resolution in determining resectability—MRI has

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several advantages in diagnosis. MRI is useful in differentiating cystic from solid lesions, and sometimes in differentiating FNH from adenoma. In addition, as it is very sensitive in its detection of small tumors and avoids ionizing radiation, it is an excellent modality for following patients postoperatively for signs of recurrence.

Physical examination must include a careful assessment for associated signs of liver disease. Although jaundice is uncommon, its presence indicates an obstruction of the common hepatic or common bile duct. This is most commonly seen in cases of biliary rhabdomyosarcoma, but can occur with any hepatic mass compressing the bile duct bifurcation. Stigmata of portal hypertension such as splenomegaly, caput medusae, spider hemangiomata, or ascites may be secondary to portal vein thrombosis or compressive obstruction, but less commonly from cirrhosis. Portal vein thrombosis is often a result of intravascular invasion of the portal vein by tumor and this must be considered during assessment of resectability. Ascites may also be caused by partial or complete hepatic vein obstruction (Budd–Chiari syndrome), or can be a sign of tumor rupture.

Laboratory assessment of patients with a hepatic mass should include a CBC, electrolytes, and a liver function panel consisting of transaminases, alkaline phosphatase, GGT, albumin, fractionated bilirubin, and PT/PTT. Of these, the only true measures of "liver function" are the albumin and INR. If the INR is elevated, especially in the setting of jaundice, the patient should receive a dose of Vitamin K. Coagulopathy unresponsive to Vitamin K usually signifies diminished functioning liver mass, and if there is a significant amount of apparently uninvolved liver on imaging, one should suspect that the remaining liver is cirrhotic. Preoperative liver biopsy should be considered to evaluate for cirrhosis, and liver transplantation may be indicated for functional reasons, even if the anatomy of the mass is favorable to resection.

Preoperative Preparation

After determining that a liver lesion should be resected, the surgeon must determine whether it can be resected safely. This decision must include consideration of both anatomic and functional resectability. Anatomic resectability is determined primarily by the relationship of the tumor to the vascular architecture of the liver. Liver surgery is really vascular surgery of the liver, which requires a detailed understanding of both extrahepatic and intrahepatic vascular anatomy (Fig. 82.1). Functional resectability is determined by the size of the expected liver remnant as well as the condition of the remaining liver (degree of fibrosis). Ultimately, all liver tumors are technically resectable if adequate replacement therapy with liver transplantation is available and appropriate.

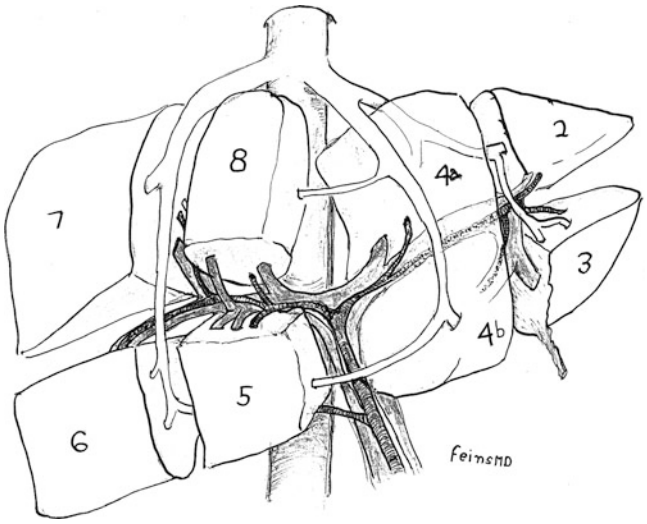

Fig. 82.1 Segmental anatomy of the liver (courtesy of Neil Feins, MD)

The most common anatomic liver resections are left lateral segmentectomy, left lobectomy, right lobectomy, left trisegmentectomy, and right trisegmentectomy (Table 82.1). In the presence of a normal liver, children can tolerate a remnant liver volume of approximately 25 %, so all of these anatomic resections can be performed with an acceptable functional outcome. However, preexisting liver disease must be taken into account when planning a resection in order to avoid leaving a patient with too little functional liver mass. On the contrary, the liver segments involved in a large liver mass may atrophy, stimulating compensatory growth in the uninvolved segments with subsequent greater-than-expected volumes of remnant liver. This type of growth is most helpful when considering a left or right trisegmentectomy.

Of the three hepatic blood vessel systems, the hepatic veins are the most important determinants of anatomic resectability, followed by the portal vein. The reason for this is that the hepatic veins are almost entirely intrahepatic and so are difficult to "peel away" from an adjacent tumor without risking significant hemorrhage or incomplete resection. Additionally, the hepatic veins are more fragile and control of bleeding is more difficult than with the inflow vessels (portal vein and hepatic arteries). The portal vein is extrahepatic well beyond the bifurcation, so the vein can be dissected free of the tumor in many cases where it appears that the bifurcation is involved. In addition, the portal plate containing the bile ducts often separates the portal vein bifurcation from the liver parenchyma and offers a natural plane of dissection from the tumor. The left portal vein remains extrahepatic through almost its entire course and ends at the obliterated umbilical vein (Rex recessus). Branches supplying segments 1–4 can be dissected free along the course of the left portal vein without entering the liver parenchyma. The right portal vein can usually be dissected

Table 82.1 Anatomic liver resections

Common terminology	Anatomic segments resected	Hepatic vein resected	Approximate remnant liver volume (%)
Left lateral segmentectomy	2, 3	Left	75
Left lobectomy	2–4 ± 1 (caudate)	Left, middle	60
Right lobectomy	5–8	Right	40
Left trisegmentectomy	1–4 (left lobe) + 5, 8	Left, middle, anterior right	30
Right trisegmentectomy	5–8 (right lobe) + 1, 4	Middle, right	25

to the level of its first bifurcation into anterior and posterior sectors (segments 5, 8 and 6, 7, respectively), although the branching pattern can be quite variable.

The hepatic artery is usually the least important vascular determinant of resectability. Biliary structures should never determine resectability, as Roux-en-Y biliary reconstruction of individual segmental ducts can be performed even in small infants.

Tumor involvement of the inferior vena cava poses its own challenges, depending on the level of involvement. Superiorly, intravascular invasion via the hepatic veins can lead to tumor extension into the right atrium. An intrapericardial approach may be necessary to place a clamp above the level of the tumor, and in some cases cardiopulmonary bypass may be necessary to complete the resection. In extreme cases particularly where there is significant hepatic vein obstruction involving the remnant liver, complete hepatectomy, ex vivo liver resection, and autotransplantation with or without cardiopulmonary bypass may be indicated to achieve a complete resection with better visualization and less blood loss than could be achieved using standard in vivo techniques. These more complex resections should be performed by a surgical team with liver transplantation experience. More commonly, a tumor may appear to be compressing the IVC inferior to the hepatic veins. Although a dissection plane can often be found between the tumor and the IVC thus leaving it intact, IVC replacement with a PTFE graft is sometimes necessary. However, if complete or near-complete IVC obstruction is present preoperatively, the majority of blood flow may already be shunted into the azygous vein collaterals (visible on CT-angiogram), and in these cases the IVC may be ligated and resected without significant adverse sequelae.

In order to best assess the location of the tumor and its relationship to the vascular structures, we prefer a combination of Doppler US and CT-angiogram. US is useful to determine direction of flow as well as to obtain baseline portal venous, hepatic venous, and hepatic arterial waveforms. CT-angiogram with arterial and venous phases gives the best assessment of the tumor relative to the vasculature and provides a roadmap for the operation. Although MRI is useful preoperatively for determining the etiology of the tumor and postoperatively for monitoring for recurrence, we generally find that the resolution is insufficient in difficult cases to accuratel y determine anatomic resectability.

Surgical Technique

The techniques of liver resection are quite variable, but have been significantly influenced in recent years by a growing experience with living-donor and split-liver transplantation. This experience has helped to define the limits of what is possible both from an anatomic and a physiologic standpoint.

All liver resections can be performed through a generous bilateral subcostal incision. A midline extension up to the xiphoid is sometimes necessary to gain better exposure of the suprahepatic IVC, especially in cases where intrapericardial IVC clamping is necessary to extract tumor thrombus. Initial exploration for malignant disease should include a careful inspection of the peritoneal surface and liver hilum for evidence of metastatic disease. In all but the most superficial wedge resections, complete mobilization of the liver is essential to provide easy exposure to the hepatic hilum and retrohepatic IVC. The falciform ligament is completely divided up to the level of the IVC, and the left and right triangular ligaments are divided. Elevation of the hepatic hilum into the operative field can be achieved by placement of one or two laparotomy pads under the right lobe of the liver. We use a Thompson retractor as gentle retraction of the liver and bowel can be achieved with minimal risk of injury. The porta hepatis should be skeletonized and the arterial system should be carefully defined as it can be quite variable. Replaced arteries should be ruled out by inspection of the gastrohepatic ligament (replaced left) and the nodal tissue behind the portal vein (replaced right).

Intraoperative determination of resectability should be made after assessment of the portal vein, hepatic arteries, and origins of the hepatic veins from the suprahepatic IVC. The hepatic veins and their major branches may be more easily located with the use of intraoperative US. Once resectability is confirmed, inflow to the liver segments to be resected may be temporarily clamped to demarcate a line of parenchymal transection, and this line should be marked with cautery or the argon beam coagulator on the surface of the liver. In most cases, the portal vein and hepatic artery branches supplying the segments to be resected should be divided prior to parenchymal transection in order to minimize bleeding. We generally do not take the outflow until the majority of the parenchymal transection is complete as there may be some collateral inflow to that

segment of the liver. If the outflow is obstructed during parenchymal transection, increased hemorrhage during the transection may result. Back bleeding from the outflow vessels during parenchymal transection can be minimized with the maintenance of a low central venous pressure by the anesthesia team.

There are many methods of parenchymal transection and all of them work, so the most important thing is to find a method that is consistently available in your institution and that you are comfortable with. Our preference is to simply use electrocautery with the coagulation level turned up sufficiently to allow for easy arcing of the current to the tissue, and to identify and ligate larger branches as they are encountered using a "clamp-fracture" technique. The argon beam coagulator is used for diffuse oozing of the surface of the liver after transection but should not be used as the primary dissecting instrument. When the liver parenchyma is particularly friable we use other devices such as the harmonic scalpel or an advanced bipolar electrocautery device for hemostasis during the parenchymal transection phase of the operation. Bile ducts should be sharply transected with a knife or scissors to preserve the fine periductular vasculature, particularly when reconstruction will be necessary. The bile duct bifurcation should be preserved if possible, but if there is involvement with tumor, the bifurcation may be resected and a Roux-en-Y biliary reconstruction performed. In these cases, we prefer to construct a 45-cm Roux-en-Y limb brought up in a retrocolic position. We perform a mucosa-to-mucosa choledochojejunostomy and do not routinely use a biliary stent although one may be placed in difficult cases. At the completion of each procedure, we routinely leave a closed-suction drain along the cut edge of the liver for several days to monitor for bleeding and bile leak.

In cases of right trisegmentectomy, care must be taken at the completion of the procedure to ensure that the remnant liver is not prone to torsion, which can cause outflow obstruction of the left hepatic vein. The liver will tend to rotate into the empty right upper quadrant, so this space should be filled by the colon and small bowel to prevent the liver remnant from rotating 180° and causing an acute Budd–Chiari syndrome due to obstruction of the left hepatic vein. Should this occur, the patient would develop ascites, a sudden rise in transaminases, and usually intraperitoneal bleeding. This is an acute surgical emergency and emergency operative intervention is necessary to relieve the acute outflow obstruction. In some cases, we secure the falciform ligament to the anterior abdominal wall or the left triangular ligament back to the diaphragm to help avoid this complication.

Postoperative Care

Most patients should be monitored in the PICU following a major liver resection. Extubation should be performed in the operating room or as soon as possible in the ICU to prevent elevations in CVP, which promotes bleeding from the IVC and the cut edge of the liver. The CVP should be maintained in the low-normal range and high pressures should be avoided for the first several days. Blood products should be given as needed, but plasma replacement should be avoided if possible so that the INR can be followed to trend liver function. We use the INR as the primary method to determine the adequacy of functional liver tissue following major liver resection. This is usually a major concern only in the case of left or right trisegmentectomy. Formal right or left lobectomy should almost never cause concern for inadequate liver function postoperatively. Transaminases can be monitored daily and any sudden elevations should prompt an emergency ultrasound to assess for a vascular complication. A routine US should be performed on the first postoperative day if there is any concern for vascular compromise.

When more extensive resections are performed, the INR may not remain normal postoperatively, and a rising INR is an indication of insufficient liver volume. In mild cases, supportive care is all that is needed to maintain the patient while the liver regenerates. This may require plasma replacement to maintain an INR <2.0 or lower if there is ongoing bleeding. Parenteral nutrition should be started in these cases, and particular attention should be paid to adequate repletion of phosphorus and other electrolytes to facilitate liver regeneration.

In more severe cases of insufficient liver volume, the "small for size" syndrome may occur. This has been defined for split-liver transplantation and consists of progressive jaundice, coagulopathy, and ascites. This can partially be due to portal hyperperfusion to a small liver remnant resulting in hepatocyte injury. If it progresses faster than liver regeneration can occur, this can eventually result in encephalopathy, liver failure, and death if liver replacement therapy is not immediately available. However, if a patient can be supported through this time period with plasma replacement and nutritional support, liver regeneration will eventually result in resolution of symptoms and normal liver function. Complete resolution can take months.

Following discharge, we routinely check liver function and perform a US three months following surgery, and then, depending on the clinical situation, only as needed. Obviously, patients with malignant disease will require lifelong follow-up for tumor recurrence. We utilize CT-angiography if there are any concerns for postoperative vascular compromise. If AFP levels were elevated preoperatively in the patient with hepatoblastoma, they should be followed carefully following surgery to detect residual or recurrent tumor.

Editor's Comment

In some pediatric centers, major hepatic resections are performed by transplant surgeons or adult surgeons. This results in fewer pediatric surgeons having the experience and training to perform these demanding operations, which in turn

results in fewer referrals and even less experience. Though one should always take the path that is safest for the child given the resources available at one's institution, the best way for pediatric surgeons to maintain their skills and preeminence in this field is to demonstrate that they can perform these operations safely and achieve excellent outcomes. This demands careful preoperative planning, meticulous technique, and attention to every detail of the operation and postoperative care.

Modern imaging allows us to define the vascular anatomy of the liver with a great deal of precision, and for any segmental or non-anatomic liver resection (anything more than a simple wedge biopsy) the surgeon should insist on having a CTA or high-quality MRI before taking a child to the OR for liver resection. This is especially important when the indication for resection is a tumor, for which a well-done major resection can be for naught if the margin is inadequate or a second nodule is left behind. It is also important to understand whether the liver is healthy or cirrhotic to be sure that what remains will be able to regenerate. Intra-operatively, the child should be carefully monitored, preferably with an indwelling arterial line and a central venous catheter. There is still no safe way to perform a liver resection through a tiny incision and therefore a generous subcostal incision is imperative. The entire liver must be mobilized and all vessels, including the suprahepatic and infrahepatic IVC, the portal vein, and the hepatic artery, should be dissected and controlled with vessel loops or ties. For major resections, the extrahepatic biliary anatomy should be defined as well, often starting with a cholecystectomy as a point of reference.

Blood loss is minimized by ligating all vessels supplying or draining the segment to be removed, which sometimes entails dissecting out second-order branches of the portal vein and hepatic artery within the liver parenchyma. How to come across the liver parenchyma is a matter of preference and experience. The harmonic scalpel works well, though bile duct branches and larger vessels need to be recognized early and ligated individually. The parenchyma just beneath the liver capsule is usually more compact and less vascular for a depth of about a centimeter or two and this cortical "rind" can be incised first with the electrocautery, exposing the deeper "pulp" of the liver where the larger vessels reside. After resection, bleeding from the raw surface of the liver is controlled with the argon beam coagulator and precise placement of clips or sutures as needed. Application of fibrin sealant is now customary, while the routine placement of drains is no longer considered obligatory. To prevent torsion of the liver remnant the falciform ligament may be reapproximated and the liver bed should be filled with colon and small bowel. Finally, even the most experienced pediatric surgeon needs to have a back-up plan in case of misadventure or unexpected difficulties, even if this means swallowing one's pride and calling for help from a colleague or transplant surgeon.

Initial postoperative care should take place in the PICU, though most healthy children recover uneventfully. Much is made of the need to have plenty of phosphate substrate available to the regenerating liver, but this is rarely a significant issue if the child is provided adequate nutrition before and after the operation. Complete regeneration of the liver in a child with healthy liver parenchyma can occur within a few weeks of a major hepatic resection. Any subtle deterioration in clinical status or bump in liver function or coagulation assays must be investigated promptly with Doppler US to assess perfusion of the liver remnant and to rule out torsion or thrombosis. Likewise there needs to be a low threshold to take the child back to the OR for re-exploration for liver ischemia or bleeding.

Suggested Reading

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Portal Hypertension

83

Caroline Lemoine and Riccardo A. Superina

Although portal hypertension (PHT) affects both adults and children, there are significant differences in etiology and treatment. Many treatment algorithms in children are based on and derived from personal experiences, expert opinions, and practice based on case reports or case series. In adults, randomized controlled trials have provided evidence for primary prophylaxis management recommendations. This same topic in the pediatric population is associated with a large variation in practice, thus preventing experts from reaching a consensus even in the modern era.

A pediatric surgeon will most likely encounter PHT in two main clinical situations. Acutely, because of complications such as acute upper gastrointestinal bleeding from esophageal or gastric varices that may be associated with hemodynamic instability, or electively, in the stable child with recurrent minor bleeds, melena, chronic anemia, or splenomegaly and thrombocytopenia. Even though the field of advanced hepatobiliary surgery is slowly evolving as a subspecialty of pediatric surgery, these two clinical scenarios share similar etiologies and underlying pathology with which a pediatric surgeon must be familiar. This is important so that patients may be offered the best treatment possible resulting in the best outcome. Just as important, one must be aware of not making decisions resulting in operations that may prevent optimal treatment later on.

Normal portal pressure is 5–10 mmHg. In adults, a portal pressure above 10 mmHg is associated with the occurrence of portal hypertension complications, including the occurrence of varices. Portal pressure can be measured indirectly using the Hepatic venous pressure gradient (HVPG). Normal HVPG is 1–4 mmHg. Portal hypertension is defined either as a portal pressure >10 mmHg or HVPG >4 mmHg. When the pressure gradient exceeds 10 mmHg, patients are at risk of developing esophageal varices; and above 12 mmHg, it is associated with an increased risk of bleeding and the development of ascites.

PHT can be classified as pre-hepatic, intrahepatic or hepatic, and post-hepatic, but this classification also correlates with vascular abnormalities or hepatocellular diseases (Table 83.1). Whereas cirrhosis is identified in a large proportion of adults, a large proportion of children with PHT actually have overall normal liver function. PHT can also be divided into cirrhotic and non-cirrhotic types. Non-cirrhotic PHT usually has a normal or close to normal HVPG while cirrhotic PHT will have an increased HVPG because of higher intrahepatic resistance.

Cirrhotic PHT in children is most often caused by biliary atresia (BA). It is also one of the most common causes of cirrhosis in the first years of life and the most common indication for liver transplantation in children. The mainstay of treatment remains the portoenterostomy described by Kasai more than 50 years ago. Age at surgery will impact the rate of successful resolution of jaundice and the rate of transplant-free survival. It is generally believed that a portoenterostomy performed before 60 days of age will result in a higher rate of jaundice resolution than if the operation is done after the first 100 days of life. Ultimately, 60 % of BA patients will eventually require a liver transplant ('failed Kasai') as they will develop complications from PHT, advancing cirrhosis and growth failure.

The second most frequent cause of cirrhotic PHT is inherited syndromes of intrahepatic cholestasis. The most common is Alagille's syndrome. Associated anomalies include cardiac anomalies in more than 90 % of patients, with peripheral pulmonary stenosis being the most common. Other anomalies can be skeletal, renal, and vascular. Patients often have characteristic facial features. Symptomatic relief includes medical treatment (ursodeoxycholic acid, fat-soluble vitamins supplements). However when chronic liver disease develops, liver transplantation may be required.

Progressive familial intrahepatic cholestasis (PFIC) is a group of rare inherited cholestatic diseases that can cause PHT. It has a worldwide incidence of 1 in 50,000–100,000,

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Table 83.1 Causes of portal hypertension in the pediatric population

Pre-hepatic	Vascular abnormalities	EHPVO PVT Splenic vein thrombosis arterio-venous fistula
Intrahepatic	Hepatocellular diseases	Biliary atresia Alagille syndrome Genetic-metabolic diseases (alpha-1-antitrypsin deficiency, galactosemia, tyrosinemia, Wilson's disease, and mitochondrial hepatopathies) Autoimmune disease (autoimmune hepatitis and PSC) Idiopathic PHT
Post-hepatic	Vascular abnormalities	Budd–Chiari syndrome Congenital cardiomyopathy Congestive heart failure

but is especially prevalent in some ethnic subgroups. There are three types of PFIC, all of which have characteristic gene mutations. They present at variable times in life; PFIC1, originally called Byler's disease, tends to present in the first months of life with recurrent jaundice and other extrahepatic clinical features (short stature, pancreatitis). PFIC2 usually presents in infancy and due to hepatic expression of the abnormal gene, there are no extrahepatic manifestations. Pruritus is a major clinical symptom. A high rate of hepatocellular carcinoma has also been reported in this group. Lastly, only 30 % of PFIC3 patients will present with cholestasis in infancy. PFIC can present with features of chronic liver disease including PHT. Treatment includes symptomatic relief of cholestasis and pruritus, which can be achieved with ursodeoxycholic acid or biliary diversion if intractable. External or internal biliary diversion can sometimes result in gratifying resolution or amelioration of pruritus and regression of liver fibrosis. However, when conservative medical and surgical measures fail to stop the progression of liver disease, liver transplantation is curative.

Alpha-1-antitrypsin deficiency (A1ATD) may present with jaundice in the first 4 months of life. It is caused by mutations in SERPINA1. It is the most common cause of inherited metabolic disorder causing liver disease in Caucasian infants with an incidence of 1 in 2500 live births. It presents in infancy in approximately 10 % of cases and requires follow-up through childhood to identify early signs of portal hypertension and cirrhosis, which may progress to require liver transplant.

Cystic fibrosis (CF) is caused by a mutation in the gene encoding the CFTR protein. This leads to an abnormal excretion of sodium and chloride anions which will ultimately affect the content of water and electrolytes in secretions, including bile. About 30 % of CF patients will have associated liver disease (CFLD), which can evolve to PHT and subsequently, cirrhosis. Patients with CF who require liver transplant have an overall worse prognosis compared to pediatric patients undergoing liver transplant for other etiologies. It is therefore currently accepted that CFLD should be treated early before the occurrence of complications. Surgical shunts have been shown to be safe and palliative in CFLD patients who have advanced hypersplenism or symptomatic esophageal and gastric varices as long as synthetic liver function is well preserved and the patient can look forward to at least 5 years of transplant-free survival.

Other causes for cirrhotic PHT in the pediatric population include chronic viral hepatitis which affects mostly older children. Various medications can also be associated with acute or chronic liver injury that progresses to cirrhosis.

Non-cirrhotic PHT is most often related to vascular abnormalities that either increase the flow of blood through the liver or cause increased resistance to the flow of portal venous blood into the liver. These can be subdivided into pre-hepatic, hepatic, or post-hepatic.

Pre-hepatic conditions include splenic vein thrombosis and Extrahepatic Portal Vein Obstruction (EHPVO).

EHPVO has an estimated incidence of 1 % in the general population, as reported in an autopsy study. It is one of the most frequent causes of PHT in the pediatric population, accounting for over 50 % clinically apparent cases. Various conditions have been mentioned as possible causes or risk factors for portal vein thrombosis (PVT), many of them occurring in the neonatal period. Premature neonates often undergo the placement of an umbilical venous catheter, which may result in portal vein trauma if introduced too deeply. Omphalitis as a result of poor umbilical stump care or phlebitis from an infected umbilical vein catheter may also cause inflammation and obliteration of the portal vein in the hilum of the liver. Occurrence of neonatal sepsis or the need for neonatal abdominal surgery has been reportedly associated with PVT. Coagulation disorders may also predispose to thrombosis of the portal vein. Genetic causes of hypercoagulable conditions such as factor V Leiden mutation or mutations in the prothrombin gene or MTHFR gene are other possible etiological factors.

Despite these possible etiologies, most children with EHPVO do not have readily identifiable causes for the thrombosis. It is quite likely that EHPVO may also be a developmental abnormality in the formation of the portal vein outside the liver.

The high incidence of associated cardiac and other congenital anomalies suggests that some of these children may be born with EHPVO as a result of an embryological malformation. These patients are therefore defined as idiopathic PVT.

Hepatic causes of PHT include congenital hepatic fibrosis (CHF). It is a rare developmental disorder of the hepatobiliary system characterized by an abnormal ductal plate malformation (DPM). DPM represents the association of abnormally branching bile ducts and progressive periportal fibrosis. CHF is associated with various other conditions, including polycystic kidney disease and Caroli's disease. It is isolated in about 10 % of cases. Many have esophageal varices and almost a third suffer from a variceal bleed. Hypersplenism has been reported in as high as in 75 % of patients. PHT occurring in CHF patients is most often managed by endoscopic measures. Repeated episodes of bleeding or progressive hypersplenism may also be substantially palliated by portosystemic shunting, preferably the selective distal splenorenal shunt. Patients with CHF may also present with intra- and extrahepatic choledochal cysts (CDC) and episodes of cholangitis. These children may benefit from CDC excision and biliary reconstruction. Most CHF patients have symptoms that can be treated by non-transplantation surgery. However, patients with advanced PHT or severe intractable cholangitis may require a liver transplant to deal with the increasing disability from severe symptoms.

Post-hepatic causes for PHT include Budd–Chiari syndrome, defined as a hepatic vein outflow obstruction leading to hepatic congestion. Causes include hypercoagulable states, congenital hepatic vein webs, and hydatid disease. It can also be the consequence of more systemic conditions, including congestive heart failure, cardiomyopathy, or pericarditis. A not infrequent cause of outflow obstruction is veno-occlusive disease subsequent to chemotherapy, particularly after bone marrow transplantation. Busulfan has been associated with this type of hepatic outflow obstruction as it causes a blockage to blood flow at the level of the liver sinusoids. Conservative measures such as anticoagulation or treatment with inflammatory agents are not uniformly successful and the mortality of this condition is high. Portosystemic shunting may allow for acute decongestion of the liver with preservation and return of liver function. Liver transplantation in the face of acute venous outflow obstruction may be lifesaving with Budd–Chiari syndrome but unlikely to resolve the issue in the face of veno-occlusive disease post stem cell transplantation.

Diagnosis

Variceal bleeding from the esophagus and stomach is probably the most frequent clinical presentation of portal hypertension. Up to two thirds of the pediatric patients with PHT present with an episode of upper gastrointestinal bleed (UGIB), either hematemesis or melena. This UGIB most often originates from an esophageal varix. Indeed, the occurrence of PHT will lead to the development of portosystemic low-pressure collaterals along the GI tract. Other sources of GI bleed can include gastric varices, portal hypertensive gastropathy, duodenal varices, and less often rectal varices. The occurrence of GI variceal bleed is due to an eventual high pressure in the variceal system, as the only way to decompress the antegrade obstruction, which results in increased varix wall tension. The precipitating factor for bleeding in children often follows an upper respiratory tract infection. Median age at the first bleeding episodes is 4 years, but it however has been reported in patients as young as 2 months of age. A patient bleeding before the age of 12 has a higher risk of subsequent bleeding episodes than if he/she had initially bled at an older age. Adolescents with EHPVO have a probability of esophageal varix bleeding of nearly 50 % by age 16, and up to 75 % by age 24.

Most patients with an UGIB are also found to have splenomegaly. Therefore, if a patient presents with both these conditions, one should think about the possibility of PHT. Splenomegaly is actually the second most common finding in children with PHT. Because it is often associated with abnormal laboratory findings (thrombocytopenia, leukopenia), pediatric patients presenting with otherwise asymptomatic splenomegaly will often be referred to a hematologist. Regrettably, children presenting with signs of hypersplenism and variceal bleeding will be referred to the pediatric surgeon for consideration of a splenectomy. Once again, it is very important *not* to perform a splenectomy in those patients, as it will most likely preclude the option of benefiting from a distal splenorenal shunt (DSRS), in the future if needed.

Other physical signs reported at the time of presentation include abdominal ascites, abdominal collateral venous prominence (*caput medusae*), and hepatomegaly. Hepatomegaly is particularly prominent with congenital hepatic fibrosis and PFIC. The liver may be small in children with EHPVO or cirrhosis. Ascites is a late sign and, if present, might indicate that hepatic function has deteriorated to the point that a liver transplant should be considered. Serum ammonia can also be elevated in patients with any kind of portosystemic shunting. Low-grade encephalopathy occurs in some children with preserved liver function and manifests as behavioral disorders or learning disabilities.

Hepatopulmonary syndrome and portopulmonary hypertension are serious complications of portosystemic shunting. Unless portal flow can be re-established in cases of EHPVO, operating to create more efficient shunts to decompress the portal circulation is not indicated, as this will only precipitate acceleration of the pulmonary hypertension or desaturation. If a meso Rex bypass is not possible, liver transplantation at this point is the only viable option. In cases of EHPVO and concomitant portopulmonary syndrome, extreme care must

be taken in any operative attempts to avoid pulmonary hypertensive crises, and the collaboration of the cardiology and pulmonary hypertension teams is essential in planning the operation and the postoperative care.

When evaluating a patient with suspected PHT, the following laboratory tests should be obtained routinely: CBC (to evaluate for leukopenia and thrombocytopenia); a coagulation panel (including an international normalized ratio (INR)); a liver function panel (to rule out underlying liver disease, with liver enzymes, bilirubin, alkaline phosphatase, gamma-globulin transferase, and albumin); and a comprehensive metabolic panel (including kidney function). An ammonia level should also be sent as a baseline value.

In any patient with EHPVO, a hypercoagulable work up should be obtained and the collaboration of hematologists with expertise in coagulation disorders should also be obtained. This includes assays for protein C, protein S, antithrombin III, plasminogen, factors V and VII, plus lupus anticoagulant, beta-2-glycoprotein, and anti-phospholipid antibodies. Genetic testing should also be included.

Imaging Studies

Doppler US of the abdomen can make the diagnosis of cavernous transformation of the portal vein or EHPVO. It can demonstrate splenomegaly, hepatomegaly, and ascites. Choledochal cysts, Caroli's disease, and polycystic diseases of the kidneys should also be readily evident in children with CHF. An US is an excellent screening study to determine the status of the portal vein and accompanying liver and spleen abnormalities. It can also be performed at bedside in the setting of a hemodynamically unstable patient in intensive care unit who cannot tolerate movement to the radiology department.

Other helpful imaging modalities in the evaluation of PHT include CT or MR venography. These can help define the presence of an intrahepatic portal vein and provide a map of the veins in the abdomen including the patency, size, and location of the portal, superior mesenteric, splenic, and renal veins in preparation for possible surgical intervention.

Arterial angiography with venous phase imaging is singularly unsuccessful at demonstrating the size and quality of the intrahepatic portal vein in children with EHPVO. The vein inside the liver is hypoplastic and the contrast is shunted away towards the varices making the intrahepatic venous anatomy very difficult to discern in most cases (Fig. 83.1). In the case of EHPVO, the most effective way of demonstrating the presence of an intrahepatic portal vein is by transjugular retrograde venogram with balloon occlusion (Fig. 83.2). Selectively cannulating one of the hepatic veins at a time and occluding it using a balloon will force contrast retrograde into an intrahepatic portal vein. This study will demonstrate whether there is a good intrahepatic portal vein network or an isolated left or right system, which could be less suitable for a Meso-Rex Bypass (MRB) with expected good results. An IR venogram study will also obtain a wedged hepatic vein pressure indicating sinusoidal pressure. A liver biopsy can also be obtained if one is clinically useful. Various studies have reported the feasibility, safety, and reliability of measurements of the HVPG in children performed by interventional radiology.

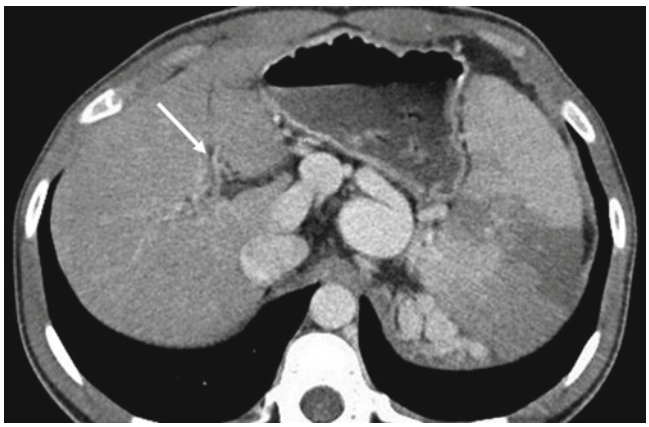

Fig. 83.1 Abdominal CT of a patient with EHPVO prior to undergoing an MRB. Note the small size of the intrahepatic portal vein (white arrow)

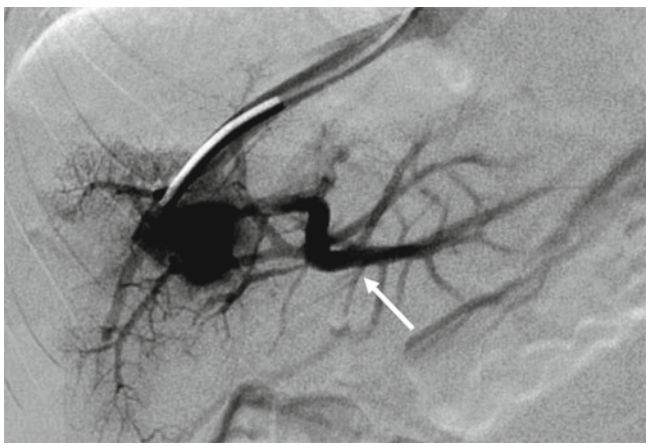

Fig. 83.2 IR venogram image of the same patient with EHPVO. Note the presence of a normal size portal vein identified in the liver (white arrow) using retrograde balloon inflation

Acute Bleeding

A patient with PHT who presents with acute bleeding must first be stabilized and admitted to an intensive care unit (Fig. 83.3). Continuous vital signs monitoring is performed. Intubation may be necessary to protect the airway or if the patient is

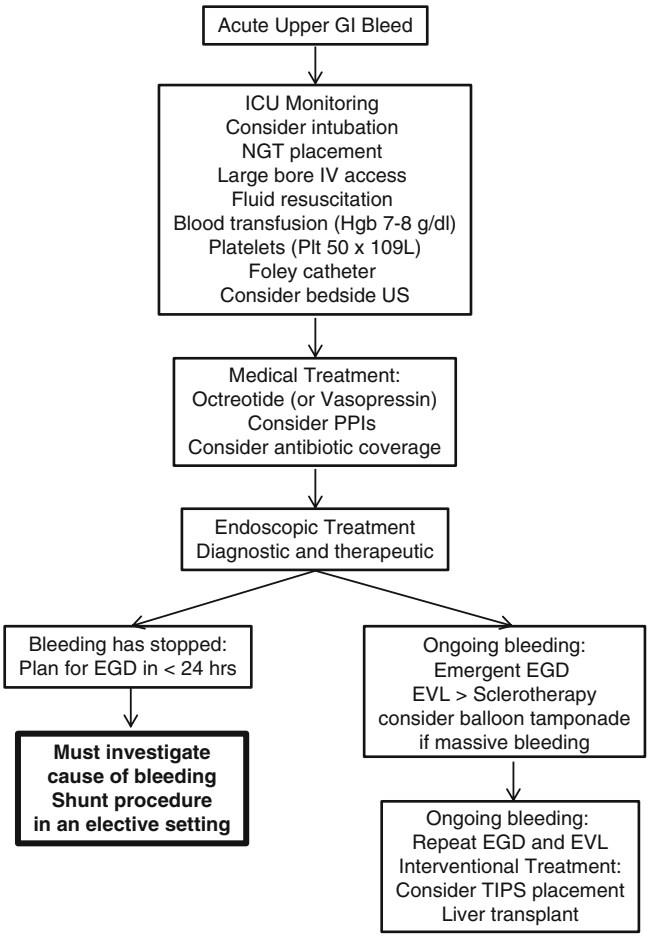

Fig. 83.3 Management of acute variceal bleed

obtunded. Fluid resuscitation is then performed judiciously, while avoiding overfilling so as not to increase portal pressure and promote bleeding. Blood transfusion should be given with a target hemoglobin level of 7–8 g/dL, although this can be adjusted if the patient has an underlying comorbidity (congenital heart disease). Platelets are administered if they are less than 50,000/mm^3. A nasogastric tube is placed and aids in quantifying the rate of bleeding, while emptying the stomach of blood, which can precipitate encephalopathy.

A pharmacologic agent like vasopressin or octreotide is added. Vasopressin will act by increasing the splanchnic tone, but will have the side effect of abdominal pain and possible bowel ischemia. Octreotide has also been shown effective in decreasing splanchnic blood flow with fewer side effects. Those drugs are effective at stopping variceal bleeds in more than 75 % of patients and they can be used in combination with the endoscopic modality for up to 5 days. Prophylactic antibiotics should also be administered.

Esophagoduodenogastroscopy should be scheduled within 24 h both for diagnostic and therapeutic reasons. Sclerotherapy and endoscopic variceal banding are both effective in controlling the bleeding from the varices. Banding is now the recommended procedure of choice for acute variceal bleeding. Sclerotherapy is preferred in younger children (12–15 kg) when the ligation endoscope is too large. Overall, sclerotherapy has now been mostly abandoned because of its associated increased risks of esophageal stenosis, ulceration, perforation, and stricture. Endoscopic varix ligation (EVL) is associated with a low theoretical risk of entrapment of the entire thickness of the esophageal wall, which could evolve in necrosis and perforation. If rebleeding were to occur, endoscopic measures can be repeated.

When facing ongoing and recurrent bleeding despite optimal therapy, balloon tamponade (Blakemore tube) is rarely indicated or used, and should be limited to bridging towards more definitive interventional therapy. A Transjugular Intrahepatic Portosystemic Shunt (TIPS) can be performed, with the advantage of not requiring surgery. However, there is limited experience with this technique in children and it may ultimately produce difficulties for planning and executing future surgical procedures. A TIPS should with rare exception only be used in children as a bridge to a transplant.

Surgical procedures are in general reserved for acute and refractory GI bleeds and can include interventions such as the Sugiura procedure. This consists of devascularization of paraesophageal and gastric collaterals, esophageal transection with a stapling device, and splenectomy. Of note, the modified Sugiura procedure allows for spleen preservation. It appears to have up to 75 % efficacy to prevent rebleeding. In intractable cases, liver transplantation may remain the last option available.

Asymptomatic Portal Hypertension

When a patient is newly diagnosed with PHT but has not suffered from a variceal bleed, the goal should be to prevent the occurrence of a first bleeding episode (primary prophylaxis). The clinician must first establish if a patient with PHT has esophageal or gastric varices and is at risk of bleeding from those varices. Most patients with variceal bleeding have thrombocytopenia and hypersplenism, and thus these patients could benefit from a screening EGD.

The primary prophylaxis of variceal bleeding in adults comprises the use of β-blocker therapy and EVL. Unfortunately, there are no data supporting identification of pediatric patients at increased risk of bleeding who could benefit from similar primary prophylaxis. The use of β-blockers for primary prophylaxis in children has been reported in case series yielding conflicting results including an inability to reduce HPVG (which is the criteria to assess efficacy in adults). Moreover, children's stroke volume is heart rate-dependant and thus there are concerns about blunting the normal compensatory

tachycardic response in the face of acute variceal bleeding and hypovolemic shock with β-blockade. Therefore, the use of β-blockers for primary prophylaxis in children is currently *not* recommended.

When a clinician estimates that a patient has an increased potential risk of bleeding, EVL is the therapy most often used as it is usually well tolerated and associated with a low complication risk. There is currently no study to support this decision, which explains why there is a wide variation in management between clinicians.

There is one subset of patients, however, for whom experts have come to a consensus on the benefits of primary prophylaxis. Patients with PHT secondary to EHPVO should benefit from a Meso-Rex bypass (MRB) as soon as the diagnosis is made. MRB restores hepatopedal blood flow to the liver, reverses hypersplenism, and eliminates the risk of upper GI bleeding from varices. The operation consists of using an autologous vein graft to create a bridge between the superior mesenteric vein and the patent intrahepatic left portal vein by going through the recessus of Rex between segments III and IV of the liver (Figs. 83.4 and 83.5). Alternate inflow options have been described. The original description utilized the internal jugular vein as the bridge and it still serves as the most efficient conduit. Alternate veins have been described as grafts. Other veins besides the SMV have been described as the site of the abdominal anastomosis, including the coronary, splenic, and inferior mesenteric veins, as well as large varices in the abdomen in the absence of any other more suitable vein.

It has been shown that following successful MRB there is improvement in neurocognitive function, with improvement in a variety of testing modalities. This finding is accompanied by a correction in the hyperammonemia. Correction in low protein C and S levels occurs as well as in coagulation factors V and VII. Portal vein size in the liver expands rapidly and liver growth occurs as well. There is also evidence that somatic growth, if delayed, catches up and z scores for height and weight normalize.

Hence, at our institution, if a patient presents with PHT secondary to EHPVO, we will aim at performing an MRB unless anatomically impossible because of the absence of a suitable intrahepatic portal vein. Successful creation of an MRB has been reported in 70–80 % of patients with EHPVO. Such interventions have been performed in patients as young as 4 months of age, and as old as 30 years. However, the plasticity of the portal vein and the chances of finding a patent intrahepatic portal vein are higher in younger patients. There is no benefit to waiting for the child to be older, as it decreases the chances of finding a patent portal vein and exposes the patient to an increased risk of suffering from a variceal bleed.

When the patient does not have evidence of a suitable intrahepatic portal vein on preoperative imaging, has evidence of intrahepatic hepatocellular disease, or difficulties

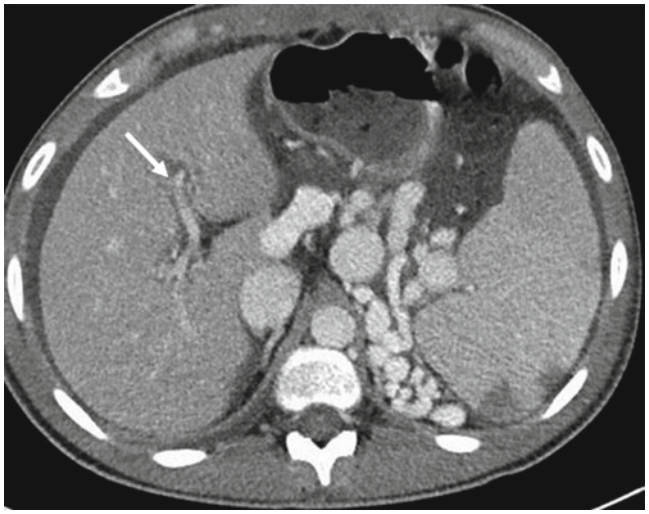

Fig. 83.4 Postoperative abdominal CT showing increase in size of the intrahepatic portal vein following MRB (white arrow)

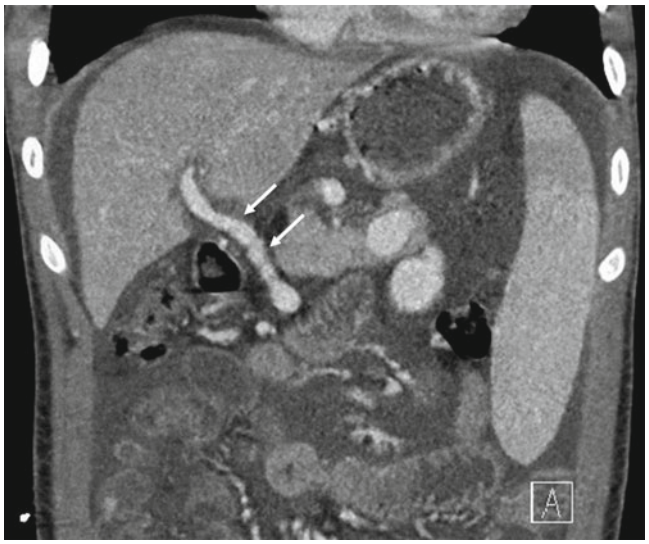

Fig. 83.5 Postoperative abdominal CT following MRB showing patency of the shunt on postoperative (white arrows)

are encountered in identifying an intrahepatic portal vein in the operative room, a distal splenorenal shunt (DSRS) is a reasonable alternative. This shunt procedure is theoretically a more selective type of shunt than a proximal splenorenal or mesocaval shunt as these operations fail to restore blood flow through the liver and thus do not address the metabolic benefits that have been described after successful MRB. The DSRS has been well described in the literature for over 40 years—it is a safe, effective means of controlling variceal bleeding, improving thrombocytopenia, and splenomegaly.

When it is impossible to perform an MRB or when there is accompanying splenic vein thrombosis or past surgical history of splenectomy, a mesocaval shunt may be the only

remaining option to decompress patients with EHPVO. This is performed by accessing the inferior vena cava below the left renal vein by kocherizing the duodenum. The SMV is found at the root of the mesentery immediately anterior to the IVC. PTFE grafts are preferred over native vein for mesocaval shunts since the vein graft may be easily compressed. The anastomosis is created from the anterior wall of the IVC to the posterolateral aspect of the SMV.

Both the DSRS and mesocaval shunts are well tolerated in children with EHPVO since the liver is essentially normal. Mesocaval shunts are generally avoided in patients with cirrhosis due to metabolic conditions, biliary atresia, or other conditions that cause PHT from parenchymal abnormalities because of the potentiation of encephalopathy, and deterioration in an otherwise well compensated cirrhotic. Both the mesocaval and DSRS are very effective at palliating the symptoms of portal hypertension and have an exceedingly low rate of thrombosis. Although effective at preventing rebleeding, the mesocaval shunt does carry the highest risk in development of postoperative encephalopathy.

Recurrent Variceal Bleeding

Patients who have already suffered from a first bleeding episode have an increased risk of rebleeding. They will therefore be offered treatment aimed at reducing their risk of subsequent bleed (secondary prophylaxis). The therapy of choice is endoscopic varix ligation. EVL appears to be associated with a lower risk of rebleeding (4 % vs 26 %) than sclerotherapy in children. It should be repeated every 2–4 weeks. There is currently no recommendation for the use of β-blockers for secondary prophylaxis of variceal bleed in the pediatric population.

In the subset of patient with EHPVO, PHT, and recurrent variceal bleeding, the treatment of choice is the meso-Rex bypass (MRB). If technically impossible to perform, DSRS will constitute a second good option. In patients with PHT but from other etiologies than EHPVO, surgical portosystemic shunts may be considered unless they already suffer from complications like hepatic encephalopathy. Since surgical shunts may cause the patients to deteriorate, they may require a liver transplant in order to improve.

Future Considerations

There is growing interest in developing tools to assess the presence and severity of PHT and esophageal varices using non-invasive measures. The development of various PHT blood biomarkers is emerging. Some non-invasive markers have already been studied in adults, including platelet count and degree of splenomegaly, but haven't been validated in the pediatric population. Markers of liver fibrosis and spleen stiffness, including transient elastography, are also now being evaluated in children.

As there is growing experience with the Meso-Rex Bypass and therefore with an increasing number of patients having been treated using this surgical technique, more conclusions will be derived about the physiological changes associated with this procedure. Larger patients cohorts will also help better characterize the short and long terms benefits that can be expected, and how it compares to other portosystemic shunts procedures.

Editor's Comment

Regardless of the etiology, children with advanced cirrhosis should be considered for liver transplantation, although a surgical portosystemic shunt or TIPS is sometimes used as a bridge to transplant. Surgical shunts are associated with excellent outcomes when performed by experienced surgeons in high-volume centers. In general, selective shunts (distal splenorenal) are preferred over nonselective shunts (central splenorenal, mesocaval) because they result in less postoperative encephalopathy. Direct reconstruction (Rex shunt) is preferred for patients with extrahepatic portal venous obstruction, patent intrahepatic veins, and no significant hypercoagulability. It is important to choose a shunt that will not make a subsequent liver transplantation operation more difficult or dangerous.

In the past it was common for patients with hypersplenism due to portal hypertension to be referred for splenectomy, usually in combination with a nonselective shunt (central splenorenal) or devascularization procedure. However, except in the rare case of splenic vein thrombosis, this practice is currently frowned upon, especially, since a well-constructed shunt improves venous drainage of the spleen and will usually reverse the hypersplenism. The spleen should be preserved whenever possible.

Suggested Reading

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Congenital Hyperinsulinism

84

N. Scott Adzick and Pablo Laje

In 1934, Evarts Graham from St. Louis, MO performed the first successful pancreatectomy on a child with HI. The pancreas was explored searching for an adenoma, but since no adenoma was found a subtotal pancreatectomy (~90 %) was performed and the patient's hypoglycemia resolved. This was done 20 years before the first description of HI, which was initially termed "syndrome of idiopathic hypoglycemia of infants." It was initially believed that HI was caused by an over-secretion of insulin secondary to an abnormally high number of pancreatic islets resulting from an anomalous phenomenon of postnatal budding of endocrine cells of the pancreatic ducts called nesidioblastosis (*nesidion* means "island"). This theory was based on the histologic analysis of pancreatic specimens from children with HI stained with insulin-specific techniques. Later studies showed that nesidioblastosis was a normal neonatal phenomenon and thus this term is no longer used. Recent advances in molecular diagnosis have conclusively demonstrated that HI does not result from a developmental abnormality but from a variety of genetic derangements that alter the regulatory mechanisms of insulin secretion and glucose homeostasis.

Histological Classification

There are two major histological forms of HI: focal and diffuse (Fig. 84.1). They differ significantly in terms of genetic basis, management strategy, and surgical approach. Focal HI consists of a focus of adenomatous islet cell hyperplasia surrounded by normal pancreatic tissue. Focal lesions retain the lobular architecture of the normal pancreas in contrast to insulinomas, which do not. The beta cells within the focal lesion have an enlarged cytoplasm and typically normal nuclei, although nucleomegaly is not uncommon. Beta cells accumulate in clusters surrounded by non-beta islet cells. The exocrine and canalicular cells are pushed toward the periphery, but are always somewhat intermixed within the endocrine cells. Focal lesions vary in size from a few millimeters to greater than a centimeter or much more, and can be superficial or deep. In our series of more than 200 operated focal lesions, 45 % were located in the pancreatic head, 25 % in the neck/body, 15 % in the tail, and 15 % in other locations that included unusually large lesions that extended beyond a single pancreatic segment, and very rarely lesions located in ectopic pancreatic tissue.

Diffuse HI, on the other hand, has one primary histological hallmark feature that distinguishes it from a normal pancreas: beta cell nucleomegaly. Nucleomegaly is defined as nuclei that occupy an area three times larger than the nuclei of the adjacent non-beta endocrine cells or four times larger than the nuclei of the adjacent acinar cells. In the vast majority of cases of diffuse HI, the abnormal beta cells are distributed homogeneously throughout the pancreas, and the total number of beta cells is normal.

Of all patients with HI, 30–40 % have focal disease and 60–70 % have diffuse disease. In our experience of more than 400 HI patients who underwent surgery since 1999, 53 % had focal disease and 47 % had diffuse disease.

There are rare histological forms of HI that are neither focal nor diffuse, and are called "atypical." Among these are focal lesions that occupy a large segment of the pancreas, cases of remarkable endocrine hyperplasia in patients with Beckwith–Wiedemann syndrome, and cases with features of diffuse HI restricted to a single area of the pancreas, or distributed in a mosaic pattern (Localized Islet Nuclear Enlargement, LINE). Patients with atypical forms of HI are clinically heterogeneous and require a medical and surgical management individually crafted according to the severity of each case.

Pathogenesis and Genetics

When the plasma glucose concentration rises, glucose enters into the beta cell and initiates a chain of events that results in prompt insulin secretion. The metabolism of glucose molecules

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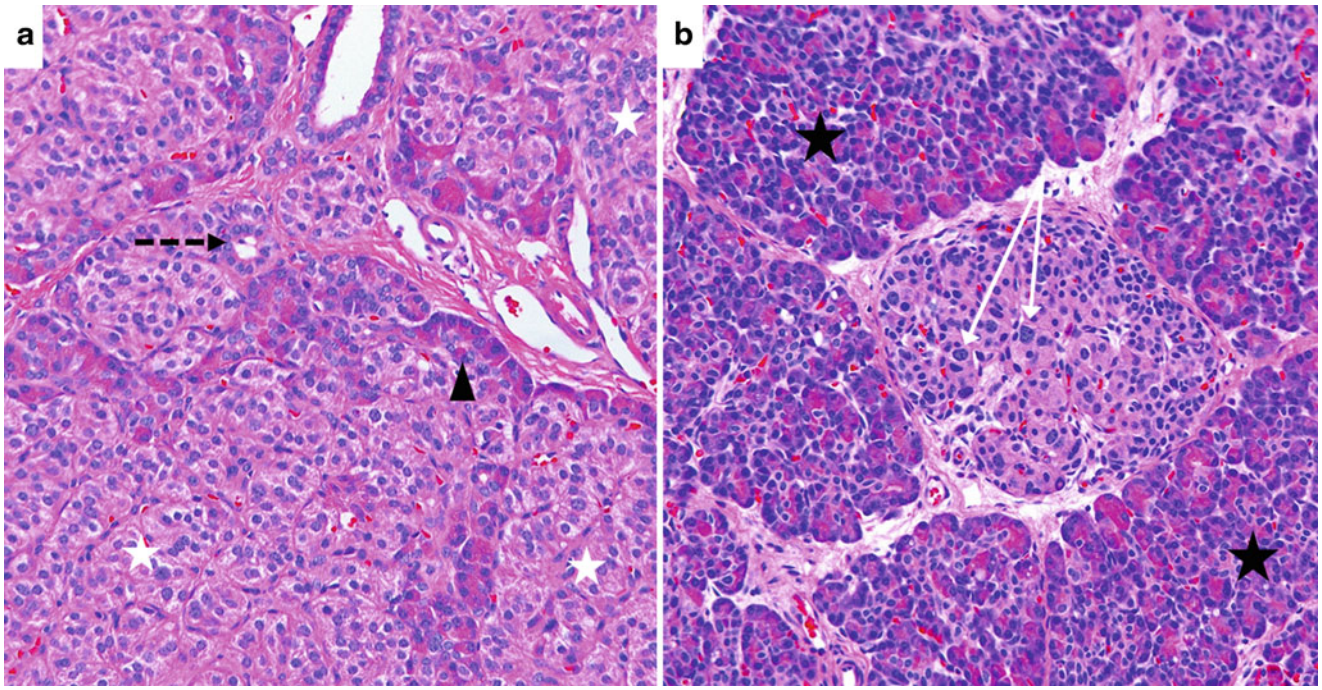

Fig. 84.1 Histology of HI. (**A**) Focal lesion. There is hyperplasia of beta cells (*white stars*), with exocrine (*black arrowhead*) and ductal (*black arrow*) components within the lesion. (**B**) Diffuse HI. Endocrine cells show nucleomegaly (*white arrows*) within an otherwise normal islet of Langerhans. The exocrine component is normal (*black stars*)

inside the beta cell derives in the conversion of ADP into ATP, elevating the ATP:ADP ratio. As a consequence, the ATP-dependent potassium (K-ATP) channels of the cell membrane become inactive and close, potassium accumulates on the inner surface of the cell membrane and depolarizes it, the depolarization of the cell membrane activates the voltage-dependent calcium channels, and calcium enters the cell, accumulates in the cytoplasm, and triggers a calcium-dependent insulin exocytosis. When the K-ATP channel is defective due to loss-of-function genetic mutations it remains closed at all times regardless of the plasma glucose level, generating a non-regulated, persistent insulin release that leads to hypoglycemia. This is the most common pathophysiologic mechanism of HI. Insulin levels, however, are never strikingly elevated in HI.

The K-ATP channel of the beta cell membrane is composed of the subunits "SUR1" (a sulfonylurea receptor, the regulatory subunit) and "Kir6.2" (the ion pore), which are, respectively, coded by two genes located next to each other in the p15.4 region of the chromosome 11: ABCC8 and KCNJ11. There are currently more than 200 known mutations in the ABCC8 and KCNJ11 genes, and about 50 % of all patients with HI have a known mutation, which means that it was identified in previous HI patients. The diffuse form of HI occurs most frequently due to homozygous mutations of the SUR1/Kir6.2 complex inherited in an autosomal recessive manner. Rarely, mutations of the ABCC8 and KCNJ11 genes are inherited in a dominant manner, and compound heterozygous ABCC8/KCNJ11 mutations cause diffuse HI. The clinical presentation of these patients is milder than patients with homozygous recessive disease. Diffuse HI can also occur due to mutations in the genes of six other enzymes and metabolic factors: glucokinase (GK, 7p15.3-p15.1), glutamate dehydrogenase (GDH, 10q23.3, "hyperinsulinism-hyperammonemia syndrome"), short-chain hydroxyacyl-CoA dehydrogenase (SCHAD, 4q22–26), hepatocyte nuclear factor 4a (HNF4A, 20q12–13.1), monocarboxylate transporter 1 (MCT1, 1p13.2–p12), and the uncoupling protein 2 (UCP2, 11q13).

The focal form of HI occurs through a "two-hit" phenomenon: for the first "hit," the individual inherits a mutation in the paternal allele of the SUR1/Kir6.2 complex, and for the second "hit," the maternal 11p15 region containing the normal maternal allele is lost in a single pancreatic beta cell. The loss of the maternal 11p15 region is a completely random event that has no inheritable component. This event is called "loss of heterozygosity" in which the allele from only one progenitor is present, and the other allele is lost. The affected beta cell not only will oversecrete insulin, but will also develop an adenomatous hyperplastic proliferation due to an imbalance in a series of genes that regulate cell proliferation that are also contained in the 11p15 region and are subject to genomic imprinting. The 11p15 region contains the tumor suppressor gene H19 and the cell cycle regulator $p57^{kip2}$. H19 is strongly imprinted and of exclusively maternal monoallelic expression, and exerts an antagonistic effect

on the insulin-like growth factor 2 (IGF2) expressed from the paternal allele. The imbalance between IGF2 and H19 is the reason for the adenomatous proliferation of the affected beta cells, the so-called focal lesion.

When a baby is diagnosed with HI in the absence of a family history, the parents and the patient should undergo genetic testing. In medically responsive HI, the genetic testing has only a diagnostic purpose. On the other hand, in medically resistant cases the genetic testing becomes more relevant since it can help differentiate between diffuse and focal HI, determine the need for imaging studies, determine the surgical approach, and provide prognostic information.

Diagnosis

The diagnosis of HI is established through a series of simple blood tests. The following three metabolic criteria must be present to confirm HI: (1) fasting and postprandial hypoglycemia with unsuppressed hyperinsulinism in which neonatal hypoglycemia is defined as a glucose plasma concentration of <50 mg/dL after the first 24 h of life, with a simultaneous plasma insulin concentration of >36 pmol/L; (2) suppression of lipolysis and suppression of ketogenesis at the time of the hypoglycemia because lipolysis and hepatic ketogenesis are a normal physiologic response to hypoglycemia, and are physiologically inhibited by insulin; and (3) a positive glycemic response to a dose of glucagon, which is a direct insulin antagonist, such that glucose must increase by 30–50 mg/dL after 0.25–1 mg of intravenous glucagon. The three criteria must be present for a prolonged period of time and outside clinical circumstances such as perinatal stress and sepsis.

The mainstay drug in the treatment of HI is diazoxide, which inhibits insulin secretion by activating the K-ATP channel. Diazoxide binds to the SUR1 subunit of the K-ATP channel and keeps it open, but in order to be effective both subunits of the channel must be structurally and functionally normal. From a therapeutic standpoint HI is divided into two groups: diazoxide-responsive and diazoxide-resistant. Since the most common cause of HI is a mutation in the SUR1/Kir6.2 gene complex, the majority of HI patients do not respond to diazoxide. The ones that do respond are those with mutations in the GK, GDH, SCHAD, and other HI-related genes. In our experience treating over 600 HI patients, about 1/3 of them were diazoxide-responsive and 2/3 were diazoxide-resistant. Diazoxide-resistant patients generally require surgery.

Prenatal Diagnosis and Counseling

Prenatal screening of all known mutations of all HI-related genes in the general population is impractical due to the low incidence of the disease. On the other hand, prenatal diagnosis in families with affected probands is possible and justified because it allows immediate postnatal management. In the case of diffuse HI, the genetic mutations follow principles of Mendelian inheritance—the chance of diffuse HI in the offspring of carrier parents is 25 %. In the case of focal HI, on the other hand, while the inheritance of a paternal ABCC8/KCNJ11 mutation follows Mendelian laws, the development of a focal lesion in subsequent siblings of an affected individual is completely unpredictable given the fact that the second event in the pathogenesis of the disease (the loss of the normal maternal allele) is a random non-inheritable event that occurs in a single somatic cell. The likelihood of focal HI in siblings is exceedingly low, but has been reported.

Medical Management

The priority in the treatment of babies with HI is to prevent hypoglycemia, because it can lead to irreversible brain damage. This is achieved by a combination of a high-concentration intravenous glucose infusion and frequent enteral feeds. The required glucose infusion rate (GIR), calculated as % dextrose × IV rate × 0.169/weight in kg, may need to be as high as 30 mg/kg/min, which is more than three times the physiological hepatic glucose release rate observed in newborns during fasting periods. In addition to glucose administration, hyperglycemic drugs must be initiated as soon as possible. The first line drug is diazoxide. Diazoxide is not effective in patients with recessively inherited mutations in the ABCC8/KCNJ11 gene complex, but it can be partially effective in patients with dominant and compound heterozygous mutations. Diazoxide is effective in patients with mutations in all the other HI-related genes of dominant inheritance known to date. After five consecutive days of diazoxide administration the response is evaluated by a fasting test during which glucose infusion and all medications must be stopped. Patients who can maintain a plasma glucose level of >70 mg/dL for 12 h or more are considered diazoxide-responsive. These patients are subsequently managed by a regimen of frequent feedings and long-term diazoxide (Fig. 84.2). Diazoxide causes sodium and water retention, which can be controlled with diuretics, and hypertrichosis.

Patients whose plasma glucose level falls below 70 mg/dL within the first few hours of the fasting test are considered diazoxide-resistant and are presumed to have ABCC8/KCNJ11-related HI. These patients resume the glucose intravenous infusion immediately and start a preoperative work-up. Patients who are able to maintain the plasma glucose level above 70 mg/dL for several hours but do not reach the 12-h mark are considered to have a partial response to diazoxide, and are managed with a combination of diazoxide and continuous (or very frequent) feedings.

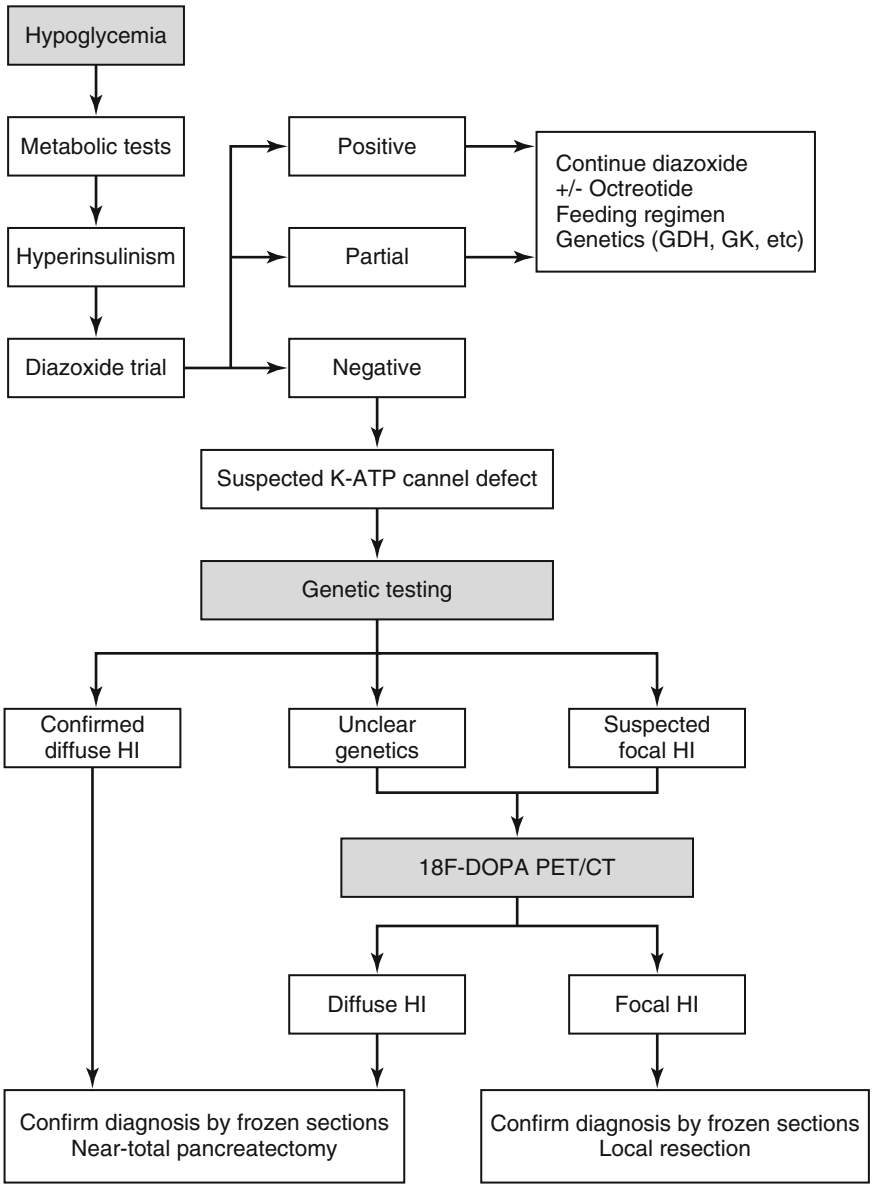

Fig. 84.2 Management algorithm for patients with HI

In patients with diazoxide-resistant HI, alternative drugs can be used to maintain euglycemia prior to surgical intervention. Those drugs include octreotide and glucagon. Octreotide is a synthetic long-acting somatostatin analog that inhibits insulin secretion by a direct inhibition of voltage-dependent calcium channels. It is generally administered subcutaneously every 6–8 h, or as a continuous subcutaneous infusion. The dose must always be titrated up due to rapid tachyphylaxis. Glucagon is a natural insulin antagonist that is mainly used to promptly reverse severe hypoglycemic episodes.

Patients with a partial response to diazoxide and patients with persistent hypoglycemia after a near-total pancreatectomy who cannot be re-operated on can potentially be managed at home with a long-term subcutaneous octreotide administration. However, the long-term use of octreotide has several concerning aspects: (1) octreotide has potential adverse effects (splanchnic ischemia), (2) octreotide receptors desensitize rapidly, and (3) octreotide interferes with other endocrine pathways (growth hormone). Other somatostatin analogues with different pharmacokinetic profiles have been used as long-term therapies in patients with diazoxide-resistant HI (a slow-release gel formulation of lanreotide administered once a month), but the experience is anecdotal. Similarly, there are anecdotal cases of HI patients treated with the immunosuppressant sirolimus.

Preoperative Management

The most important aspect of the preoperative planning is to determine whether the patient has diffuse or focal disease, because the surgical strategy is radically different between

the two. Genetic testing is the first step (Fig. 84.2). Ideally, either a known disease-causing K-ATP channel mutation is found on the maternal and paternal alleles, confirming recessive diffuse HI, or only one disease-causing mutation is found in the paternal allele, suggesting focal disease. The identification of only a mutation in the paternal allele does not exclude the rare possibility of a diffuse-HI-causing postzygotic mutation on the maternal allele, which would not be detected by peripheral blood leukocyte genetic testing. Occasionally, a previously unknown genetic variant is found. In those cases it is impossible to determine if it is a new disease-causing mutation or simply a rare polymorphism.

Patients with genetically confirmed recessive K-ATP-related diazoxide-resistant diffuse HI do not need preoperative imaging studies and nearly always require a near-total pancreatectomy. Resection of <95 % of the pancreas is associated with a high failure rate and need for further resection. Patients with genetic testing suggestive of focal HI must undergo imaging studies to confirm focal disease and to localize the suspected lesion (Fig. 84.2). When the genetic background is unknown or unclear, the patient should undergo imaging studies to determine if it is a case of focal or diffuse HI.

Imaging

Conventional non-invasive imaging studies such as transabdominal US, CT, and MRI are not helpful to distinguish between focal and diffuse HI or to localize focal lesions. Invasive interventional tests developed in the 1990s (arterial stimulation/venous sampling, and transhepatic portal venous sampling) are somewhat helpful, but they take several hours to be performed, are technically very demanding, and a large amount of blood needs to be withdrawn from the patient to obtain relevant data. Those studies have been largely replaced by what is now considered the standard imaging study for HI: ^{18}Fluoro-L-3-4 dihydroxyphenylalanine positron emission tomography merged with a low-radiation CT (^{18}F-PET/CT). Islet cells of the pancreas take up L-dihydroxyphenylalanine (L-DOPA), convert it to L-dopamine by the enzyme DOPA decarboxylase, and store it in vesicles. Similarly, these cells can take up ^{18}fluoro-L-3-4 dihydroxyphenylalanine (^{18}F-DOPA), convert it into ^{18}fluoro-dopamine, and store it in vesicles that can be tracked by their gamma radiation.

We administer the ^{18}F-DOPA under an FDA-approved Investigational New Drug protocol with the approval of our IRB. The ^{18}F-DOPA has a half-life of 110 min and is manufactured on the day of the study in the Cyclotron Facility of the University of Pennsylvania. The study is done under general anesthesia in a PET/CT hybrid scanner that initially captures the radioactive signal and then generates a low-radiation CT scan of the abdomen, without moving the patient. Focal lesions (which represent hyperplastic adenomatosis of beta cells) are seen as bright spots over a dark background due to the high concentration of the tracer, whereas in cases of diffuse disease the tracer is homogeneously distributed throughout the organ (Fig. 84.3). The sensitivity of the ^{18}F-PET/CT to detect a focal lesion is 85 % and the correlation between the location on the

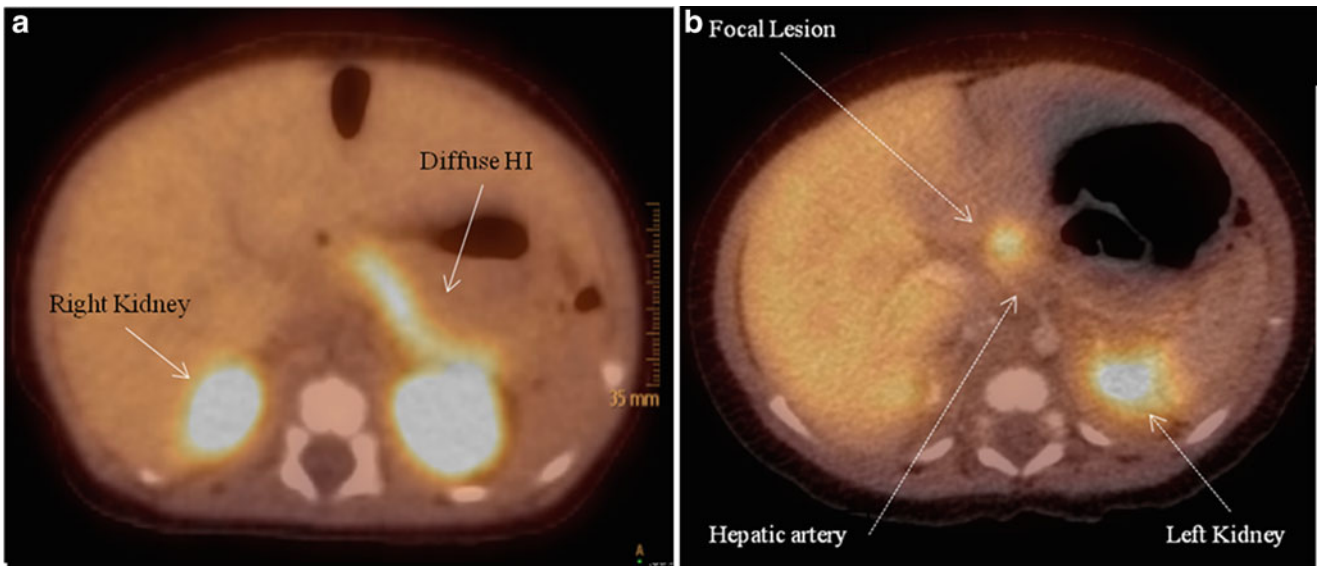

Fig. 84.3 ^{18}Fluoro-L-3-4 dihydroxyphenylalanine positron emission tomography merged with a low-radiation computerized tomography (^{18}F-PET/CT). (**A**) Diffuse HI: the entire pancreas takes up the tracer homogeneously. (**B**) Focal HI: the lesion is a discrete bright spot in the pancreatic head

images and the location at surgery is nearly 100 %. The ^{18}F-PET/CT is also sensitive in the detection of the very rare ectopic focal lesion.

Surgical Management

The operation is done through a transverse supraumbilical laparotomy. The pancreas is completely exposed by an extended Kocher maneuver, entry into the lesser sac, and mobilization of the inferior border of the pancreas. The pancreas is inspected with 4X loupe magnification and carefully palpated to identify a focal lesion. Focal lesions are often firmer than the normal pancreatic tissue and may have subtle differences in appearance and texture. If no obvious focal lesion is identified, tiny biopsies are taken sharply (cautery is avoided because it hampers frozen section pathology interpretation) from the pancreatic head, body, and tail for intraoperative frozen section analysis.

If diffuse HI is confirmed, the patient undergoes a near-total pancreatectomy, which involves resection of the entire pancreas leaving only a tiny residual piece of pancreatic tissue between the common bile duct and the duodenal wall. The intrapancreatic segment of the CBD must be identified and skeletonized. To help with the identification and dissection of the CBD when it is embedded in the pancreatic head, we place a vessel loop or two around the extrapancreatic section of the CBD posterior to the duodenum and then swing it medially within the duodenal C-loop. This maneuver is not needed if the CBD follows a visible course completely posterior to the pancreatic head. In babies with diffuse disease we place a gastrostomy for long-term enteral access.

If intraoperative biopsies confirm normal pancreatic histology on the random biopsies of the head, body, and tail, a further search for the focal lesion is conducted. The preoperative PET/CT study greatly facilitates the search. Intraoperative high-resolution US can help in localizing focal lesions and we routinely arrange for this if the genetics suggest a focal lesion but the PET/CT does not show it, which occurs in 15 % of cases. We have been able to identify by 4X loupe magnification visualization or palpation approximately two-thirds of all focal lesions. Focal lesions that are buried within the pancreatic tissue can be impossible to see or feel, so it is necessary to patiently take additional biopsies of suspicious areas for frozen section analysis until the lesion is found.

Expert pediatric anatomic pathology interpretation is crucial. Focal lesions are generally less than 10 mm in diameter, but can be much larger. They are irregularly shaped and frequently have octopus-like tentacles, which make the intraoperative frozen section confirmation of clear margins imperative. Once the focal lesion is identified, a partial pancreatectomy is performed (free-of-disease margins must be confirmed before concluding the surgery). Small and superficial lesions in the body or tail can be treated by simple resection, and intraoperative ultrasound can visualize the relationship of the less than 0.5 mm diameter pancreatic duct to the focal lesion. Deep periductal lesions in the body and tail are treated by distal pancreatectomy. Superficial and small lesions in the head of the pancreas can also be treated by simple resection. On the other hand, deep lesions of the pancreatic head can be difficult to excise with clear margins without causing damage to the CBD or pancreatic duct. To ensure a complete resection of the lesion in these challenging cases, we remove almost all the pancreatic head and construct a Roux-en-Y pancreaticojejunostomy to drain the remaining pancreatic body and tail, thereby preserving the endocrine and exocrine functions of the pancreas. This approach is required in about 40 % of focal lesions located in the pancreatic head. The end of a retrocolic, 25 cm-long Roux-en-Y jejunal limb is meticulously anastomosed to the capsule of the pancreatic body (just beyond the cut end of the pancreas) with fine interrupted monofilament suture to tuck the cut end of the pancreas into the jejunal lumen (Fig. 84.4). The omentum is then wrapped around the anastomosis in case of an anastomotic leak. Rarely, a focal lesion in the head will extend into the duodenal wall in which case a Whipple procedure may be needed. In cases of near-total and pancreatic head resections it is crucial to preserve the gastroduodenal artery as well as the vessels supplying the third and fourth portion of the duodenum (superior/inferior posterior/anterior pancreaticoduodenal arteries), if possible, to avoid duodenal ischemia. Either the monopolar or bipolar cautery can be used to take the tiny pancreatic venous branches that drain into the splenic vein and take the splenic arterial branches to the pancreas. We do not routinely use drains after any pancreatic resection for HI.

Laparoscopic surgery is particularly suitable in HI patients with focal disease of the pancreatic body or tail. We use three or four 3–5 mm ports and to facilitate pancreatic exposure the stomach is tacked up to the anterior abdominal wall with 2–3 transabdominal-transgastric stitches near the greater curvature. A major drawback to the laparoscopic approach is the very limited tactile feedback to help palpate a non-visible focal lesion. The dissection and resection of the pancreatic head is more technically demanding than the distal pancreas. A high rate of CBD injury has been observed in cases of laparoscopic near-total pancreatectomies in which the CBD is identified and dissected laparoscopically. Recent reports claim a lower rate of CBD injuries, but a detailed analysis reveals that in those cases the CBD is neither identified nor dissected and the pancreatectomy ends just beyond the superior mesenteric vessels, which means that those cases are not near-total but rather subtotal or distal pancreatectomies with an attendant risk of difficult to manage postoperative hypoglycemia.

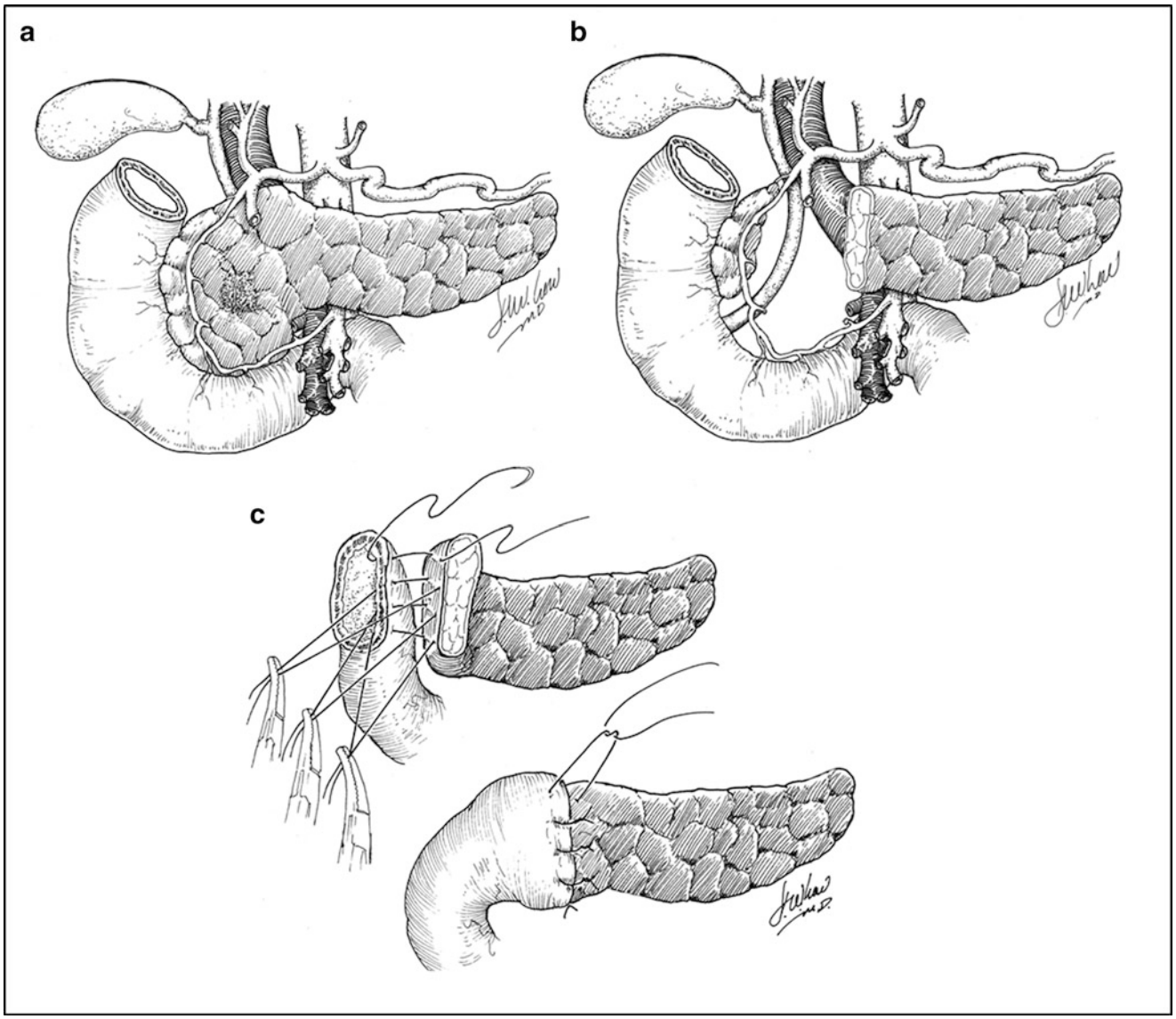

Fig. 84.4 (**A**) Focal lesion in the head of the pancreas that has octopus-like tentacles that extend into the normal tissue. (**B**) Near-total pancreatic head resection. The common bile duct (CBD) is skeletonized and the duodenal vasculature is preserved. A tiny portion of the pancreatic head is left between the CBD and the duodenal wall. (**C**) Pancreaticojejunostomy. Fine interrupted monofilament stitches are placed from the end of the jejunal limb (full thickness) to the capsule of the pancreas just beyond the cut edge so that the cut end of the pancreatic body is tucked into the jejunal lumen. The posterior aspect of the anastomosis is performed first, with all sutures placed first and then tied serially leaving the knots on the inside of the anastomosis. The anterior aspect is performed in the same manner, but leaving the knots on the outside. From Laje et al: *Pancreatic head resection and Roux-en-Y pancreaticojejunostomy for the treatment of the focal form of congenital hyperinsulinism*. (Reproduced from Laje P, Stanley CA, Palladino AA, Becker SA, Adzick NS. Pancreatic head resection and Roux-en-Y pancreaticojejunostomy for the treatment of the focal form of congenital hyperinsulinism. J Ped Surg. 2012; 47(1): 130–135, with permission from Elsevier.)

Postoperative Management

Postoperative pain after pancreatectomy is managed by an epidural catheter or intravenous narcotics. Patients are kept NPO until bowel function resumes. The intravenous glucose infusion is re-started immediately after the operation at a low GIR (2 mg/kg/min) because the stress of the surgery induces hepatic glycogenolysis. The GIR is advanced to 5 mg/kg/min 12–18 h after the surgery and to 8 mg/kg/min (equivalent to the physiological hepatic glucose release during fasting periods) 24–36 h after the surgery. Plasma glucose levels are measured hourly in the beginning and spaced out if they are stable. If the plasma glucose levels are excessively high (>400 mg/dL), then an intravenous insulin infusion is started. The immediate postoperative oscillations in the plasma glucose levels do not predict the eventual long-term outcome, because factors like surgical stress and pain can alter glucose

homeostasis. When bowel function is evident, enteral feedings are resumed and the intravenous glucose infusion is gradually weaned off. When patients are exclusively on enteral feeds, a "cure" fasting test is performed. If patients are able to maintain euglycemia for 18 h, they are considered completely cured. If the time to hypoglycemia is less than 18 h, the next step is to determine a regimen of frequent feeds and short fasting periods that will allow the patient to be managed safely at home. Patients who are unable to be weaned from the intravenous GIR are not cured and will need further assessment to determine if additional surgery or medical management is required.

Outcomes

In our experience, patients with focal HI are cured with the surgery in more than 95 % of the cases. The outcome of patients with diffuse HI who undergo a near-total pancreatectomy is less predictable. In our experience, approximately 50 % of cases continue to have hypoglycemia after surgery and require supportive management with frequent or even continuous feeds. Despite this less-than-ideal outcome, these patients are much more easily manageable after surgery than before the operation and are at home off intravenous infusions. Approximately 25 % of patients who undergo near-total pancreatectomy achieve normoglycemia and do not require any additional therapy. Lastly, approximately 25 % of cases develop early diabetes requiring insulin. Recent studies have shown that the incidence of insulin-dependent diabetes increases with time, to reach more than 90 % ten years after the operation. The long-term incidence of clinically evident exocrine insufficiency is as high as 50 %.

Editor's Comment

The pediatric surgeon must be aware of the immediate management and differential diagnosis for newborns with persistent hyperglycemia. Infants with hyperinsulinism should be managed very aggressively with high-dose intravenous glucose infusions oftentimes necessitating central venous access. The long-term profound neurodevelopmental sequelae secondary to hypoglycemia can be devastating and irreversible and thus a systematic multidisciplinary treatment strategy between neonatologists, endocrinologists, and surgeons must be clearly defined.

Diffuse disease is treated with a near-total (95–98 %) pancreatectomy. Focal disease is treated by complete resection of the tumor with negative margins. Classically described interventional radiology studies such as arterial stimulation with venous sampling or hepatic portal venous catheterization and selective sampling of the pancreatic veins have fallen out of favor. The preoperative localization with ^{18}Fluoro-L-DOPA-PET-CT is currently acknowledged to be the most accurate investigation for distinguishing between focal and diffuse. Although this has become the standard for preoperative localization it still remains limited in its availability. With this in mind, the treating team and pediatric surgeon consultation must take this into consideration.

High case volume and experience are necessary to generate consistently good results and a very low complication rate. Laparoscopic techniques are clearly feasible in the treatment of patients with HI and will likely become standard for initial biopsy and diagnosis and for the resection of focal lesions. As we learn more about the genetics and molecular biology of congenital HI, we will soon have many more options for diagnosis, classification, and treatment, perhaps in some cases obviating the need for surgical intervention.

Suggested Reading

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Pancreatic Disorders

85

Pablo Laje and N. Scott Adzick

Pancreatic Tumors

Almost all types of neoplasms that commonly occur in the adults have been reported in children and must be included in the differential diagnosis of a pancreatic mass in a child. Pediatric pancreatic neoplasms are infrequent. According to the National Cancer Institute, between 1973 and 2007 only 73 cases of pancreatic malignant neoplasms in patients younger than 19 years were reported, which represents an incidence of 0.02 cases per 100,000 people per year, with a female to male ratio of 1.7/1. Because of their rarity, our understanding of the natural history of pancreatic neoplasms in children is limited, and the therapeutic regimens are not standardized.

In general, pancreatic neoplasms in children have an overall better prognosis than in adults, and the benign/malignant ratio is significantly higher. Nonetheless, some pancreatic tumors in children are very aggressive and have a poor survival rate. Complete surgical resection is the key in the treatment of all pancreatic neoplasms in children, but unfortunately is rarely achieved in cases of poorly differentiated infiltrative neoplasms.

The pancreas can develop primary neoplasms but can also contain secondary neoplasms (metastasis of distant primary neoplasms), non-neoplastic solid lesions (lymphangiomas and focal lesions of congenital hyperinsulinism), and non-neoplastic cysts (choledochal cysts, enteric duplication cysts, and pseudocysts).

Among all different types of pancreatic neoplasms in children, pancreatoblastoma (PBT) and solid pseudopapillary tumor (SPPT) are the most common ones in the first and second decade of life, respectively. The most common signs at presentation are abdominal pain or a palpable abdominal mass. Jaundice is rarely the presenting sign in children.

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Classification and Staging

The most recent classification developed by the World Health Organization in 2010 divides pancreatic neoplasms by cell line of origin, histological configuration, and degree of cellular dysplasia (Table 85.1). Pancreatic neoplasms are divided into *epithelial* and *non-epithelial* types. Epithelial tumors are those with a cell line that resembles the lining of the pancreatic ducts ("ductal" differentiation, typically mucin-producing cells), the lining of the pancreatic acini ("acinar" differentiation, typically enzyme-producing cells), or the cells that form the islets of Langerhans ("endocrine" differentiation, functional or non-functional). Non-epithelial tumors are those that arise from tissue of mesenchymal or ectodermal origin (liposarcomas, myosarcomas, and primitive neuroectodermal tumors) and they are extremely rare. The staging system for pancreatic neoplasms in children is based on the TNM classification and follows the criteria used in the adults (Table 85.2).

Pancreatoblastoma

Pancreatoblastoma (PBT) is the most common pancreatic neoplasm in the first decade of life, and it affects males four times more frequently than females. The mean age at presentation is 4–5 years, the vast majority of cases occurring before 10 years, and it very rarely occurs in adults. PBT belongs to a group of neoplasms called "embryonal" tumors, which occur mainly in children and appear to arise from multipotent stem cells. Nephroblastoma (Wilms tumor), hepatoblastoma, and neuroblastoma are also embryonal tumors. Embryonal tumors share a common genetic derangement: the loss of heterozygosity (LOH) of different regions of the short arm of chromosome 11, which affects the expression of imprinted genes that regulate cell proliferation. The 11p15.5 locus has two imprinted genes: Insulin-like Growth Factor 2 (IGF2) and H19, which have opposite roles in cell proliferation. The IGF2 gene is only expressed from the paternal allele (the maternal

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Table 85.1 Classification of pancreatic tumors

• Invasive ductal adenocarcinoma – Conventional – Atypical histologic variants	• Acinar cell neoplasms – Cystadenoma – Carcinoma – Cystadenocarcinoma
• Pancreatic intraepithelial neoplasia (PanIN) – 1A – 1B – 2 – 3	• Serous neoplasms – Cystadenoma – Cystadenocarcinoma – Solid serous adenoma
• Intraductal neoplasms • Intraductal papillary-mucinous neoplasms – *with low-, moderate-, or high-grade dysplasia* – *with invasive carcinoma* • Intraductal tubular neoplasms – *with low-, moderate-, or high-grade dysplasia* – *with invasive carcinoma*	• Pancreatic endocrine neoplasms • Well differentiated – *Functional* – *Non-functional* • Poorly differentiated
• Mucinous cystic neoplasms – *with low-, moderate-, or high-grade dysplasia* – *with invasive carcinoma*	• Solid pseudopapillary tumor
	• Pancreatoblastoma • Mesenchymal neoplasms • Secondary neoplasms

Source: Data from International Agency for Research on Cancer, World Health Organization, 2010

Table 85.2 TNM classification and staging system of pancreatic neoplasms

• T-Primary tumor – TX: Cannot be assessed – T0: No evidence of primary tumor – Tis: Carcinoma in situ—PanIN3 – T1: Limited to the pancreas ≤ 2 cm[a] – T2: Limited to the pancreas >2 cm[a] – T3: Tumor extends beyond the pancreas – T4: Tumor involves celiac trunk or SMA[b]			
• N-Regional lymph nodes – NX: Cannot be assessed – N0: No lymph node metastasis – N1: Lymph node metastasis			
• M-Distant metastasis – M0: No distant metastasis – M1: Distant metastasis			
• Staging	T	N	M
• Stage 0:	is	0	0
• Stage 1A:	1	0	0
• Stage 1B	2	0	0
• Stage 2A:	3	0	0
• Stage 2B:	1, 2, 3	1	0
• Stage 3:	4	Any	0
• Stage 4:	Any	Any	1

[a]Maximum diameter
[b]Superior mesenteric artery

allele is silent), whereas the H19 gene is only expressed from the maternal allele (the paternal allele is silent). IGF2 and H19 must be expressed in balance in order to maintain a normal cellular proliferation rate. LOH of the maternal region 11p15.5 with the subsequent imbalance towards cell proliferation in the IGF2/H19 expression has been demonstrated in nephroblastoma, hepatoblastoma, PBT, and interestingly in the focal form of congenital hyperinsulinism which is characterized by an abnormal proliferation of cells in the form of an adenomatous hyperplasia. Moreover, the LOH of the 11p15.5 region is one of the key features of Beckwith–Wiedemann syndrome, which is associated with disorders of cell proliferation (macroglossia, hemihypertrophy, and pancreatic islet cell hyperplasia) and a high incidence of embryonal tumors.

PBT is a solid epithelial tumor with cells that have usually some degree of differentiation towards acinar lineage and much less frequently towards ductal or endocrine lineages. Cells are divided into lobules separated by stromal bands. The pathognomonic feature of PBT is the squamoid corpuscle, which is a cluster of spindle-shaped cells of unknown origin (Fig. 85.1). Because of the acinar-type differentiation, PBT cells are usually positive for lipase and trypsin immunostaining. PBT develops more frequently in the head of the pancreas (60 %) than the body or tail (40 %), and extremely rarely it can occur in ectopic locations. The most common form of presentation is an incidentally found abdominal mass and less commonly abdominal pain.

Despite the usually large size at presentation, jaundice is rarely the initial sign of a PBT. Alpha-fetoprotein is elevated in approximately 30 % of PBT, and can be used as a long-term follow-up marker of disease status. On imaging studies PBT presents as a heterogeneous large mass. Some PBT are well-circumscribed and lobulated, and others are completely infiltrative (Fig. 85.2). Calcifications are frequent. Complete surgical resection, if possible, is the treatment of choice, even if an extensive surgical resection is required. Infiltrative tumors that are unresectable at presentation may respond to neoadjuvant therapy followed by surgical resection.

There is no standard chemotherapy protocol for the treatment of PBT, but the most significant responses have been observed after multiple cycles of cisplatin and doxorubicin (Fig. 85.2). Adjuvant therapy is also recommended for Stage III and IV tumors, and for recurrences. The role of radiotherapy remains unclear but there is evidence that it might be useful for local recurrences. Local recurrences are not uncommon even in cases with clean resection margins by pathology. The prognosis is generally good in cases that present without metastasis and can be resected completely, which occurs in 60–70 % of the cases. For the other 30–40 % of patients who present with stage IV disease, the overall survival rate is less than 50 % at 5 years. The most common sites of PBT metastasis are liver and lung.

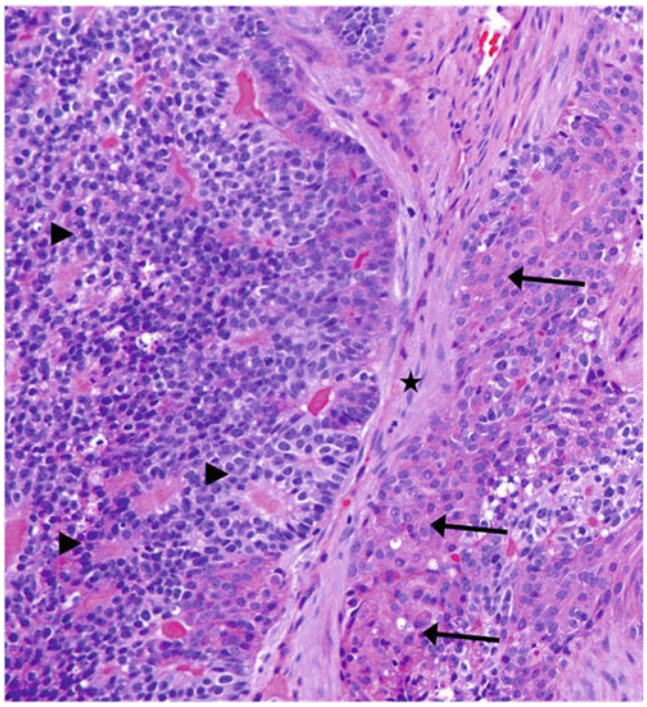

Fig. 85.1 Pancreatoblastoma. Hematoxylin and eosin, 40×. Acinar differentiation (*arrowheads*), squamoid corpuscles (*arrows*), and stromal band (*star*)

Solid Pseudopapillary Neoplasm

This neoplasm has had several different synonyms over the years: solid and papillary tumor, solid-cystic tumor, papillary-cystic tumor, and Frantz's tumor. They have all been replaced by the current term "solid pseudopapillary neoplasm" (SPPN). SPPN is the most common pancreatic neoplasm in the second decade of life and it affects females 10 times more frequently than males. The typical age at presentation is 20–30 years. SPPN is considered a malignant neoplasm due to its ability to form metastases, which are present at the time of diagnosis in 10–15 % of cases (Stage IV). However, SPPN usually has a remarkably benign behavior.

SPPN is an epithelial solid tumor that invariably develops cystic degeneration. The cellular lineage of origin is unknown. Cells are negative for mucin, enzymes, and hormones, which supports the theory that SPPN arises from an embryonal pancreatic pluripotent cell. Other histochemical markers such as neuron-specific enolase, beta-catenin, vimentin, and progesterone receptors are frequently positive but non-specific. A particular dot-like intracytoplasmatic expression of CD99 is highly specific for SPPN. Common serum tumor markers (CA 19-9, CEA, and CA 125) are consistently negative in patients with SPPN. Most SPPN are located in the body/tail of the pancreas, but they can also occur in the head, and very rarely in extrapancreatic locations. Histologically, SPPN has a very characteristic appearance of solid areas mixed with areas of poorly cohesive cells that form pseudopapillae around thin blood vessels (Fig. 85.3). Vascular or neural invasion are unusual findings in SPPN.

On imaging studies, SPPN are usually large and heterogeneous at presentation, but encapsulated and well demarcated from the surrounding structures. The most common forms of presentation are abdominal pain or an incidentally found abdominal mass, but jaundice is also common in tumors located in the pancreatic head (Fig. 85.4). Preoperative cytological diagnosis by percutaneous or endoscopic biopsy is feasible but has a sensitivity of only 50 %.

The mainstay treatment of SPPN is surgical resection, which should be as complete as possible even in Stage IV

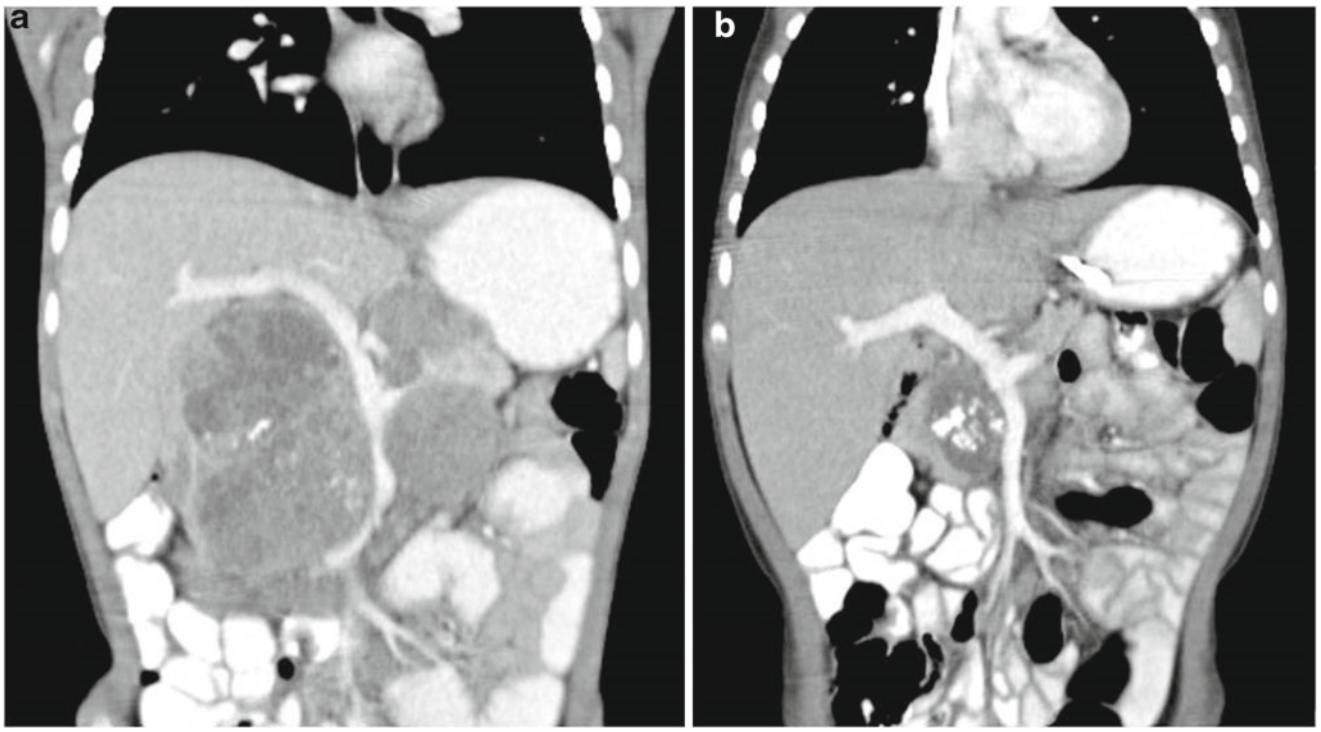

Fig. 85.2 (**A**) Large PBT at the head of the pancreas with calcifications in a 4-year-old male who presented with abdominal pain. Initially unresectable and stage IV (lung metastasis). (**B**) It shrank significantly after several cycles of cisplatin and doxorubicin after which he underwent a Whipple procedure

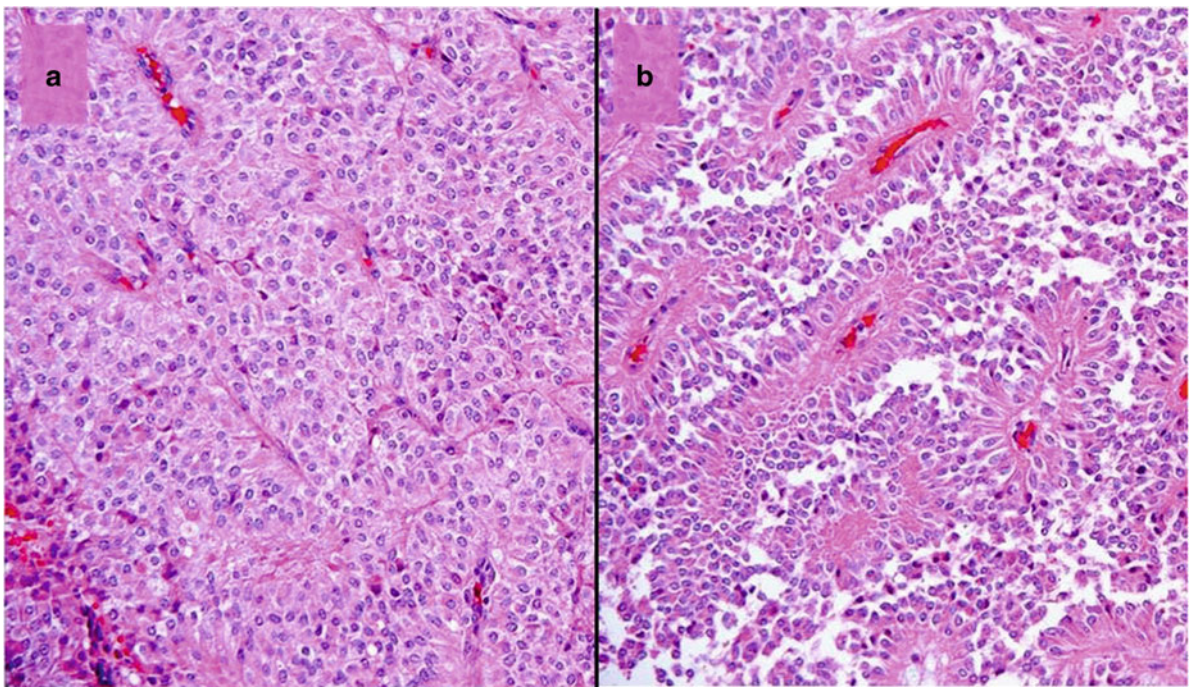

Fig. 85.3 Solid pseudopapillary neoplasm (SPPN). These heterogeneous neoplasms combine (**A**) solid regions of homogeneous cells and (**B**) pseudopapillary regions where poorly cohesive cells surround small and thin blood vessels

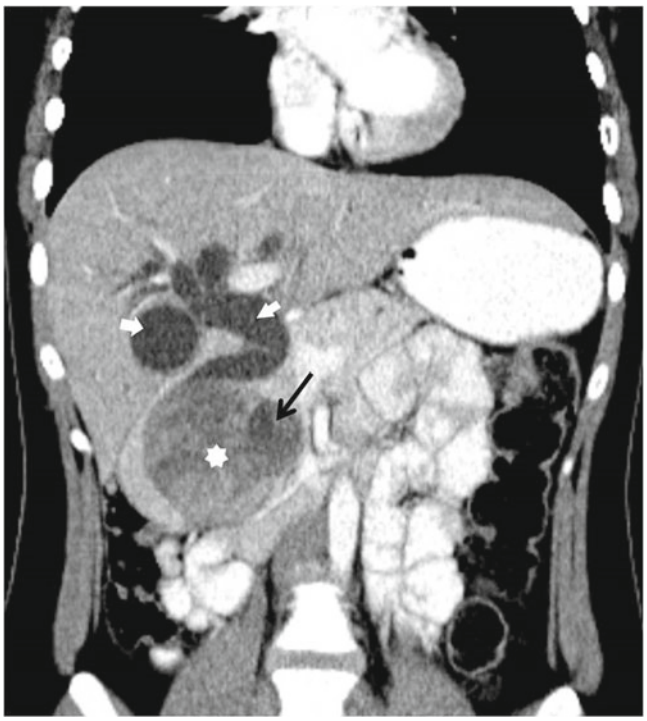

Fig. 85.4 Solid pseudopapillary neoplasm in the pancreatic head in a 16-year-old female. The tumor (*star*) is heterogeneous and well demarcated, and has an area of cystic degeneration (*black arrow*). It caused significant biliary obstruction (*white arrows*); jaundice was the sign at presentation

cases. Simple enucleation and incomplete resections are associated with more frequent local recurrences and a poorer prognosis. Distal pancreatectomy is the procedure of choice for pancreatic body/tail tumors, and pancreaticoduodenectomy is the procedure of choice for pancreatic head tumors. Lymph node involvement is very rare in SPPN and therefore lymphadenectomy is not required. The most common metastatic sites are the liver and the peritoneum. When feasible, metastases should be surgically resected, otherwise chemotherapy is the treatment of choice.

Chemotherapy has also been used as single or neoadjuvant therapy in cases that were deemed unresectable, and in cases of aggressive local recurrences, but its role in less aggressive tumors is not yet defined. Radiotherapy and hormonal therapies (anti-progesterone due to the frequent presence of progesterone receptors) have been used in the past without salutary effect and have been abandoned as therapeutic options in patients with SPPN. The prognosis of SPPN is generally very favorable, with an overall long-term survival rate greater than 90 %, even in Stage IV cases. There is a subset of SPPN, however, that is very aggressive and undergoes sarcomatous degeneration, with invasion of adjacent organs, neural and vascular elements. Factors that appear to be related to a more aggressive behavior are male gender, infiltrative growth pattern, nuclear pleomorphism, and vascular and extrapancreatic invasion.

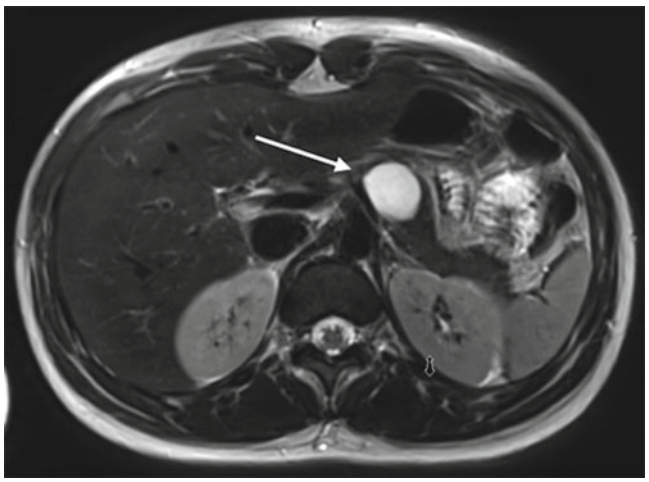

Fig. 85.5 Magnetic resonance of a cystadenoma located in the pancreatic body (*white arrow*)

Acinar Cell Neoplasms

Acinar cell neoplasms arise from cells that resemble normal acinar cells and produce pancreatic exocrine enzymes, testing positive for enzyme-like markers on immunohistochemical staining. This group of neoplasms includes cystic (cystadenoma and cystadenocarcinoma) and solid lesions (acinar cell carcinoma). *Acinar cell cystadenoma* is a rare, benign, and cystic pancreatic neoplasm. The cysts are lined by acinar cells and the fluid inside the cysts is rich in amylase and lipase. Cells have no atypia and do not cross the basal membrane. They can be unilocular or multilocular (Fig. 85.5). Surgical resection is the treatment of choice. *Acinar cell carcinoma* (ACC) is relatively common within the uncommon malignant pancreatic tumors in children, and it has been extensively reported in the literature. ACC is an aggressive neoplasm that affects males more frequently than females. Early metastases are common (>50 % at the time of diagnosis, mainly in the liver). The prognosis is relatively poor, compared to PBT and SPPN, but it appears to be better in children than in adults. Most ACC are located in the head of the pancreas and are large at diagnosis. Alpha-fetoprotein is frequently elevated. Histologically, the cells can have an acinar arrangement or, less frequently, a completely solid arrangement. Cells are almost always positive for trypsin, chymotrypsin, and lipase. ACC can be confused with PBT on histologic analysis due to the marked acinar differentiation of some PBT. The absence of squamoid corpuscles favors the diagnosis of ACC. A combination of surgery and chemotherapy offers the best outcome in ACC. Nevertheless, even patients with no metastases at presentation and a complete surgical resection have a high incidence of distant and local recurrence, and a poor survival rate.

Invasive Ductal Adenocarcinoma

The most common malignant pancreatic neoplasm in the adult population (>90 %), ductal adenocarcinoma (DAC) is very rare in children. Few pediatric cases have been reported in the literature, and almost all of them were diagnosed as Stage IV and had an eventual fatal outcome. Most DAC are solid and located in the pancreatic head. Rapid local invasion and early distant spreading are the rule, with 80 % of cases being unresectable at presentation. The most common sites of metastases are liver, lungs, lymph nodes, and bone. On imaging studies pancreatic DAC are irregular, heterogeneous, and infiltrative lesions. Macroscopically pancreatic DAC are firm and hard tumors. Histologically there is a *conventional* type (the most frequent) and several different variants (colloid, hepatoid, adenosquamous, and others). The neoplastic tissue consists of a tubular proliferation within a desmoplastic stroma that infiltrates the non-neoplastic ducts, islets of Langerhans, and acini. Immunohistochemical markers consistently positive in DAC are mucin, the glycoproteins CA19-9, CEA, and CA125, and the cytokeratins 7, 8, and 18. However, none of them is an unequivocal indicator of DAC. The treatment of choice is surgery, but a complete resection is rarely achieved. Chemotherapy is used in unresectable cases but there are no standardized protocols in children. The survival rate is very poor, with a median survival of less than 20 months from the time of diagnosis.

Pancreatic Endocrine Neoplasms

Pancreatic endocrine neoplasms (PEN) are relatively frequent in adults and, as expected, rare in children. The key feature of this group of neoplasm is the production of hormones or hormone-like bioamines. The group is divided into *well-differentiated* versus *poorly differentiated* lesions based on their histological features, and into *functional* versus *non-functional* lesions based on the clinical effects of hormone hypersecretion. The vast majority of PENs are well differentiated: uniform cells with normal-appearing nuclei and less than 20 mitoses per 10 high power fields (HPF). The minority of PEN is poorly differentiated: irregular cells with marked nuclear atypia and more than 20 mitoses per 10 HPF (these are also called "*neuroendocrine carcinomas*"). Despite the clear histological distinction between well- and poorly differentiated PEN, determining the benign or malignant character of an endocrine neoplasm is not always straightforward in the absence of obvious metastases. Factors associated with a more aggressive behavior are: size (>2 cm in diameter), the presence of necrosis, vascular or neural invasion, and local invasion. Some poorly differentiated PEN are very aggressive, metastasize early, and have an invariable fatal outcome.

Most PEN are functional (65 %). The nomenclature of these lesions is based on the clinical picture and not on the immunohistochemical (IHC) profile (a PEN that stains positive for insulin but does not produce symptoms is not an insulinoma). Non-functional PEN produce hormone precursors that can be detected by IHC, but tend to be diagnosed later in development due to the absence of early paraneoplastic signs.

In adults, approximately 90 % of PEN are sporadic and 10 % are syndromic. In children, on the other hand, the percentage of syndromic cases is higher. The syndromes that are most commonly associated with PEN are Von Hippel–Lindau, tuberous sclerosis, and multiple endocrine neoplasia type I (Wermer's syndrome, autosomal dominant, characterized by parathyroid, gastropancreatic, and pituitary tumors). Patients with syndromic PEN can develop multiple synchronous lesions that produce the same or different hormones, and are always at risk for metachronous neoplasms. The treatment of PEN is complete surgical resection. Functional tumors may need symptomatic treatment prior to surgery. PEN are generally small (particularly the functional ones) at the time of diagnosis, and preoperative imaging localization is only achieved in 50 % of the cases.

Insulinoma

Insulinomas are neoplasms that arise from the insulin-producing beta-cells of the islets of Langerhans. The vast majority are benign (>90 %), but malignant stage IV cases with aggressive behavior have been reported. Clinically, insulinomas manifest with "Whipple's triad": symptoms of hypoglycemia (syncope and seizures), hypoketonemic hypoglycemia (insulin inhibits the production of ketonic bodies), and rapid resolution of the symptoms with glucose intake. Most insulinomas in children are sporadic, and about 25 % are syndromic. Most insulinomas are small (<2 cm) at the time of diagnosis and their preoperative identification can be challenging. Larger lesions can be identified with standard techniques, but this does not occur often (Fig. 85.6). Sterile intraoperative ultrasound has the highest rate of success. Histologically, insulinomas consist of a proliferation of homogeneous cells that do not respect the limits and anatomy of the pancreatic lobules, displacing the normal elements towards the periphery. The treatment of insulinomas usually starts by counteracting the effects of the insulin hypersecretion by a high intravenous glucose infusion and hyperglycemic drugs like diazoxide or somatostatin analogs. Once the patient is euglycemic the next step in the treatment is the complete surgical excision of the insulinoma. If preoperative localization is not possible, all efforts should be made to identify the insulinoma intraoperatively by means of inspection, palpation, and sterile ultrasound. Complete resection of the insulinoma by enucleation or

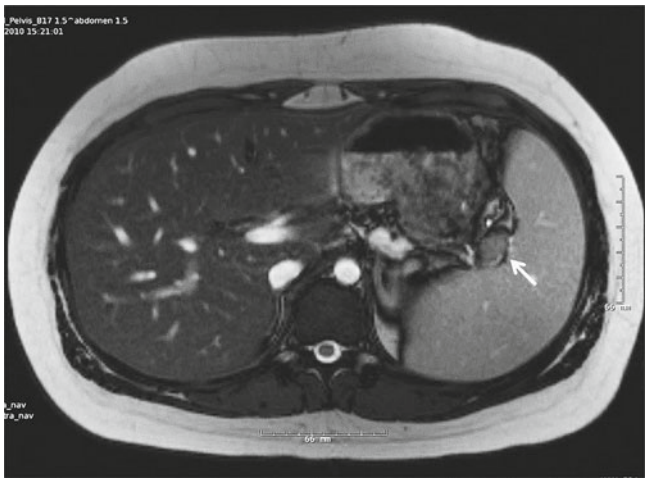

Fig. 85.6 Abdominal MRI of a 13-year-old male with MEN1 showing a relatively large insulinoma in the splenic helium. This patient had multiple synchronous smaller insulinomas and glucagonomas

segmental pancreatic resection is curative in non-syndromic cases. In syndromic cases, tiny undetectable synchronous insulinomas can be present, preventing a cure despite complete resection of the identified insulinoma. Obviously syndromic patients are at risk for metachronous tumors at any time later in life and require close clinical surveillance. In a series of eight patients we treated over a 5-year period at the Children's Hospital of Philadelphia, one patient had MEN1 and a previous insulinoma resection, no cases of malignancy were seen, and all patients were cured after surgery.

Gastrinoma

Gastrinomas in children have been reported numerous times. Only 25 % are syndromic. Gastrinoma is the most common pancreaticoduodenal endocrine neoplasia in patients with MEN1. Most of them are malignant (80 %) with metastasis to the liver and lymph nodes present at diagnosis. Clinically, gastrinomas manifest with Zollinger–Ellison syndrome, a severe form of peptic ulcer disease. The diagnosis is confirmed with an elevated serum gastrin level (>500 pg/mL). Nuclear studies are particularly helpful for the preoperative localization. The treatment starts with the administration of histamine H2-receptor blockers, proton-pump inhibitors, and octreotide, and is followed by surgical resection. Neoadjuvant or adjuvant chemotherapy is indicated in unresectable tumors and disseminated disease.

Glucagonoma

Glucagonomas are rare neoplasms that arise from the alpha cells of the islets of Langerhans. The overproduction of glucagon produces a constellation of metabolic effects that are similar to those of diabetes mellitus: hyperglycemia, lipolysis, and gluconeogenesis, resulting in pronounced weight loss. In the adult population, the majority of glucagonomas are malignant. Glucagonomas can be sporadic or associated with MEN1 syndrome. They can co-exist with insulinomas in patients with MEN1. The treatment of choice is the complete surgical resection. Sterile intraoperative ultrasound is helpful for the intraoperative localization of small, previously undetected lesions, as is the case with all other endocrine tumors (Fig. 85.7).

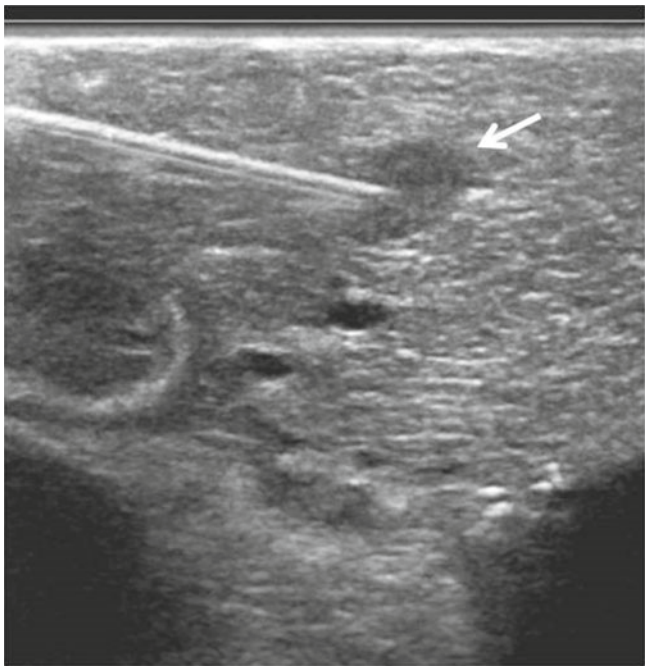

Fig. 85.7 Intraoperative ultrasound-guided needle localization of a 7×6×5 mm, 1 cm deep nonpalpable glucagonoma in the pancreatic head of an 11-year-old girl with MEN1. She had an insulinoma resected 4 years previously

Other Epithelial Pancreatic Tumors

Pancreatic Intraepithelial Neoplasia (PanIN) is a group of *microscopic* lesions confined to the epithelium of the pancreatic ducts that are precursors of invasive carcinomas. These lesions are classified by the degree of atypia in PanIN 1A, 1B, 2, and 3. PanIN are found incidentally in normal pancreatic specimens and in pancreatic specimens that contain neoplastic or non-neoplastic lesions. PanIN lesions are well-known to progress gradually from grade 1A to 3 and eventually turn into invasive ductal carcinomas. They can be found in children, particularly frequent in those with hereditary pancreatitis.

Pancreatic Intraductal Neoplasms are a group of *macroscopic* (>1 cm in diameter by definition) lesions that arise from the epithelium of the main pancreatic duct (rarely from branches) and are precursors of invasive carcinoma. These

are frequently found in men in their 7th and 8th decade, but have been reported in children.

Mucinous Cystic Neoplasms (MCN) are a group of cystic premalignant lesions characterized by a proliferation of mucin-producing ductal-like cells embedded in an "ovarian stroma" that do not involve the common bile duct. Most MCN occur in the distal pancreas of women in their 3rd and 4th decades of life, but several cases of non-invasive and invasive MCN have been reported in children.

Serous Neoplasms are cystic lesions that are relatively common in adults. The most common entity is the *serous cystadenoma*, which is benign in nature and has been reported in children. It is composed of multiple microcysts (<1 cm in diameter; rarely macrocysts) lined by cuboidal cells with acinar resemblance but without complete acinar differentiation. The fluid within the cysts does not contain enzymes or mucin. Macroscopically they are well-circumscribed lesions and the definitive treatment is surgical excision. The malignant version, *serous cystadenocarcinoma* has the potential to metastasize, and has not been reported in children.

Congenital Pancreatic Anomalies

The pancreas is prone to a number of well-defined developmental anomalies that are frequently associated with anomalies of the duodenum, bile ducts, and related anatomical structures.

Annular Pancreas

Annular pancreas is the result of an abnormal development of the pancreaticoduodenal unit, which occurs during the 5th and 6th weeks of gestation. The head of the pancreas surrounds the duodenum, as opposed to being located entirely within the duodenal c-loop. The portion of the duodenum that is encircled by pancreatic tissue is, in general, partially or completely obstructed. It is still unknown if the annular pancreas is what causes the duodenal obstruction, or if there is initially a duodenal stenosis/atresia that results in an abnormal pancreatic head development. From a surgical standpoint, the pancreas should be left untouched and the obstruction bypassed via a duodenoduodenostomy. Annular pancreas has an incidence of 1 in 20,000 live births and is twice as common in males.

Pancreas Divisum

Most of the exocrine pancreas drains into the duodenum via the major pancreatic duct, or duct of Wirsung, which merges with the common bile duct right before the ampulla of Vater and empties through the major papilla. A remaining minor portion of the pancreas drains into the duodenum via the accessory pancreatic duct, or duct of Santorini through the minor papilla. Commonly both pancreatic ducts have some degree of communication. In approximately 10 % of the population the normal anatomical arrangement is reversed, with most of the organ draining through the duct of Santorini, which has no communication with the otherwise rudimentary or absent duct of Wirsung (Fig. 85.8). Pancreas divisum is not a disease per se. However, in a subset of people with this anatomical variant, the minor papilla is functionally stenotic, which causes obstruction of the pancreatic outflow resulting in recurrent acute pancreatitis and chronic pancreatitis. The diagnosis is confirmed by ERCP or MRCP. There are a variety of options to treat this condition when it becomes symptomatic. The least invasive form is an endoscopic sphincterotomy of the minor papilla. This technique is well developed in adults, but is not always feasible in children due to size limitations. When the endoscopic approach is not available, a surgical sphincteroplasty of the minor and major papillae can be done via a transduodenal approach. In cases of pancreas divisum that have progressed to chronic pancre-

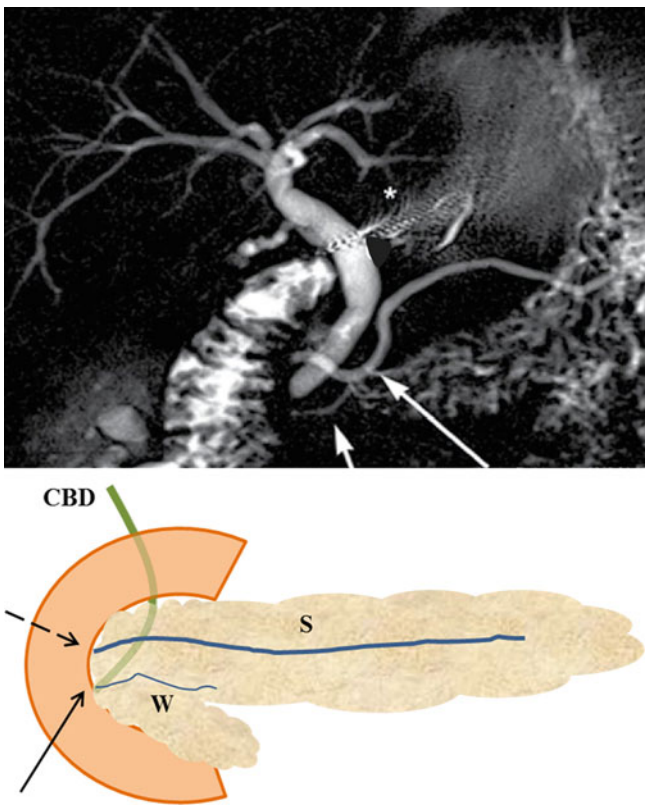

Fig. 85.8 MRCP of a patient with pancreas divisum (*above*) and schematic representation. The majority of the pancreas drains through the duct of Santorini (S, *long white arrow*). The duct of Wirsung (W, *short white arrow*) is rudimentary and drains a minor portion of the pancreas. CBD: common bile duct (*asterisk*). *Black arrow*: major papilla. *Dotted black arrow*: minor papilla

atitis with dilatation of the duct of Santorini, the Beger, Frey, or modified Puestow procedures become potential options for enteric drainage via Roux-en-Y jejunal reconstruction without the need to modify the anatomy of the minor papilla.

Pancreatic Pseudocysts

Pancreatic pseudocysts are localized collections of pancreatic fluid that has leaked out of the pancreas due to a disruption in the pancreatic ductal tree. These cysts, by definition, do not have an epithelial lining but are surrounded by a fibrous capsule that develops over the course of several weeks. The concentration of amylase in the fluid of the pseudocyst is typically very high.

The most common pancreatic problems that can result in a pseudocyst are severe inflammation (acute pancreatitis) and trauma, but a pancreatic pseudocyst can also occur when there is a blow out of the pancreatic duct secondary to a distal obstruction in the context of chronic pancreatitis (Fig. 85.9). The most common symptom is abdominal pain. Jaundice and vomiting are not infrequent, and develop when the biliary tree, the stomach, or the duodenum is extrinsically compressed by the pseudocyst. US, CT, and MRI are all helpful in the diagnosis. Serial US is generally used for evaluating the changes that occur with time. Without treatment pancreatic pseudocyst has an unpredictable behavior. Some pseudocysts continue to increase in size; some remain unchanged for long periods, and others regress and disappear spontaneously.

There is ongoing debate regarding the need to treat asymptomatic pseudocysts. The morbidity of any potential intervention must be balanced against the potential, although rare, risk of infection and hemorrhage. Symptomatic pseudocysts must be treated, but there is no standard treatment. There is a general consensus that no form of internal drainage should be attempted until the pseudocyst has formed the fibrous capsule that surrounds it, which takes at least 4 weeks. If a patient needs drainage prior to that time because of severe symptoms, an external percutaneous drainage is indicated. This approach is relatively easy, but carries a high risk of turning into a long-term pancreatic-cutaneous fistula. An alternative is endoscopic sphincterotomy with a temporary stent. The rationale behind this approach is that decreasing the pressure at the papilla may favor the outflow of pancreatic juice and turn the pancreatic duct into the path of least resistance. This approach is not always feasible in children.

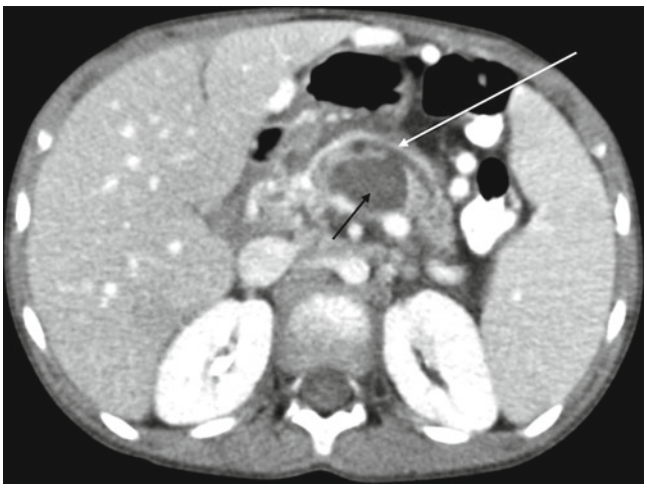

Fig. 85.9 Pancreatic pseudocyst (*black arrow*) in a patient with chronic pancreatitis and a severely dilated pancreatic duct. There is a communication between the pseudocyst and the duct (*white arrow*)

Once the pseudocyst has formed the fibrous capsule it becomes amenable to internal drainage. The current prevailing approach is an endoscopic drainage, which usually involves connecting the lumen of the pseudocyst with the lumen of the stomach or duodenum with double pigtail catheters. The most common surgical procedures used when endoscopy is not an option are cystogastrostomy and Roux-en-Y cystojejunostomy, both of which can be done open or laparoscopically. Very rarely a pancreatic resection, either proximal or distal, is required in the management of a pseudocyst.

Chronic Pancreatitis

There is no consensus regarding the exact definition of chronic pancreatitis, but in general it is diagnosed when a patient with any type of sustained pancreatic damage has anatomical changes in the pancreas on imaging studies (calcifications, atrophy, or ductal dilatation). US, CT, and MRI are all excellent studies for the diagnosis of CP. MRCP also provides very accurate images of the pancreatic ducts, the biliary tree, and the pancreaticobiliary junction. Furthermore, MRCP images can be processed to render three-dimensional reconstructions, which are very helpful when it comes to surgical planning. ERCP was in the past the most accurate diagnostic tool, but it has gradually been replaced by the non-invasive MRCP. ERCP still holds, however, an important role. If left untreated, chronic pancreatitis invariably progresses towards pancreatic endocrine and exocrine insufficiency. From a pathophysiologic perspective, the damage to the pancreas can occur due to persistent subtle inflammation and/or recurrent episodes of acute severe inflammation.

The causes of chronic pancreatitis are many, but are divided into four groups: *obstructive* (characterized by a ductal obstruction to the outflow of pancreatic secretions such as pancreas divisum with obstructive papillae, choledochal cyst, annular pancreas, or pancreaticobiliary malunion, and trauma-related obstructions), *toxic* (caused by certain drugs and, most frequently, ethanol), *systemic* (where pancreatitis is

part of a multi-organ disease, such as hypertriglyceridemia, lupus erythematosus, cystic fibrosis, or IgG4-related pancreatitis), and *hereditary* (a variety of genetic disorders characterized by an intrinsic process of pancreatic autodigestion based on mutations in a variety of genes that codify different components of pancreatic fluid). The toxic, systemic, and hereditary causes of chronic pancreatitis can provoke severe damage to the pancreatic duct, generating fibrosis, scarring, and obstruction to the outflow, which in turn results in an added mechanism of pancreatic damage.

Several genes have been implicated in the pathogenesis of hereditary pancreatitis, the *protease-serine-1* (PRSS1), the *serine protease inhibitor, Kazal type 1* (SPINK1), the *CTRC* (chymotrypsin C), and the *CFTR* (cystic fibrosis transmembrane conductance regulator). PRSS1 encodes the cationic trypsinogen, precursor of the proteolytic enzyme trypsin. A number of "disease-causing" mutations in the PRSS1 gene can lead to enhanced trypsinogen autoactivation and/or increased trypsin stability within the pancreas. SPINK1 encodes the pancreatic serine protease inhibitor which exerts a protective mechanism against prematurely activated trypsin. Therefore loss-of-function mutations in the SPINK1 gene can lead to pancreatic autodigestion. The diagnosis of hereditary pancreatitis is established when a patient with recurrent pancreatitis of unknown etiology has 1 or more first-degree relatives or 2 or more second-degree relatives, in 2 or more generations with recurrent acute pancreatitis and/or chronic pancreatitis of unknown etiology. Additionally, the diagnosis of hereditary pancreatitis is also established when a patient has recurrent/chronic pancreatitis and a known "disease-causing" mutation in the genes described above. Hereditary pancreatitis can occur in the setting of a familial pedigree or, less frequently, by de novo mutations. There are still patients with recurrent/chronic pancreatitis who do not have an identifiable cause. These cases are usually referred to as "idiopathic." Hopefully in the future advances in molecular genetics will allow finding the currently unknown genetic derangements that cause the disease.

The goal of all forms of therapy is to eliminate the pain and, if possible, to arrest the progression to pancreatic insufficiency. Patients are generally managed by gastroenterologists and pain specialists. From a surgical perspective, patients are divided into two groups: those with ductal dilatation and those without ductal dilatation. For patients with ductal dilatation, the treatment options are: (1) sphincteroplasty (endoscopic or surgical) and (2) a pancreatic drainage procedure. The optimal option depends on the exact anatomy of each case. Patients with a discrete obstruction in the proximity of the major papilla/ampulla of Vater are good candidates for an endoscopic sphincteroplasty with or without a temporary stent, as long as concomitant proximal obstructions have been ruled out. This approach is the least invasive but it requires great expertise, is not always feasible in children due to size limitations, and has a higher pain recurrence rate than the surgical options. Surgical transduodenal sphincteroplasty is rarely used, except in those with pancreas divisum.

Pancreatic drainage procedures have been used for many decades and are safe and effective. The most commonly performed procedure in children is the Puestow procedure modified by Partington and Rochelle. The abdomen is entered either using a transverse supraumbilical or a Chevron incision. The lesser sac is opened and the duodenum mobilized to expose the entire anterior aspect of the pancreas. The dilated main pancreatic duct is delineated by palpation or intraoperative ultrasound and needle aspiration is used to confirm its location. The anterior wall of the dilated pancreatic duct is filleted open with electrocautery along its entire dilated length. If intraductal stones are present, they are removed. A 20–30 cm-long Roux-en-Y jejunal limb is created, an end-to-side jejunojejunostomy is performed, and the Roux-limb is brought to the pancreatic area in a retrocolic manner. The Roux-limb is laid over the pancreas oriented with its free end on the pancreatic tail.

The pancreaticojejunostomy is built in two layers. First, a series of interrupted 3-0 silk sutures are placed between the seromuscular layer of the jejunum (just posterior to the antimesenteric edge) and the capsule of the pancreas, 2–3 mm away from the inferior edge of the opened duct. Next, the antimesenteric border of the jejunum is opened matching the length of the opened pancreatic duct and a running suture of 3-0 polydioxanone is placed between the full-thickness jejunal wall and the edge of the opened duct including the ductal mucosa in order to obtain a water-tight apposition between the jejunal and pancreatic ductal mucosa. The pancreaticojejunostomy is completed with interrupted 3-0 silk sutures placed between the seromuscular layer of the jejunum and the pancreatic capsule, cephalad to the superior half of the previous running suture. Lastly, an omental flap is used to cover the entire pancreaticojejunostomy. Drains are not necessary.

An alternative to the modified Puestow procedure are the Frey and the Beger procedures, which are designed for cases in which the fibrotic pancreatic head causes compression of the biliary tree, the duodenum, or the retropancreatic vessels. In the Frey procedure the majority of the pancreatic head is cored out, leaving a thin layer on the posterior aspect and a thin rim on to the duodenum, and the pancreatic duct on the body and tail is filleted open as in the modified Puestow procedure (Fig. 85.10). In the Beger procedure, the pancreatic head is cored out and the pancreas is transected at the neck, reconstructing the drainage with a lateral pancreaticojejunostomy to the remaining head and an end-to-end pancreaticojejunostomy to the pancreatic body (Fig. 85.10).

All surgical pancreatic drainage procedures are effective in providing a low-resistance outlet for the pancreatic secretions. However, the long-term outcomes in terms of pain control depend largely on the etiology and on whether or not the causative factor persists after the operation. Patients with *obstructive* disease are likely to have definitive pain relief

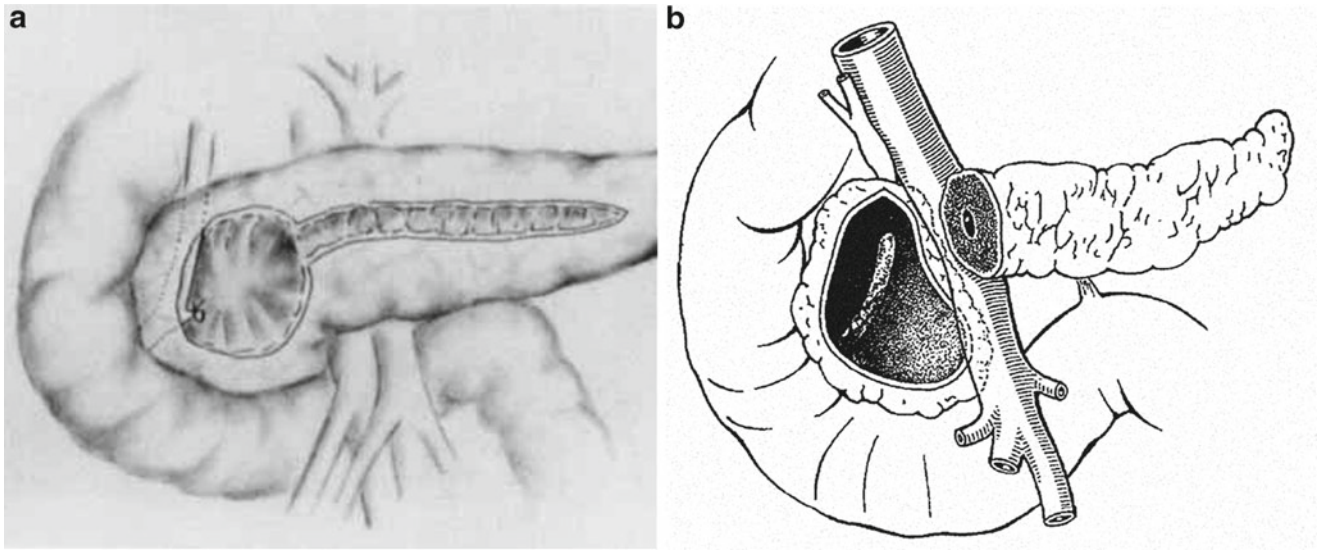

Fig. 85.10 (**A**) Frey procedure. The pancreatic head is cored out and the remaining pancreatic duct filleted open. The reconstruction is done with a lateral pancreaticojejunostomy. (Reprinted from Frey C, Smith G. Description and Rationale of a New Operation for Chronic Pancreatitis. Pancreas. 1987; 2(6): 701–7, with permission from Wolters Kluwer Health.) (**B**) Beger procedure. The pancreatic head is cored out and the pancreas transected at the neck, reconstructing the drainage with a lateral pancreaticojejunostomy to the remaining head and an end-to-end pancreaticojejunostomy to the pancreatic body. (From Buchler MW. Duodenum-preserving pancreatic head resection: long-term results. J Gastrointest Surg. 1997; 1(1): 13–9, reprinted with kind permission from Springer Science + Business Media.)

after the surgery, as long as the pancreatic duct remains appropriately decompressed. Similarly, patients with *toxic* chronic pancreatitis, particularly ethanol-induced, are likely to have definitive pain relief after the decompression of the pancreatic duct unless they continue to consume ethanol. In contrast, in patients with hereditary pancreatitis the intrinsic cause of the disease does not disappear after the operation, and while most patients improve their pain score after the surgery, the long-term results are variable. The same is true regarding the efficacy of the drainage procedures in arresting the progression to pancreatic insufficiency. For patients without ductal dilatation and intractable pain, the only surgical option is a pancreatectomy. In the right anatomical setting, partial pancreatectomy may be feasible, but in most patients the entire organ is affected and a total pancreatectomy is required.

From a technical perspective, a total pancreatectomy is straightforward to perform, but the operation turns the patient instantly diabetic. This can be prevented by total pancreatectomy and concomitant pancreatic islet autotransplantation (TPIAT). The principle of the technique is to harvest the islets contained in the pancreatectomy specimen and infuse them via the portal vein into the liver. The islets embolize into the liver capillaries and achieve long-term survival by inducing revascularization. The success of the procedure relies on the number of islets isolated from the pancreatectomy specimen. The islet yield is generally lower in patients with severe pancreatic fibrosis and in patients who underwent previous pancreatic surgical drainage procedures. TPIAT is a procedure that can only be done in centers with extensive pancreatic surgery experience and the appropriate expertise in pancreatic islet processing. Even though TPIAT was developed over 30 years ago, there is still an ongoing effort among experienced centers to optimize every aspect of the procedure. Appropriate patient selection is the first step. Among many other conditions, the eligibility for a TPIAT includes an adequate residual beta-cell function (measured by c-peptide levels), strong psychosocial support, and a thorough understanding of the potential risk of diabetes and the irreversibility of the operation. TPIAT is the only surgical option for small duct CP patients of any etiology that meets eligibility criteria, but because of the unavoidable progression of the disease, it has been suggested that TPIAT might be the procedure of choice in patients with hereditary pancreatitis and dilated pancreatic duct, instead of a surgical pancreatic drainage procedure. An additional benefit of this approach in patients with hereditary pancreatitis is the complete elimination of the risk of pancreatic cancer.

The optimal timing of TPIAT is still unknown. On one side, delaying the procedure delays the potential risk for failure and diabetes, but on the other side long-term narcotic dependence causes central sensitization of pain, among other effects, which makes pain very difficult to reverse even after the operation. From a technical perspective, attention to detail is critical to achieve the highest possible islet yield. Warm ischemia time must be minimized by isolating the entire duodenopancreatic block without compromising its perfusion, ligating the gastroduodenal and splenic arteries immediately before the harvest.

Heparinization after the transplant is critical to avoid portal vein thrombosis, which would affect the oxygenation of the engrafting islets that are only perfused by the already hypoxic portal blood. Tight glucose control in the immediate postoperative period after TPIAT is also critical, because hyperglycemia induces beta-cell apoptosis. Significant improvement in the severity of pain can apparently be achieved in the majority of cases and 40–50 % of patients can expect to achieve long-term insulin independence. Improvements and refinements in the islet isolation technique will hopefully result in much better TPIAT outcomes in the future.

Editor's Comment

Most of the pancreatic disorders commonly seen in adults are much less prevalent but much better tolerated in children. Annular pancreas is probably not an actual cause of duodenal obstruction but rather an anatomic variant that occurs in the setting of duodenal atresia. Although previous concerns about the risks of dividing the pancreas are probably exaggerated, there is no reason to disturb it, as a duodenoduodenostomy is therapeutic. Pancreas divisum is probably a normal anatomic variant and not a frequent cause of acute pancreatitis. Nevertheless, some patients with recurrent or chronic pancreatitis appear to benefit from endoscopic sphincterotomy.

Acute pancreatitis in children is usually idiopathic though the workup should include a search for gallstones, severe hyperlipidemia, toxins (L-asparaginase), anatomic abnormalities, cysts, and a positive family history. Treatment is supportive and individualized but the Ranson criteria are not very useful and imaging typically does not correlate with clinical severity. Pancreatic necrosis is uncommon and infected pancreatic necrosis requiring intervention is exceedingly rare. If the patient is stable, percutaneous drainage or laparoscopic debridement might be reasonable before embarking on a morbid and protracted course of serial surgical resections.

Pancreatic pseudocysts in children almost always eventually resolve spontaneously. Indications for intervention include persistent symptoms or a cyst that persists for more than 6 weeks. Radiology-guided percutaneous drainage and placement of internal stents is gaining popularity and seems to work in many cases. When indicated, surgical therapy should be performed using a minimally invasive approach.

Chronic pancreatitis with a dilated pancreatic duct responds well to Puestow procedure but the drainage should be extended to include the head of the pancreas (Frey procedure).

Pancreatic tumors include not only endocrine tumors such as insulinoma and gastrinoma but also pancreatoblastoma, solid pseudopapillary tumors, inflammatory myofibroblastic tumor, and sarcoma. The treatment is primarily surgical but should be coordinated with an experienced pediatric oncologist. The operations are the same as those used in adults, namely distal pancreatectomy for lesions in the body or tail and Whipple procedure for lesions in the head of the pancreas. Whipples are very rarely performed but very well tolerated in children. Aggressive attempts to balance negative margins and normal function of adjacent organs should be made.

Suggested Reading

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Surgical Disorders of the Spleen

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Elisabeth T. Tracy and Henry E. Rice

For children with many benign and malignant conditions, a splenectomy can cure the disease or control the associated clinical symptoms. However, the risks associated with total splenectomy (TS) such as overwhelming postsplenectomy sepsis (OPSI) limit the use of splenectomy, and there is increasing recognition of other risks of splenectomy, such as increased rates of vascular thrombosis or hypertension. For select conditions, a partial splenectomy (PS) may effectively remove enough spleen to gain the desired clinical outcome while minimizing these risks.

The public health impact of spleen surgery for children is substantial. Approximately 2000 children each year in the USA receive a splenectomy, with annual aggregate hospital charges of over $25,000,000 for the surgical procedure itself in addition to long-term expenditures for care of asplenia.

Risks of Splenectomy

Total splenectomy is associated with a lifelong increased risk of overwhelming infection, particularly with pneumococcal and meningococcal species. The risk of postoperative infection is difficult to conclusively measure however, given the complexity of accurately detecting infection in this population over an extended time period. The infectious risk is dependent on the underlying disease process, duration since the splenectomy was performed, and age of the child. The overall incidence of infection requiring hospitalization in splenectomized adults is approximately 7–8 per 100 person-years compared to 2 per 100 person-years for the general population, with the adjusted relative risk (RR) being the highest in the first 90 days after splenectomy. The subgroups at the highest risk are those with splenomegaly/splenic disease and congenital hemolytic anemia, while the lowest risk is in patients with ITP. It is further estimated that lifelong risk of infection among splenectomized children is 4–5 % with a mortality rate of approximately 2 %; the corresponding figures for each in adults approach 1 %. When compared to a non-splenectomized cohort, patients with ITP or congenital hemolytic anemias (CHA) are at slightly higher infection risk during the first 90 days after splenectomy, but not after this time point.

Importantly, the infectious risk after splenectomy is not completely eliminated by pre-operative vaccinations and postsplenectomy antibiotic prophylaxis. Patients should be vaccinated against high-risk organisms according to national guidelines, which are regularly updated to reflect local epidemiologic disease patterns. The infection risk following partial splenectomy remains unclear. Our practice is to manage children preoperatively with the same immunizations and antibiotic chemoprophylaxis as children undergoing total splenectomy. Whether antibiotic prophylaxis can be safely terminated earlier for children undergoing partial splenectomy compared to total splenectomy remains poorly defined, and some centers incorporate evaluation of splenic function (clearance of Howell–Jolly bodies, radionuclide imaging) as part of this decision-making process.

An increased risk of venous and arterial thrombosis, thromboembolism, vasospasm, and atherosclerosis has been increasingly recognized as a complication of splenectomy. The risk of vascular events varies depending on the underlying condition for which the splenectomy is performed and whether or not the condition is associated with ongoing intravascular hemolysis. The rate of vascular complications has been estimated to be in the range 10–35 %. Thromboembolic complications have been most frequently reported after splenectomy in thalassemia intermedia and in Hgb E/β-thalassemia. Although the efficacy of preventive interventions remains unknown, particular attention to perioperative anticoagulation may be prudent in these disorders. The risk of vascular events in partial splenectomy has not been defined.

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Indications for Splenectomy

Indications for splenectomy include congenital hemolytic anemias, ITP, traumatic injury, splenic cysts, and tumors.

Congenital Hemolytic Anemias

Congenital hemolytic anemias can be divided into abnormalities of the erythrocyte membrane such as hereditary spherocytosis and primary hemoglobinopathies such as sickle cell anemia and thalassemias. The clinical and laboratory manifestations, associated molecular defects, and indications for splenectomy for these disorders vary widely.

Erythrocyte membrane disorders include hereditary spherocytosis (HS), hereditary elliptocytosis, and related disorders. HS occurs worldwide in all racial and ethnic groups, and is the most common inherited anemia in individuals of northern European ancestry, affecting approximately 1 in 2500 individuals. The principal abnormality in HS is loss of erythrocyte membrane surface area relative to intracellular volume and increased membrane fragility due to abnormalities in erythrocyte membrane proteins, particularly ankyrin, α- and β-spectrin, band 3, and protein 4.2.

The majority of children with HS have mild hemolysis and do not require splenectomy. For severely affected children such as those with severe anemia, accelerated hemolysis, extramedullary hemopoietic tumors, skeletal changes, or transfusion-dependence, surgical treatment is clearly indicated. For children with moderate hemolysis, the role for surgical intervention is less well-defined, and is generally indicated in the presence of disease-related complications.

Sickle cell disease (SCD) is a group of hemoglobinopathies (Hemoglobin SS, SC, or S-beta thalassemia) in which the abnormal hemoglobin polymerizes, distorting the red blood cells into a sickle shape. Severely affected children with SCD have increased rates and severity of infections, pain episodes, stroke, kidney failure, chest infections, and acute chest syndrome.

Splenectomy in SCD is indicated for children with history of severe or repeated acute splenic sequestration crises or chronic splenomegaly. Splenic sequestration occurs when red blood cells in SCD become entrapped in the spleen, and is generally defined as a fall of two grams per deciliter or more in hemoglobin concentration from the persons' normal levels, associated with an enlarging spleen. Sequestration recurs in about 50 % of survivors of the first attack, with diminishing intervals between subsequent crises. Due to the frequency of recurrences, both long-term blood transfusion therapy and splenectomy (total or partial) are indicated in severely affected children to prevent recurrent sequestration. In many parts of the world, early splenectomy is employed when chronic transfusion therapy is not feasible.

Immune-Mediated Thrombocytopenia Purpura

Primary immune thrombocytopenia purpura (ITP) is an autoimmune disease characterized by low platelet counts, increased platelet destruction, and suboptimal platelet production. An International Working Group defines three phases of ITP: (1) newly diagnosed (first 3 months since diagnosis); (2) persistent ITP, for patients not achieving spontaneous remissions or not maintaining their response after stopping treatment between 3 and 12 months from diagnosis, and (3) chronic ITP lasting longer than 12 months. Spontaneous remission is most likely to occur during the persistent phase and deferral of splenectomy until 12 months after diagnosis is generally suggested whenever possible.

In newly diagnosed ITP patients, first line treatment is generally either with corticosteroids or immunoglobulin and achieves an initial response in approximately 70–80 % of patients. However, relapse or prolonged treatment courses are often required with burdensome toxicity, hence splenectomy may eventually be considered. Guidelines from the American Society of Hematology also recommend splenectomy as one of the second-line treatment choices in patients failing initial treatment. Rituximab, the chimeric monoclonal antibody targeted against the B-cell surface protein CD-20, is also used as a second-line treatment in ITP, although it has a lower long-term response than splenectomy and associated with significant toxicities, including a low risk of fatal adverse events.

Traumatic Injury

Non-operative management of blunt splenic injury in children has been widely adopted in many parts of the world since the early 1980s. For the past 20 years, evidence-based practice guidelines have been developed to care of these patients, including recommendations for length of ICU stay, hospital stay, and activity restrictions based on the grade of injury. With success rates greater than 90 %, non-operative management has become the standard of care for hemodynamically stable children with blunt splenic injury, although care by providers and hospitals experienced in non-operative care is required. Hemodynamic instability is the only consistent predictor of failure of non-operative management in the literature. Presence of a contrast blush on cross-sectional imaging has not been shown conclusively to predict failure of non-operative management; however, recent reviews have suggested that as many as one-third of children with a contrast blush on CT scan will require intervention by either angioembolization or laparotomy.

For hemodynamically unstable children, the goal of surgical intervention or angiographic embolization is to control bleeding. For this reason, total splenectomy is often required.

However, spleen preserving techniques, including angiographic embolization, partial splenectomy, or splenorrhaphy, should be considered for children who respond to resuscitation and do not have ongoing hemodynamic compromise. Depending on the location of injury, the splenic remnant for partial splenectomy can be based on the upper or lower pole of the spleen. The line of parenchymal transection can be determined by the demarcation of splenic parenchyma after selective devascularization and can be performed by a variety of techniques including the linear cutting stapler or various energy sources as described below.

Splenic Cysts

Although splenic cysts are relatively uncommon in children, they are being increasingly detected by imaging done for other purposes. The majority of splenic cysts in children in the USA are congenital cysts with a true epithelial lining and far less likely to result from a parasitic infection. Splenic cysts are thought to arise from inclusions of mesothelial lining of the spleen during development into the splenic parenchyma. The epithelial lining may consist of mesothelium, transitional or squamous epithelium. Workup includes a complete history, including exposure to parasitic disease or trauma, and imaging by US or cross-sectional imaging. Imaging characteristics of benign, nonparasitic cysts include a regular cyst wall, absence of any solid components, and absence of contour defects. Calcifications, daughter cysts, and cysts in other organs raise suspicion for parasitic cysts, although calcifications are occasionally seen in long-standing congenital cysts. For inconclusive imaging, tumor markers including CEA and CA 19-9 may be helpful.

Surgical management has been advocated for symptomatic splenic cysts as well as for large asymptomatic splenic cysts due to risks of hemorrhage, rupture, or infection. Because these complications are more common in cysts >5 cm in diameter, this has been the traditional threshold for intervention. Although splenic cysts have been treated historically by total splenectomy, more recent strategies have emphasized splenic preservation. Aspiration with injection of sclerosing agents and marsupialization are associated with a high rate of recurrence and should be reserved for temporary treatment of a symptomatic cyst or for cyst recurrence. Cystectomy, defined as resection of the cyst and a portion of splenic parenchyma contiguous to the cyst, was first described in 1980 and is associated with a low risk of recurrence. Partial cystectomy or "unroofing," which involves leaving the portion of the cyst wall contiguous with the splenic parenchyma in situ, has recurrence rate as high as 60–80 % in children. Partial splenectomy with resection of the cyst, although more technically challenging, is associated with a lower recurrence than partial cystectomy, while still preserving splenic function and providing an intact pathologic specimen. Total splenectomy, partial splenectomy, or complete or partial cystectomy may all be performed laparoscopically. Cyst recurrences can be managed non-operatively with image guided drainage and sclerosis with acceptable short term results, as well as by partial or total splenectomy.

Tumors

Primary malignant tumors of the spleen are rare and include lymphoma, angiosarcoma, and metastatic tumors to the spleen. Primary splenic angiosarcoma, although rare in the pediatric population, is an aggressive malignancy often presenting with advanced disease and poor survival due to nodal and systemic dissemination. Improved survival is associated with small tumor size (<5 cm) and splenectomy prior to splenic rupture. Although US, MRI, and CT are useful in establishing the presence of a solid splenic tumor, their ability to distinguish benign from malignant tumors such as rhabdomyosarcoma, angiosarcoma, and desmoid tumors and other soft tissue sarcomas is often limited. The role of imaging in these tumors may be limited to guiding the decision for total or partial splenectomy, although in general partial splenectomy with potential incomplete tumor resection is not indicated in splenic malignancies.

Fortunately, most splenic tumors in children are benign. These masses include hamartoma, adenoma, leiomyoma, and lipoma. Vascular malformations including hemangiomas may affect the spleen and usually have a characteristic appearance on cross-sectional imaging. Patients with tuberous sclerosis may have hamartomatous tumors affecting the spleen along with other organs. Inflammatory myofibroblastic tumor (IMT) of the spleen is a benign tumor with malignant potential which should be completely excised. Although partial splenectomy has been used successfully in these patients, they should be monitored for local recurrence. Primary tuberculosis of the spleen is also rare but should be considered in the appropriate clinical context.

Surgical Technique

Splenectomy can be total or partial and can be performed using an open technique or a minimally invasive approach.

Total Splenectomy

Laparoscopy has generally replaced laparotomy in the USA for total splenectomy, although laparoscopic splenectomy should only be performed in settings where there are skilled surgeons and available necessary equipment. There is a substantial and growing amount of high quality data that has shown that compared to laparotomy, a laparoscopic splenectomy results

in less pain, shorter length of stay, and decreased time to return of bowel function. Particularly for immune-mediated disorders such as ITP, following removal of the spleen a careful search for spleniculi (accessory splenic tissue) should be performed on the assumption that any splenic tissue left behind could lead to a recurrence of disease, although the risk of recurrent disease remains poorly defined.

For laparoscopic splenectomy, we prefer a supine approach, although a lateral approach can also be used. We use a 4-trocar technique, placing an 11 mm working port in the umbilicus, a 5 mm working port in the left upper quadrant, and two additional upper-midline 5 mm ports for a 45° camera placement and retraction (Fig. 86.1). In case of concurrent cholecystectomy, an additional 5 mm port can be placed in the right upper quadrant. We ligate the splenic vessels using a harmonic scalpel, advanced bipolar cautery device, clips, or surgical stapler, depending on the size of the vessels. After ligation of all vessels and lateral attachments, the spleen is placed into a 10- or 15-mm specimen bag introduced through the umbilical incision (either through the port or directly into the abdomen), with the spleen morcellated inside the bag so that the contents can be removed through this site with minimal extension of the incision. In cases of massive splenomegaly or with tumors that require intact tissue for diagnosis, the spleen may be removed through an open incision.

Partial Splenectomy

For partial splenectomy, use of either laparotomy or laparoscopy is feasible, and is generally dependent on surgeon expertise and preference. The first step is to inspect the vasculature to identify the short gastric vessels to the upper pole and gastroepiploic vessels to the lower pole. We generally prefer to preserve 1–2 short gastric vessels to the upper pole, to allow for retention of 10–20 % of normal splenic volume. However if there is not adequate blood flow to the upper pole, preservation of the lower pole is feasible, although the remnant splenic tissue should be fixed to the lateral abdominal wall to prevent torsion.

Parenchymal transection of the spleen can be performed using one of several techniques. If the spleen is small and compressible such as in younger children with hereditary spherocytosis, ligation with a stapler can be performed relatively easily. However, in cases of a large or firm spleen, such as in the setting of repeated sequestration episodes, the parenchyma can be divided using a combination of electrocautery, harmonic scalpel, or advanced bipolar cautery device, similar to a liver transection. Hemostasis of the splenic bed can generally be controlled relatively easily with an Argon-beam coagulator and topical hemostatic agents.

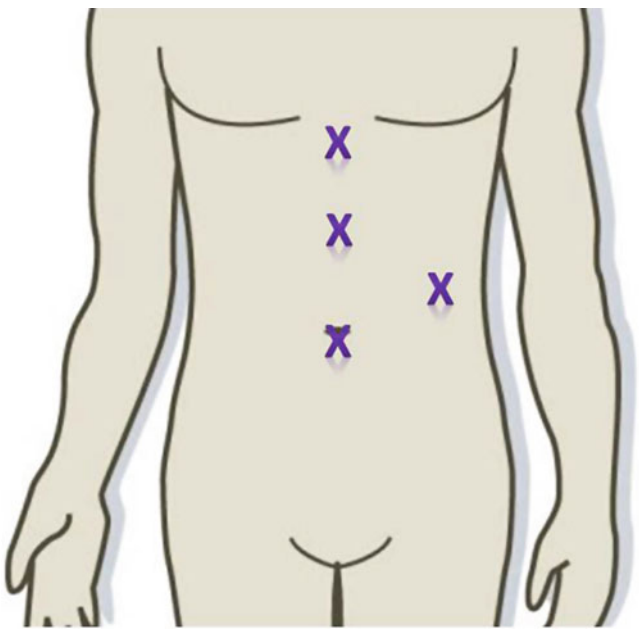

Fig. 86.1 Placement of trocars for a laparoscopic splenectomy

Postoperative Care

Recovery following total splenectomy is rapid, with most children able to be discharged the following day if performed laparoscopically. For partial splenectomy, we generally keep a child hospitalized for 2–3 days to monitor for signs of bleeding, although the risks of bleeding are quite low. If performed by laparotomy, recovery is slightly prolonged due to pain control, although most children can be discharged relatively rapidly after surgery. Our practice is to discharge all children, regardless of age or type of procedure, on antibiotic prophylaxis for at least one year, with the duration of antibiotic prophylaxis individualized to family, hematologist, and surgeon preference.

Outcomes

To improve our understanding of the role of splenectomy for children with congenital hemolytic anemia, we formed SICHA (Splenectomy in Congenital Hemolytic Anemia), a research consortium of pediatric surgeons and hematologists at 16 sites across North America. Our consortium developed a web-based patient registry to collect standardized outcomes of children with CHA undergoing total or partial splenectomy using the Research Electronic Data Capture (REDCap) platform and recently summarized the outcomes of the first 100 children in this registry.

Hematologic Outcomes

Almost all children with HS in the registry had resolution of their clinical symptoms following TS or PS (Table 86.1), as well as an increase in hemoglobin, decrease in reticulocyte count, and decrease in bilirubin (Fig. 86.2). Children with

Table 86.1 Clinical symptoms at baseline and after total splenectomy or partial splenectomy for children with hereditary spherocytosis or sickle cell disease

	Hereditary spherocytosis			Sickle cell disease		
	Baseline	Postop	*p*-value	Baseline	Postop	*p*-value
Splenic sequestration	8 (20 %)	1 (2.6 %)	0.034	45 (90 %)	1 (2.1 %)	<0.001
Transfusions	8 (20 %)	0 (0 %)	<0.001	13 (26 %)	1 (2 %)	<0.001
Aplastic or anemic crisis	5 (12.5 %)	0 (0 %)	<0.001	NR	NR	
Hypersplenism	0 (0 %)	0 (0 %)		4 (8 %)	0 (0 %)	<0.001
Splenomegaly	11 (27.5 %)	0 (0 %)	<0.001	5 (10 %)	0 (0 %)	<0.001
Poor growth	0 (0 %)	0 (0 %)		1 (2 %)	0 (0 %)	
Abdominal pain	3 (7.5 %)	0 (0 %)	<0.001	1 (2 %)	0 (0 %)	

Numbers represent counts (%) for symptoms at baseline and postoperatively for children with hereditary spherocytosis or sickle cell disease following total splenectomy or partial splenectomy. Transfusions—History of multiple transfusions or participation in regular transfusion program. *p*-values represent McNemar's for matched pair differences between baseline and postoperative symptoms. Any symptom reported during 1 year follow-up was counted as having a postoperative symptom, with multiple episodes of the same symptom during follow-up counted only once. *NR*—not recorded

Source: Rice HE, Englum BR, Rothman J, et al. Clinical outcomes of splenectomy in children: report of the splenectomy in congenital hemolytic anemia (SICHA) registry. Am J Hematol. 2015;90:187–92

SCD also had resolution of their clinical symptoms following TS or PS. However, in contrast to children with HS, children with SCD had similar hemoglobin, reticulocyte count, and serum bilirubin postoperatively compared to baseline (Fig. 86.3). At this stage, there is not adequate data to definitively compare outcomes between TS and PS, although further study of these procedures should help us understand the expected options in different diseases as well as allow personalization of the optimal procedure to a particular child's disease phenotype and genotype.

Adverse Events

The overall rate of adverse events (AE) within 30 days of surgery for children in the SICHA registry was 11 %, with no deaths recorded. For children with HS, there was a 2.5 % rate of infection. In children with SCD, there was a 10.0 % rate of infection and a 12.0 % rate of acute chest syndrome (ACS). The overall rate of long-term AE (31–365 days after surgery) was also 11 %, with no deaths recorded. For children with HS, there were no infections or thrombotic events, and one reoperation (3.1 %) over one year of follow-up. Children with SCD had a 14.3 % rate of infection, including two with sepsis, one with upper respiratory tract infection (URI), one with parainfluenza, one with influenza B, and one unspecified. Children with SCD had a 9 % rate of ACS. There was one child (2 %) with a thrombotic event, who had a transient ischemic attack 24 weeks after TS.

Future Considerations

Our understanding of the risks and benefits of spleen surgery for children should continue to improve, resulting in ongoing changes to long-standing practices. In particular, the increasing use of conjugated and non-conjugated pneumococcal vaccines appears to lessen the risks of postsplenectomy sepsis, and could lead to expanded indications for splenectomy. The incidence of pneumococcal infections following the introduction of PCV7 and PCV13 vaccines has rapidly decreased in many parts of the world. In children with sickle cell disease, the prototype of functional asplenia, there is a 92 % decrease of infection among children under 5 years of age in the post-conjugate PCV7 era compared with the preconjugate vaccine era. PCV13 should also expand protection against additional serotypes that are the most common causes of pneumococcal disease globally in children.

Our increased understanding of the precise hematologic outcomes following total and partial splenectomy for children with different conditions should allow us to individualize surgical recommendations in the future. Data are rapidly accumulating to allow tailoring of recommendations for a particular type of splenectomy depending on the age of the child, type of disease, severity of phenotype, and associated genetic mutation.

Editor's Comment

There is almost never a valid reason to perform an open total splenectomy in a child as a planned procedure. The open incision is invariably large, painful, and potentially morbid, whereas the instrumentation and expertise to perform the procedure safely using the laparoscopic approach are widely available. The patient can be supine or slightly tilted with a bump. A line should be drawn where an open incision would be made should it become necessary to do so in a hurry. For reasons of exposure, postoperative comfort, and cosmesis, this incision should be transverse, though some prefer a subcostal approach. Three or four ports are used, all 5 mm except for the umbilical port which should be a 10/12-mm port. For total

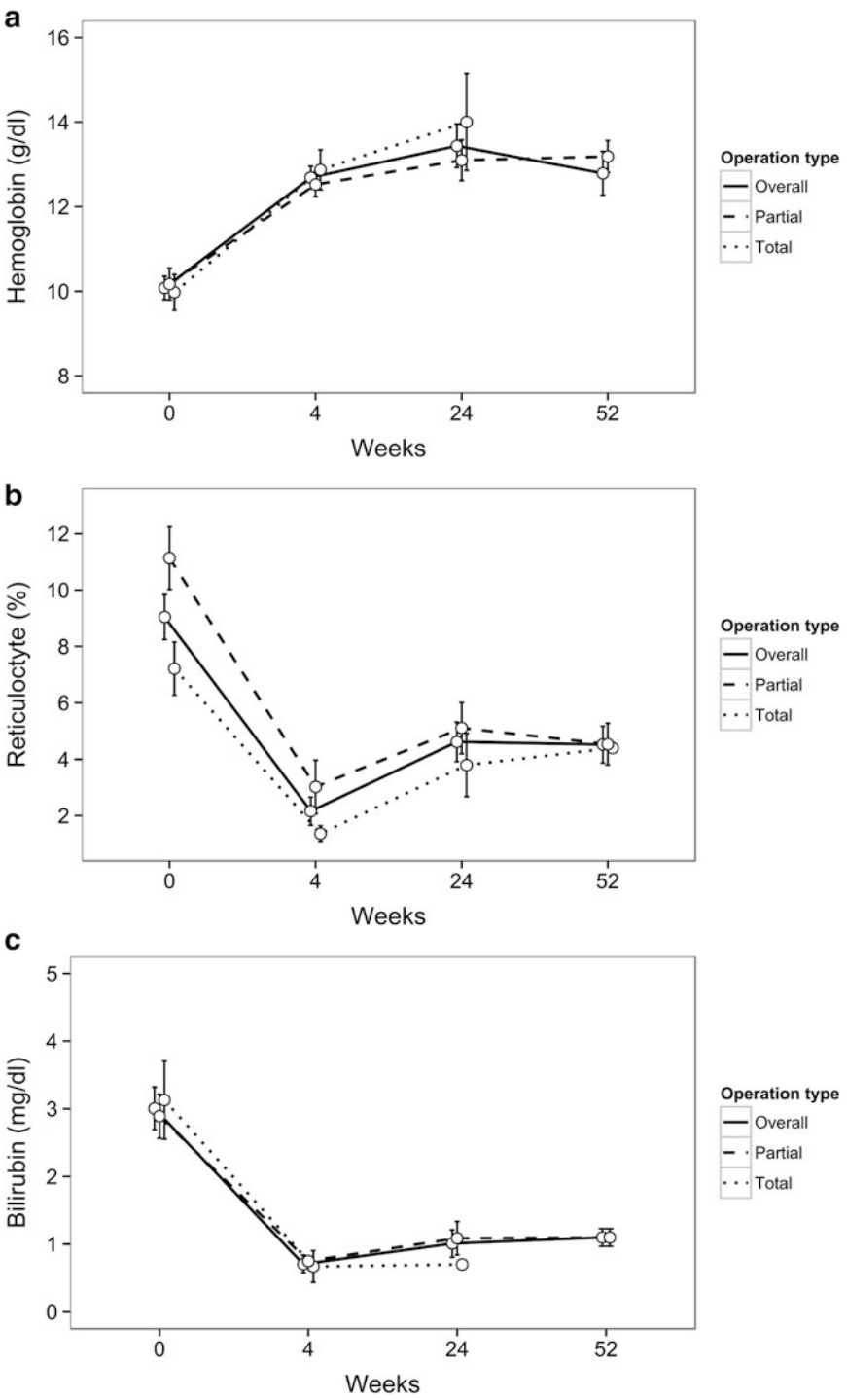

Fig. 86.2 Hematologic outcomes following partial splenectomy or total splenectomy in 40 children with hereditary spherocytosis: (**A**) hemoglobin, (**B**) reticulocyte count, and (**C**) serum bilirubin at baseline and at 4, 24, or 52 weeks after partial splenectomy ($n=19$) or total splenectomy ($n=21$). All data expressed as mean, with error bars representing standard error. (From Rice HE, Englum BR, Rothman J, et al. Clinical outcomes of splenectomy in children: Report of the Splenectomy in Congenital Hemolytic Anemia (SICHA) registry. Am J Hematol 2014.)

splenectomy, it is best to completely mobilize the spleen, leaving the hilum for last. The hilar vessels can be easily controlled with an endoscopic stapling device maneuvered through the umbilical incision, being careful not to transect the tail of the pancreas, which though actually generally well-tolerated is best avoided. A 15-mm endo-bag device will fit through the periumbilical incision after removal of the port and slight enlargement by stretching with a large hemostat. A safe, effective, and inexpensive morcellator has yet to be developed; however, morcellation by hand using curved sponge clamps and a large plastic Yankauer suction tip works quite well.

Partial splenectomy can also be performed laparoscopically, but parents should be warned about higher rates of blood loss and conversion to laparotomy. The upper-most short gastric vessels should be preserved until it is clear that

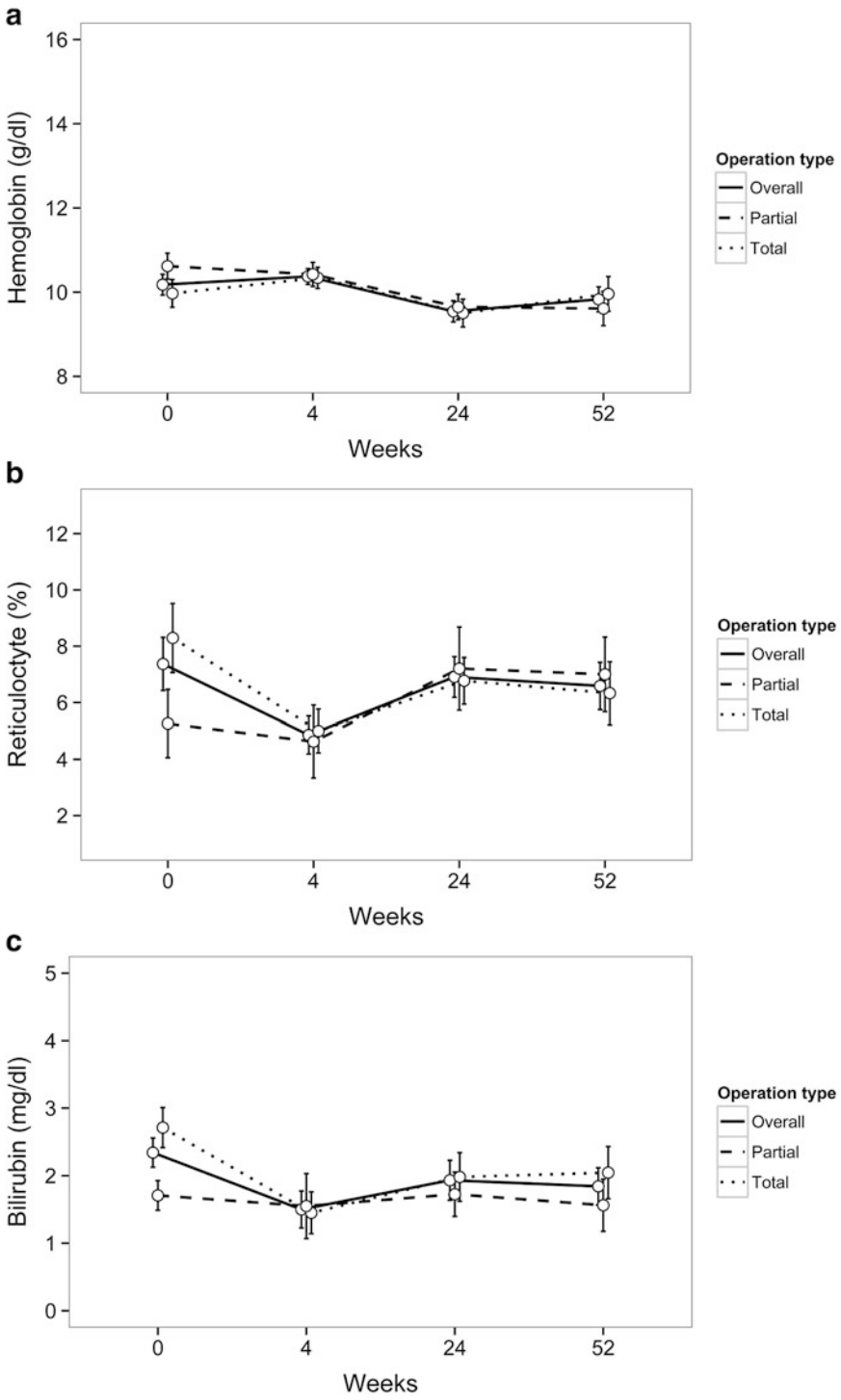

Fig. 86.3 Hematologic outcomes following partial splenectomy or total splenectomy in 50 children with sickle cell disease: (**A**) hemoglobin, (**B**) reticulocyte count, and (**C**) serum bilirubin at baseline and at 4, 24, or 52 weeks surgery after partial splenectomy ($n=16$) or total splenectomy ($n=34$). All data expressed as mean, with error bars representing standard error. (From Rice HE, Englum BR, Rothman J, et al. Clinical outcomes of splenectomy in children: Report of the Splenectomy in Congenital Hemolytic Anemia (SICHA) registry. Am J Hematol 2014.)

suitable branches of the hilar vessels can been preserved. Division of the appropriate hilar vessels causes the spleen to demarcate. Transection of the splenic parenchyma is challenging and sometimes daunting. The devascularized portion of the spleen is a reservoir for a large amount of blood and release of this blood while coming across the spleen can be difficult to distinguish from active bleeding. Also, although the harmonic scalpel is probably the best energy source to use to come across the spleen, it is not perfect and adjuncts, such as clips, electrocautery, fibrin sealants, or stapling devices, are often needed. The argon-beam coagulator can be used on the raw surface of the cut spleen with good effect. The clearest and perhaps most common indication for partial splenectomy is the splenic cyst. Some surgeons have advocated partial excision of the cyst, using the argon-beam coagulator to "destroy the remaining epithelium" on the back

wall that remains. This is impossible of course, especially since the epithelial surface of the splenic cyst is usually trabeculated. The recurrence rate for cysts managed in this fashion is extremely high.

Partial splenectomy for hematologic conditions makes sense and certainly should be studied in a formal way to be certain that the recurrence rate is low and that splenic function can indeed be adequately preserved. There are sometimes requests for splenectomy for unusual indications. The wandering spleen syndrome is presumably due to intermittent volvulus of the spleen because of inadequate peritoneal attachments. The diagnosis is suggested in patients with intermittent abdominal pain or by imaging studies that reveal a spleen with an unusual lie or tilted axis of orientation. The diagnosis is confirmed at laparoscopy and best treated by creating a peritoneal pocket within which the spleen can be placed and secured. Rarely, the pediatric surgeon will be asked to remove a spleen simply because it is too big, due to a perceived risk of traumatic or "spontaneous" rupture. Unless the spleen is truly massive, reassurance and the use of a spleen guard are probably the best recommendations.

Pediatric surgeons are still sometimes asked to remove the spleen in the child with portal hypertension and secondary hypersplenism. The preferred management of these children is treatment directed at the underlying cause, namely portosystemic shunt or liver transplantation. Finally, we are occasionally asked to biopsy the spleen, which is not as difficult or dangerous as it sounds. It can be done safely as a core-needle biopsy under image guidance and with a surgeon on standby, or laparoscopically with electrocautery or sutures used on the capsule to stop the bleeding after tru-cut needle biopsy.

Suggested Reading

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Part XI

Genitourinary

Vesicoureteral Reflux

87

Ruthie Su

Vesicoureteral reflux (VUR) is defined as the abnormal retrograde flow of urine from the bladder across the ureterovesical junction up the ureter to the renal pelvis and tubules. VUR is a common problem and usually asymptomatic until in the presence of bacteriuria when pyelonephritis and renal scar may ensue. The challenge is to identify and treat those with clinically significant VUR while balancing the risks and benefits of diagnosis and treatment.

Since VUR is usually only apparent following a bout of pyelonephritis, its true incidence is difficult to assess. Those who are at higher risk for urinary tract infection—females and uncircumcised males—will more often be screened and found to have VUR. About 30–70 % of children who present with UTI will be found to have VUR. Caucasians are at higher risk compared to those of African descent. The natural history of reflux is spontaneous resolution over time so VUR is more common in younger children, particularly in those less than 1 year old.

Embryology

During normal development, the ureter, which forms from the ureteral bud, meets and becomes incorporated with the urogenital sinus, the future bladder trigone. This incorporation results in an intramural portion of the ureter, which travels a short distance within the detrusor muscle. The intramural ureter acts as a valve mechanism as it is compressed during bladder filling. Primary or congenital VUR occurs if budding occurs too early resulting in lateral displacement of the ureteral orifice, thus shortening the length of intramural ureter and yielding an incompetent valve mechanism. An abnormality in the ureteral bud may also affect the interaction with metanephric blastema and development of the future kidney, leading to the renal dysplasia that can accompany severe VUR.

VUR can also occur secondary to a valve mechanism overwhelmed by altered bladder dynamics. This is why VUR often coexists with conditions of high-pressure voiding, which can structurally or functionally impair the ureterovesical junction mechanism. Posterior urethral valves, ureterocele causing bladder outlet obstruction, acquired voiding dysfunction, or neurogenic bladder should also be considered when VUR is diagnosed since treatment of these may correct the secondary VUR.

Imaging

VUR is diagnosed radiographically by cystography. The most common modality is the Voiding Cystourethrogram (VCUG), which is performed by direct injection of iodinated contrast into the bladder and observation for reflux of urine up the ureters to the pelvicalyceal system. Alternatively, one can perform a radionuclide cystogram, which carries 1 % of the radiation exposure of a VCUG but lacks the anatomic definition afforded by the VCUG. There are five grades of VUR in VCUG, and the severity depends on the degree of blunting of the calyces and the dilation of ureter (Table 87.1). It should be pointed out that this grading system is not always adequate in capturing the anatomy that is observed (there is no grade for a dilated ureter without calyceal blunting); thus, it is always helpful to review the images. Other aspects of the VCUG to note are when reflux occurs (during early or late filling or during voiding), the bladder contour (smooth or trabeculated), bladder neck anatomy, the presence of diverticula, ureterocele, and the patency of the male urethra. The bladder should be filled to capacity. In a child <1 year of age, bladder capacity is calculated in mL by the equation of $38 + (2.5 \times \text{Age in months})$. In a child >1 year of age, capacity (mL) = (age in years +2) × 30, and more than 1 cycle of filling should be performed to increase the sensitivity of detection.

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Table 87.1 International classification of vesicoureteral reflux

Grade	Description
1	Into a nondilated ureter
2	Into the pelvis and calyces without dilation
3	Mild to moderate dilation of the ureter, renal pelvis, and calyces with minimal blunting of the fornices
4	Moderate ureteral tortuosity and dilation of the pelvis and calyces
5	Gross dilation of the ureter, pelvis, and calyces; loss of papillary impressions; and ureteral tortuosity

Source: From Duckett JW, BellingerMF. A plea for standardized grading of vesicoureteral reflux. Eur Urol.1982; 8(2): 74–7, reprinted with permission from Elsevier

If the patient has an active infection, then he or she should be treated, and the study should be delayed for at least 1 week because of the risk of transmitting bacteria and potentiating pyelonephritis.

The ^{99m}Tc-labeled dimercaptosuccinic acid (DMSA) renal scan is the standard imaging technique of functioning renal tissue by which relative renal function can be assessed. The presence of photopenic cortical defects indicates the absence of normal tissue due to renal dysplasia or scar. There is a direct correlation between the grade of VUR and prevalence of renal abnormalities. Children with VUR have a nearly three times higher incidence of abnormalities on DMSA renal scan compared to those without VUR.

Natural History

There is an expected rate of spontaneous VUR resolution as the bladder grows and the valve mechanism is allowed to mature. The likelihood of resolution is inversely correlated with VUR grade and age at VUR diagnosis. About 80 % of grade 1 or 2 VUR, 50 % of grade 3 VUR, and 10–25 % of grade 4 or 5 will resolve over time. Older children are less likely to outgrow VUR compared to infants diagnosed with VUR. The presence of voiding dysfunction will delay spontaneous resolution of VUR. The traditional period of observation from the time of diagnosis is 5 years, but intervention may be required earlier for breakthrough infections.

Diagnosis

VUR is usually asymptomatic until pyelonephritis occurs; therefore, the circumstances of this event are important to ascertain. One should note the age, gender, fever, and severity of illness (flank pain, nausea, vomiting) and history of previous similar illnesses. If the child is toilet trained, symptoms indicative of bladder or bowel dysfunction (BBD) should be queried, including urinary frequency and urgency, daytime incontinence, voiding postponement maneuvers (curtsy), constipation, and encopresis. The urinalysis, culture, and method of urine collection (the bagged method carries a risk of contamination and a clean catch or catheterized specimen is preferable although difficult in the uncircumcised male) should be reviewed. On examination, indicators of renal health include height, weight, and blood pressure. The genitourinary examination should include circumcision status and hygiene. The sacral spine should be examined for signs of spinal dysraphism such as a skin tag, dimple, hair tuft, or skin discoloration.

Medical Management

With the possibility of spontaneous resolution, the mainstay treatment of reflux disease is watchful waiting during which time antibiotic prophylaxis may be used. Antibiotic prophylaxis decreases the risk of urinary tract infections by 50 %. Under the age of 2 months, amoxicillin or trimethoprim is preferred; over the age of 2 months, when infants are able to metabolize sulfa, sulfamethoxazole-trimethoprim or nitrofurantoin is administered. Nighttime dosing allows maximum antibiotic concentration in children who are toilet trained. Follow-up is necessary to adjust the dose of antibiotics, assess compliance, and monitor for breakthrough infections. The risks of breakthrough infection, acquiring antibiotic-resistant organisms, and compliance should be discussed with family. Bowel and bladder dysfunction in the toilet-trained child is a modifiable factor that delays VUR resolution, decreases the success of endoscopic surgery, and increases the risk of UTI despite being on antibiotics and should therefore be simultaneously screened and addressed. Treatment options include treatment of constipation, timed voiding, anticholinergic or alpha-blocker pharmacotherapy, and biofeedback pelvic floor therapy.

Surgery

Indications to surgically address reflux include breakthrough infections while on prophylaxis, poor family compliance with or refusal of medical therapy, or persistent high-grade VUR. Anti-reflux surgery may be performed either by one of two methods: ureteral reimplantation, which may be approached by either open or with a minimally invasive technique, or endoscopic surgery using most commonly dextranomer-hyaluronic acid copolymer (Deflux®, Salix Pharmaceuticals, Inc.) as an injectable agent. Choice of procedure depends on surgeon experience as well as a decision with the family, who should be informed of the risks and benefits of each. Both open and endoscopic surgeries have been shown to reduce the risk of recurrent febrile infections.

Open ureteral reimplantation is the standard surgical treatment of VUR. The success of correcting VUR is so high, about 98 %, that a postoperative VCUG is often not necessary. The risks of an open ureteral reimplantation include contralateral reflux (which may be observed due to the likelihood of spontaneous resolution), obstruction (an ultrasound should be obtained at 6–12 weeks postoperatively), and persistent reflux, in which case workup for bladder dysfunction should be initiated. The surgical plan should include an initial diagnostic cystoscopy to look for signs of inflammation, duplication, diverticula, or ureterocele.

The open reimplant procedures can be further divided into intravesical and extravesical approaches and slight variations thereof. The underlying principle for either approach is the same: to reconstruct the ureterovesical junction valve mechanism by providing underlying detrusor support. In general, the submucosal tunnel should be about five times the diameter of the refluxing ureter. If the ureter is very large such as in the case of megaureters, then plication or excisional tapering to decrease the ureteral diameter can be done. Care should be taken with any approach to ensure that the path of the ureter is straight to avoid kinking and obstruction postoperatively.

The advantage of the intravesical approach is the minimal dissection involved once the bladder is accessed, especially if bilateral repair is planned. Popular intravesical techniques include the Cohen cross-trigonal, Politano-Ledbetter, and Glenn-Anderson repairs. All rely on developing the submucosal tunnel inside the bladder leaving the detrusor support intact; delivering the dissected ureters through these new, longer tunnels; and securing the ureters with absorbable suture. The disadvantage of these repairs is the postoperative gross hematuria and bladder discomfort that result from opening the bladder.

On the other hand, the extravesical approach (the Lich-Gregoir repair is most popular) avoids the morbidity of open bladder surgery but requires perivesical dissection in the territory of vesical plexus. This risks postoperative urinary retention especially with bilateral repair. Here lengthening of the submucosal tunnel is still accomplished, but from approaching outside the bladder: the detrusor is incised and detrusor flaps are developed without disturbing the mucosa. The ureter is placed in the new tunnel and the detrusor flaps are closed over the ureter.

Endoscopic Surgery

The lure of endoscopic surgery to correct VUR is that it is an outpatient procedure and avoids major surgery. Success is 75–80 % at 3 months but is grade dependent. Long-term success remains unknown and should be discussed with the family as a disadvantage of this approach. Deflux is the most popular injectable substance used in the USA. It is formed of cross-linked dextranomer microspheres suspended in a carrier gel of stabilized sodium hyaluronate. The carrier gel is reabsorbed and the dextranomer microspheres become encapsulated by fibroblast migration and collagen ingrowth. Deflux loses about 25 % of its volume beyond 3 months of follow-up.

Endoscopic techniques differ based on the location of the injection. The principle is to add support to the valve mechanism with submucosal bulk and mucosal coaptation from the injected substance. The STING (Subureteric Teflon Injection) procedure is the oldest technique described. Injection with the Deflux needle is performed at 6 o'clock in the submucosal plane just distal to the ureteral orifice. One should assess the bulking response after 0.1–0.2 mL is injected and adjust or re-puncture if necessary. The amount of substance injected is indicated when a mound or volcano shape is achieved and the ureteral orifice acquires a crescent slit shape appearance.

Another technique is the double hydro-distention implantation (double HIT) method. Here fluid irrigation is opened widely through the cystoscope, which is aimed at the ureteral orifice. The ureteral orifice is distended open, and the injection needle is placed at mid ureteral tunnel at 6 o'clock. Enough bulking agent is injected until minimal distention is observed. A second injection with another 1–1.5 mL of Deflux at the distal intramural tunnel is done until no hydrodistention is observed.

Following Deflux injection, a VCUG is optional and should be discussed with the family who may desire to avoid further invasive testing. A renal US should be done to ensure the upper tracts are stable. Alternatively, one could agree to observe for future febrile infections, which would necessitate workup at that time for recurrent reflux.

Associated Anomalies

VUR occurs with several other congenital anomalies such as multicystic dysplastic kidney (MCDK), renal agenesis, VACTERL, CHARGE, and imperforate anus. VUR can occur concomitantly in 10–20 % with congenital ureteropelvic junction (UPJ) obstruction. If this occurs, the UPJ obstruction should be fixed first since proximal obstruction poses a risk of renal dysfunction. In duplicated systems, VUR is usually associated with the lower pole moiety, and in these cases, VUR may take longer to resolve spontaneously. The presence of paraureteral diverticula does not appear to affect the rate of VUR resolution but depends on the size and location of the diverticulum; if the ureter enters within the diverticulum, the lack of any muscular support will make the resolution of VUR unlikely.

Summary

Vesicoureteral reflux (VUR) is frequently a silent, asymptomatic self-resolving disease in the majority of patients. Surgical intervention is indicated when VUR fails to resolve and recurrent urinary tract infections lead to renal injury. The gold standard of surgical therapy is the ureteral reimplantation. Although endoscopic techniques are being used with greater frequency, the durability and efficacy of these less invasive approaches is unclear.

Editor's Comment

Much like GE reflux, most VUR improves over time, especially in infant and young children, but the likelihood of spontaneous resolution depends on the severity. Although there are a number of surgical approaches for this condition, the gold standard remains ureteral implantation. Minimally invasive approaches, including laparoscopic and robotic techniques, have gained favor at some institutions and will likely soon be considered the standard of care.

Although most pediatric surgeons will not be performing surgical repairs to correct VUR, the frequency with which VUR occurs with other congenital anomalies mandates the pediatric surgeon to understand the diagnosis and when to refer a patient to a pediatric urologist. VUR occurs with several other congenital anomalies such as multicystic dysplastic kidneys, renal agenesis, VACTERAL syndromes, CHARGE, and imperforate anus. In particular, the frequency with which imperforate anus and VACTERAL-associated syndromes occur places the pediatric surgeon in a position of early diagnosis, management, and referral as necessary. Most often, the pediatric surgeon will encounter secondary VUR, which occurs when the bladder pressure is chronically or persistently elevated such that the ureter cannot empty properly. As such, when the ureter cannot empty properly, it becomes dilated, eventually causing the valve mechanism to fail. This is a common scenario in patients with bladder dysfunction as is associated with neurogenic bladder and spina bifida but may also be due to anatomic abnormalities such posterior urethral valves in boys or ureteroceles in girls. The diagnosis should be considered also in patients who present with signs and symptoms of a urinary tract infection. A VCUG is the definitive test for reflux, but many use renal US as an initial noninvasive screening study. A complete workup is indicated in children less than 5 years of age with a documented UTI, in any child with a febrile UTI, girls with recurrent UTI, and boys with a UTI who are not sexually active and have no urologic history. Recurrent ascending infection can cause renal scarring, progressive nephropathy, and eventually even hypertension or renal insufficiency. Thus, children with documented reflux should be treated with low-dose antibiotic prophylaxis, usually with amoxicillin, trimethoprim-sulfamethoxazole, or nitrofurantoin, and monitored with urine cultures every 3 months. In this manner, neonates or children managed by pediatric surgeons can be appropriately referred for further workup as necessary.

Suggested Reading

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Renal Abnormalities

88

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Congenital anomalies of the kidney and urinary tract represent a diverse spectrum of conditions (Table 88.1). Many congenital renal anomalies are the direct result of discrete events that occur during the embryologic process. Thus, an understanding of the normal genitourinary anatomy and embryology provides an important foundation for understanding conditions of anomalous renal development.

Renal development begins with formation of the nephric duct from the intermediate mesoderm on gestational day 22. Two primitive kidneys, the pronephros and mesonephros then sequentially form in the mesoderm adjacent to the nephric duct. Ultimately both the pronephros and mesonephros regress and provide no contribution to the final kidney. Of these two transient structures, the mesonephros provides some excretory function to the developing fetus, whereas the pronephros is a primitive and nonfunctional structure.

During the 4th week of gestation, development of the final metanephric kidney begins with formation of the ureteric bud as an outgrowth from the caudal end of the nephric duct. The ureteric bud undergoes dichotomous branching as it invades the metanephric mesenchyme and ultimately gives rise to the ureter, pelvicalyceal system, and collecting ducts. The remainder of the nephron and all other stromal and epithelial components of the kidney are derived from the metanephric mesenchyme.

Reciprocal inductive interactions between the ureteric bud and metanephric mesenchyme are essential to development of the metanephric kidney. Glial-derived neurotrophic factor (GDNF) elaborated by the metanephric mesenchyme is the primary mediator of ureteric bud branching through its interaction with the RET receptor tyrosine kinase expressed on the ureteric bud. The RET-GDNF pathway is highly regulated to ensure outgrowth of only a single ureteric bud from the caudal nephric duct. Ingrowth of the ureteric bud into the metanephric mesenchyme induces epithelial differentiation of the surrounding mesenchymal cells through the process of mesenchymal-epithelial transformation. Caps of mesenchymal cell aggregates adjacent to the ureteric bud tips form renal vesicles, which subsequently form the glomerulus, and remainder of the nephron proximal to the collecting duct. The developing kidney ascends from a pelvic location to its final position in the retroperitoneum by the 8th week of gestation. Vascular supply is provided by the adjacent common iliac or aortic segment. As the kidney ascends, it is progressively revascularized by more cranial branches from the aorta.

Anomalies of Renal Number

Renal Agenesis

Renal agenesis is when the metanephric kidney fails to develop as a result of aberrant or abortive interactions between the ureteric bud and metanephric mesenchyme. By definition, renal agenesis should be distinguished from other conditions in which renal tissue is absent, such as involution of a multicystic dysplastic kidney.

Renal agenesis can occur as an isolated finding or in association with other anomalies. Indeed, renal agenesis is a component of many syndromic conditions. The molecular and genetic etiology of renal agenesis is incompletely characterized; however, mutations in a number of genes involved in renal development, including WT1, HNF1b, PAX2, SALL1, SIX1, and EYA1, have been described in patients with syndromic forms of renal agenesis, and given the important role of this pathway in formation of the ureteric

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Table 88.1 Renal abnormalities

Anomalies of number
Renal agenesis
Bilateral renal agenesis
Unilateral renal agenesis
Supernumerary kidney
Renal cystic diseases
Simple renal cyst
Multicystic dysplastic kidney
Polycystic kidney disease
Autosomal recessive polycystic kidney disease
Autosomal dominant polycystic kidney disease
Anomalies of position, rotation, and fusion
Malrotation
Renal ectopia
Fusion anomalies
Horseshoe kidney
Crossed-fused renal ectopia

bud, abnormalities in the GDNF-RET pathway have been reported in non-syndromic forms of renal agenesis.

Bilateral Renal Agenesis

Bilateral renal agenesis (BRA) is a lethal disorder that often results in fetal demise. It occurs with an incidence of approximately 1 in 10,000 and is 2–3 times more common in males. Severe oligohydramnios results from absent fetal urine production. Potter's sequence describes characteristic physical features resulting from intrauterine compression associated with severe oligohydramnios, including prominent epicanthal folds, flattened nose, low set ears, deformity of the extremities, and pulmonary hypoplasia. Infants with BRA are often stillborn or perish shortly after birth secondary to renal failure and severe pulmonary hypoplasia.

The diagnosis of BRA is often be suspected on prenatal ultrasound imaging showing severe oligohydramnios, bilateral absence of renal tissue, and non-visualization of the bladder. Associated anomalies are common in patients with BRA with the genitourinary, skeletal, cardiothoracic, and gastrointestinal systems representing the most frequently involved sites.

Bilateral absence of functional renal tissue may also result from asymmetric combinations of renal pathologies. The combination of renal agenesis with contralateral multicystic dysplasia or severe hypoplasia will result in a clinical scenario similar to that of BRA. This suggests that a common developmental etiology can produce a variable clinical phenotype.

Unilateral Renal Agenesis

Unilateral renal agenesis (URA) occurs in approximately 1 in 1000–3000 live births with a slight predilection for the left side and a nearly twofold higher incidence in males. Most individuals with URA are asymptomatic. Therefore, isolated unilateral renal agenesis often presents later in life when detected as an incidental radiographic finding. The ubiquitous utilization of prenatal ultrasonography has increased the detection of URA in patients who would be otherwise asymptomatic. Additionally, better characterization of the natural history of multicystic dysplastic kidney with prenatal imaging indicates that involution of a multicystic dysplastic kidney prior to initial imaging may masquerade as URA.

The diagnosis of URA is generally confirmed by ultrasound or cross-sectional imaging. Frequently, the contralateral kidney will exhibit compensatory hypertrophy, defined by a renal length more than two standard deviations above the mean. The phenomenon of compensatory hypertrophy is unique to individuals with a congenitally solitary kidney and is generally not observed in individuals who have undergone nephrectomy. Compensatory hypertrophy likely represents a developmental response to the globally decreased nephron endowment associated with an absent contralateral kidney**.** If the diagnosis of URA is uncertain, confirmatory nuclear renography (DMSA or MAG-3) will show absence of radiotracer uptake on the ipsilateral side. Nuclear renography is generally unnecessary in the evaluation of URA, but may be useful to assess for the presence of ectopic or atrophic renal tissue.

URA can occur as an isolated finding or in association with other anomalies or syndromic conditions. Up to half of patients with URA will have a coexisting abnormality of the contralateral kidney or collecting system. Vesicoureteral reflux (VUR) occurs in approximately 25 % of patients with URA and is the most common abnormality affecting the contralateral kidney. Less common anomalies of the contralateral urinary tract include ureteropelvic junction (UPJ) obstruction (5 %), megaureter (5–10 %), and collecting system duplication (<5 %). Because of the frequent association with VUR, it is our practice to obtain a voiding cystourethrogram (VCUG) in all newborns with URA.

Given the integral role of the Wolffian (mesonephric) duct in renal development through its contribution of the ureteric bud, it is not surprising that abnormalities of ipsilateral Wolffian duct structures are common in individuals with URA. Congenital absence of the vas deferens, seminal vesicle, or epididymis occurs in nearly 70 % of individuals with URA. Similarly, Müllerian duct abnormalities frequently occur in females with URA. Unicornuate, bicornuate, or didelphic uterus, duplication of the cervix or vagina, or uter-

ine or vaginal agenesis occur in approximately one third of girls with URA.

The *Mayer-Rokitansky-Küster-Hauser* (MRKH) syndrome is a rare syndrome characterized by renal anomalies, 46XX karyotype, and variable degrees of Müllerian duct agenesis, including vaginal agenesis. The incidence of MRKH is approximately 1 in 4000–5000 girls. Renal anomalies are identified in roughly half of patients, with URA being the most common.

Previously, URA was generally considered a benign condition. While prospective series assessing the long-term renal outcomes in patients with unilateral renal agenesis are lacking, a growing body of evidence suggests the possibility of increased risk for renal functional impairment in individuals with URA. Some have suggested that hyperfiltration in the setting of a decreased nephron endowment might be the cause of progressive renal injury. According to the hyperfiltration hypothesis, individual glomeruli see an increased filtration burden, thereby inducing injurious glomerular hypertension. The cycle is propagated as glomerular hypertension induces further renal damage. URA is associated with an impaired GFR of <60 mL/min/1.73 m^2 in about 10 % of patients. In children with a solitary functioning kidney, 35–40 % have evidence of renal injury as evidenced by hypertension, proteinuria, impaired GFR, or need for renoprotective medications. Additionally, renal impairment is more common in patients whose contralateral kidney did not achieve compensatory hypertrophy.

It is our practice to monitor renal growth with US until compensatory hypertrophy is achieved. Management of vesicoureteral reflux is similar to that in patients with two kidneys. Given the potential risk of renal functional impairment, routine blood pressure screening, assessment for proteinuria, and intermittent laboratory evaluation of renal function are indicated in individuals.

Supernumerary Kidney

Supernumerary kidney is a rare anomaly characterized by the presence of an additional or accessory kidney. Bilateral variants, including those with horseshoe morphology, have been reported. The supernumerary kidney typically occupies a position caudal to the normal kidney, which is usually in an anatomically normal position. Additionally, the supernumerary kidney typically has an independent collecting system; however, it is not uncommon for the ureter of the supernumerary kidney to join the ureter of the normal ipsilateral kidney in a bifid or Y configuration.

Supernumerary kidney is most often identified during the evaluation of nonspecific symptoms of abdominal and flank pain, urinary tract infection, or hematuria. Since most individuals with supernumerary kidney are asymptomatic, treatment is directed by the presence of symptoms or associated anatomic abnormalities.

Renal Cystic Diseases

Simple Renal Cyst

A broad spectrum of renal cystic conditions is observed in pediatric populations. Simple renal cysts are universally benign lesions that are usually detected as an incidental finding. The incidence of simple renal cysts is variable according to age. Simple renal cysts occur in approximately 20 % of adults, but are much less frequent in children, where the incidence is less than 1 %. On US, simple renal cysts appear as rounded, well-defined homogeneous lesions, which that have imperceptible wall thickness and lack internal echoes (Fig. 88.1). Enhanced posterior through transmission is an additional characteristic sonographic finding. Simple renal cysts sometimes enlarge over time, but are generally asymptomatic and do not require treatment. Given the rarity of this condition in children, it is important to consider the possibility of calyceal diverticulum or dilated upper pole moiety of a duplicated system, especially when the lesion is located in the upper renal pole.

Multicystic Dysplastic Kidney

Multicystic dysplastic kidney (MCDK) is a common anomaly of renal development and an important congenital cause of functionally solitary kidney in children. MCDK is characterized by the presence of multiple non-communicating cysts of various size and number, which replace all normal renal tissue (Fig. 88.2). The ipsilateral ureter is characteristically atretic. The incidence of MCDK is estimated to be one in 4000 live births, with a slight predilection for males and for the left side.

The exact cause of MCDK is unknown; however, several etiologies have been proposed. Abnormalities in the ureteric bud and its interaction with the metanephric mesenchyme have been proposed. Supporting this hypothesis is the finding of genetic mutations in several key genes involved in the interaction between the ureteric bud and metanephric mesenchyme, including the PAX2, EYA1, and SIX1 genes. Early severe urinary tract obstruction resulting from ureteral atresia has also been proposed as a potential cause.

Historically, MCDK presents as a palpable abdominal mass in a newborn child. However, with widespread use of prenatal US, MCDK is now more commonly diagnosed prenatally. The characteristic sonographic findings of MCDK are those of multiple non-communicating cysts that are peripherally located and a lack of reniform morphology. A less common hydronephrotic variant has been described, in

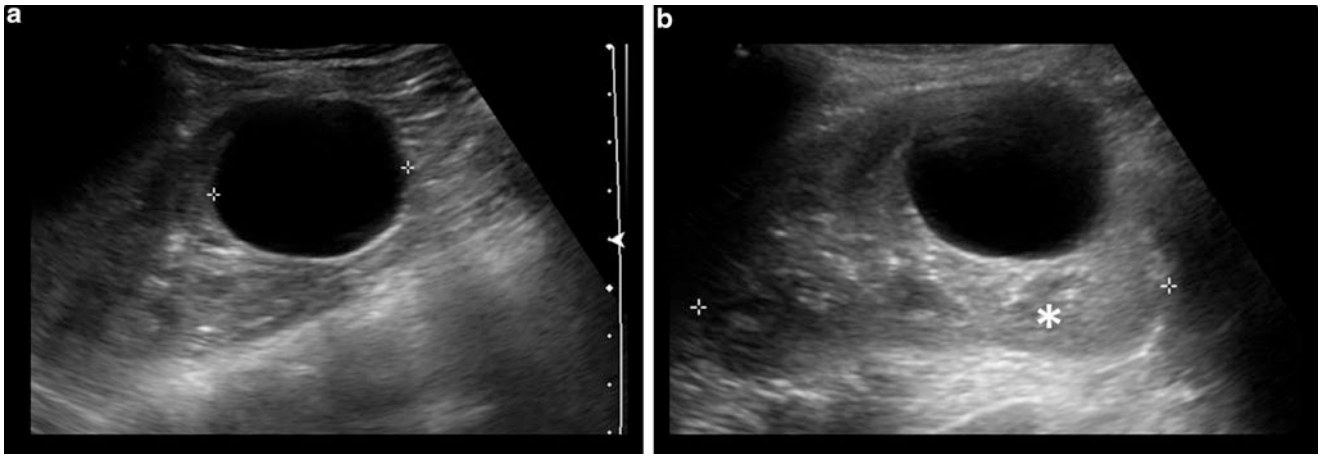

Fig. 88.1 Renal ultrasound showing simple renal cyst. (**a**) The cyst is a well-defined, rounded structure with imperceptible wall thickness and lack of internal echoes. (**b**) Posterior enhanced through transmission is a characteristic sonographic finding (*asterisks*)

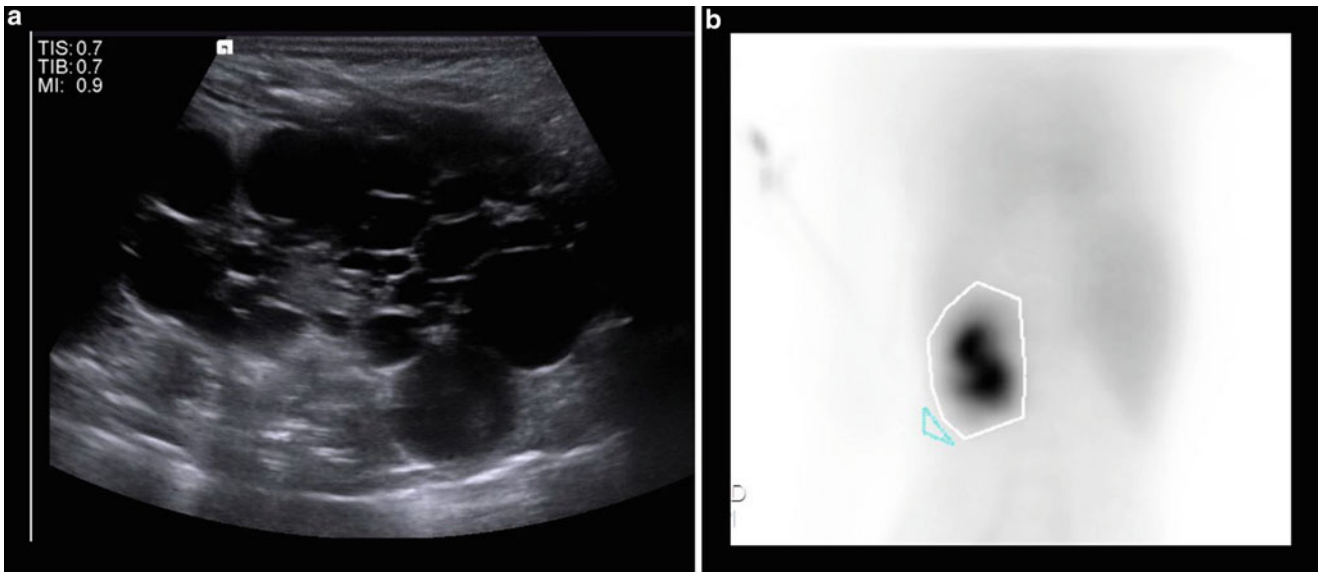

Fig. 88.2 Renal ultrasound showing characteristic features of multicystic dysplastic kidney. (**a**) Multiple cysts of variable size are present with no apparent normal renal parenchyma. (**b**) DMSA study showing absence of renal function on the right side in a patient with right multicystic dysplastic kidney

which peripheral cysts surrounded a centrally located prominent that is thought to represent the renal pelvis.

The US appearance of the MCDK is generally diagnostic; however, a severely hydronephrotic kidney might occasionally be confused for a MCDK. Differentiating between the two is of critical importance as the management of MCDK typically follows an observational approach, whereas a severely obstructed hydronephrotic kidney requires intervention to preserve residual renal function. Nuclear renography (MAG-3 or DMSA) will demonstrate the complete absence of ipsilateral renal function, thereby securing the diagnosis of MCDK. The need to perform routine nuclear renography in all patients with suspected MCDK remains controversial. In patients with classic US findings of unilateral MCDK, a normal bladder, and no other associated anomalies, nuclear renography nearly always confirms absence of ipsilateral renal function, suggesting that such patients may not require confirmatory nuclear renography.

MCDK is associated with a variety of other urinary tract anomalies. Vesicoureteral reflux is the most common, occurring in 15–30 % of individuals with MCDK. Reflux may occur into the ipsilateral atretic ureter or, more importantly, into the contralateral kidney (Fig. 88.3). The spectrum of other urinary tract anomalies reported in association with MCDK includes ureteropelvic junction obstruction in up to 15 % of patients and, less commonly, ureterocele, ureterovesical junction obstruction, and ureteral ectopia. The ideal diagnostic approach for asymptomatic VUR in patients with

MCDK remains controversial. Given the high incidence of VUR and the potential risk of infection-induced scarring and renal damage in the solitary kidney, it is our practice to perform VCUG during the evaluation of the newborn with MCDK.

Once the diagnosis of MCDK is made, management generally follows an observational approach. Most MCDKs will undergo some degree of involution over time. Complete involution of the MCDK occurs in up to three quarters of cases; however, the timing of involution is highly variable.

Anecdotal reports of malignant transformation, primarily Wilms tumor and renal cell carcinoma, occurring in the MCDK have been used as an indication for prophylactic nephrectomy in individuals with MCDK. However the exceedingly low risk of malignant transformation in the MCDK probably does not justify the risk of prophylactic nephrectomy. The risk of Wilms tumor is approximately 1 in 2000. Notably, no case of Wilms tumor has ever been reported following documented involution of an MCDK. Only six cases of renal cell carcinoma have been reported, highlighting the rarity of this phenomenon.

Additional considerations in the management of unilateral MCDK are similar to those for unilateral renal agenesis. Routine blood pressure monitoring and assessment for proteinuria are warranted. Additionally, serial renal US confirms involution of the MCDK and compensatory hypertrophy of the contralateral kidney.

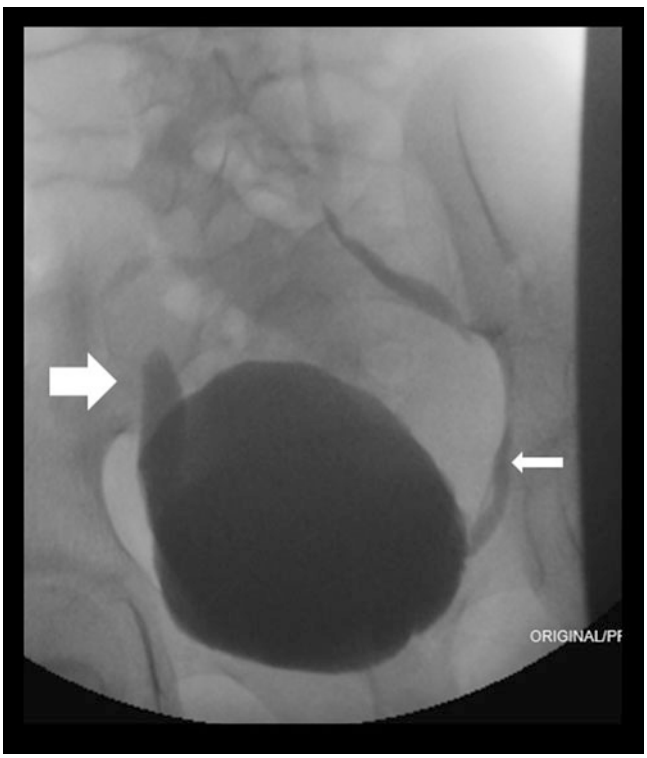

Fig. 88.3 VCUG of a patient with right multicystic dysplastic kidney. Note that there is vesicoureteral reflux into both the left (*small arrow*) and blind-ending right ureter (*large arrow*)

Polycystic Kidney Disease

Autosomal Recessive Polycystic Kidney Disease

Autosomal recessive polycystic kidney disease (ARPKD) is a rare but important cause of chronic kidney disease in children with an incidence of approximately 1 in 10,000 to 40,000. ARPKD is caused by mutation in the PKHD1 gene on chromosome 6p, which codes for the fibrocystin/polyductin protein. There is prominent expression of the PKHD1 gene in the kidney and biliary epithelium; however, the exact function of the protein is unknown.

Myriad mutations in the PKHD1 gene have been linked to ARPKD in humans. Significant phenotypic variability for a given PKHD1 mutation is well described, suggesting that phenotype may be significantly influenced by epigenetic modification. However, the presence of two chain-terminating mutations in PKHD1 portends a severe form of the disease that uniformly results in perinatal demise.

ARPKD typically presents during the prenatal period with a sonographic findings of enlarged and echogenic kidneys bilaterally and severe oligohydramnios secondary to poor fetal urine production. Congenital hepatic fibrosis is a consistent extrarenal manifestation of ARPKD, although the severity of hepatic disease is variable. Notably, the severity of hepatic and renal disease appears to have an inverse relationship, in which the hepatic manifestations are less prominent when renal manifestations are severe and vice versa.

Perinatal mortality in infants born with ARPKD is approximately 30 % and is most often secondary to pulmonary hypoplasia resulting from severe oligohydramnios. Among infants surviving the neonatal period, survival rates approach 95 % at 1 year and 85 % at 5 years. Progression to end-stage renal disease (ESRD) occurs at variable time points depending on the severity of the disease. Renal disease is generally most severe in patients diagnosed perinatally or in infancy, and early need for renal replacement therapy is common. Severe systemic hypertension occurs in approximately 80 % of patients with ARPKD and often precedes a decline in renal function in patients with less severe forms of the disease. Hypertension may be difficult to control and often requires treatment with multiple medications. Hepatobiliary disease resulting in portal hypertension is an important consideration in patients with ARPKD. Portal hypertension may often be initially medically managed with propranolol and with endoscopic control of gastroesophageal varices. Portosystemic shunting may be complicated by severe hyperammonemia or hepatic encephalopathy due to

impaired renal ammonia processing in patients with poor renal function. Combined or sequential liver and renal transplantation may be considered in patients with severe kidney and liver disease.

Autosomal Dominant Polycystic Kidney Disease

Autosomal dominant polycystic kidney disease (ADPKD) is the most common heritable renal cystic disease. It is characterized by development of multiple bilateral renal cysts and progressive chronic kidney disease often leading to ESRD. In fact, ADPKD accounts for approximately 10 % of patients with ESRD worldwide. The prevalence of ADPKD is estimated to be 1 in 500–1000.

Approximately, 85 % ADPKD cases are caused by mutations in the PKD1 gene on chromosome 16p13.3. The remaining 15 % result from mutations in the PKD2 gene on chromosome 4q21. Approximately, 10–15 % of cases are caused by de novo mutations. Clinical evidence of ADPKD, including renal cystic changes, typically develops during the third and fourth decade and is generally absent during childhood. The decline in renal function is not generally noted until after the fourth decade.

ADPKD is a systemic disease that impacts multiple organ systems. The most common extrarenal manifestations of ADPKD include cysts of the liver and pancreas, intracranial aneurysms, and hypertension. Presymptomatic screening of children for ADPKD is not currently recommended due to potential adverse impact of early diagnosis in the absence of effective early treatment. Presymptomatic sonographic screening may be beneficial to the well-informed, at-risk adult, in whom such information might impact family planning, allow early detection and treatment of complications of ADPKD, or aid in identifying unaffected family members who wish to serve as a living related donor.

Anomalies of Position, Rotation, and Fusion

Malrotation

During the course of its ascent, the developing kidney undergoes 90° of medial rotation along its longitudinal axis so that the renal pelvis and hilum are oriented medially. Renal malrotation occurs when the ascending kidney fails to undergo normal medial rotation. Incomplete rotation resulting in an anteriorly oriented renal pelvis is the most common configuration. Additionally, renal malrotation is commonly seen in association with renal ectopia and renal fusion anomalies. The incidence of renal malrotation is estimated at 1 in 1000 individuals. An abnormal configuration of the renal pelvis in the malrotated kidney occasionally results in symptomatic urinary obstruction; however, the majority of cases are diagnosed incidentally in asymptomatic patients. Excretory or retrograde urography demonstrates calyces that project medial to the renal pelvis; however, an extensive radiographic evaluation is generally not indicated unless symptoms are present (Fig. 88.4).

Renal Ectopia

The normal position of the kidney is in a retroperitoneal location adjacent to the second lumbar vertebra. Renal ectopia occurs when the kidney is located outside of its normal position. The incidence of renal ectopia in autopsy studies is estimated to be approximately 1 in 1000, whereas screening studies have reported a much lower incidence of about 1 in 5000 patients. Most ectopic kidneys are situated caudal to the normal position, along the normal course of renal ascent. A variety of sites of renal ectopia have been reported, including sacral, pelvic, abdominal, and, rarely, thoracic locations. Of these, the pelvic kidney is the most common variant. Crossed ectopia is another important variant of renal ectopia in which the kidney crosses the midline during its ascent. The ectopic kidney is often malrotated and lacks normal

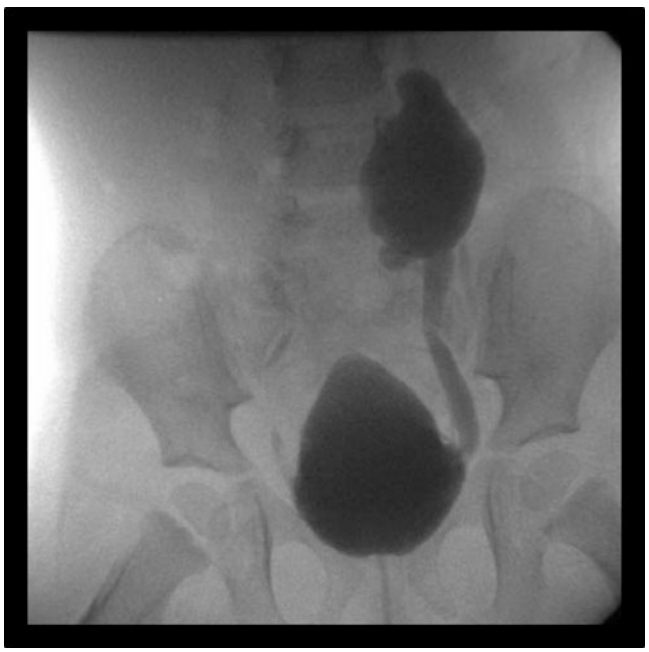

Fig. 88.4 Voiding cystourethrogram showing VUR into a malrotated left kidney. Note that the calyces project medial to the renal pelvis

reniform morphology. The vascular supply to these kidneys derives from the adjacent aortic or common iliac segments and is thus abnormal. An abnormally positioned kidney with vasculature arising from the normal aortic location describes a *ptotic kidney*, which presumably ascended to a normal location during development and was later displaced into an abnormal position. This uncommon clinical entity should be distinguished from a truly ectopic kidney.

Renal ectopia is associated with increased risk of other genitourinary anomalies, with VUR being the most common. The true incidence of UPJ obstruction of the ectopic kidney, although probably greater than in the general population, is likely much lower than reported in these highly select populations. Additionally, ectopic kidneys are at increased risk for nephrolithiasis due to both anatomic abnormalities and increased risk of metabolic risk factors for stone disease.

Renal ectopia is often detected on prenatal ultrasonography or as an incidental radiographic finding. Treatment is for symptoms or associated abnormalities. Because of the high incidence of VUR in this patient population, VCUG should be considered for newborns and young children with a history of renal ectopia or if there is a history of febrile urinary tract infection.

Renal Fusion Anomalies

Horseshoe Kidney

Horseshoe kidney is the most common renal fusion anomaly with an incidence of approximately 1 in 400–500 individuals. Males are affected nearly twice as often. In the horseshoe kidney, the kidneys are joined in the midline by a common isthmus. Fusion occurs between the lower poles in 95 % of cases. Although specific genetic causes have not been identified, horseshoe kidney is a component of a variety of chromosomal and congenital anomalies. Approximately, 60 % of girls with Turner's syndrome and 20 % of patients with trisomy 18 have a horseshoe kidney.

Horseshoe kidney is thought to result from fusion between the left and right metanephric mesenchyme early in development while these two structures are in close proximity in the pelvis. During the course of its ascent, the isthmus of the horseshoe kidney engages the interior mesenteric artery (IMA) at its branch point from the abdominal aorta, thereby preventing normal renal ascent. As a result, the horseshoe kidney is typically located in a pelvic position with the isthmus located at the level of L3–L5 (Fig. 88.5). The horseshoe kidney is often supplied by multiple vessels, which may arise from the abdominal aorta, common iliac arteries, IMA, or combinations thereof. It is common for abnormal renal vessels to enter the horseshoe kidney at a polar location, rather than the hilum. Additionally, the isthmus is typically supplied by its own vascular branches from the abdominal aorta.

Coexisting urinary tract anomalies are common in individuals with horseshoe kidney, affecting probably more than half of patients. An incidence of vesicoureteral reflux of up to a third has been reported. Hydronephrosis is common and suggests the presence of UPJ obstruction in up to a third of individuals. Additionally, urolithiasis occurs in up to 60 % of individuals with horseshoe kidney. The predisposition to urinary tract stone formation in the horseshoe kidney is multifactorial and is related to urinary tract infection, urinary stasis due to an abnormally configured collecting system, and, commonly, metabolic predisposition to urolithiasis .

An increased risk of Wilms tumor has been reported in association with horseshoe kidney. The risk of developing Wilms tumor is approximately two- to sevenfold greater. The implications of this with respect to surveillance imaging remain controversial. At present, Wilms tumor screening, including ultrasound imaging of the kidneys at 3–4 month intervals, is not widely utilized in individuals with horseshoe kidney due to uncertain benefit.

Treatment is reserved for symptoms and associated anomalies. Most patients are asymptomatic and require no treatment. Urinary tract infection, hematuria, and abdominal pain represent the most common symptomatic presentations. Because of the increased incidence of VUR, VCUG should be considered in children with history of febrile urinary tract infection and in infants who are diagnosed with horseshoe kidney on prenatal ultrasonography. Additionally, Turner's syndrome should be considered in girls with characteristic dysmorphic features.

Diuretic renography is indicated if clinical or radiographic findings suggest UPJ obstruction. UPJ obstruction in the horseshoe kidney is most often secondary to a high insertion

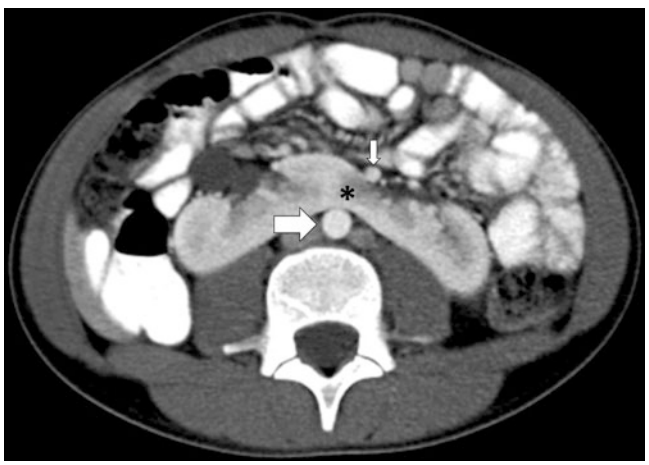

Fig. 88.5 CT scan in a patient with horseshoe kidney. Note that the isthmus (*asterisks*) connecting the left and right kidney is situated between the aorta (*large arrow*) and the inferior mesenteric artery (*small arrow*)

of the ureter on the renal pelvis, with less common causes being congenital stricture, kinking of the ureter as it passes over the isthmus, and complications of stone disease. The classic treatment of UPJ obstruction in the horseshoe kidney involves dismembered pyeloplasty, division of the isthmus, and nephropexy; however, division of the isthmus might not be necessary in all cases. Because of the highly variable vascular supply to the horseshoe kidney, preoperative imaging with CT or MR angiography is strongly recommended.

Crossed-Fused Renal Ectopia

Crossed-fused ectopia occurs when the kidney is situated on the opposite side of the body as the ureter and is fused to the companion kidney. Most often, the left kidney crosses to the right side (left to right crossed ectopia). The incidence of crossed-fused ectopia is approximately 1 in 1000–7500 with a 2:1 male predominance. Crossed ectopia without fusion is much less common, accounting for approximately 10 % of cases.

Crossed-fused ectopia is typically diagnosed on sonographic or cross-sectional imaging. Excretory urography or retrograde pyelography confirms the diagnosis by demonstrating the course of the ureter as it crosses the midline. Notably, cystoscopy typically demonstrates that the ureteral orifice of the ectopic kidney in a normal trigonal position.

Treatment of the cross-fused ectopic kidney is guided by symptoms or associated abnormalities. Up to one half of patients with crossed-fused ectopia have associated anomalies, which most often involve the genitourinary, gastrointestinal, and skeletal systems. VUR occurs in approximately 20 % of individuals with crossed-fused ectopia (Fig. 88.6). UPJ obstruction may occur in up to a third of cases. As with horseshoe kidney, renal vasculature is variable and often abnormal. Thus, dedicated vascular imaging should be considered when planning surgical interventions.

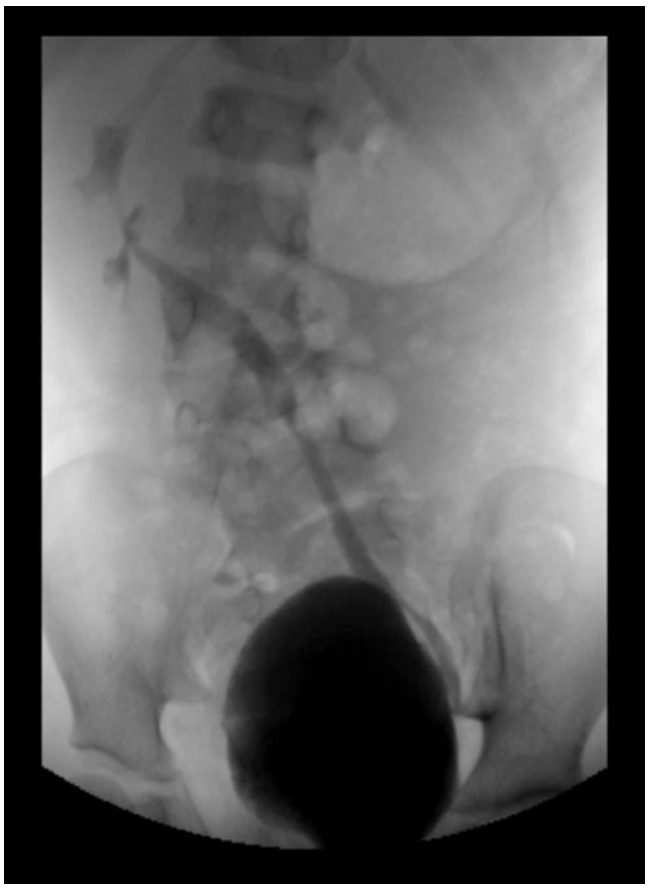

Fig. 88.6 Voiding cystourethrogram demonstrating vesicoureteral reflux into a crossed-fused ectopia. *Left* to *right* crossed fusion is the most common form of crossed-fused ectopia

Editor's Comment

Renal anomalies are not uncommon and beyond their obvious significance in terms of renal function, they are important to understand when incidental to other conditions such as VACTERL association and imperforate anus. Ectopic and horseshoe kidneys are susceptible to injury and need to be identified early in the course of a trauma evaluation. Tumors arising within an ectopic kidney are generally straightforward to deal with, while those that arise within a horseshoe kidney require careful planning and meticulous technique. The patient with a Wilms tumors arising in a horseshoe kidney is treated like the patient with two kidneys, not like one with a single kidney. Pelvic kidneys have been confused for tumors and impacted feces, sometimes with negative consequences.

When in doubt, abdominal US usually settles the question easily and noninvasively. Boys with absence of the vas deferens and girls with vaginal anomalies should be screened for renal agenesis. As the vast majority of individuals with a solitary kidney are identified antenatally by US, it is becoming increasingly rare to encounter one incidentally in the course of another workup. Nevertheless, it is surprising how frequently patients and their families forget this important fact about their anatomy, placing the onus on the physician to be astute to this possibility.

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Penile Anomalies and Circumcision

89

Eric D. Nelson

Understanding issues regarding the phallus in children is important, especially as a subspecialty provider. Most initial evaluations are done by non-surgeons and many questions are generated. There often is a lack of understanding of basic anatomy and physiologic processes. It is up to us to educate practitioners and families and to know when to treat or refer to a pediatric urologist.

As a surgeon, we are often asked to comment on infections, injuries, and abnormalities of the penis. Unfortunately, referring providers sometimes make it challenging in that they are unable to precisely describe the anatomy and what they are seeing. A thorough understanding of anatomy and topical landmarks is imperative.

The penis is constructed of two cylindrical bodies, the *corpora cavernosa*, which provide rigidity for erections. Ventrally, the *corpus spongiosum* contains the urethra. This extends distally to form the glans. The *corona* is the ridge that runs circumferentially around the glans and provides definition from the corpora.

Extending proximally from the meatus to the shaft skin is the *frenulum*. This can sometimes cause tethering and most importantly houses a significant blood vessel that can cause issues during a circumcision. In the uncircumcised male, the foreskin hangs over the glans. The wrinkly pink skin that is seen when the prepuce is retracted is the *inner prepuce*, and the *outer prepuce* is an extension of the penile shaft skin. After circumcision, there is a circumferential scar surrounding the phallus. The proximal skin is referred to as the *shaft skin*, and the skin between the scar and glans is referred to as the *inner preputial collar*. A pigmented line is often seen on the ventrum (underside) of the phallus and scrotum—the *median raphe*.

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Early in gestation, the male and female genitalia are identical. At approximately the 9th week of gestation, with the presence of testosterone and dihydrotestosterone, the genitals masculinize. The genital tubercle develops into the glans. The genital folds form the penile shaft and the genital swellings become the scrotum (Fig. 89.1). It is easiest to think of this development as a wrapping process—the tissues wrap around from the dorsum to the ventrum. Additionally, the urethra develops in a proximal to distal direction. This is important in that alterations in these processes lead to anomalies like hypospadias and congenital curvature (*chordee*). As gestation continues, phallic size increases. At birth, there is a "miniature puberty" with a testosterone surge and phallic growth. Size remains stable until puberty.

Physical Examination

A precise and detailed physical examination can diagnose most penile anomalies accurately. However, this can be quite challenging in children. A warm and relaxing environment with engaged parents and plenty of distractions can facilitate a good examination. First, get a general sense of phallus size and appearance. You should trust yourself if something "just doesn't look right" as this might be enough to warrant another opinion. Evaluate the prepuce: is it complete ventrally? Is it splayed out laterally consistent with a dorsal hooded prepuce seen in hypospadias? Evaluate for retractability and phimosis. Pay particular attention in the phimotic patient to signs of skin thickening and scarring. If it is retractable, are there any adhesions that remain between the prepuce and glans? The meatus should also be evaluated for size and position. Some meatal openings have a transverse bar of tissue that could deflect the urine stream and leave a distal urethral dimple. This is a mild hypospadias variant. Palpate the penis and evaluate the girth and length. If it looks diminutive, a mean stretched penile length should be obtained. Look for penile curvature. Evaluate the skin for dysplasia ventrally or signs of skin tethering or webbing.

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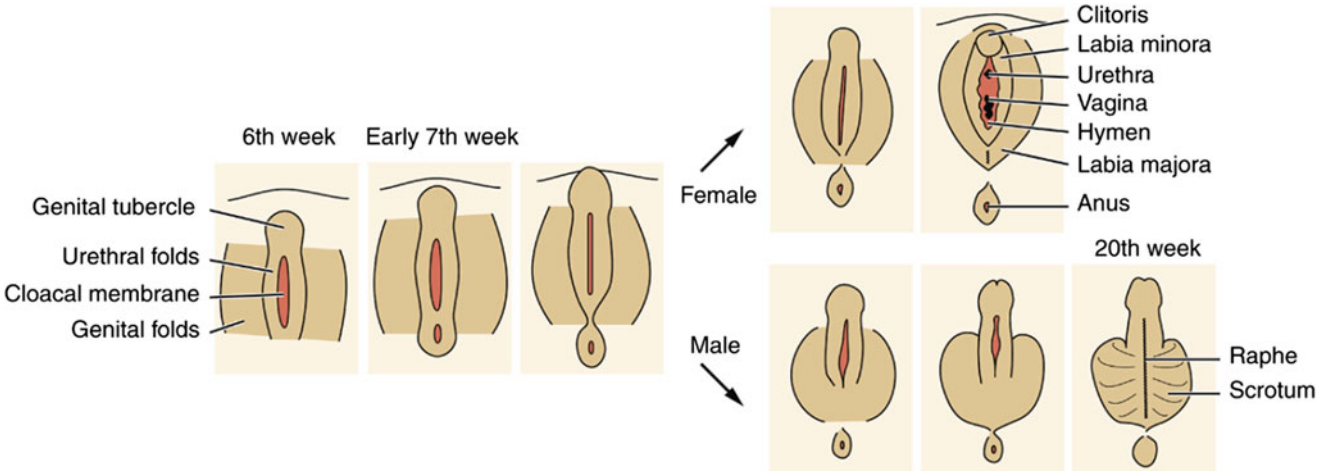

Fig. 89.1 Embryology of urinary tract. The genitalia begin as indifferent structures. In the presence of androgens, the genitalia become masculinized. In males, the urethral folds become the penile urethra, and the genital tubercle enlarges to form the glans penis. The labioscrotal folds fuse in the midline to form the scrotum. (Reprinted from Pediatric Urology, 2nd edition, Gearhart JP, Rink RC, Mouriquand PD, editors, Copyright Elsevier 2010)

If the patient is circumcised, look at the circumcision line. Is it symmetric? Is it adhered to the glans (penile skin bridge)? Are there cysts? Lastly, evaluate the median raphe. These can sometimes spiral around the penile shaft and are indicative of penile torsion.

Accompanying the penile exam should be a thorough testicular exam as well. Disorders of sexual differentiation can present with penile and testicular anomalies.

Abnormalities of the Foreskin

The foreskin (prepuce) is a deceivingly complex anatomic structure that includes two types of skin, an intricate blood supply, and dermal glandular elements. Disorders of the foreskin can cause pain, anxiety, and more severe complications, especially if unrecognized or mismanaged.

Phimosis

Phimosis is the inability to fully retract the foreskin. This can be a physiologic or pathologic process. Most newborn males (96 %) have a phimosis. As the child grows, the inner foreskin is gently separated from the glans by the accumulation of epithelial cells between the layers (*smegma*) and recurrent spontaneous erections. By age 3, at least half of boys have outgrown the phimosis. The prepuce should be evaluated for any signs of inflammation, including skin thickening, scarring, and cracking. The patient and his caregivers should be asked whether there have been issues with ballooning of the foreskin with urination, recurrent infection or irritation, pain, or bleeding. In the absence of symptoms and signs of inflammation, this is likely a physiologic phimosis that should resolve on its own. It can take into the teenage years for complete resolution. Routine hygiene should be continued, and forceful retraction should be avoided—this causes pain for the patient and significant parental dissatisfaction.

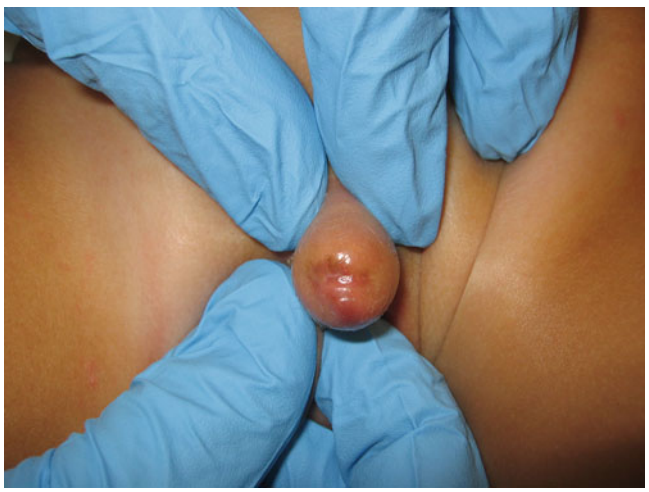

Fig. 89.2 Pathologic phimosis. In this patient, the trumpeting of the inner prepuce is not seen. The skin is flattened, thickened, and scarred without any obvious opening

A *pathologic* phimosis causes symptoms and problematic issues with the foreskin. A child with significant ballooning with urination or signs of scarring and inflammation would be classified as having a *pathologic* phimosis (Fig. 89.2). The probability of spontaneous resolution is low, and treatment is usually warranted. This can be surgical (circumcision or prepuceplasty) or medical (topical corticosteroids). Topical corticosteroids are very effective in treating phimosis, and success rates up to 80 % have been reported. Various cortico-

steroid formulations, treatment lengths, and frequencies are utilized. In our practice, we prescribe betamethasone valerate 0.1 % ointment, a medium-potency steroid. This is applied twice daily for two months. Of critical importance is that the parent gently stretches and retracts the phimotic ring. The ointment serves to soften the tissues, but the manual stretching is required for resolution. Routine retraction is required after treatment. Failure of steroid treatment is an indication for surgical correction.

Paraphimosis

This is an emergent condition in a patient with a phimotic prepuce. This occurs when the foreskin has been forcefully retracted and the phimotic band is pulled back behind the corona. The glans is trapped, and without urgent treatment, this leads to significant edema, pain, and possible gangrene (Fig. 89.3). The most definitive treatment is manual reduction. The phallus is grasped and squeezed for about five minutes to allow the edematous fluid to drain. The phimotic band is grasped on either side with the fingertips. The physician's thumbs are placed on the glans, pressing inward while the fingertips try to slide the band distally over the head. Significant traction and pressure are often required, and therefore sedation is sometimes necessary.

Other techniques described to reduce the edema include application of granulated sugar and multiple pinpricks. Alternatively, a *dorsal slit procedure* is performed. The patient is sedated, and generous local anesthesia is administered. After appropriate cleaning and sterile preparation, the phimotic band is clamped with a straight hemostat and the band divided. Once released, the longitudinal skin incision is then closed transversely (Heineke-Mikulicz) for hemostasis. This procedure can also be used for phimosis causing significant acute urinary difficulties. A circumcision for cosmetic reasons is often later performed once the inflammation has subsided.

Penoglanular Adhesions

Penoglanular adhesions should be distinguished from a phimosis. In this case, the prepuce is fully retractile, but the foreskin is still adherent to the glans. These usually look fairly benign and flimsy. Although distressing to parents, these resolve with time but can sometimes take into the teenage years to do so. If they are causing discomfort for the child or they are thought to be the cause of recurrent irritation, they can be treated with either topical steroids or reduction in the office. It is not recommended to simply tear them down. This causes bleeding, pain, and significant parental anxiety. In our practice, we will apply a topical anesthetic cream for 30 min and then gently peel the adhesions from the glans. If tight or it is difficult to grasp, we will insert a closed curved hemostat at the junction of the adhesions and glans and sweep it around circumferentially. Antibiotic ointment is then applied.

Penile Skin Bridges

Penile skin bridges are caused by adherence of the incision to the glans during healing after a circumcision. This creates an epithelialized bridge that has poor cosmesis and can allow for trapped debris (Fig. 89.4). These can occasionally be difficult to distinguish from physiologic *penoglanular adhesions*. The trick is to follow the circumcision scar all the

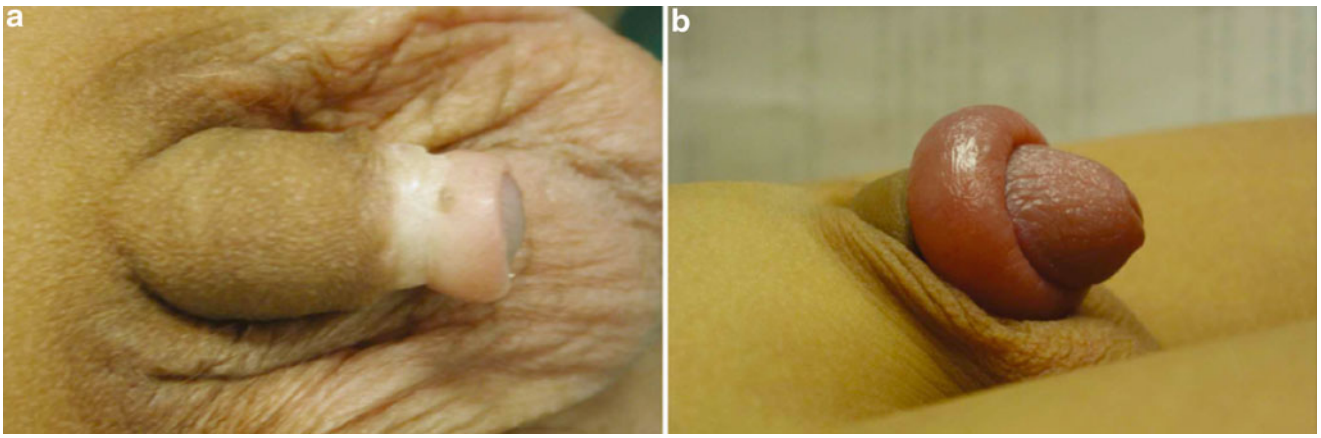

Fig. 89.3 Paraphimosis. (**a**) Prepuce retracted with a scarred phimotic ring just proximal to the glans. Reduction of the foreskin to place the skin in its "normal" position is required to avoid paraphimosis. (**b**) Paraphimosis. The phimotic band is at the junction of the normal shaft skin and the edematous preputial collar. Left untreated, tissue loss is possible. (Reprinted from Campbell-Walsh Urology, 10th edition, Palmer JS, Chapter 126: Abnormalities of the external genitalia in boys, Copyright 2012, with permission from Elsevier)

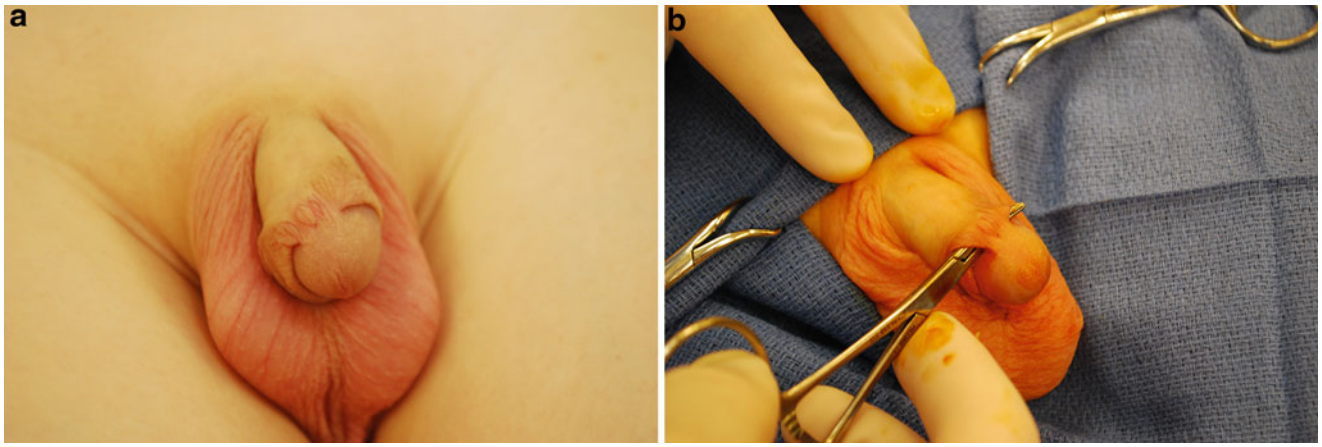

Fig. 89.4 Penile skin bridge. (**a**) The circumcision line has healed to the glans. The circumcision line can be seen entering the glans. (**b**) During surgical repair, it is imperative to gain circumferential access around the skin bridge prior to clamping and cutting to ensure the proper planes are encountered

way around. If it is "lost" and seems to run into the glans, assume there is a skin bridge. In some borderline cases, I will attempt a lysis of adhesions in the office or a trial of steroid ointment as a diagnostic tool.

We generally recommend surgically treating penile skin bridges. They are unattractive and can become irritated, trap debris, and potentially even tear or bleed with intercourse. For small, thin bridges in a compliant patient, a local anesthetic can be used and the bridge lysed in the office, but this is a rare scenario. More commonly, the patient is brought to the operating room. After prepping, the bridge is dissected circumferentially, clamped with a curved hemostat, and incised with curved iris scissors. This leaves tags of tissue on either side that can be excised. The remaining epithelial defects on the glans and shaft are closed with absorbable monofilament sutures. In more complex cases, multiple skin bridges interconnect and are on top of one another. Careful attention is paid to achieving circumferential access around each one and to avoid becoming disoriented in the skin layers. With multiple large bridges, circumcision revision is sometimes necessary.

Penile Shaft Abnormalities

These are penile anomalies that do not necessarily involve the foreskin or glans but could nevertheless require intervention.

Penile Torsion

Penile torsion is a twisting of the phallus. When one looks at the glans straight on, the meatus will be angled, usually in a counterclockwise direction, ranging from very minimal torsion to over 90°. This is thought to be secondary to dysplastic tethering of the shaft skin causing rotation. One hypothesis is that compression by the heel of the fetus alters the penile skin development. The corpora retain their normal orientation. One can often follow the median raphe wrapping obliquely around the phallus and inserting in a lateral location.

In the absence of penile curvature or meatal issues, there should be no functional significance. Treatment is usually considered when there is at least 60–90° of rotation. For mild cases noted during circumcision, simply rotating the phallus in one direction and rotating the skin in the opposite direction before closing will correct it. In more severe cases, a circumcising incision is made, and the penis is then sharply degloved to Buck's fascia. Any dysplastic bands are lysed. Rarely needed, a flap of dartos fascia can be mobilized from the shaft skin and secured to counteract the torsion.

Penile Chordee

Chordee refers to curvature of the penile shaft and includes about 8 % of all penile anomalies. Curvature can be ventral (pointing down), dorsal, or lateral. Dorsal and lateral chordee is sometimes associated with penile torsion, while ventral chordee is common in hypospadias anomalies (Fig. 89.5). These can be congenital or acquired (skin tethering after circumcision). The two main etiologies include true intrinsic disease of the corpora or issues with skin formation. The corpora can be hypoplastic or disproportionate to one another. Abnormal dartos fascia insertion and dysplastic skin development can lead to apparent penile curvature as well. The decision whether or not to correct the chordee should be based on both cosmesis and, more importantly, the degree of potential functional impairment with intercourse. Significant curvature undoubtedly can impact urination and sexual penetration, and it can have a psychological impact. Many use curvature of 30° or more as a guide.

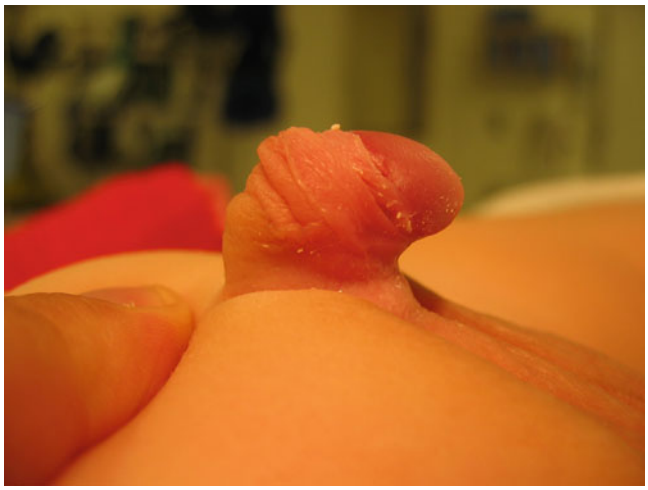

Fig. 89.5 Ventral penile curvature (chordee). The penis is angulated downward creating a "shepherd-hook" appearance. In severe cases, the ventral skin can be dysplastic and foreshortened

To correct chordee, the penis is sharply degloved down to Buck's fascia using a circumcision incision. Very often in mild cases, this release of the skin is enough to release the tethering of the phallus. Once degloved, an artificial erection is performed. A vessel loop tourniquet is applied to the base of the penis. A 25 gauge butterfly needle is then inserted in a proximal and lateral location paying careful attention to avoid the neurovascular bundles (which run at the 2 and 10 o'clock positions) and the ventral spongiosum and urethra. Injectable saline is then pushed using a 10 mL syringe, and an artificial erection is created. If the penis has straightened at this point, no further management is necessary, and one can move on to circumcision and skin closure and reconstruction. If chordee remains, there are a few options for management.

Either shortening the side opposite the curvature or lengthening the side of the curvature can accomplish correction of chordee. In most cases, curvature can be corrected with a plication stitch or a Nesbitt excision procedure. In the former, Buck's fascia is opened at the point of maximal curvature on the surface opposite the curvature (ventral curvature would be opened on dorsal surface). A buried permanent plication stitch is placed to effectively shorten that side. Buck's fascia is then closed over the stitch with a monofilament absorbable stitch. Alternatively, elliptical excision or simple incision of the corpora can be done with closure in an opposite direction (Heineke-Mikulicz). Closure is performed with long-acting monofilament absorbable stitches.

True superiority of one procedure over the other has not been demonstrated. A repeat artificial erection is performed to ensure straightening. The advantage of this technique is that it is generally safe and quick. The downside is that the procedure effectively shortens the phallus which is not very obvious in small penises. However, for larger boys and adolescents, a loss of length might be noticeable.

In severe cases, a lengthening procedure is done. This is much more morbid but can address more severe curvature and avoids the shortening issue. A transverse incision is made in the corpora at the area of maximal curvature. This defect is then filled with either autologous dermis or a commercial product, like small intestinal submucosa (SIS). This is sewed in place and then covered with a dartos flap. Depending on the location of the curvature, the neurovascular bundles or urethra may have to be elevated to access the appropriate spot in the tunica albuginea.

Micropenis

Micropenis is defined as a phallus with a mean stretched penile length less than two standard deviations from the mean, based on the patient's age. The circumference of the phallus is also decreased—the ratio of circumference to length is normal. This is a very anxiety-provoking diagnosis for the parent. There are many etiologies, but there is frequently an issue with testosterone production.

Evaluation of the child with a micropenis should start with a good genitourinary examination. Mean stretched penile length is obtained by pressing a tape measure down to the symphysis pubis, stretching the phallus, and measuring to the distal extent of the glans. This step can be challenging in patients with large suprapubic fat pads, a tight phimosis, or buried penis. This length is then compared to the normal range for age. Attention is also paid to the circumference of the corpora. The testicles should be identified, as they are sometimes small or undescended. Treatment should include a multidisciplinary approach with Endocrinology in the lead. A karyotype, hormonal levels (testosterone, FSH, LH, βHCG), and head MRI (to rule out a pituitary lesion) are often undertaken.

There is no surgical treatment for micropenis. Historically, gender reassignment was considered. However, because these patients usually identify as male, presumably due to early testosterone imprinting on the brain, this is less commonly recommended. A cause should be sought and treated, if appropriate, with hormonal manipulation. Interestingly, recent data indicate that these boys generally do well, achieving satisfactory levels of sexual function and gender identity. The importance of a multidisciplinary approach with endocrinology, psychiatry, and genetics should be considered and is standard of care at our institution.

Buried Penis

This anomaly is also referred to as a "hidden" or "concealed" penis. This can be congenital or secondary to cicatricial trapping after circumcision. On examination, the glans is not

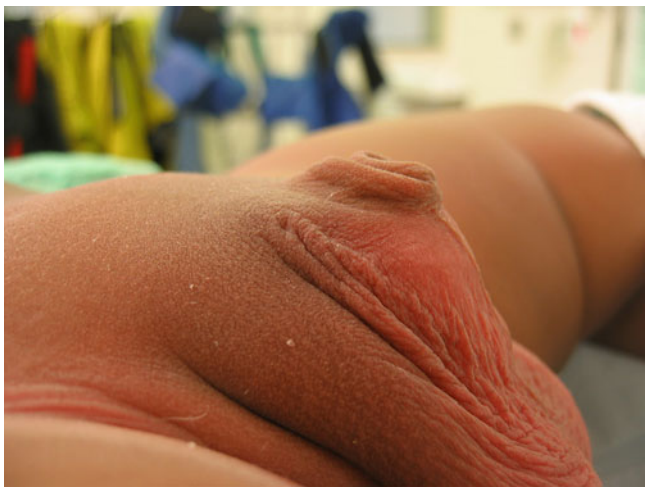

Fig. 89.6 Buried penis. The penis lacks typical shaft-scrotal definition and has a "volcano" type of appearance. Retraction of the fat reveals minimal shaft skin

seen and the prepuce cannot be retracted. There may be a volcano type of appearance in that there is no good definition of shaft skin and fat pad (Fig. 89.6). There are many theories as to the etiology of the buried penis: poor penopubic fixation of the fascial layers of the skin to the phallus, deficiency of normal shaft skin, excess adipose tissue, and inappropriate elasticity of fascial layers (dartos). The indications for surgical treatment include recurrent infections and irritation, ballooning with urination, spraying of urine, and poor cosmesis.

Surgical treatment can be challenging. After preparing and draping, the phimotic ring is reduced. A circumferential incision is made just proximal to this so that the phimotic ring is ultimately removed. The challenge is that there is often a paucity of good shaft skin in these patients and every millimeter should be saved, if possible. The penis is sharply degloved down to Buck's fascia to release dysplastic bands. If there appears to be adequate shaft skin, a second incision is made along the preputial collar about 4–5 mm from the corona as for a typical circumcision. Some surgeons like to fix the skin to the tunica albuginea of the shaft to help recreate the penopubic and penoscrotal angles. This helps create penile shaft definition.

In cases where the skin is too short, other options for coverage are available: the inner preputial skin can be kept longer than normal to bridge the gap, which is cosmetically less desirable as the skin tends to be more wrinkled and very prone to edema; skin from the dorsum can be incised longitudinally and then rotated to the ventrum (Byers flaps); the suspensory ligament can be divided; and the fat pad can be excised by liposuction and Z-plasty, pedicle skin flaps, or free skin grafts are also used. In older children, weight loss and thinning of the suprapubic fat pad is helpful.

In patients with a secondary buried (trapped) penis from a cicatricial ring after circumcision, it can be challenging to find enough skin at all. Rotation flaps or free grafts may be necessary.

Webbed Penis

Webbed penis (penoscrotal fusion) is characterized by a veil of scrotal skin that inserts distally on the ventral shaft of the penis. With the penis on stretch, it is seen hanging down. Although not a functional issue in the future, cosmesis is quite poor.

The decision to repair and the technique chosen depend on the severity of the anomaly. In the most minor cases, simple degloving of the phallus and fixation of the skin proximally to the tunica albuginea of the shaft will provide a more symmetric look. In some cases, a diamond-shaped excision and closure can accomplish this. Some describe a horizontal incision and closure in a vertical manner to provide length. If length is required, a z-plasty type of plastic flap or skin flap can be used.

Penile Masses

Unexpected lumps and bumps are a common cause of referral to the specialist. One of the most common is a *smegma cyst*. This is characterized by a mobile lump under the prepuce in an uncircumcised boy. It often looks white on examination. This is a buildup of epithelial debris, smegma, under the prepuce that resolves when the phimosis improves. This is the body's natural way to help release the adhesions.

An *epidermal inclusion cyst* is a mobile soft mass directly underneath the previous incision in circumcised boys (Fig. 89.7). This is an island of epithelium that was trapped as the circumcision was healing. These can grow with time. Simple surgical excision is recommended.

Abnormalities of the Meatus

The external opening of the urethra is prone to a number of congenital and acquired abnormalities.

Meatal Stenosis

Meatal stenosis is a very common problem seen by both primary care providers and specialists. This is defined as narrowing of the urethral meatus almost exclusively seen in circumcised boys. Congenital narrowing in the absence of

Fig. 89.7 Epidermal inclusion cyst. A soft, mobile, white mass is seen at the 5 o'clock position. This is at the previous circumcision line indicating it is an inclusion cyst. In this patient, the cyst was excised and the redundant inner prepuce removed for circumcision revision

hypospadias is very rare. The most common presenting complaints are an upwardly deflected urinary stream and a thin, forceful stream. Some boys have initial dysuria. The etiology is not completely clear. Some believe that recurrent irritation of the meatal edges after circumcision creates an inflammatory process that causes scarring and narrowing. Others believe that it is caused by disruption of the frenular artery and subsequent ischemia after circumcision. The end result is a lip of scar tissue that forms across the ventral aspect of the meatus (Fig. 89.8). This creates a "finger over the garden hose" effect—the urine stream hits the ventral tissue and is deflected upward. Commonly, the parents complain of urine repeatedly hitting the back of the toilet and the patient needing to press down on the phallus to aim the stream into the toilet. Although not harmful to the patient, a deflected urinary stream can be messy and troublesome for the patient and family.

Treatment of meatal stenosis is surgical. Some advocate an in-office procedure using local anesthesia. The ventral scar tissue is clamped with a straight hemostat and then incised with iris scissors. Most urologists favor correction in the operating room (Fig. 89.8). After standard prepping, the ventral tissue is clamped with a straight hemostat in a "V" configuration. This is then sharply excised and the tissue discarded. The glanular epithelium is then reapproximated to the urothelium using interrupted monofilament absorbable stitches for cosmesis and hemostasis. The meatus can be calibrated at this point with a Bougie dilator. For boys under 4 years old, 10 Fr is a normal caliber. For ages 4–10, 12 Fr is appropriate. For boys over 10, 14 Fr is an appropriate goal. Local anesthetic is then applied. Postoperatively, many surgeons will have the family or patient gently spread the meatus or use a meatal dilator temporarily to avoid restenosis. Time frames and frequency vary among surgeons, but no more than a few weeks is probably required.

Hypospadias

The incidence of hypospadias is thought to be increasing, affecting about 1 in 250 boys. It is not clear whether the increasing incidence is real or secondary to improved diagnosis and reporting. Genetic predispositions and environmental exposures likely play a role. Hypospadias results from incomplete virilization of the genital tubercle. There is a failure of tubularization of the horizontal segment of the urogenital sinus. This leads to the three hallmark aspects of hypospadias: (1) abnormal meatus, (2) abnormal prepuce, and (3) ventral chordee. A patient may have any combination of these depending on the location and severity of the defect. The meatus can be present anywhere from the glans to the perineum. Different classification systems have been used to describe the various anomalies, but the most common describes the meatus as glanular, distal shaft, mid-shaft, proximal shaft, penoscrotal, scrotal or perineal.

During dissection, one can see the spongiosum proximal to the meatus diverge. The more proximal urethra and spongiosum are usually normal. Distally, there is often a remnant of urethral plate that can be well or poorly developed. Next, there can be some ventral chordee. This chordee can be intrinsic to the corporal bodies or secondary to dysplastic skin tethering and can range from no defect to >90° curvature. Finally, there is anomalous skin coverage. In the most basic form, the prepuce fails to wrap around ventrally leaving a "dorsal hooded prepuce." Looking from above, one can see the sides of the prepuce flaring out giving a "batwing" type of look. Ventrally, there is no inner preputial collar. In more severe cases, there is a significant paucity of ventral shaft skin. Rotational flaps from the dorsum are required in these patients.

The decision whether or not to repair hypospadias is sometimes very straightforward. Patients with a meatus below the glans with associated chordee are universally repaired. There are obvious concerns for erections and sexual function as well as issues with the urinary stream. The psy-

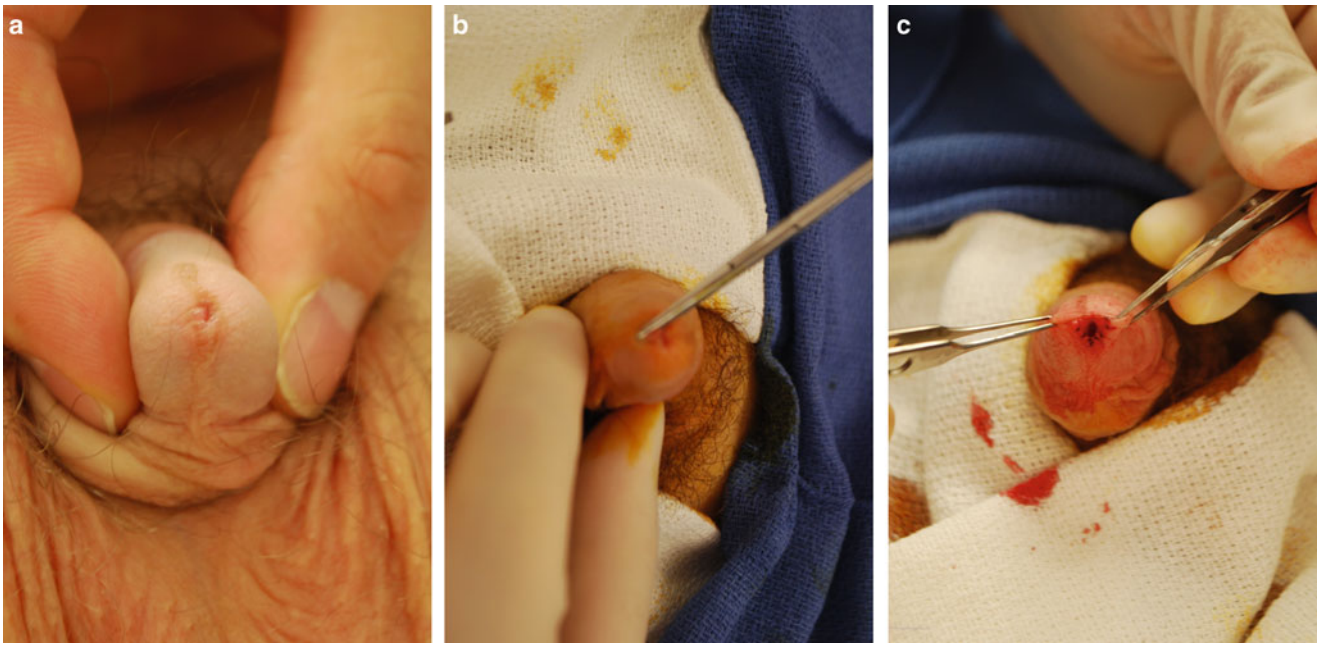

Fig. 89.8 Meatal stenosis.l (**a**) Urethral meatus is stenotic with a typical ventral lip of scar tissue. (**b**) The tissue is clamped in a V-shaped pattern to aid in hemostasis. (**c**) Result after excision of the scar tissue and reapproximation of the urothelium to the glanular epithelium with monofilament dissolvable stitches

chosocial aspect should also be considered. Glanular hypospadias presents more of a gray area. One must consider cosmesis and the effects on the urinary stream. Ventrally placed meatuses with a web or transverse bar of tissue can deflect the stream downward. With more minimally invasive techniques, a goal for a cosmetic repair has become more reasonable. If decided upon, we always make sure to discuss with the parents the reconstructive nature of the procedure and the possibility of surgical complications, like stricture and urethrocutaneous fistula.

After anesthesia is induced, the penoglanular adhesions are lysed, and the patient is prepped and draped. Intravenous antibiotics are usually provided. A glanular holding stitch is placed. A feeding tube is then passed into the bladder. Difficulty with this proximally could indicate a prominent utricle and may require cystoscopy for catheter placement. The penis is then sharply degloved. Care must be taken ventrally to keep a light touch as the urethra and tissues can be severely hypoplastic. If chordee is present, the dysplastic tissue along either side of the spongiosum is resected. An artificial erection is performed and this is repaired as necessary.

The urethroplasty is then planned and executed. This is one of the most variable parts of the procedure, and choice of technique depends upon the quality of the urethral plate (Fig. 89.9), position of the meatus, and surgeon preference. A longitudinal incision is made on each side of the urethral plate, and these are extended into the glans, forming glanular wings. Next, the urethral tubularization can begin. If the urethral plate is supple and wide, the plate can simply be tubularized over an 8 Fr feeding tube (Thiersch-Duplay urethroplasty). Most surgeons prefer a running subcuticular stitch, everting the mucosa into the lumen. This is brought out to an appropriate position in the glans. A second, imbricating layer of Lembert-type sutures is then placed for additional support and to minimize fistulization. Very often, however, the plate is not quite wide enough, and the incision is made longitudinally through it allowing greater mobility (tubularized incised plate urethroplasty—the "TIP repair" popularized by W. Snodgrass). This is currently one of the most common methods for closure. An alternative method of closure is the Mathieu urethroplasty, or "flip flap." A rectangular area of ventral skin is harvested proximal to the meatus and then rotated up to lay on the urethroplasty. Another method for repair for this type of hypospadias is the onlay urethroplasty. A segment of inner prepuce is harvested on its dartos blood supply stalk and rotated ventrally. This is laid upon the urethroplasty and secured into place. In sum, many options exist and none have proven superiority. Patient factors and surgeon experience are key components.

Once the urethroplasty is complete, many surgeons choose to place a barrier layer to minimize fistulization. Most commonly, a dartos flap is harvested from the dorsal hooded prepuce, rotated ventrally, and secured. Finally, skin coverage is accomplished. This actually can be one of the most challenging aspects of the procedure. Most commonly, if there is insufficient ventral skin, the dorsal hooded prepuce is split down the middle at the 12 o'clock position creating "Byers flaps." The skin is sharply unfurled. The flaps are

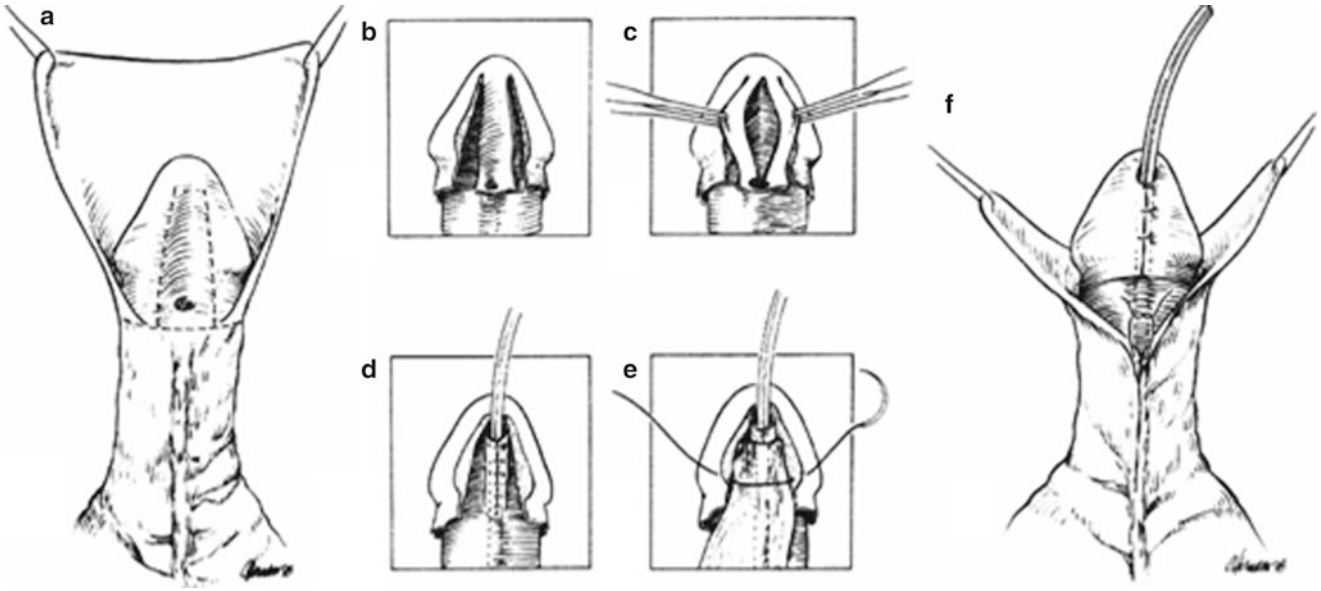

Fig. 89.9 Tubularized incised plate hypospadias repair. (**a**) *Horizontal dotted line* indicating circumscribing incision approximately 2 mm proximal to the meatus. *Vertical dotted lines* indicate the junction of the urethral plate to the glans wings. (**b**) Urethral plate is separated from the glans wings, which are then mobilized laterally. (**c**) The key step of the operation is a deep, midline incision into the urethral plate extending from within the meatus to its distal margin, but not continuing into the glans apex. (**d**) The plate is tubularized over a small stent leaving a generous, oval meatus. (**e**) The neourethra is covered by a dartos flap, and then glansplasty begins at the coronal margin. (**f**) Glans wings, mucosal collar, and ventral shaft skin are closed. (Reprinted from Urology, Snodgrass WT, Tubularized incised plate hypospadias repair: indications, technique, and complications, pp. 6–11, Copyright 1999, with permission from Elsevier)

rotated ventrally and positioned and trimmed as appropriate to ensure symmetric coverage of healthy skin. The feeding tube is exchanged out for a smaller catheter and secured to the glans. A dressing made of Tegaderm or equivalent is fashioned.

Postoperatively, the urethral stent is left in place for 5–15 days depending on surgeon preference. Antibiotics are usually recommended. Admittedly, however, choice of catheter, dressing, and antibiotics has not been objectively studied, and there is no clear superiority of any specific protocol.

More severe hypospadias anomalies, like proximal shaft and penoscrotal hypospadias with severe chordee, often require a staged approach. In the first stage, the penis is degloved and the severe chordee is addressed. The urethral plate sometimes needs to be transected and a ventral graft placed. The skin is rotated ventrally and allowed to heal in for 6 months. At that later time, a urethral tube is fashioned from this healed-in skin. Alternatively, it can be done in a single-stage approach using a rolled tube of inner preputial skin.

Complications after hypospadias repairs unfortunately occur as this is a reconstructive surgery. The more severe the defect and abnormal the tissues, the greater chance of complications. In addition to bleeding and infection, meatal stenosis and stricture along the urethroplasty are possible. Additionally, a urethrocutaneous fistula may occur months to years after surgery along the reconstructed urethra (Fig. 89.10). These often occur at the level of the corona or site of the original meatus. Unfortunately, repeat surgery for these patients is sometimes required.

Megameatus Intact Prepuce

Megameatus intact prepuce is a rare hypospadias variant that is important to be aware of because it is often found as a surprise when doing a circumcision. In this anomaly, the uncircumcised phallus looks normal. There is no obvious chordee or ventral dysplasia. However, once the prepuce is reduced, an abnormal meatus is identified (Fig. 89.11). Some defects are mild and have no functional or cosmetic sequelae. In the more severe cases, there is a very abnormal meatus that widens proximally, creating a fish-mouth appearance. The cosmesis is quite poor and the urinary stream is usually disrupted. Surgical correction follows general hypospadias principles but can be quite challenging given the thin and laterally displaced urethral tissues.

For the general practitioner performing a circumcision, this entity can be surprising and anxiety provoking. If the operator is uncomfortable with hypospadias surgery, it is recommended to abort the circumcision and refer the patient to a pediatric urologist. If a dorsal slit has been performed, closure of the epithelial edges is performed in a Heineke-Mikulicz fashion for hemostasis.

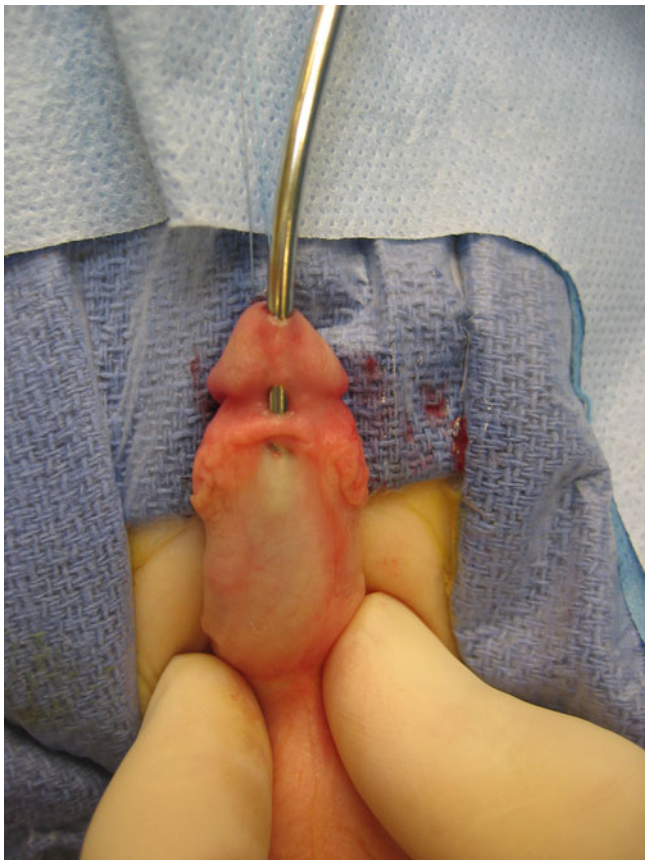

Fig. 89.10 Urethrocutaneous fistula. In this patient, the glans has been reconstructed with good cosmesis. However, two fistula sites have opened up proximal to the reconstruction as seen with the exposed dilator

Epispadias

Epispadias is a rare defect of the urethra. Unlike hypospadias, this anomaly is on the bladder exstrophy spectrum. The meatus is located on a dorsal position of the phallus (Fig. 89.12). The more proximal the defect, the greater the possibility of associated urethral sphincter malfunction. Proximal penopubic meatuses act very much like bladder exstrophy in that the external sphincter may be incompetent and additional incontinence procedures required. Surgical principles are similar to hypospadias and are most often addressed by pediatric urologists.

Other Penile Anomalies

Diphallia refers to a duplication of the phallus. It is very rare and present in only one in five million boys. Presentation can range from a small accessory phallus to a fully duplicated one (Fig. 89.13). The etiology is unknown. Other genitourinary abnormalities are often present (renal anomalies, bladder duplication, bifid scrotum), and extra-genitourinary abnormalities may also exist. A renal bladder sonogram and voiding cystourethrogram are indicated. Surgical treatment is based on tissue and organ characteristics to attain satisfactory cosmetic and functional outcome.

Penile agenesis (aphallia) is also a very rare condition. This results from failure of development of the genital tubercle and occurs in 1 in 10–30 million births. Only about 70

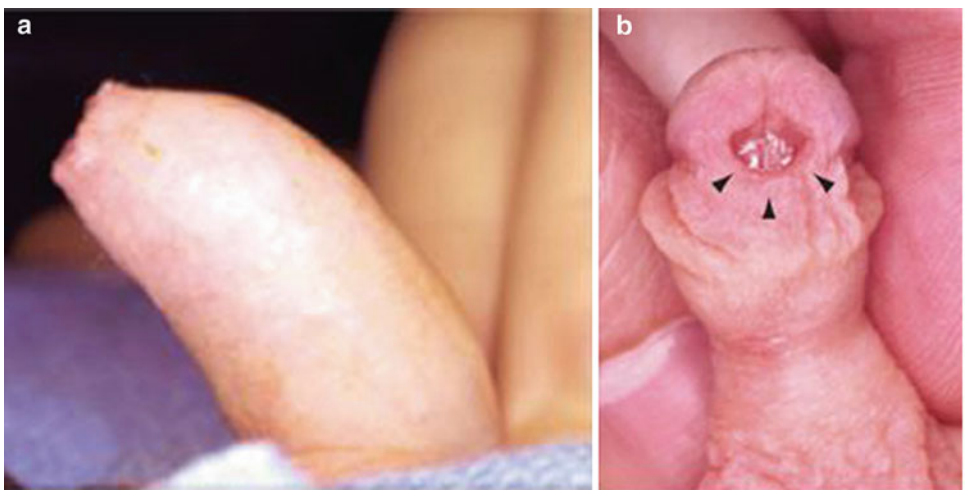

Fig. 89.11 Megameatus intact prepuce (MIP) variant of hypospadias. (**a**) Normal appearance of foreskin on lateral view. (**b**) Typical appearance of meatus (*arrowheads*) after newborn circumcision in a patient with the MIP variant. (Reprinted from Campbell-Walsh Urology, 9th edition, Authors: Borer JG, Retik AB, Copyright 2007, with permission from Elsevier)

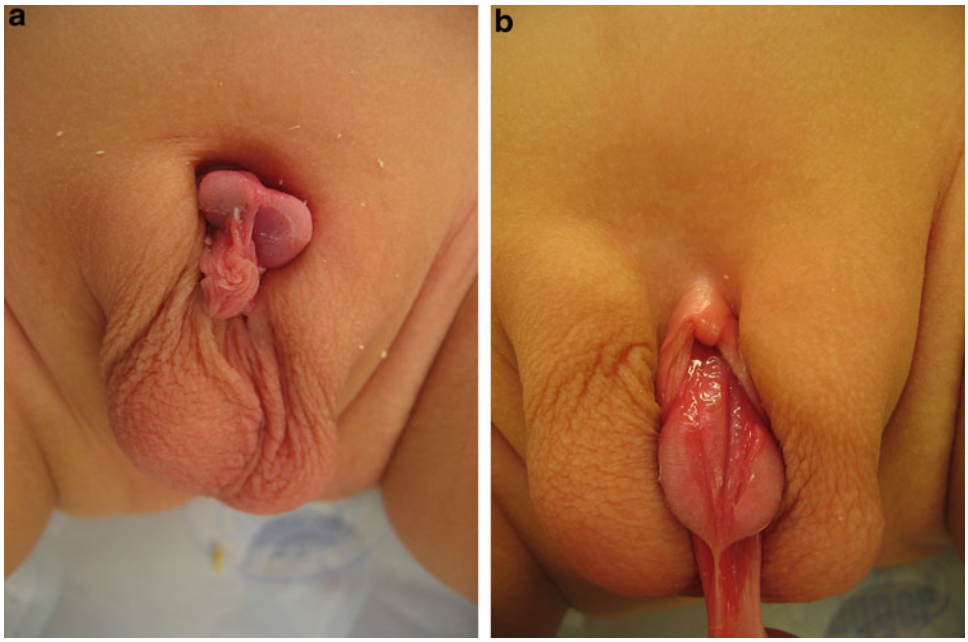

Fig. 89.12 Epispadias. (**a**) Epispadias penis at rest. Ventrally the foreskin is seen and the meatus is in the dorsal position. The phallus and corpora are more separate and flattened. (**b**) On stretch, the dorsal open urethral plate is seen

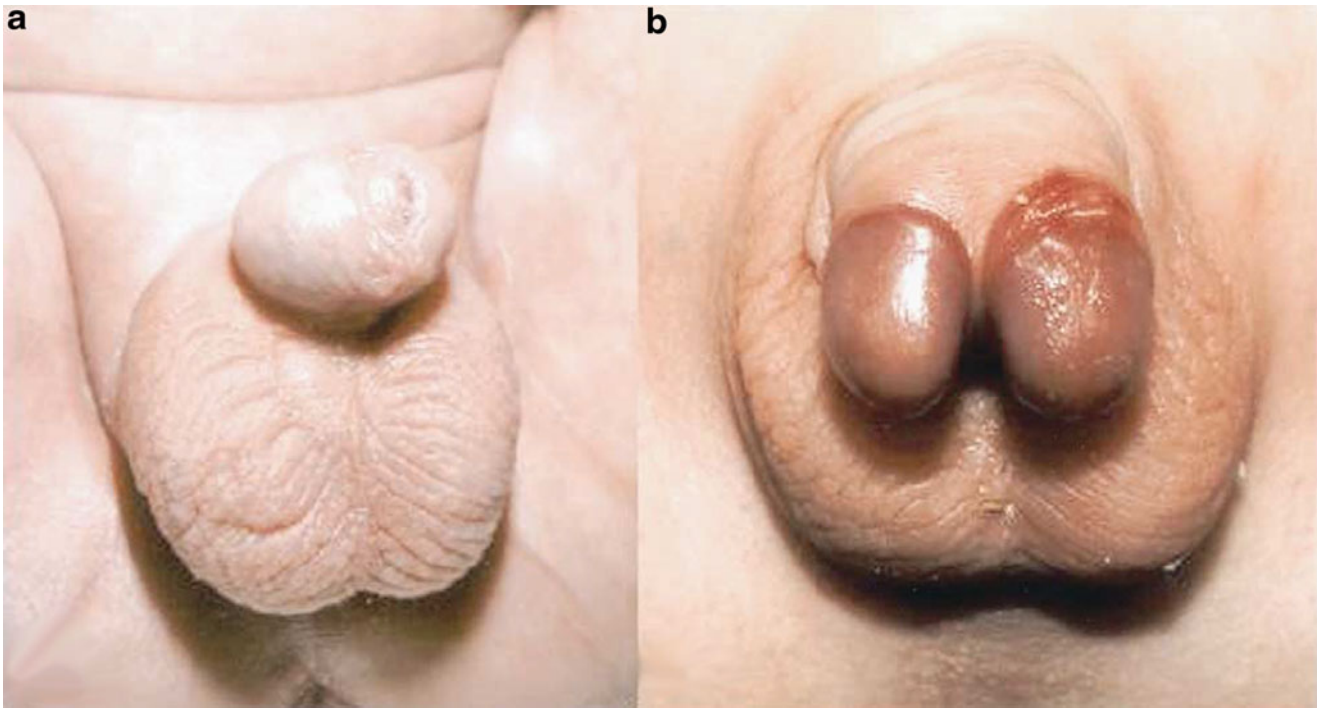

Fig. 89.13 Diphallia. (**a**) Prior to preputial retraction, the penis looks fairly normal. (**b**) After retraction, lateral penile duplication is identified. (Reprinted from Urology, Gyftopoulos KP, et al., Clinical and embryologic aspects of penile duplication and associated anomalies, pp. 675–679, Copyright 2002, with permission from Elsevier)

cases are reported in the literature. There is a complete absence of the corpora cavernosa while the scrotum and testicles are generally normal (Fig. 89.14). The urethral meatus is present somewhere between this area and the rectum, often as a skin tag near the anus. In general, the more proximal the meatus, the higher the likelihood of other abnormalities, some of which are potentially lethal. Other malformations should be searched for, and a multidisciplinary approach at a tertiary care center is required to address the complex issues. Traditionally, gender reassignment was performed, but recent

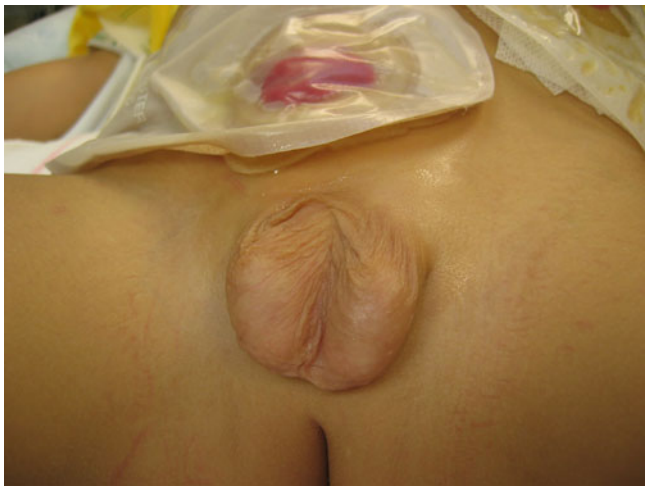

Fig. 89.14 Aphallia. No penile structures are present, but the scrotum and testicles are normally developed. Note the colostomy bag: aphallia commonly has other gastrointestinal and non-genitourinary anomalies

concerns about testosterone imprinting of the fetal brain and male gender identity have challenged this thinking.

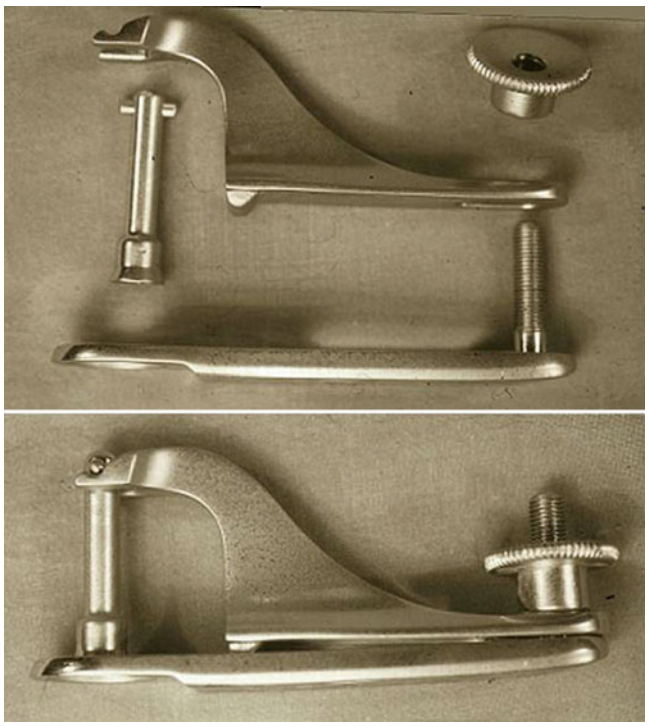

Fig. 89.15 The Gomco clamp. The four non-assembled parts (*top*) and after assembly (*bottom*)

Circumcision

Few procedures have generated more controversy, anxiety, and litigation as circumcision. Currently, there is no policy or recommendation for universal circumcision. Many studies have cited potential medical benefits including improved hygiene and decreased rates of urinary tract infection, sexually transmitted diseases, balanitis, and penile cancer. The American Academy of Pediatrics (AAP) released a guideline statement in 2012 stating "the health benefits of newborn male circumcision outweigh the risks and that the procedure's benefits justify access to this procedure for families who choose it." The American College of Obstetricians and Gynecologist has endorsed this statement. Most importantly, a dialogue needs to be had between the parents and practitioner comparing the risks of the procedure to the potential benefits.

In the newborn setting, most circumcisions are performed by pediatricians and obstetricians. The penis should first be evaluated for any abnormalities, like penile webbing, buried penis, congenital curvature, or abnormal meatus. If identified, the procedure should be aborted and the patient referred to pediatric urology if the practitioner feels uncomfortable with these reconstructive techniques. If normal, the patient is secured to a papoose board and local anesthesia is administered. The prepuce is gently retracted and the penoglanular adhesions are lysed. One of three devices is then used.

The Gomco clamp is the safest device available. It consists of four parts—the bell, base plate, arm/yoke, and screw nut (Fig. 89.15). The bell is placed on the glans and the prepuce drawn over it. The penis and bell are then passed through the hole in the base plate. The yoke is positioned to catch the bell under its two small studs. The screw nut is applied to cause a crushing force on the prepuce. The excess foreskin is cut away and the device is disassembled. The clamping action provides the hemostasis. Proper fitting of the bell to the glans is crucial. This bell provides protection against glanular injury.

A variation of this principle is the Plastibell. A dorsal slit is performed and an appropriately sized plastic bell is place over the glans. A heavy suture is tied around the prepuce in the groove of the bell, compressing the skin. The excess preputial skin is excised along the edges of the device and the handle detached. The bell is left in place and falls off in about eight days.

The third device used by many, including many mohels, is the Mogen clamp (Fig. 89.16). This device utilizes a guillotine transection of the foreskin after crushing or entrapping the tissue. The advantages of this device are that it is very quick and one device can be used for all size penises. The major drawback is that the glans is not visualized and can be amputated if the device is not used correctly.

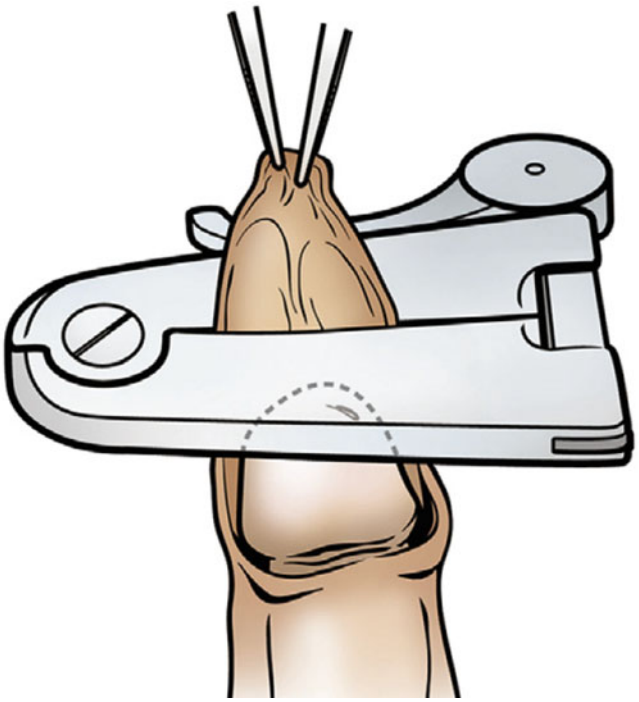

Fig. 89.16 The Mogen clamp. The prepuce distal to the glans is clamped and excised. Careful attention must be paid to release the adhesions and stay distal to the glans to avoid a guillotine type of injury. (Reprinted from Journal of Pediatric Urology, Pippi Salle JL, et al., Glans amputation during routine neonatal circumcision: Mechanism of injury and strategy for prevention. pp. 763–768, Copyright 2013, with permission from Elsevier)

Sleeve Circumcision

For circumcisions in older patients, a traditional sleeve circumcision is most commonly utilized. This is done under general anesthesia and can provide an excellent cosmetic outcome with minimal risk. There are many variations. We start by gently retracting the prepuce and lysing penoglanular adhesions with a hemostat. The patient is prepped, and a 4-0 silk is placed through the dorsum of the glans as a holding stitch. Although not necessary, a holding stitch is very helpful when working alone or on a small phallus. The frenulum is sometimes divided with electrocautery. A circumferential incision is made about 5 mm from the corona along the inner preputial collar. A second incision is made along the outer shaft skin. The position of this is generally at the level of the corona with the penis at rest. The intervening sleeve of tissue is excised with electrocautery. All individual vessels are cauterized and meticulous hemostasis is maintained. The shaft skin is then reapproximated to the inner preputial collar with interrupted short-acting absorbable monofilament stitches. The holding stitch is removed and pressure applied. We then apply antibiotic ointment and forego a formal dressing, but that is to the surgeon's discretion. Postoperatively, straddle toys are avoided for one month and submersion in water avoided for about one week. Antibiotic ointment is applied multiple times daily and the shaft skin retracted proximally to avoid penile skin bridge formation, especially in the boy with a large suprapubic fat pad.

Complications from circumcision are very rare. The most common is bleeding, occurring in <0.1 %. The site of bleeding is most commonly the frenular artery, and control can often be achieved with compression and silver nitrate application. In some cases, excessive bleeding is the presenting symptom for an underlying coagulopathy. Penile skin bridges can be a nuisance and are more likely to occur in babies with large fat pads. Good post-procedure care and retraction can avoid this complication. Rarely, an excess of skin is removed during a clamp circumcision. The parents can be reassured that the penis generally heals quite well and skin will granulate in. Suturing of the shortened shaft skin to the collar or skin grafting is not required. Liberal application of antibiotic ointment is all that is usually required for a satisfactory cosmetic result. In the rare case that there is a glanular amputation after a clamp circumcision, the amputated portion should be wrapped in saline gauze and cooled in a bag of ice. Care should be transferred to a tertiary care center for pediatric urological assistance.

Editor's Comment

Congenital anomalies and injuries of the penis are rare and should only be managed by experienced pediatric urologic specialists. Meticulous planning and precise technique are required to achieve normal urologic function, an acceptable appearance, and adequate future sexual performance. Filmy foreskin adhesions should be left alone as they always recur and tend to bleed and cause pain. Repeated lysis can lead to skin bridges, which require incision under anesthesia. Hypospadias, even its mildest form, must be recognized when performing a circumcision as any abnormality of the meatus is a contraindication—the foreskin might be needed for the reconstruction. Likewise, webbed penis, buried penis, and micropenis should all be considered relative contraindications to circumcision.

There are very few valid medical indications for circumcision. The purported benefits are minimal, it is painful even in newborns, and the procedure is associated with a small but significant risk of major complications. Parents are nearly always motivated by misplaced cosmetic or cultural concerns. Some feel that the procedure should be condemned as a form of genital mutilation and only be performed when there is a clear medical indication. Nevertheless, if we can ethically justify performing the procedure at all, it is our obligation as surgeons to at least do it well and with an absolute minimal risk of complications. Anesthesia and antiseptic should always be used. The freehand technique provides a

nice result, but it is important to avoid taking too much skin. It is far better to take too little than to take too much. It is best to place the penis on maximal stretch before deciding how much should be removed and then err on the side of leaving a little extra. Parents should be gently reassured that the boy is likely to need the extra skin in the future.

A relatively common postoperative complication is bleeding, which can be profuse and sometimes requires a trip back to the OR. The clamp techniques all involve crushing the skin prior to incising it. Many use the Mogen clamp, variations of which have been used for centuries. The foreskin is stretched beyond the glans and then pinched transversely in the hinged metal clamp. There is a small risk of amputation of the glans. The Gomco clamp uses a metal bell placed within the foreskin. The skin is pinched against the heavy outer part of clamp by tightening a screw. Although safe in experienced hands, some find the heavy metal clamp unwieldy and the fact that the glans seems to disappear into the machinery disconcerting. The Plastibell technique is increasingly popular and comes in various sizes between 1.1 and 1.7 cm. After performing a dorsal slit and, if necessary, dividing the frenulum, the bell is placed within the foreskin and a linen cord is tied very tightly around, crushing the skin against the bell. The excess skin is trimmed and the bell is allowed to fall off in 7–10 days. After the bell detaches, the foreskin should be pulled back behind the corona at frequent intervals to prevent "recurrent" phimosis. The bell will sometimes fall off prematurely, but this is rarely an issue even if there is a short distance between the skin edges. If the bell is too large, the glans can become trapped and strangulated in the opening. When performing a dorsal slit, it is important to avoid inadvertently placing a jaw of the hemostat inside the urethra. Dividing the frenular artery can result in meatal stenosis, which usually presents in children as a narrow urine stream that is directed at an upward angle.

As circumcisions become less common in the USA, we should expect to see an increase in foreskin complications. Phimosis is the inability to retract the foreskin and is one of the rare medical indications for at least a partial circumcision. Paraphimosis is when the foreskin retracts but gets stuck, strangulating the glans. This can usually be relieved with firm manual compression of the glans to make it smaller, allowing the prepuce to be reduced. Ice does not help and risks frostbite. Usually the result of rigorous sexual activity, frenular artery tears can bleed profusely. It can sometimes be treated at the bedside with direct pressure but sometimes requires ligation under anesthesia. Balanitis is a painful skin infection that is more common in the uncircumcised. It is usually treated with frequent retraction of the foreskin, gentle cleaning, and topical antibiotics. Systemic antibiotics are indicated for invasive infection.

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Inguinal Hernia and Hydrocele

90

Nicole M. Chandler and Paul D. Danielson

Inguinal hernia repair is one of the most common operations performed in children. It is a type of abdominal wall defect in which an intra-abdominal organ, such as intestine, ovary, or omentum, protrudes through an opening in the inguinal region. Most hernias diagnosed in childhood are indirect inguinal hernias, caused by a patent *processus vaginalis*. True direct inguinal hernias are quite rare in children.

At 6 weeks gestation, primitive germ cells migrate to the urogenital ridge, located on the posterior wall of the abdomen near the developing kidneys, where they differentiate into testes or ovaries. The gonads then descend to the level of the internal ring at 12 weeks. From here, the peritoneal lining of the ventral abdominal wall protrudes through the internal ring to form a diverticulum known as the processus vaginalis. During the 7th month, the testes continue their descent by following the course of the gubernaculum, a fold attached to the caudal portion of the testes, through the inguinal canal, pushing the vaginalis toward the scrotum. The testes then exit the external ring to finally rest in the lower scrotum, with gradual obliteration of the processus vaginalis, which subsequently becomes the tunica vaginalis. The pathophysiology of the development of pediatric inguinal hernias and hydroceles is the incomplete obliteration of the processus vaginalis. Failure of this obliteration is the reason why inguinal hernias and hydroceles are classified as congenital anomalies, although they may not be clinically apparent at birth. In girls, the canal of Nuck corresponds to the processus vaginalis and enters into the labium majora. The gubernacular remnant in girls then becomes the ovarian and uterine ligaments.

The incidence of pediatric inguinal hernia is 0.8–4 %, which corresponds to approximately 10–20 per 1000 live births. Incidence is highest in premature infants at 30 %. Males develop inguinal hernias six to ten times more often than girls. Approximately two thirds occur on the right and 10–15 % are bilateral. The higher incidence on the right side is possibly related to the fact that the right testis descends later than the left. As a consequence, patients who present with a left inguinal hernia have a higher incidence of an occult right inguinal hernia, as do girls, premature infants, children who present within a year of birth, and boys with undescended testes. A positive family history occurs in up to 20 % of patients. There is also an increased incidence of inguinal hernias in twins. No significant association between race and inguinal hernia has been reported. Certain associated conditions are known to have an increased incidence of inguinal hernias including bladder exstrophy, Ehlers-Danlos syndrome, and prune belly syndrome. Patients who are treated with a ventriculoperitoneal shunt are at higher risk for developing an inguinal hernia presumably as a result of the increased intra-abdominal pressure.

Clinical Presentation

Most patients present with an intermittent asymptomatic mass or bulge in the groin, scrotum, or labium (Fig. 90.1). Parents will note the bulge especially when the patient strains or cries. The description of a groin mass that comes and goes is so specific that many surgeons will perform an hernia repair based on the history alone, even if an hernia is not demonstrated on physical exam. Some surgeons request the parents to take a discreet digital photograph of the hernia at home to document its presence.

Patients should be examined in both the supine and standing positions. In boys, the location of the testes should be determined to differentiate an hernia from an undescended testis. If the hernia is not apparent, a variety of age-appropriate Valsalva maneuvers can be employed. Crying, blowing on a finger, jumping, and bearing down may result in an apparent inguinal bulge. If the hernia sac remains empty, the spermatic cord structures are palpated and a thickening of the cord, known as the "silk glove sign," indicates

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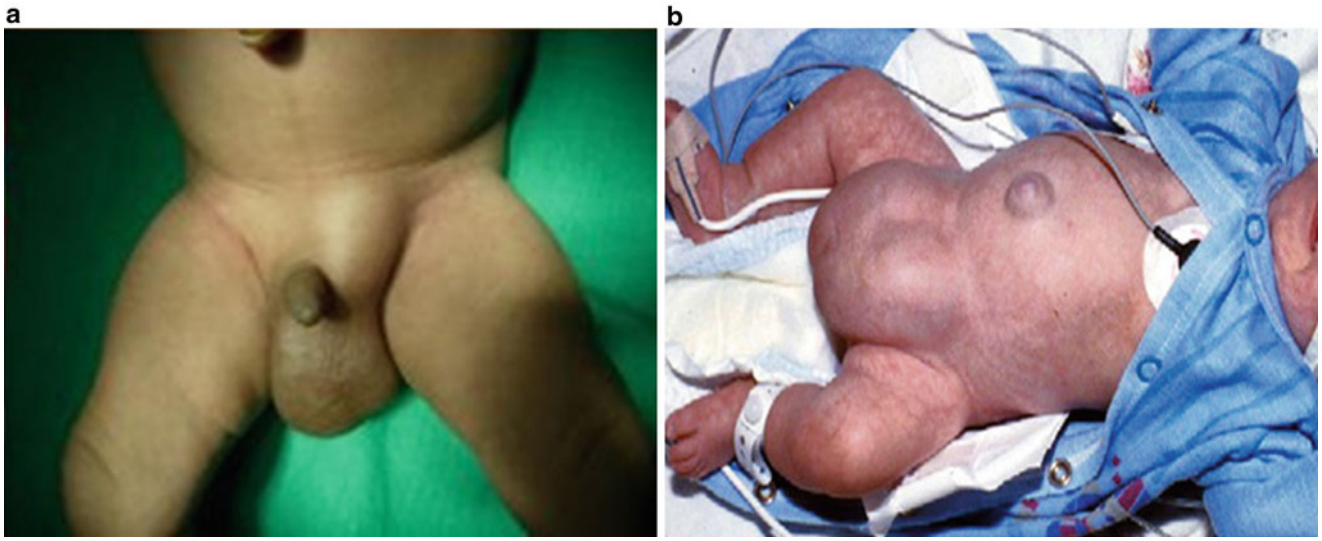

Fig. 90.1 (**a**) Asymptomatic reducible left inguinal hernia in an infant. (**b**) A premature baby boy with giant bilateral inguinal hernias

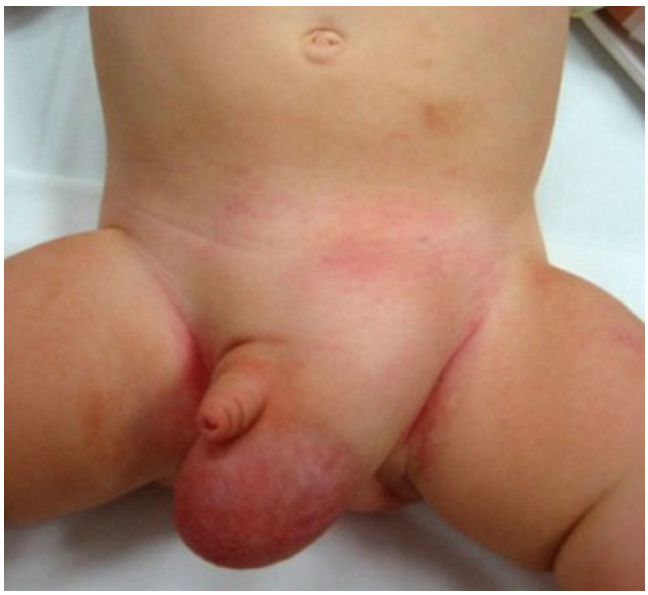

Fig. 90.2 An infant boy who presents with an incarcerated inguinal hernia. The hernia appears tense and edematous with erythema of the overlying skin

the presence of the hernia sac. In girls, the ovary may be present in the hernia sac.

Incarceration may be the presenting symptom of an inguinal hernia (Fig. 90.2). Incarceration occurs in 5–15 % of all hernias and up to 30 % under the age of 1 year. Symptoms of incarceration include pain, abdominal distention, and emesis. Since the symptoms of incarceration are due to partial bowel obstruction, all patients with signs and symptoms of a bowel obstruction should be examined for the presence of inguinal hernia. Most incarcerated hernias can be reduced. Adjuncts that assist with reduction include Trendelenburg positioning, sedation, and elongation of the sac with gentle manipulation at the level of the internal ring. Following successful reduction of an incarcerated hernia, hernia repair should be performed once edema subsides, usually 24–48 h later. If the hernia was reduced easily, some surgeons favor elective repair. If an incarcerated hernia cannot be reduced, the patient should be taken urgently to the operating room for reduction, repair, and inspection of the intestine.

Preoperative Preparation

In the majority of patients, the diagnosis of inguinal hernia or hydrocele is made on the basis of history and physical examination. In indeterminate cases, ultrasound may be useful. US criteria for the diagnosis of an inguinal hernia includes the presence of one of the following: inguinal internal ring diameter greater than 4 mm, presence of fluid in the processus vaginalis, presence of bowel, or other peritoneal structures in the inguinal canal. There have been no significant differences noted in the size of the internal ring based on age, gender, or side of the hernia. The sensitivity of US in detecting an inguinal hernia is approximately 95 %.

Inguinal hernias do not resolve spontaneously, and therefore all need to be repaired surgically. The American College of Surgeons recognizes three age groups of inguinal hernia repairs: less than 6 months, 6 months to 5 years, and older than 5 years. Premature infants have a higher incidence of inguinal hernia and incarceration. Therefore, many recommend hernia repair once the baby is 1800 g and prior to discharge from the neonatal unit. The literature reports conflicting retrospective data with some favoring repair prior to discharge and others recommending elective repair later dur-

ing infancy. Premature babies up to 60 weeks postconceptual age are typically monitored overnight for apnea following inguinal hernia repair. Recent data have raised concerns regarding early anesthetic exposure on the developing brain and long-term neurodevelopment. This warrants a discussion with the parents regarding the risks of anesthesia versus the risks of incarceration. Full-term infants more than 44 weeks postconception and older children typically undergo elective outpatient hernia repair.

Open Repair

For over 100 years, high ligation of the hernia sac has been recognized as the key feature of pediatric inguinal herniorrhaphy. The open technique approaches this through an incision along the inguinal crease lateral to the pubic tubercle. Dissection is carried down through Camper's and Scarpa's fascia with care taken not to injure the inferior epigastric vein.

In boys, the intent is to identify the spermatic cord after it exits the internal ring. This is most easily accomplished by opening the external oblique in the direction of its fibers to gain access to the inguinal canal. In premature infants and some term newborns, the inguinal canal is short, and so the internal and external rings overlap. In this situation, the procedure can be performed distal to the external ring, thus avoiding an external oblique incision. Efforts are made to identify and preserve the ilioinguinal nerve as it traverses the inguinal canal.

Attention is then turned to the spermatic cord. Once the investing cremasteric fibers are spread, the hernia sac is typically encountered anterior and medial to the testicular vessels and vas deferens (Fig. 90.3). These delicate structures are gently dissected away from the sac. This dissection is carried up to the level of the internal ring. The sac is then opened to rule out a sliding hernia and to allow access for laparoscopy if one intends to rule out a contralateral hernia. In the presence of a sliding hernia, a purse-string suture is used to close the proximal sac at the level of the internal ring. When there is no sliding hernia, the sac can be given a few twists before placing a transfixing suture ligature and then a more proximal-free ligature. An absorbable suture is preferred to minimize the risk of abscess and foreign body reaction. The residual sac is then amputated.

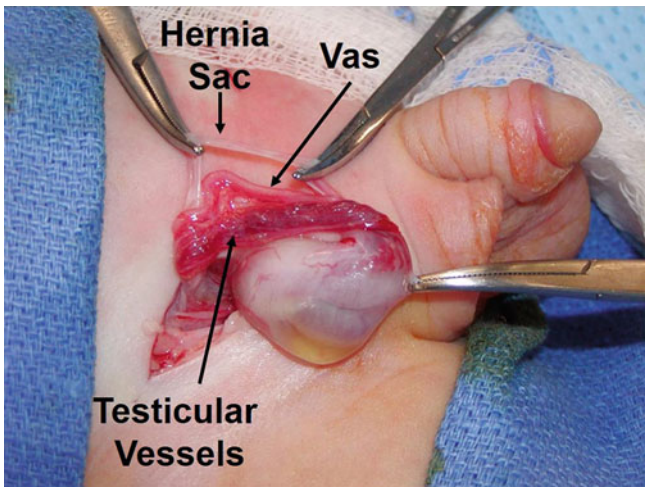

Fig. 90.3 Illustration of an open inguinal hernia repair

The incidence of direct inguinal hernias in children is extremely low and is more often associated with connective tissue disorders. Therefore, routine repair of the inguinal floor is unnecessary. Similarly, tightening of the internal ring only risks entrapment of vessels or nerves without any demonstrated effect on recurrence rate. When the hernia sac terminates in the scrotum, it is often easier to divide the sac mid-canal and address the proximal and distal portions separately. Debate exists regarding the necessity of excising the distal sac. Stripping out the residual processus vaginalis runs the risk of injuring the vas and vessels. Opening the residual sac widely to drain any hydrocele and to prevent postoperative hydrocele formation is sufficient. In some cases, the testicle's gubernacular attachment is inadequate or has been divided during the dissection process. In this situation, an ipsilateral orchiopexy should be performed to prevent acquired undescended testis and future testicular torsion.

Once the high ligation is complete, the wound is then closed in layers using absorbable sutures beginning with the external oblique (if opened), followed by the Scarpa's fascia, and then the skin, with the last typically closed in a subcuticular manner to avoid the need for postoperative suture removal.

The technique in girls carries fewer risks as there are no testicular vessels or vas deferens to preserve. However, the sac must still be handled gently to prevent tearing, and it is important to open the sac in every patient. This is not only to rule out sliding hernias, which are more common in girls, but also to help identify intersex abnormalities. It is good practice to confirm a Mullerian-derived structure, typically a fallopian tube, in the phenotypic female hernia patient in order to rule out androgen insensitivity (previously referred to as testicular feminization syndrome). After high ligation, the internal ring may be sutured closed, but this is only required if it is enlarged. As with boys, there is no need to repair the floor of the inguinal canal unless a direct hernia is specifically identified.

The anesthetic options for a patient undergoing an open inguinal hernia repair include general, regional, and local techniques. The anesthetic selection is informed by both patient factors (age, comorbidities) and the type of operation planned. The majority of patients undergo general anesthesia with endotracheal intubation, especially if insufflation for laparoscopy is planned. Premature infants who are less than

60 weeks postconceptual age have a higher incidence of postoperative apnea and bradycardia, which has led some to rely on regional techniques, such as spinal or caudal anesthetics. However, no difference in postoperative apnea, bradycardia, or oxygen desaturations has been reported between these two techniques. Evidence is accumulating that exposure to general anesthesia in childhood has long-term neurocognitive effects. This may favor more regional anesthetic approaches and limit the indications for laparoscopy.

An ilioinguinal nerve block is an excellent adjunct for postoperative analgesia. A 25-gauge needle is used to inject a long-acting local anesthetic (0.25 % bupivacaine hydrochloride) between the internal oblique and transversus abdominis muscles. The point at which the nerve traverses the anterior abdominal wall is variable. The external landmark for needle insertion is classically described in adults as 2 cm medial to the anterior iliac spine. This distance will be proportionally shorter in children and as little as 5 mm in a newborn. The anesthetic can then be injected for a field effect that ranges 2 cm superior and inferior to this location.

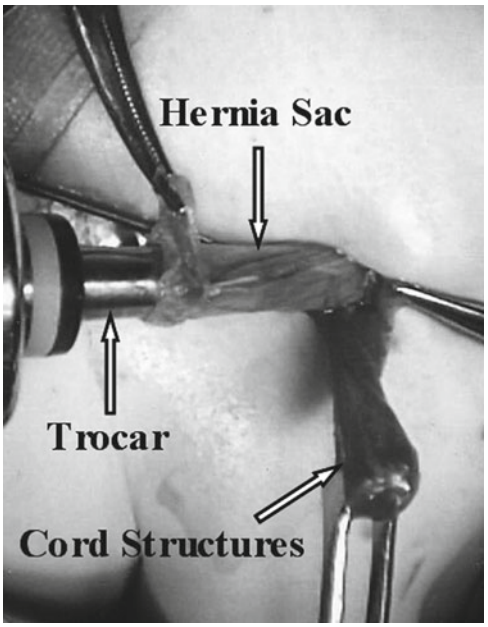

Fig. 90.4 Illustration of the technique for intraoperative diagnostic laparoscopy to evaluate the presence of an asymptomatic contralateral hernia

Contralateral Exploration

The least invasive method for determining if there is a contralateral patent processus vaginalis is to take advantage of the access to the peritoneal cavity afforded by the ipsilateral hernia sac. The edge of the opened sac is held with two fine clamps. A 3-mm blunt trocar is introduced through the sac. A temporary tie can be placed around the sac to prevent the leakage of the insufflation gas; however, it is often quicker to twist each clamped edge of the sac around the trocar in opposite directions to tighten the seal (Fig. 90.4). Pneumoperitoneum to a pressure of 8 mmHg is then achieved with carbon dioxide. Some surgeons feel that overdistension with higher insufflation pressures will flatten the patent processus vaginalis and shorten the perceived tunneled, thereby leading to a false-negative finding. Underinflation may also disguise a patent processus vaginalis by not adequately displacing the overlying peritoneal fold. A 2.7 mm 70° telescope is introduced through the trocar to view the contralateral internal ring. Scopes with a smaller angle of view are unable to provide adequate visualization. Once the contralateral side is assessed, the scope and trocar are withdrawn and the insufflation is allowed to escape. The hernia sac can then be secured.

The incidence of contralateral metachronous inguinal hernia in a pediatric patient undergoing unilateral inguinal hernia repair is difficult to define. The laparoscopic findings can guide the decision to proceed with contralateral repair. Recent studies suggest it to be a cost-effective approach and therefore recommended in all children. However, there have been reports of hernias developing after a negative laparoscopic evaluation. Steps that can be taken to reduce this rate include using a broad definition of what constitutes a patent processus vaginalis, employing a large angle endoscope (≥70°) during transinguinal laparoscopy, or utilizing transumbilical laparoscopy for a more direct view. Some surgeons have described probing the internal ring to determine patency by means of a blunt instrument introduced through a channel of a working laparoscope or directly through a separate stab incision in the anterior abdominal wall.

Laparoscopic Repair

There are many surgical variations in the laparoscopic approach to inguinal hernia repair in children. The different approaches can be categorized as intracorporeal and extracorporeal. Intracorporeal techniques typically require placement of two laparoscopic instruments in addition to the laparoscope. The hernia sac is then obliterated with ligation, excision, or a combination of the two. The extracorporeal techniques all include percutaneous placement of a suture circumferentially around the internal ring under laparoscopic guidance.

During an extracorporeal laparoscopic hernia repair, the patient is placed under general anesthesia following endotracheal intubation. The patient is positioned supine in the midportion of the operating table. A monitor is placed at the foot of the bed. The bladder is emptied with a Credé maneuver. The umbilicus is cleaned with an alcohol wipe prior to sterile surgical preparation with a betadine solution

to include the abdomen and genitals. No prophylactic antibiotics are given.

All sites are infiltrated with local anesthetic (0.25 % bupivacaine hydrochloride) prior to incision. This injection is also used to hydrodissect the peritoneum away from the posterior cord structures, allowing for easier passage around the hernia sac. A 2 or 3 mm trocar is placed in a transumbilical location. Pneumoperitoneum is achieved with carbon dioxide to a pressure of 8–12 mmHg based on the patient's size. Flow is maintained at 4 L/min. A 30° telescope is inserted. The patient is placed in Trendelenburg position to allow the small bowel to lift out of the pelvis. The pelvis is explored to include the bilateral internal rings to determine the presence of unilateral or bilateral inguinal hernias (Fig. 90.5). In girls, the uterus or adnexal structures are visualized to rule out androgen insensitivity syndrome. In males, a 2–3 mm Maryland locking grasper is inserted directly through the lower lateral abdominal wall on the contralateral side of a unilateral hernia or the contralateral side of the more symptomatic hernia for bilateral hernias. The grasper is used to retract the median umbilical ligament to stretch and flatten the internal ring. The cord structures are not grasped. If a patent processus vaginalis is identified, a depth of 1 cm indicates need for repair. The external location of the internal ring is identified by gently pressing in the inguinal crease with a narrow blunt tip instrument, such as a Jake clamp and visualizing the impulse with the telescope. A 1–2 mm incision is made at this location, and the subcutaneous tissues are gently spread to bury the knot. A 2-0 polypropylene suture on a CT-1 needle (or SH-1 in a neonate) is then passed through the incision and is identified intracorporeally with the telescope so the tip is located just beneath the peritoneum at the level of the internal ring. The needle is passed in the properitoneal space in a lateral to medial direction and is navigated between the peritoneum and the cord structures. The needle is directed lateral to the epigastric vessels and is brought back out through the skin. The heel of the needle is passed retrograde through the subcutaneous tissue to exit the original inguinal incision. Intracorporeal inspection with the telescope assures complete encircling of the internal ring (Fig. 90.6). The telescope is removed and the abdomen is desufflated. Any gas that remains in the scrotum is manually reduced. The suture is then tied, and the knot is placed in the subcutaneous layer. Pneumoperitoneum is reestablished, and the internal ring is inspected for good closure and hemostasis. A bilateral hernia, if present, is repaired in the same manner. If convenient, the suture on the contralateral side may be passed medial to lateral so that the surgeon is operating forehand. Small to moderate hydroceles that are not able to be drained through the internal ring are aspirated through the scrotum with a 25-gauge needle. The peritoneum is desufflated and the port is removed. The umbilical fascia is closed with 3-0 absorbable suture. The skin incisions are simply closed with Steri-Strips™.

Variations to this procedure include the use of an awl-shaped instrument or spinal needle to perform the dissection around the hernia sac and to pass the suture. Others have advocated cauterizing the peritoneum around the ring, sparing the area around the cord structures, to help ensure obliteration of the processus vaginalis and the use of two sutures to ligate the hernia sac.

There is ongoing controversy and discussion whether the laparoscopic approach is comparable to the open repair. Data suggest that the operative times are shorter with laparo-

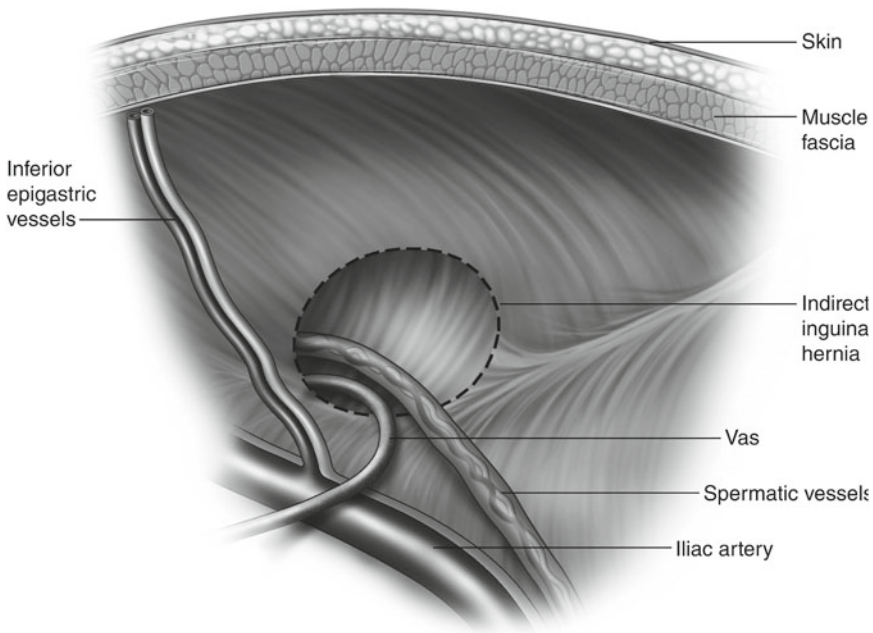

Fig. 90.5 Laparoscopic view of a right indirect inguinal hernia

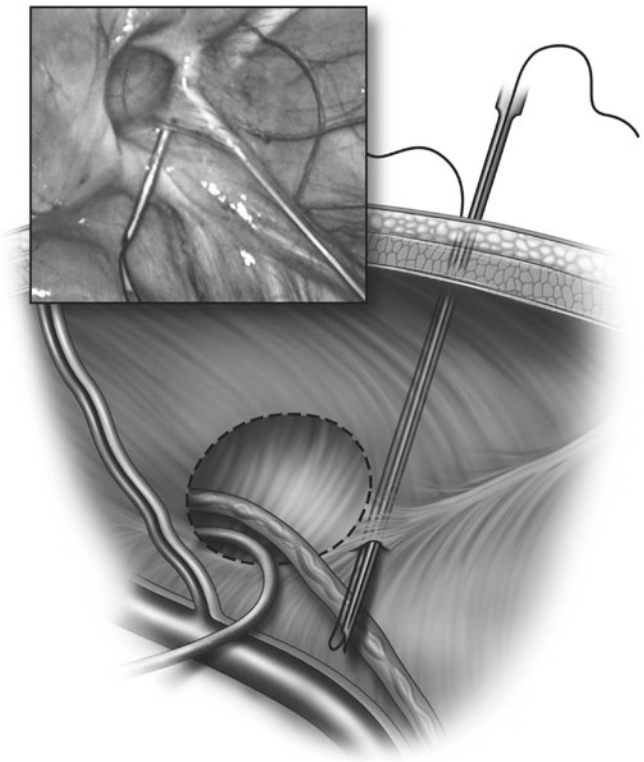

Fig. 90.6 Complete closure of the internal ring following placement of polypropylene suture

scopic repair, while the recurrence rates are similar (5–6 %). Complications, including wound infections, hydrocele, iatrogenic cryptorchidism, and testicular atrophy, appear to be higher following open repair at 2–3 % compared to laparoscopic repair at <1 %. Nevertheless, there is no evidence in the literature that conclusively determines which approach is better.

Advantages of laparoscopic repair include improved visualization of the cord structures; the testicular vessels and vas deferens are not directly dissected, and thus injury to these structures should be rare; there is direct visualization of the contralateral internal ring without need for additional maneuvers or instruments; and uncommon hernias such as direct, femoral, or pantaloon hernias are identified in 5–10 % of patients undergoing laparoscopic repair. There have been no complications reported related to the transabdominal nature of the laparoscopic repair or cosmetic issuer related to the location of the incisions.

Hydrocele

A hydrocele is peritoneal fluid present within the tunica vaginalis. Hydroceles are common in infants, may be bilateral, and are sometimes associated with an inguinal hernia. A noncommunicating hydrocele is typically an asymptomatic, cystic swelling in the scrotum whose size remains constant because the proximal processus vaginalis has obliterated. The spermatic cord can usually be palpated above the scrotal mass, indicating a noncommunicating hydrocele, rather than an incarcerated hernia. Daily fluctuation in size of the scrotal swelling indicates a communicating hydrocele, in which fluid passes from the abdominal cavity into the scrotum across a patent processus vaginalis. A hydrocele of the cord may be seen where fluid is trapped along the spermatic cord with the processus vaginalis obliterated both proximally and distally. Hydroceles can typically be observed for the first 1–2 years of life and may resolve spontaneously.

Editor's Comment

It is safe to assume that every inguinal hernia in a child is congenital and indirect. It is a very rare child who will present with a true direct inguinal hernia, usually in the setting of a connective tissue disorder (Ehlers-Danlos), though a second or unexplained recurrence should probably be repaired with reconstruction of the floor of the inguinal canal, such as a Cooper's ligament repair. Artificial mesh should almost never be needed in the repair of an inguinal hernia in a child, except maybe in the patient with multiple recurrences.

The hernia defect is actually a normal muscular hiatus that allows passage of the spermatic cord or round ligament and should therefore not require repair. In fact, closing the internal ring in a boy risks entrapment of cord structures. Instead, simple ligation and division of the hernia sac should allow the hiatus to close down to a normal size. In fact some surgeons simply excise the hernia sac rather than ligating it, which purportedly allows the normal muscular hiatus to come together naturally—recurrence occurs when even a small wisp of this membrane is left within the internal ring.

Standard open repair has withstood the test of time: it is safe, well-tolerated, associated with a recurrence rate of <1 %, takes less than 10–15 min per side, and leaves a scar that is small and nearly invisible. It seems unlikely that laparoscopic repair could ever replace the traditional operation because of the risk of recurrence and residual hydrocele. Nevertheless, the technology is steadily improving and it could someday become standard.

Ligation of the hernia sac should be performed with absorbable suture, as there is no advantage to using silk and it can occasionally create a foreign body reaction or a cutaneous fistula. There is no need for routine pathologic analysis of the sac. The distal sac should be partially excised, but to avoid injury to the vas deferens the portion of the sac that is adherent to the spermatic cord should be left intact. Sliding hernias can pose a challenge and are repaired using a purse-string suture placed at the level of the internal ring with care to avoid injury to the vas or salpynx. The fallopian tube often

has an avascular "mesentery" medially that can be divided longitudinally up into the abdomen. The first bites of the purse-string suture should then be placed so as to effectively close the resultant slit in the sac at the internal ring.

Incarceration is higher in neonates and prematures. Though the risk of bowel injury is low, there is a risk of testicular atrophy and a higher complication rate of the subsequent repair, including recurrence. Therefore, repair should be undertaken soon after diagnosis, within 1–2 months, and on the same admission for those who present with incarceration. Reduction of an incarcerated hernia is a skill that is learned by experience. Success is increased by sedation, applying constant pressure over long periods (2–3 min at a time) rather than ever-increasing pressure in a short burst, and being patiently steadfast despite straining by the patient and the critical stares of the parents. Often the first sign that the hernia will be reduced successfully is the frictional sensation of two edematous surfaces rubbing against each other (like two pickles rubbing together). It is useful to take a short break every 2–3 min and to try again several times before giving up. Incarcerated ovaries are almost never reducible and should probably be repaired within 1–2 weeks to avoid ischemia or injury to the exposed ovary.

Since repair does not involve muscular reconstruction, most children need no activity restrictions, except maybe avoiding competitive sports for 1–2 weeks. Infection is exceedingly rare, and recurrence should occur in less than 1 in about 200–300 repairs. Recurrence is more common in very young premature boys, sometimes evident the morning after surgery.

Suggested Reading

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Undescended Testis

91

Francois I. Luks and Anthony A. Caldamone

Undescended testis or cryptorchidism is found in approximately 5 % of full-term male neonates and is bilateral in 1–2 %. Normal testicular descent is a complex process that starts as the undifferentiated gonad becomes exposed to a series of factors around the 7th week of gestation. Male differentiation is initiated under the influence of the SR-Y gene product, leading to testosterone secretion by Leydig cells and Müllerian-inhibiting substance (MIS) secretion by follicle-stimulating hormone (FSH)-primed Sertoli cells. The first abdominal component of normal testicular descent occurs between 12 and 16 weeks gestation. It is regulated by MIS, testosterone, and calcitonin gene-related peptide (CGRP), among other factors. Growth and rhythmic contraction of the gubernaculum will gradually guide the testis toward the internal inguinal ring. The role of abdominal pressure is unclear, but congenital conditions that affect normal abdominal wall development, most notably gastroschisis and prune belly syndrome (PBS), are typically associated with cryptorchidism.

The second phase of testicular descent is regulated by androgens and their receptors and occurs between 26 and 40 weeks gestation. Children with androgen insensitivity syndrome (AIS) will typically have undescended testes along with varying degrees of inadequate external virilization. The testis reaches the scrotum by 35 weeks gestation. Postnatal descent can occur up to 3–4 months of age and is thought to be mediated by the perinatal luteinizing hormone (LH) surge, which results in elevated levels of testosterone. As a result, the incidence of undescended testis requiring treatment is approximately 1 % in full-term males.

While most cases of cryptorchidism are congenital, ascended testis, whereby a testis that was scrotal at birth gradually returns to an inguinal location, has been documented in up to 60 % of children older than 2 years who undergo orchidopexy. Although the mechanism is unclear, the ascended testis likely represents an incompletely descended testis or one that was inadequately fixed in the scrotum. Somatic growth then leads to gradual "retraction" out of the scrotum. Cryptorchidism can also be acquired or iatrogenic, after inguinal hernia repair. Here, scar formation, rapid somatic growth, and a gubernaculum that has failed to maintain the testis in the scrotum may be at fault.

Indications for Treatment

An undescended testis exposes the child to several risks. It is thought that a combination of intrinsically abnormal histologic morphology and environmental factors lead to poor function of the undescended testis. Core body temperature, which is 3–5 °C higher than scrotal temperature, may contribute to the progressively decreased spermatogenesis and abnormal germ cell morphology seen in undescended testes. Pathological changes, which include abnormal spermatogonia, fibrosis, and myelin and lipid deposits, can be seen in children as young as 12–18 months. Therefore, orchidopexy offers the best chances to preserve testicular function if performed before 1–1.5 years. Fertility in cryptorchidism is also affected by a 25 % incidence of ductal abnormalities, such as a detached epididymis or an atretic or blind-ending vas deferens.

The vast majority of undescended testes have an associated patent processus vaginalis, which leaves the child at risk for inguinal hernia. This is addressed during orchidopexy. An undescended testis also places the child at higher risk of testicular torsion (typically the extravaginal form of torsion), presumably because of its lax gubernaculum and overall poor attachments.

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The incidence of malignancy is clearly elevated in undescended testes, possibly related to progressive germ cell degeneration and dysplasia. The exact risk is not known, but may be as high as 10–15 times that of the normal population and up to 30 times higher in bilateral cryptorchidism. The risk appears to vary based on the location of the testis, higher for abdominal testes than for inguinal ones. Age at orchidopexy is a factor in malignancy rate as well—orchidopexy after 12 years of age is associated with a relative risk of 5.4, compared with 2.2 for patients operated at a younger age. In children operated on in infancy, however, the increased risk of malignancy has, to date, not been shown to be mitigated by orchidopexy. Nevertheless, an intrascrotal location facilitates examination of the testes and improves early detection rates. The age at presentation of cryptorchidism-associated malignancies is similar to that of testicular cancer in non-cryptorchid testes (third to fifth decade of life). The most common testicular germ cell tumor associated with cryptorchidism is seminoma.

It has been suggested that an inguinal testis is at increased risk of trauma. Whether a scrotal location offers better protection is debatable. Similarly, the psychological effect of cryptorchidism (both on the parents and later on the child) is difficult to quantify and is hardly the sole reason for orchidopexy.

Retractile testis is a normal condition related more to a hyperactive cremasteric reflex than to abnormal testicular descent. This condition does not require treatment. It may be difficult to distinguish from an undescended testis during an office examination, especially if the child is less cooperative. As a result, it is imperative that an examination under anesthesia be done before proceeding with orchidopexy.

Diagnosis

In evaluating a child with cryptorchidism, history is a very important first step. Associated conditions (abdominal wall defects, prune belly syndrome) and other congenital or genetic anomalies (Präder-Willi syndrome, Opitz syndrome, Noonan syndrome) may be present. Premature infants have a much higher incidence of undescended testis, but testicular descent will occur in most of them by 3–6 months of age. In evaluating an empty scrotum, the most important question is whether a scrotal testis was ever present on that side. If the testis can be palpated in the groin or high in the scrotum, is normal in size, can be easily brought down into the scrotum, and, when released after cremaster muscle fatigue, stays in the scrotum transiently, this most likely represents a retractile testis. No further treatment is necessary, as 85–90 % will be fully descended by puberty. Often, a hyperactive cremasteric reflex will make an aggressive examination counterproductive. An important teaching point is to look before you palpate, as one may see the testis down. As contact is made in the genital area, the testis may retract to the groin by a brisk cremasteric reflex, which makes the diagnosis difficult. One can recommend that the parents check for an intrascrotal testis at home, possibly when the child is being given a bath and is relaxed. In rare situations, all attempts at establishing the diagnosis of a retractile testis have failed, and the child is scheduled for an operation, only for the testis to spontaneously descend into the scrotum following induction of general anesthesia. In that case, the operation is aborted and the parents can be reassured.

Underdevelopment of the ipsilateral hemiscrotum can be an indication of true cryptorchidism. Conversely, a normal appearing and symmetric scrotum with well-developed rugae argues against a primary undescended testis and in favor of a retractile or an ascended testis. If the hemiscrotum is empty, the palpation of the external inguinal ring and the inguinoscrotal fat pad may reveal the intermittent presence of a cord or testis, manifested by an often ill-defined, compressible "lump." Other times, a well-defined ovoid structure is identified within the inguinal canal. In these cases, a primary inguinal orchidopexy is indicated.

If, despite a thorough physical examination in a relaxed environment, no structure can be identified in either the inguinal or scrotal regions, one is dealing with a non-palpable (as opposed to merely undescended) testis. A non-palpable testis may represent (a) an inguinal testis that can simply not be palpated, often because of the patient's body habitus or inability to cooperate during the examination, (b) an intra-abdominal testis (including a "peeping testis" that resides close to the internal ring and occasionally protrudes into the inguinal canal), (c) a vanishing testis, or (d) testicular agenesis.

A *vanishing testis* most often represents in utero (or perinatal) testicular torsion, necrosis, and atrophy, and is characterized by the presence of a blind-ending vas deferens and testicular vessels. In true testicular agenesis, the ipsilateral vas and vessels will be absent as well. Because of the close embryologic association between the kidney and testis, renal US should be obtained in this scenario.

Further evaluation of a non-palpable testis is the source of much debate. Ultrasonography is usually accurate at identifying a scrotal or inguinal testis and will most often confirm the presence of a testis that is located distal to the internal ring. Identification of an intra-abdominal testis is more difficult, and a negative ultrasound does not guarantee that a testicle is in fact absent. MRI has been utilized by some and may be more sensitive than US for identifying an intra-abdominal testis, but few clinicians will feel comfortable with a definitive MRI diagnosis. In addition, MRI requires sedation or anesthesia in the infant age group. With the

advent of minimally invasive surgery, which has supplanted open surgical exploration through an extended inguinal or flank incision, preoperative imaging is no longer recommended. It has been abandoned in favor of examination under anesthesia and laparoscopy for the definitive diagnosis of the non-palpable testis.

Medical Evaluation

Identifying anomalies of the hypothalamo-pituitary-testicular axis may be indicated if a genetic or chromosomal syndrome is suspected, particularly if the cryptorchidism is bilateral or associated with other anomalies. Determination of the levels of FSH, LH, and testosterone can verify the presence or absence of testicular tissue. Elevated FSH in a prepubertal boy suggests anorchia. The diagnosis of *bilateral* anorchia in a phenotypic 46 XY male can be made if there are undetectable levels of Müllerian inhibitory substance (MIS) and inhibin B along with an elevated FSH, making surgical exploration unnecessary. Regardless of the degree of external virilization, bilateral non-palpable gonads require an evaluation for a disorder of sex development, and in particular congenital adrenal hyperplasia, the work-up of which should include an electrolyte panel, 17-hydroxyprogesterone level, testosterone level, pelvic US, and karyotype.

Medical Treatment

Both human chorionic gonadotropin (hCG) and gonadotropin-releasing hormone (GnRH) have been used for primary treatment of the undescended testis. While initial reports showed success rates of 25–55 %, randomized, blinded studies have reported success in only 6–21 % of patients. In addition, side effects of hCG in particular may be significant, especially if doses exceed 15,000 IU. These include premature epiphyseal plate fusion and delayed somatic growth. Some reports have raised concerns of a detrimental effect on the germinal epithelium in boys 1–3 years of age who were treated with hCG and GnRH and did not respond. Therefore, primary hormonal treatment should be reserved for those boys who have significant anesthesia or surgical risks.

Several reports have indicated, however, that neoadjuvant or adjuvant treatment with GnRH in addition to orchidopexy may optimize germ cell maturation and eventual sperm production. If these results can be confirmed, this approach remains a possibility for the future, especially with bilateral undescended testes, where the fertility potential remains relatively low despite bilateral orchidopexy.

Surgical Treatment

Ideally, orchidopexy should be performed before 12–18 months of age. After that, fertility is more likely to be affected by persistent cryptorchidism. However, it is important to know and to reassure patients and parents that, even when cryptorchidism is not diagnosed and treated until adolescence or early adulthood, the chance of fertility is not zero.

A testis that can be palpated in the inguinal canal or more distally is best approached through a primary inguinal route, much like an inguinal hernia repair. In older children and when the testis is closer to the internal inguinal ring (lateral portion of the inguinal canal) a primary inguinal approach may be very difficult, as it can be hard to obtain sufficient length on the testicular vessels to bring the testis into a scrotal location. For these patients, and for all patients with a truly non-palpable testis, laparoscopic exploration usually affords better access to a more proximal dissection of the spermatic vessels.

Inguinal Approach

The incision is the same as for an inguinal herniorrhaphy, but the length of the incision may need to be a little more generous, as exposure of the entire inguinal canal is necessary. If need be, the incision can always be extended laterally during the operation. Scarpa's fascia is incised, and the deeper tissues are bluntly and carefully dissected to identify the external oblique fascia and the external inguinal ring. If the testis is located distal to the external inguinal ring, it is first freed of its distal attachments and then carefully retracted distally. The external ring and external oblique fascia are divided sharply, as in a traditional hernia repair. An inguinal testis will be exposed in this way. The concentric layers (external spermatic fascia, cremasteric fascia, internal spermatic fascia) are divided sharply, and the testis and epididymis are visualized. At this stage, the cord will not allow further descent of the testis. Exploration for an inguinal hernia, if present, and careful blunt dissection of the external spermatic fascia around the cord will untether it. Careful dissection of the cremasteric fibers off the cord structures will in essence free the cord from its attachments within the inguinal canal and provide a variable amount of length for the testis to reach the scrotum.

Separation of the processus vaginalis from the spermatic cord is sometimes challenging, as the hernia sac almost surrounds the vas and the testicular vessels (Fig. 91.1). This is in contrast to isolated inguinal hernias or communicating hydroceles, where the sac runs parallel with, distinctly separate from, and anteromedial to the cord structures. Not

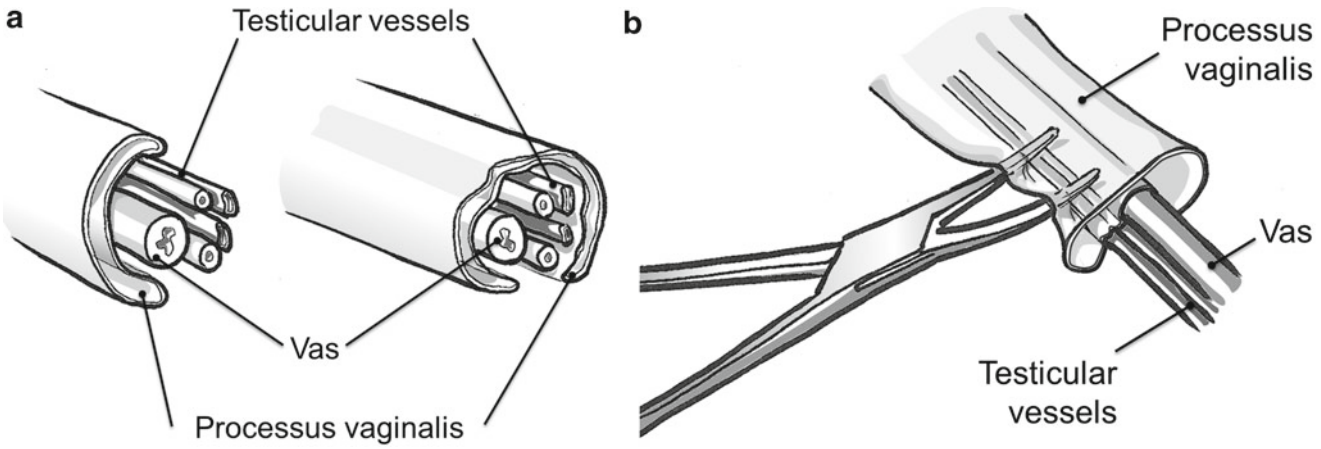

Fig. 91.1 (**a**) Anatomic relationship of processus vaginalis, vas deferens, and testicular vessels in inguinal hernia and communicating hydrocele, left, and in undescended testis. Note that the double-layered processus almost completely surrounds the cord structures, giving the impression that the vas and vessels lie inside the processus. (**b**) Dissection of the sac is performed by carefully peeling it away from the cord structures

uncommonly, the sac will have to be opened, and the deep layer will have to be carefully teased off the vas and the vessels (Fig. 91.1). It is useful, therefore, to open the sac sufficiently distal to the internal ring, to allow enough purchase on the edge of the sac during the dissection. Once the thin sac has been isolated circumferentially, off the cord structures, it can be dissected in a cephalad direction toward the internal inguinal ring. As with any herniorrhaphy, the sac is suture-ligated at its base. Alternatively, the cord and processus can be approach from their posterior aspect by flipping the testis and cord laterally to expose the posterior surface. The external spermatic fascia is incised longitudinally, exposing the spermatic cord. Careful separation of the cord structures from the external spermatic fascia and the processus by dissecting the internal spermatic fascia can then be accomplished with the cord structures in direct view. Once the separation is complete, the processus and external spermatic fascia are clamped with a hemostat, and the usual dissection to the internal ring can proceed.

Dividing the hernia sac and separating the sac from the cord to the level of the internal inguinal ring provides the greatest length on the spermatic cord in most cases, allowing the testis to reach further toward the scrotum. If despite these maneuvers the testis will still not reach with tension, the epigastric vessels can be divided, along with the lateral aspect of the transversalis fascia, which constitute the medial edge of the internal inguinal ring and the distinction between a direct and an indirect inguinal hernia. Since the testicular vessels curve around the epigastrics as they course through the inguinal canal, dividing that edge will provide the testicular vessels with a straighter course, adding some degree of length. This is known as the Prentiss maneuver.

If the testis is located close to the internal ring, especially in an older boy, and it is clear that it will not reach into the scrotum, it is safer to abandon the inguinal approach early, without disturbing any collateral vascularization. Instead, laparoscopy is performed, and the first stage of a Fowler-Stephens procedure is done.

Prescrotal Orchidopexy

In situations where the testis can be milked into the scrotum on examination under anesthesia (EUA) but does not stay, the repair can be approached through a single incision between the lateral edge of the scrotum and the perineum. These are usually older boys, and since the testis is in the superficial inguinal pouch, the processus vaginalis is likely to be closed. This approach allows for a single incision with an optimal cosmetic result. A pouch between the scrotal skin and dartos can be made from the same incision.

Fowler-Stephens Procedure

Most often the limiting factor in performing a successful orchidopexy is the length of the spermatic vessels. The vas deferens, which courses to the midline toward the prostatic urethra, is usually of sufficient length, regardless of the position of the testis. Dividing the testicular vessels allows the necessary length for the testis to reach the scrotum—provided there is enough collateral blood flow to ensure testicular survival. The Fowler-Stephens procedure consists of dividing the testicular vessels and pulling the testis through on a peritoneal pedicle, with collateral vascularization from the peritoneum and the deferential arterioles. This was originally described as a single-stage procedure for the anatomical variation of a long looping vas deferens, allowing for

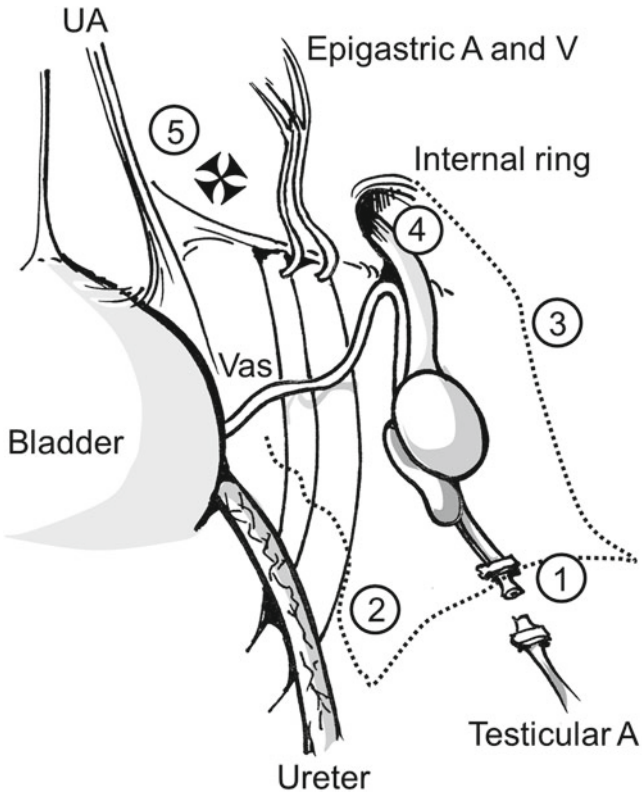

Fig. 91.2 Laparoscopic second-stage Fowler-Stephens procedure. (*1*) The previously clipped testicular vessels are divided, and the testis is freed on a wide peritoneal pedicle, (*2*) along the ureter medially and (*3*) lateral to the internal inguinal ring. (*4*) The gubernaculum is divided as distally as possible, to avoid injury to the looping vas deferens. Finally, (*5*) the testis is pulled into the scrotum through the lower abdominal wall, medial to the epigastric vessels (✠)

ample collateralization. Today this operation is usually performed in two stages, to allow neovascularization before the pull-through.

The first stage of the Fowler-Stephens operation lends itself perfectly to laparoscopy. In addition to a 30° telescope in the umbilicus, two ports are placed in the lower quadrants, and the testicular vessels are visualized behind the posterior peritoneum. One or two metal clips are placed across all the vessels, as high as possible toward the renal hilum, to preserve a maximum of collateral vessels to the testis. No further dissection is attempted, for fear of damaging these branches.

In more than 80 % of cases, the testis will survive and appear normal in size at the time of the second stage, which is typically performed several months later. While this procedure is more complex than the initial vessel ligation or clipping, it can be safely and effectively performed laparoscopically (Fig. 91.2). Alternatively, an extended inguinal or flank incision can be made to allow mobilization of the testis. If the procedure is performed laparoscopically, it is important to introduce a urethral catheter first, to decompress the bladder. First, the peritoneum overlying the clipped vessels is dissected, and the vessels are clipped proximally and then divided. A wide swath of peritoneum is dissected toward the internal ring laterally and down to approximately 1 cm of the vas deferens medially. Care must be taken to avoid injury to the ureter during the medial dissection. Countertraction is obtained by grasping the distal, clipped end of the testicular vessels and gently pulling the testis to the opposite direction of the dissection.

Once the testis can easily be brought to the level of the *contralateral* internal inguinal ring (suggesting that it will reach the scrotum), the gubernaculum can be divided. It is of utmost importance to deliver as much distal gubernaculum as possible from the inguinal canal as the vas deferens often courses distal to the testis and epididymis, along the gubernaculum, before turning toward the pelvic midline. Transecting the gubernaculum too close to the testis increases the risk of a vas injury. While applying traction to the gubernaculum, it is divided as distal as possible, in the internal ring, using electrocautery or harmonic scalpel. Care must be taken not to cause collateral thermal damage.

Once the testis is freed from the gubernaculum, it can be pulled through the anterior abdominal wall for the final step of the orchidopexy. If the testis is close to the internal inguinal ring ("peeping testis"), the testis can be brought through the inguinal canal into a scrotal position, through a small incision in the scrotal margin. Most often, however, a tunnel will be created through the anterior abdominal wall, typically medial to the epigastric vessels. As a clamp is passed through the scrotum and the subcutaneous tissues medial to the inguinal canal, laparoscopic visualization ensures that the tip of the instrument enters medial to the epigastric vessels, but safely lateral to the edge of the bladder.

Scrotal Fixation

Whether the testis is dissected inguinally or through a Fowler-Stephens procedure, the scrotal step is the same. The scrotal skin is incised transversally, taking care not to enter the dartos fascia. A subcutaneous plane is created by blunt dissection, above and below the level of the incision. This space will house the testis and needs therefore to be large enough. Next, the dartos fascia is grasped and incised transversally. That incision must be wide enough to allow passage of the testis. It will be narrowed by placing one or two sutures on either side of the cord, once the testis has been pulled through. In so doing, the testis cannot ascend and will remain in its dartos pouch (Fig. 91.3). The testis can be anchored in the subcutaneous pouch using absorbable sutures. It is important during the pull-through to ensure that the testicular vessels and the vas are not twisted and that no undue tension is present. If, despite all maneuvers, the testis still cannot reach the scrotal pouch, it is acceptable to tack it high in the scrotum and consider reexploration at a later date.

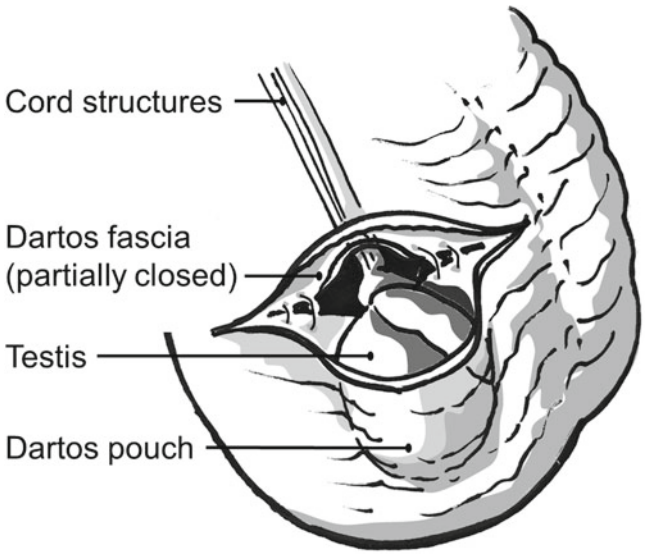

Fig. 91.3 Scrotal portion of the orchidopexy. A subcutaneous pocket is created before the dartos fascia is incised transversally. Once the testis is pulled through into the pouch, the dartos is partially closed around the cord structures, to prevent testicular ascent

The scrotal incision is typically closed using absorbable sutures, with or without skin glue. The inguinal and laparoscopic incisions are closed as per routine.

Postoperative Care

Although orchidopexy represents a very common surgical procedure in the pediatric population, complications do occasionally occur. These complications include damage to the ilioinguinal nerve, injury to the vas deferens, hematoma, surgical site infection, testicular retraction, and testicular atrophy. Testicular atrophy can result from cautery injury, severe traction on the spermatic vessels, excessive skeletonization of the cord, torsion of the spermatic vessels, or division of the spermatic vessels during a Fowler-Stephens repair.

The success rate of orchidopexy is directly related to the preoperative testicular location and the type of repair performed. A successful orchidopexy can be defined as scrotal position without testicular atrophy. Overall success rates based upon preoperative position are 75–80 % for abdominal, 85–90 % for canalicular, and 90–95 % for testes located distal to the external ring.

Editor's Comment

An undescended testis increases the risk of cancer and sterility. Orchidopexy, especially when done early, can apparently improve both to some degree. The main reasons to perform an orchidopexy are to improve fertility and to allow adequate self-examination for the early detection of a tumor. It is usually best to recommend orchidopexy when the child is about a year of age, as there is no urgency, the risks of general anesthesia are minimized, and in some cases the testis will descend on its own.

A palpable testis can usually be made to reach the lower scrotum after high ligation of the patent processus and mobilization of the spermatic cord, though this occasionally requires some dissection into the retroperitoneum. The hernia sac is almost always extremely thin and difficult to separate from the spermatic cord structures. Though rarely clinically evident preoperatively, these are among the most challenging hernia repairs that we encounter, demanding patience and meticulous technique. Non-palpable testes are rarely able to reach the scrotum using standard techniques and almost always require laparoscopy to confirm the presence of a viable testis and, if a viable testis is found, a more sophisticated surgical approach such as the Stephens-Fowler operation or microvascular revascularization. The testicular salvage rate is clearly highest when these procedures are performed by surgeons with a great deal of experience in a high-volume pediatric urologic practice.

Boys with retractile testes can usually be safely observed, but they need to be followed closely as they approach adolescence to be sure that the testis continues to descend. Some will need an orchidopexy as they grow older if the testis remains in the upper scrotum or inguinal canal and can no longer be brought down into the scrotum proper. When repairing an inguinal hernia in a child with a retractile testis, it is important to assess the adequacy of the gubernaculum and the length of the spermatic cord before closing the incision because these patients are at risk of the testis becoming tethered in the upper scrotum or inguinal canal by scarring in the area of the repair and along the spermatic cord. If the gubernaculum is absent or ineffective, it is appropriate to perform an orchidopexy at the time of the herniorrhaphy.

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Acute Scrotum

92

Ruthie Su

Torsion can occur at any age, but its incidence clusters during the neonatal period and during adolescence, with a peak at 12–16 years. Different anatomic configurations are thought to predispose the two waves. In the first 30 days or so of life, the tunica vaginalis has not yet fused to the scrotal wall, and so the spermatic cord and tunica vaginalis are permitted to twist along the long axis of the cord, a so-called *extravaginal* or neonatal torsion. Asynchronous contralateral neonatal torsion resulting in anorchia has been reported, which is why although the rates of testis salvage for neonatal torsion are low, urgent exploration is driven by the possible risk of contralateral torsion. On the other hand, in the adolescent, incomplete fixation of the tunica vaginalis to the epididymis results in a "bell-clapper" deformity, and the spermatic cord is allowed to twist within the tunica vaginalis layer, resulting in *intravaginal* torsion. Possible precipitating factors for testicular torsion in adolescents include cold temperature, sudden movement or trauma with activation of the cremasteric reflex, rapid growth of the testis during puberty, or an undescended testis.

The clinical history for testis torsion usually includes sudden onset of scrotal pain that can occur during sleep, at rest, or with activity. The pain is severe, unremitting, localizes to one hemiscrotum, and may be associated with nausea or vomiting. In contrast, epididymitis causes a more insidious onset of pain and is often associated with fever and voiding symptoms, while nausea and vomiting are rare.

The review of systems should help rule out competing diagnoses. Key points to note include recent trauma (although testis torsion is still possible in this context, trauma can be an independent or related event subject to recall bias), abdominal or flank pain (passing kidney stones can cause referred scrotal pain), a history of UTI, recent viral illness, fever, dysuria, or urinary frequency. In the adolescent, one should inquire about a sexual history and penile discharge (Table 92.1).

On physical examination, potential diagnoses can share the same gross appearance of an erythematous and indurated scrotum, but there are subtle aspects one can look for that may be helpful in narrowing the differential. A torsed testis may be observed in a higher scrotal position compared to the normal testis due to the twisting and shortening of the spermatic cord. A blue dot may be seen on the scrotal skin of the affected side and has historically been associated with a torsed testis appendage (appendix testis, a Mullerian duct remnant; appendix epididymis, a Wolffian duct remnant) but can also be seen with testis torsion. Tenderness may be localized to the epididymis in epididymitis, whereas global tenderness of the affected hemiscrotum is more typical of testis torsion. The cremasteric reflexes should be tested by lightly scratching the patient's inner thigh. This maneuver stimulates the genitofemoral nerve and causes the ipsilateral cremaster muscle to contract. An active cremasteric reflex, whereby a brisk upward movement of the testis is elicited, makes testis torsion unlikely. One should also palpate the abdomen and flank for other causes of scrotal pain and inspect the urethra for discharge.

A urinalysis is helpful in evaluating scrotal pain. Hematuria suggests nephrolithiasis, while pyuria or leukocyte esterase suggests epididymitis. If testis torsion is strongly suspected based on history and physical examination alone, then emergent scrotal exploration should not be delayed. Testis salvage is inversely correlated with duration and degree of torsion with >24 h and at least 360° , resulting in severe atrophy or complete loss. The surgical informed consent form should include surgical exploration with possible orchiopexy or orchiectomy of the affected testis and contralateral orchiopexy to eliminate the risk of metachronous torsion. If the history is equivocal, then Doppler US might be helpful to clarify the diagnosis. If US is not available and torsion cannot be ruled out, then one should proceed to surgical exploration.

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Table 92.1 Differential diagnosis of the acute scrotum

Hernia/hydrocele
Appendage torsion
Spermatic cord torsion
Epididymitis
Epididymo-orchitis
Scrotal edema
Vasculitis
Trauma
Tumor hemorrhage
Musculoskeletal pain
Referred pain

Color Doppler ultrasonography has an estimated 85 % sensitivity and 100 % specificity for testis torsion, but the accuracy is dependent on the technician's experience. The key piece of information from the examination is the appearance of intratesticular arterial flow compared to the contralateral testis. If flow is reduced or absent, then testis exploration is indicated. Spiral twisting of the spermatic cord (whirlpool sign) is associated with a 96 % sensitivity and 99 % specificity but requires an experienced technician to examine the entire spermatic cord and high-resolution US. Increased flow and size of the affected testis or epididymis is more consistent with inflammation caused by either infection or trauma. In the case of testis trauma, the tunica albuginea should be evaluated for evidence of rupture. A hyper- or hypo-echoic nodule without blood flow indicates a torsed appendage.

Treatment

Manual detorsion can be attempted if torsion is suspected, if the patient can tolerate the physical manipulation, or if there will be a delay in getting the patient to the OR. If successful, manual detorsion reduces the ischemia time and alleviates the patient's symptoms. This attempt should not delay surgical exploration because there may still be residual torsion and the testis remains at risk for torsing again. The maneuver is performed by rotating the testis between thumb and forefinger laterally, as if opening a book. If the patient has increased discomfort by rotating in this direction, then one should try rotating the testis in the opposite direction. Success is indicated by the patient's immediate relief.

The surgical approach for testis torsion can be either through separate transverse incisions in each hemiscrotum or with a single midline incision. Dissection is carried down to the tunica vaginalis. In the case of intravaginal torsion, the tunica vaginalis is opened and the ischemic testis delivered. The direction and number of twists of the spermatic cord should be observed, and the untwisted testis should be wrapped in warm saline-soaked gauze while the contralateral orchiopexy is performed (Fig. 92.1). After opening the tunica vaginalis and delivering the contralateral testis, the testis appendages are removed with light cautery. A subdartos pouch is developed, and small permanent suture such as polypropylene is used to secure the testis to the deep dartos fascia medially, inferiorly, and laterally. This should be done by taking small bites of tunica albuginea along the direction of the testis blood supply, which runs along the equator, to avoid iatrogenic testis ischemia. After this is done, the affected testis should be evaluated for viability. Reperfusion will be indicated by an improvement in the congested discoloration, or a Doppler probe can be used. The tunica albuginea can also be incised to observe for arterial bleeding. If there are no signs of vascular recovery, then an orchiectomy should be performed. In the prepubescent patient, a prosthesis can be considered near the end of puberty around 18 years old or 6 months later in the older adolescent patient. Alternatively, it has been hypothesized that testis compartment syndrome may contribute to persistent ischemia following surgical detorsion and that a fasciotomy in the tunica albuginea followed by a tunica vaginalis flap may improve testis salvage. Currently, the concept remains speculative but indicates an area in the management of torsion that may evolve in the future.

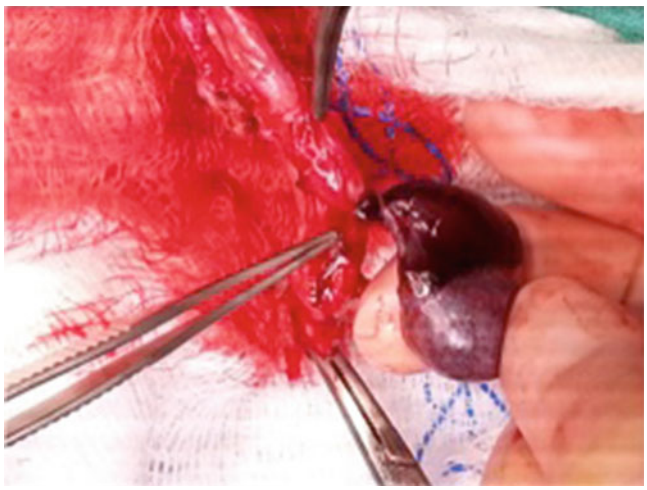

Fig. 92.1 Spermatic cord torsion at the junction of the cord and epididymis

Management of a torsed appendage consists of supportive care with scrotal support, rest, and pain control. Epididymitis in otherwise healthy younger boys is typically noninfectious or viral in origin and is treated with supportive care. If bacterial infection is suggested on urine screening, then empiric antibiotic treatment is indicated, and at follow-up the patient should be evaluated for voiding dysfunction or urethral anomalies obstructing flow. The sexually active adolescent should be screened for *Chlamydia* and *N. gonorrhea*.

All patients with suspected epididymitis should be instructed for close follow-up especially if symptoms worsen despite antibiotics.

Prognosis

The impact of torsion on fertility remains unknown due to the lack of uniform long-term follow-up of patients treated for torsion. Subtle differences in sperm quality and gonadotropin levels have been detected among patients treated for torsion compared to normal controls, suggesting global testicular dysfunction in males with torsion. The autoimmune hypothesis has not been supported by analysis of antisperm antibodies in individuals with torsion. Although torsion is a common event, it is not a significant contributor to male infertility.

Editor's Comment

It is important for the pediatric general surgeon to be able to evaluate and treat boys with acute scrotal pain appropriately, especially if a pediatric urologist is not immediately available, as minutes count if the testis is to be salvaged. For the same reason, it is also preferable to perform a careful surgical exploration under general anesthesia, even if the diagnosis turns out to be epididymitis or torsion of the appendix testis, rather than to allow a testis to infarct while trying to establish the right diagnosis with certainty. Unfortunately, most cases will present beyond 8–12 h, in which case the distinguishing features of the possible diagnoses become more subtle.

The boy with acute scrotal pain will often describe a history of trauma, which is usually a red herring. They are invariably painfully embarrassed, and it is important to approach them with compassionate patience—we should validate their anxiety, but a measured, confident, and professional demeanor is important. The examiner's hands should be warm. For many boys, even a normal examination is painful. The examination should be systematic and precise, looking for point tenderness, masses, the "blue dot" sign associated with a torsed appendix testis, and secondary signs like redness, edema, or ecchymosis.

It was long taught that an ischemic testicle generates antisperm antibodies that can cause infertility. This is not currently a widely held belief and does not appear to be supported by the data. Nevertheless, a testis that is frankly necrotic should be removed as it can be painful, is at risk of becoming infected, and will atrophy and need to be removed eventually anyway.

An incarcerated inguinal-scrotal hernia can mimic an acute scrotum and is also a relatively common cause of testicular ischemia. When in doubt, prompt exploration through an inguinal incision will confirm the diagnosis and allow reduction of the bowel. An ultrasound can be helpful, but if the results are equivocal, surgical exploration is justified and necessary.

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Cloacal Exstrophy

93

John M. Gatti and David Juang

Cloacal exstrophy is a variant of the bladder exstrophic anomalies and occurs with an incidence of approximately 1 in 200,000–400,000 live births. The male-to-female ratio of occurrence has been reported to be 2:1 in some studies and almost equal in others. It is distinguished from the other various bladder exstrophies by its association with other malformations including omphalocele, imperforate anus, and spinal defects. Cloacal exstrophy is sometimes referred to as the omphalocele/exstrophy/imperforate anus/spinal defect (OEIS) complex. Surgical reconstruction was previously thought to be futile due to a 90 % mortality related to prematurity, short-bowel syndrome, sepsis, and renal and central nervous system deficits. In 1960, Rickham described four patients in which the vesico-intestinal fissure was preserved, and this segment of bowel incorporated in continuity with the cecum and hindgut. The importance of separating the genitourinary tract from the gastrointestinal tract and preserving bowel to prevent short-gut physiology became apparent and survival increased, but mortality remained at nearly 50 % mostly due to malnutrition and sepsis. Numerous improvements in neonatal care including the advent of parenteral nutrition and innovative approaches to reconstruction have allowed survival rates to approach 90 %. Treatment now centers on improving the quality of life of these patients.

Controversy exists regarding the timing of the development of cloacal exstrophy. Failure or damage earlier in development is supported by the many associated anomalies found with cloacal exstrophy. The development of cloacal exstrophy is believed to occur sometime between the 4th and 8th week of fetal development. In development, the cloaca is separated from the amniotic space by the cloacal membrane. This membrane exists below the level of the umbilicus. Mesoderm derived from the mesenchyme migrates between the ecto- and endodermal layers of the membrane, leading to the development of the lower abdominal muscles and the pubis. Simultaneously, the mesenchyme contributes to the formation of the urorectal septum and the lumbosacral somites. Earlier damage would affect the mesenchyme and ultimately disrupt the infraumbilical mesoderm, the urorectal septum, and the lumbosacral somites. Failure of development or migration of these structures would lead to the anomalies that are classically recognized as cloacal exstrophy: a persistent cloaca and a rudimentary hindgut with imperforate anus; breakdown of the cloacal membrane, which causes exstrophy of the cloaca; failure of fusion of the genital tubercles and omphalocele (85 % incidence); and incomplete development of the lumbosacral vertebrae.

Diagnosis

Early radiographic diagnostic accuracy in addition to amniocentesis has allowed for early identification of chromosomal sex and permits an early discussion with parents regarding gender assignment. Prenatal diagnosis with ultrasonography is achievable (Fig. 93.1). The absence of bladder filling; a large, anterior abdominal wall defect; and vertebral anomalies are considered characteristic findings, and renal and pelvic anomalies may also be appreciated. Fetal MRI has also further increased diagnostic accuracy, giving high-quality anatomic detail similar to that achieved with fetoscopy.

Treatment

Given the rarity and variability of findings in cloacal anomalies and cloacal exstrophy, it is best managed at tertiary care centers with experience with the spectrum of this malformation and with resources for high-risk pregnancies and

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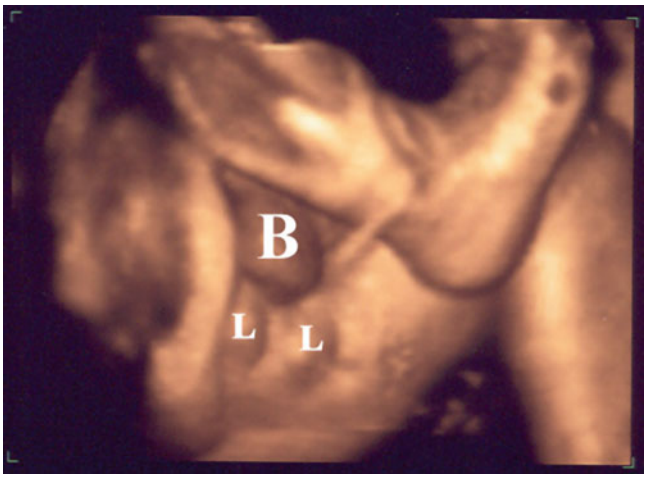

Fig. 93.1 3D prenatal ultrasound revealing bladder exstrophy: *B* Exstrophic bladder plate. *L* Labia

complex neonatal management. Advances in imaging have allowed for prenatal diagnosis and planning for delivery at or near the treatment center. A multidisciplinary team, including perinatologist, pediatric urologist, pediatric surgeon, orthopaedic surgeon, neonatologist, with input from a gastroenterologist, endocrinologist, and neurosurgeon, is best equipped to treat these patients and thus organized can provide early counseling in the setting of antenatal diagnosis. The neonatologist is especially important because many of these patients are premature or small for gestational age. Treatment considerations should account for complications of prematurity including sepsis, respiratory distress, and necrotizing enterocolitis.

At or after delivery, it is important to control the umbilical cord with suture rather than a plastic clamp that can abrade the exposed exstrophic tissues. We recommend covering the mucosalized surfaces with a barrier such as plastic wrap to prevent abrasion from the diaper. Early diagnostic studies should include chromosomal assessment with a karyotype or FISH to help in gender assignment. The antiquated approach of commonly assigning genotypic males a female gender due to small phallic size resulted in significant gender dysphoria and has been abandoned for a more individualized approach heavily weighted on the genotype. Imaging studies including ultrasonography of the abdomen, internal genitalia, kidneys, and spine should be performed to identify comorbidities. Antibiotic prophylaxis is generally administered because of the exposed bladder and high incidence of renal abnormalities.

A multidisciplinary consensus regarding the overall treatment plan should be proposed as soon as possible after birth. Consideration should be given to issues related to the genitourinary tract, gastrointestinal tract, abdominal wall, sex assignment, and management of spinal and orthopedic anomalies, and a timeline should be constructed for the family.

Surgical Reconstruction

Both staged and complete primary repairs have been described. It has been our preference to use a staged approach. This allows some flexibility for the involvement of multiple team members and a prioritization of treatment. Spina bifida may require urgent closure prior to ventral abdominal wall closure. Once the infant has stabilized, the initial surgical goal is separation and closure of the preserved intestinal tract culminating in an end colostomy.

Primary closure of the omphalocele can be accomplished in 80 % of cases. If we are unable to close the fascia, skin closure or staged closure is utilized. Closure of the omphalocele with reapproximation of the hemi-bladders, tubularization of the cecum, and incorporation of the hind gut into the GI tract, with delayed repair of the exstrophic bladder and genitalia, has reduced the incidence of postoperative abdominal compartment syndrome. Unification of the hemibladders creates a natural silo and facilitates closure of the body wall. The exposed bladder plate can be managed with plastic wrap until the neonate has gained weight and grown before the remaining reconstructive procedures are attempted. A delayed closure guarantees the need for later osteotomy for pelvic closure, but early repair will not likely change this need given the uniformly wide pubic diastasis seen in cloacal exstrophy.

Stage I: Gastrointestinal Reconstruction

The reconstruction of the GI tract begins with catheterization of the lateral ureteral orifices (Fig. 93.2). The omphalocele is repaired with the initial dissection starting at the superior portion of the defect. The lateral bladder plates are separated from the adjacent skin. The umbilical vessels are ligated as they are identified. Cloacal exstrophy has been grossly described as an "elephant's face." The bladder plate is divided in half by the hindgut plate. The ileum enters and intussuscepts into the middle of the hindgut, creating the "trunk" appearance with classically duplicated appendiceal appendages located laterally to give the impression of "tusks." The intusscepted ileum is carefully reduced, and the mucosal junction between the bladder walls and the intestine should be incised. This can be done carefully with electrocautery. The cecal plate is then tubularized.

The hindgut segment can be anastomosed either in an isoperistaltic or antiperistaltic fashion. In some cases, there are hindgut duplications, which if possible can also be brought into continuity or preserved for later use. Given the long-term potential for malabsorption due to short gut syndrome, no segment of bowel should be discarded. The bowel may be utilized in the future for reconstruction of the bowel, bladder, or vagina. Appendiceal segments should be preserved for possible use in later reconstruction of the urinary tract, but are often quite rudimentary. The end of the reconstructed

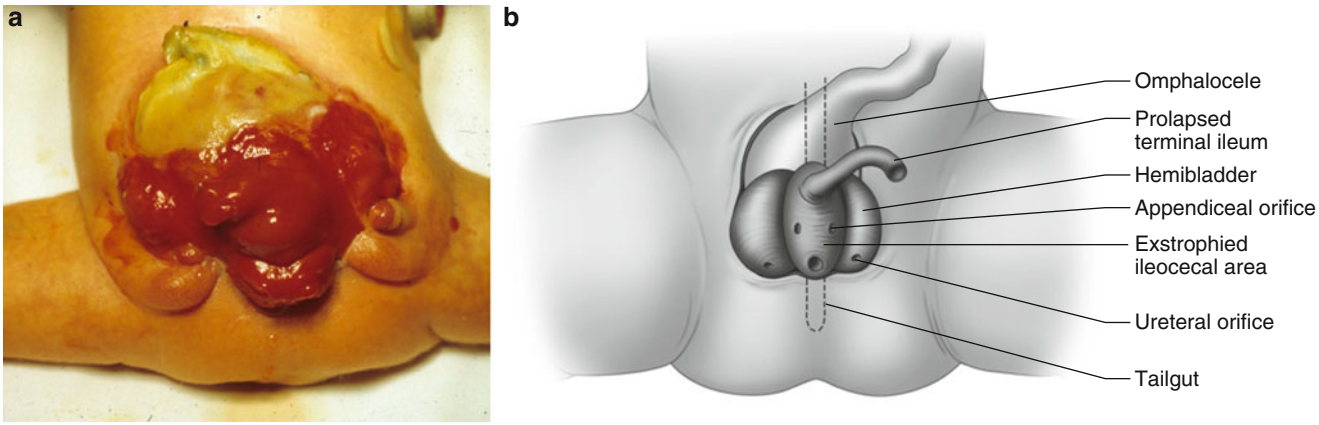

Fig. 93.2 Classic cloacal exstrophy with midline vesico-intestinal fissure dividing the bladder halves. A large omphalocele is found cephalad to this structure, and many times the prolapsed terminal ileum is noted as well. The key is identifying the hindgut or tailgut which tends to be a diminutive structure and yet can be refunctionalized following closure of the vesico-intestinal fissure

colon should be brought out well lateral and superior to avoid fecal contamination of the bladder and to also allow for proper appliance application. Closure of the vesico-intestinal fissure completes this first stage. If inguinal hernias are identified, these may also be closed at this portion of the procedure.

Because of altered innervation to the pelvis, only a few patients with cloacal exstrophy are candidates for an anal pull-through procedure. Preservation of colonic length is crucial to the success of this approach; therefore, patients with a foreshortened colon may function best with end colostomy. Complete anorectal reconstruction is possible. Recent series have shown promising results in select patients. Candidates for reconstruction must have few if any neurologic deficits, adequate pelvic floor musculature assessed by magnetic resonance imaging and cutaneous stimulation, and successful bowel management while diverted with the ability to form solid stool through the stoma. These patients have poor bowel control but can remain clean with bowel management regiments.

Stage II: Closure of the Genitourinary Tract with Osteotomy

The first stage of closure is generally temporizing and allows the infant to grow and develop. The second stage is planned when the infant is more robust, and other comorbidity is sufficiently managed to optimize the outcome of the second stage.

The second stage is similar in many ways to closure of classic bladder exstrophy. After canulation of the ureteral orifices, the unified bladder plate is mobilized from the abdominal wall superiorly and laterally. Distally, the dissection is more challenging. The bladder and bladder neck are mobilized with transection of the intersymphyseal bands inferolaterally to allow the reconstructed bladder neck a more posterior and orthotopic position in the perineum within the pelvic floor musculature. The urethra is tubularized over an 8–10 F tube. It is generally short, and a perineal meatus is often the outcome in both sexes. The bladder and urethra are closed in two layers, and ureteral stents and a suprapubic tube are brought to the skin through the dome of the bladder. This is an ideal time to create a neo-umbilicus orthotopically positioned in the midline at the level of the iliac crests using one of various flap techniques. Bringing these drainage tubes through the neo-umbilicus facilitates the persistence of this depression after tube removal. We generally leave a soft 6 F silastic urethral stent for approximately 5–7 days postoperatively, but some argue against this for concerns of urethral erosion.

It is critical to address the Mullerian duct structures in females at this juncture. Vaginal duplication is common, and failure to recognize a second vagina at this stage can result in an excluded system that might manifest with abdominal pain related to hematometrocolpos with menses at the onset of puberty. The hemivaginas may be unified by incising the medial wall with a primary anastomosis, but should one be more robust, the hypoplastic vagina and associated uterus may be discarded. A more creative maneuver to gain vaginal length for reconstruction, particularly in the long-channel variant of cloacal malformation, is the "vaginal switch," where one uterus is discarded, the associated vagina rotated on its axis, and then matured to the other vagina to elongate the vaginal channel to reach the perineum.

Closure of the abdominal wall invariably requires pelvic osteotomy performed by the orthopaedic team. Different approaches have been championed, but we have favored a bilateral combined anterior innominate and vertical posterior iliac osteotomy using an anterior approach.

The pubic bones are approximated in the midline with two separate 00 PDS sutures while holding the symphysis in

approximation. The bladder and bladder neck are pushed deep into the pelvis and protected with a malleable retractor during this process. The urethra and vagina are matured to the perineum, but this is often facilitated by starting this process prior to approximation of the symphysis as these structures can become difficult to expose once the pubic bones are approximated.

Male genital reconstruction is more challenging. The hemicorpora are freed from the overlying shaft skin and mobilized, taking care to avoid the lateral neurovascular bundles. Modestly mobilizing the crura laterally off the inferior aspect of the pubic bones has enhanced relative penile length, and it probably also improves the negative impact of pubic approximation on penile perfusion. We have observed the penis to become dusky after approximation of the pubis, which requires takedown and additional mobilization to avoid a devastating outcome. Rotation of the corporal bodies in a closed-book fashion during the reconstruction improves the dorsal chordee and brings the neurovascular bundles into a more orthotopic, superolateral position for future reference.

The penis is resurfaced variably with local skin as in hypospadias repair incorporating Byer's flaps, and the urethra usually positioned at the base of the shaft if possible. This commonly requires later urethroplasty for an orthotopically poised meatus. Unifying the bifid scrotum may be included at this stage if possible. An intestinal pull-through procedure could also be considered at this time, but in our experience is uncommon and generally considered at a later time.

Despite similarities in anatomy, cloacal abnormalities are remarkably variable, and reconstruction must be individually tailored, often with elements of flexibility and creativity. Hendren's classic article characterizing cloacal reconstruction is a collection of individual case descriptions and is a testament to the variability in both anatomic features and reconstructive maneuvers required in the repair of these anomalies (Fig. 93.3). These children are generally incontinent, and ureteral reimplant, bladder neck reconstruction, possible bladder augmentation, and creation of a catheterizable urinary stoma are considered as the child approaches school age.

Postoperative Care

The patient is managed in modified Bryant's traction for approximately 3 weeks, after which a mermaid-type wrap is employed for roughly a month to take some tension off of the closure. We have been dissatisfied with the use of the Spica cast as it has insufficiently immobilized the pelvis likely due to the early need for cast revision as the abdominal distention rapidly improves, creating room for movement. We have been enthusiastic with the use of external fixation, but have found that this is an undependable option until approximately 1 year of age when iliac bone density allows for its reliable use. Whether delaying closure to that degree is of ultimate benefit has not been determined. In the setting of repeat or late-staged operation when the child is older, external fixation has allowed a shorter hospital course and earlier discharge home.

The urethral stent is removed after 5–7 days, and the ureteral stents are removed sequentially once the urine output shifts from these stents to the suprapubic tube or urethra. At 3 weeks, a cystogram is performed to rule out a bladder leak and confirm urethral patency. At that point, the suprapubic tube can be occluded for a voiding trial and then removed. Ultrasonography is important to rule out any element of obstruction once drainage tubes are removed. Virtually all ureters reflux, so antibiotic prophylaxis is generally utilized.

Additional Procedures

As patients approach school age, continence is assessed. Voiding cystourethrography and urodynamic assessment yield information on persistence of reflux and bladder capacity. Our experience has been that very few store urine well due to low outlet resistance. As a result, the bladder capacity tends to be low. If the bladder capacity is greater than 80–120 mL, a bladder neck reconstruction with bilateral ureteral reimplant and creation of a catheterizable stoma as a safety net for poor bladder emptying can be entertained. More often, bladder augmentation is also incorporated. The selection of bowel segment for this purpose must be tailored to gastrointestinal issues of malabsorption, constipation/diarrhea, renal function, and sensory impairment if considering a gastric component. The high incidence of the hematuria dysuria syndrome precludes the isolated use of stomach for augmentation in the sensate patient.

Although tissue-engineered bladder substitution has shown exciting progress, this option is certainly in its infancy and is still considered experimental. Reassessment of the genitalia in girls is revisited as they approach puberty with examination under anesthesia and cysto-vaginoscopy to assess for patency in anticipation of menstruation. Colonic substitution is often considered for reconstruction in cases of an inadequate vaginal length or stenosis. The cloaca population is prone to short-gut syndrome, and so this is often not an option. Growing experience with buccal graft vaginoplasty has provided a promising new alternative for reconstruction.

Outcomes

Survival rates today for patients with cloacal exstrophy exceed 90 %. Deaths occur largely due to complications related to prematurity and complex anomalies incompatible

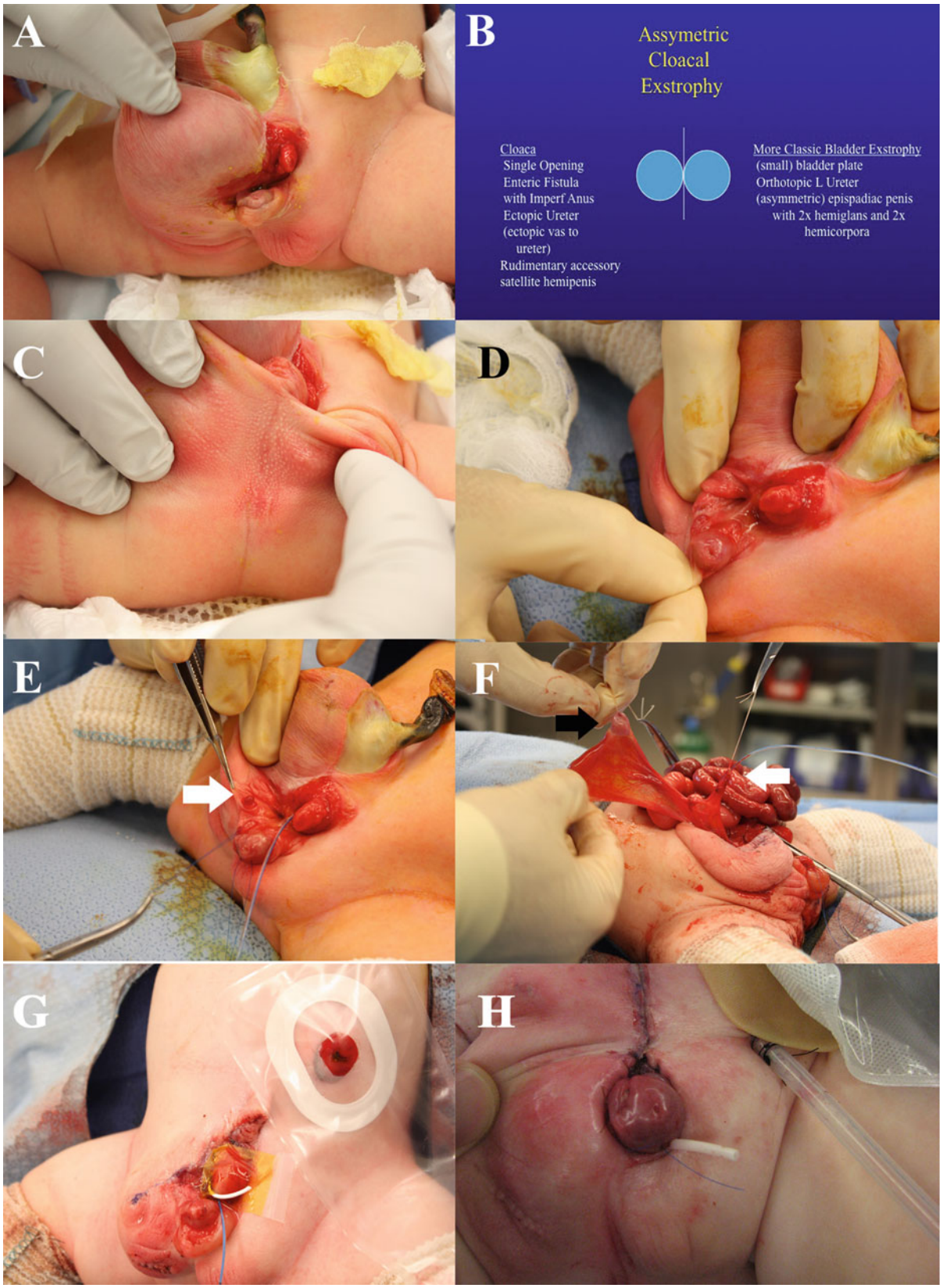

Fig. 93.3 Asymmetrical cloacal exstrophy variant: (**a**) Initial appearance. (**b**) Vertical division of asymmetric anatomic findings. (**c**) Absent anus. (**d**) Fingertip-sized bladder left of midline, asymmetric penis, and meconium in cloaca to right of midline. (**e**) *Arrow* indicates extranumerary rudimentary right hemipenis. (**f**) *Black arrow* indicates right testis with vas deferens ectopic to ureter. *White arrow* indicates right ureter ectopic to the cloaca. (**g**) At completion of first stage closure with end colostomy and enteric fistula closure, right orchiopexy with vasectomy, and right ureteral reimplant. (**h**) At completion of second stage at 10 weeks of age. Pelvic osteotomy was performed with excision of right extranumerary hemipenis, bladder closure, penile reconstruction resulting in subcoronal hypospadias, and right to left transureteroureterostomy for distal right ureteral stenosis

with life such as renal agenesis. Interestingly, these patients have not been found to have major cardiac anomalies. Bladder dehiscence remains higher than those with classic bladder exstrophy. Gastrointestinal morbidity remains low, and most patients will have satisfactory gastrointestinal function. Numerous improvements in neonatal care including the advent of parenteral nutrition and innovative approaches to reconstruction have allowed treatment now to focus on improving the quality of life of these patients.

Trends and Controversies

The immediate postnatal repair of exstrophy anomalies has become less requisite, and a delay of weeks to months to allow coordination of a team of surgeons with particular interest and experience in exstrophy repair may be a more favorable approach. With this growing flexibility, several institutions have begun to share cases of bladder exstrophy closure in an effort to enhance experience and collaboration in real-time with surgeons travelling to other institutions to participate. This trend will likely increase in the future due to the relative rarity of these cases and the growing ease of this process as telemedicine technology evolves. Its objective benefit has yet to be determined.

Controversy exists regarding the ideal mechanism for pelvic immobilization in the immediate postoperative period, which continues to be hotly debated. At present, there are champions for the varied approaches and the choice is largely based on personal preference.

Gender assignment is less controversial. It is primarily based on genotype rather than phallic size or other anatomic considerations as it once was. The penis in bladder exstrophy is not only shorter than average overall; a larger proportion of the crura are attached proximally to the pubic rami, further decreasing functional length. Despite this, sexual function and satisfaction appear reasonable and do not justify gender conversion at the expense of later gender dysphoria, which can occur in the virilized brain after early testosterone exposure.

Editor's Comment

Cloacal exstrophy is one of the most challenging combinations of anomalies to manage, and a dedicated and experienced multidisciplinary team is crucial. There are several groups from multiple institutions who regularly share their experiences, involve each other in the care of their patients, and learn from each other. This unprecedented example of collegiality, innovation, and mutual noncompetition appears to have been highly successful and should be a model for treating rare and complex surgical disorders.

Although in some cases a primary reconstruction is feasible, many patients benefit from a staged approach. An overaggressive attempt to incorporate all structures and close the abdomen can result in abdominal compartment syndrome. The idea of a colonic pull-through in the newborn period is appealing, although clearly the infant needs to be stable and have well-developed pelvic anatomy. Likewise, if vaginal reconstruction can be performed early, the results are usually better. Phallic reconstruction can be most difficult, especially since the native tissue is often diminutive and the two halves can be quite separate. Finally, in cases of sexual ambiguity, karyotyping is extremely important because proper sex assignment needs to be established early and with certainty.

Suggested Reading

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Disorders of Sex Development

94

Thomas F. Kolon

Phenotypic sex results from the differentiation of internal ducts and external genitalia under the influence of hormones and other factors. When discordance occurs among three processes (chromosomal, gonadal, phenotypic sex determination), a DSD is the result. The diagnosis and management of DSD conditions can be confusing because of the wide spectrum in physical appearance often observed. An important issue with any DSD evaluation is not to be overwhelmed by the enormity of the differential diagnosis possibilities. Instead, by working systematically through the differential diagnosis pathway based on the physical examination and laboratory findings, many possible diagnoses can be discarded along the way.

A newborn with bilateral impalpable testes or a unilateral impalpable testis and severe hypospadias should be regarded as having a DSD until proven otherwise, whether or not the genitalia grossly appear ambiguous. The reported incidence of DSD in individuals with hypospadias and cryptorchidism ranges between 17 and 50 %, with increasing risk of a DSD associated with increasing severity of hypospadias combined with an undescended testis (UDT). A complete patient history should include the gestational age at birth, ingestion of exogenous maternal hormones (such as those used in assisted reproductive techniques), and maternal use of oral contraceptives or soy products during pregnancy. It is also useful to take a careful family history of urologic abnormalities, neonatal deaths, precocious puberty, amenorrhea, infertility, or consanguinity. The patient's mother should also be observed for virilization or a cushingoid appearance. An early clue to possible DSD is discordance between the fetal karyotype and the genitalia visible by antenatal sonogram.

For the purposes of diagnosis and treatment, the most important physical finding is the palpable presence of one or two gonads. If no gonads are palpable, four main categories are possible: 46XX DSD, 46XY DSD, gonadal dysgenesis (GD), or ovotesticular DSD. Of these, 46XX DSD is most commonly seen, followed by mixed GD. A palpable gonad is highly suggestive of a testis or, rarely, an ovotestis (with primarily testis histology), since ovaries and streak gonads do not descend. If one gonad is palpable, 46XX DSD and pure GD are ruled out, while mixed GD, ovotesticular DSD and 46XY DSD remain possibilities. If two gonads are palpable, 46XY DSD, or, rarely, ovotesticular DSD, is most likely (Fig. 94.1).

The child should be examined in a warm room, supine in the frog leg position with both legs free. It is important to check the size, location, and texture of both gonads, if palpable. The UDT may be found in the inguinal canal, the superficial inguinal pouch, at the upper scrotum or, rarely, in the ectopic femoral, perineal, or contralateral scrotal regions. One should also note the development and pigmentation of the labioscrotal folds along with any other congenital anomalies of other body systems. An abnormal phallic size should be documented by width and stretched length measurements. Included is a description of the position of the urethral meatus, the amount of penile curvature, and the number of orifices.

Another critical finding on physical examination is the presence of a uterus that is palpable by digital rectal examination as an anterior midline cord-like structure. A thorough general physical examination should make note of any dysmorphic features indicating syndromic manifestations (short broad neck, widely spaced nipples, aniridia).

In the immediate newborn period, all patients require a karyotype and laboratory evaluation: serum electrolytes, 17-hydroxyprogesterone (17OHP), testosterone (T), dihydrotestosterone (DHT), luteinizing hormone (LH), and follicle-stimulating hormone (FSH) levels. Once the karyotype is determined, theses levels will assist in narrowing the differential diagnosis. If the serum 17OHP level is very elevated, a diagnosis of congenital adrenal hyperplasia (CAH) can be made. Testing should be performed in the

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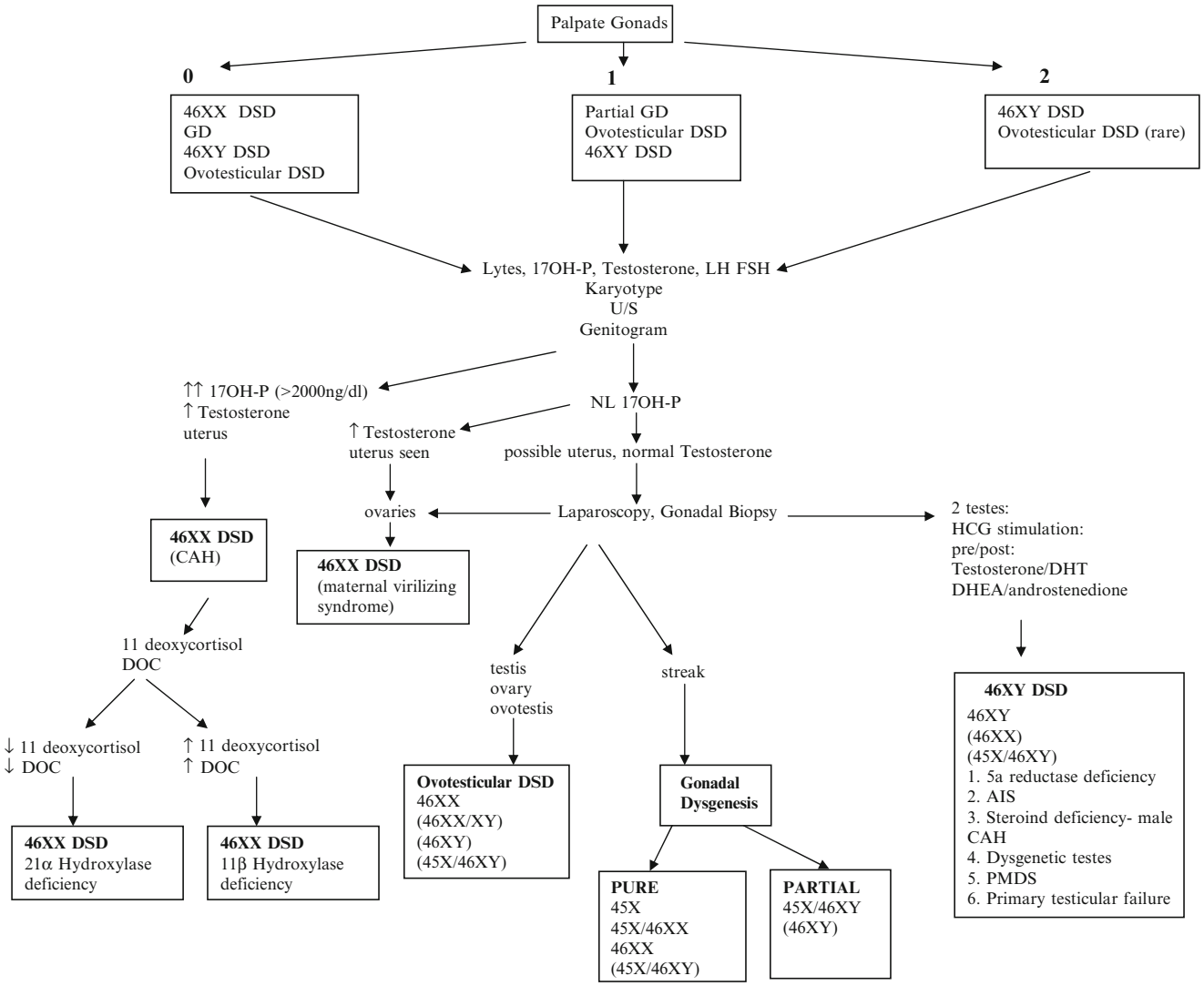

Fig. 94.1 Diagnostic algorithm for patients with DSD

early morning as there is diurnal variation of serum 17OHP concentration. Determining the serum levels of 11-deoxycortisol and deoxycorticosterone (DOC) levels will help differentiate between 21-hydroxylase and 11β-hydroxylase deficiencies. If the levels are elevated, then a diagnosis of 11β-hydroxylase deficiency can be made; low levels confirm 21-hydroxylase deficiency.

If the 17OHP level is normal, a T:DHT ratio along with androgen precursors before and after hCG stimulation will help elucidate the 46XY DSD etiology. In order to avoid surgical exploration on the 46 XY male with bilateral anorchia, studies to assess for the presence of any viable testicular tissue should include serum Müllerian inhibitory substance (MIS) and consider additional hormone testing (inhibin B, FSH, LH, and testosterone). It is important to remember that in the first 60–90 days of life, a normal gonadotropin surge occurs with a resultant increase in the testosterone level and its precursors. During this time, exogenous hCG stimulation for androgen evaluation can be postponed, allowing for the body's maternal hormonal changes to help in the evaluation. The failure of the testosterone to increase after hCG stimulation alone is not diagnostic of anorchia; testicular dysgenesis with UDT may fail to respond to hCG stimulation. If the hCG stimulation test is used, it must be confirmed with a significant elevation in serum FSH and LH. If the patient has anorchia and is less than 12 months of age, serum LH is high, FSH is high, MIS and inhibin B are undetectable, and testosterone is low. In infants with bilateral anorchia, the postnatal testosterone surge will be absent. While the utility of hCG stimulation testing remains disputed, most recent studies suggest that a phenotypic 46 XY male with bilateral nonpalpable testes has isolated anorchia if undetectable levels of MIS and inhibin B with an elevated FSH level are present, making neither hCG stimulation testing nor surgical exploration necessary

for the diagnosis of isolated anorchia. However, if the endocrine markers of Sertoli and Leydig cell function are normal, then testicular tissue is present despite being not palpable and warrants surgical therapy.

A US should be the first radiologic examination obtained; it is noninvasive, quick, and relatively inexpensive. Although it is only accurate in detecting intra-abdominal testes about half the time, US can detect gonads in the inguinal region and can help assess Müllerian anatomy. Although more expensive, CT and MRI can also further delineate the anatomy. A genitogram can be performed to evaluate a urogenital sinus including the entry of the urethra in the vagina as well as highlighting a cervical impression.

Infants with intra-abdominal or nonpalpable testes in whom ovotesticular, mixed GD, or 46XY DSD is considered will require an open or laparoscopic exploration with bilateral deep longitudinal gonadal biopsies for histologic evaluation. This will aid in determining the presence of ovotestes, streak gonads, or dysgenetic testes and confirming the diagnosis. It is important to note that this procedure is a diagnostic maneuver. Therefore, removal of gonads or reproductive organs should be deferred until the final pathology report is available, a diagnosis is confirmed, and a discussion has occurred between the family and all consultants regarding a gender decision.

46XX

The most common DSD is 46 XX DSD. The patient has a 46XX genotype with normal ovaries and Müllerian derivatives. Sexual ambiguity is limited to masculinization of the external genitalia from in utero exposure to androgens. Maternal sources of elevated androgens during pregnancy include ovarian tumors (arrhenoblastoma, luteoma of pregnancy, Krukenberg tumors) and ingestion of androgens. Congenital adrenal hyperplasia, which accounts for the majority of 46XX DSD patients, describes a group of autosomal recessive disorders that arise from a deficiency in one of five genes required for the biosynthesis of cortisol from cholesterol (Fig. 94.2). While all five of these biochemical defects are characterized by impaired cortisol secretion, only deficiencies in 21-hydroxylase (21-OH) and 11β-hydroxylase (11β-OH) activity are predominantly masculinizing disorders, with 3β-hydroxysteroid dehydrogenase (3βHSD) deficiency to a lesser extent. Females are masculinized by the excess androgens, while most male fetuses have normal genitalia.

A deficiency in activity of 21-hydroxylase accounts for approximately 90 % of CAH cases. The enzyme is encoded by the *CYP21* gene and *CYP21P* pseudogene, both located on chromosome 6 between HLA-B and HLA-DR

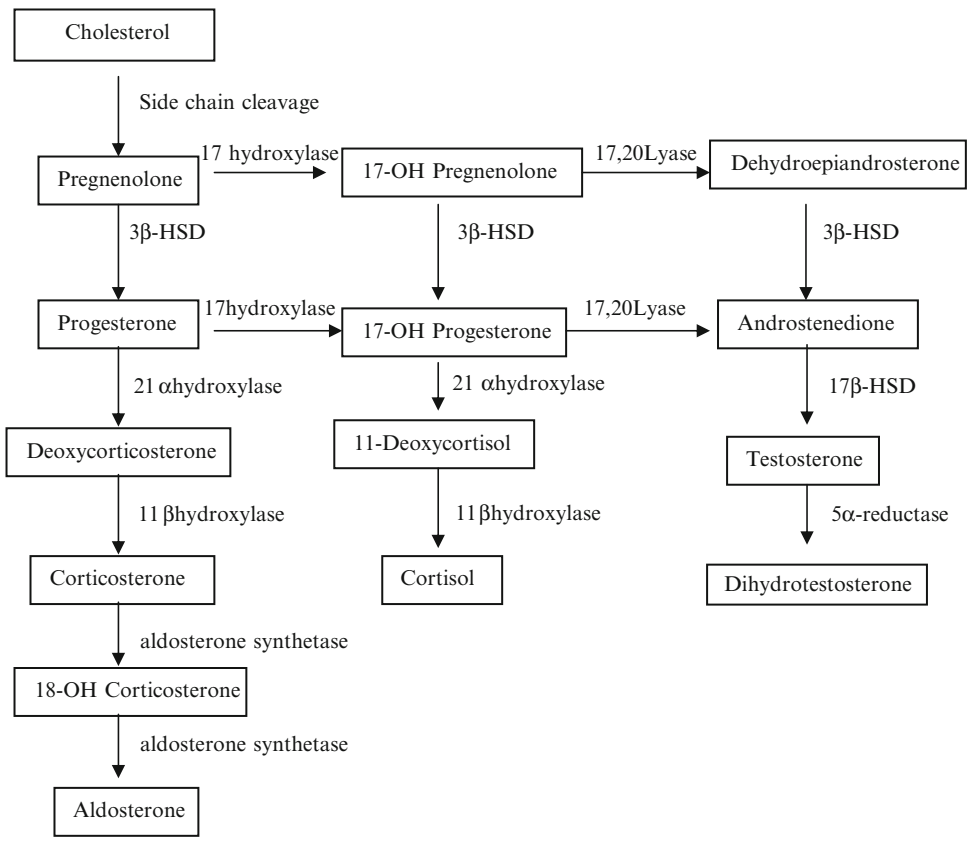

Fig. 94.2 The steroid biosynthetic pathway

Table 94.1 Genetic etiologies of DSD

Syndrome	Karyotype	Genital phenotype	Gene	Locus
21-Hydroxylase deficiency	XX	Masculinized	*CYP21B*	6p21.3
11-Hydroxylase deficiency	XX	Masculinized	*CYP11* (B1,B2)	8q21–22
3βHSD deficiency	XX	Ambiguous	*HSD3B2*	1p13.1
17α-Hydroxylase or 17,20 lyase deficiency	XX XY	Ambiguous	*CYP17*	10q24–25
17βHSD deficiency	XY	Ambiguous	*17BHSD3*	9q22
Lipoid adrenal hyperplasia	XX XY	Female, ovarian failure (XX)	*StAR*	8p11.2
Leydig cell failure	XY	Ambiguous	hCG/LH receptor	2p21
Androgen insensitivity	XY	Ambiguous (female- AIS 7)	*AR*	Xq11–12
5α-Reductase deficiency	XY	Ambiguous, pubertal virilization	*SRD5A2*	2p23
Persistent Mullerian duct	XY	Male	*AMH* AMH II receptor	19q13.3 12q13
Complete gonadal dysgenesis	XX 45X, 45X/46XX XY	Female, sexual infantilism	FSH receptor X monosomy *SRY* *DSS* (*DAX-1*) *SOX9* *WT-1*	2p16–21 Paternal X loss Yp53.3 Xp 21–22 17q24.3–25.1 11p13
Partial gonadal dysgenesis	45X/46XY XY	Ambiguous	Unknown	Unknown
XY dysgenesis	XY 45X/46XY	Ambiguous	*SRY* *DSS* (*DAX-1*) *XH-2* *WT-1* *SOX9* *SF-1*	Yp53.3 Xp 21–22 Xq13.3 11p13 17q24.3–25.1 9q33
Ovotesticular DSD	XX XX/XY XY	Ambiguous	*SRY* Testis cascade Downstream genes	Yp53.3 Unknown
Klinefelter	47XXY 46XY/47XXY	Variable androgen deficiency	XY	Sex chromosome Nondisjunction
XX testicular DSD	XX	Ambiguous to normal	*SRY*	Y translocation to X

(Table 94.1). Recombination between *CYP21* and the homologous but inactive *CYP21P* account for approximately 95 % of 21-OH deficiency mutations. The result is excessive androgen levels in addition to cortisol and mineralocorticoid deficiencies. Characteristic lab abnormalities include a markedly elevated level of 17OHP (as much as 50-fold above normal).

In 75 % of patients with classic 21-OH CAH, an associated salt loss crisis is observed in the first week of life. Electrolyte disturbances in these patients include low serum sodium, elevated potassium, and very elevated renin levels. Because most male CAH patients have normal external genitalia, the diagnosis of the 21-OH salt-wasting type is often unsuspected and thus delayed. Patients with simple masculinizing 21-OH deficiency have been identified with a conversion mutation causing severely decreased enzyme activity, but sufficient aldosterone production to prevent salt wasting. Postnatal treatment is based on replacement of glucocorticoid and mineralocorticoid needs, typically hydrocortisone (ideally 10–15 mg/m^2/day) and fludrocortisol (30–75 mcg/day) in 2 or 3 daily doses. Salt supplementation (2–3 g/day) in infants is recommended for those with the salt-losing type.

In 5 % of patients with CAH, a deficiency can be identified in 11β-OH, which is the last step in production of cortisol. Two 11β-OH genes, both located on chromosome 8q, have been identified in the adrenal cortex. Like 21-OH deficiencies, defects in *11β-OH* will result in androgen excess leading to varying degrees of fetal masculinization. In addition *11β-OH* defects also result in an accumulation of deoxycorticosterone, a potent mineralocorticoid, resulting in arterial hypertension in about two thirds of patients. Salt loss is not commonly seen; rather, patients will typically have an expanded fluid volume, low potassium, high sodium serum levels, and low renin activity. Therapy is directed toward glucocorticoid replacement. The diagnosis is made by elevated serum concentrations of DOC and 11-deoxycortisol, while plasma renin levels remain suppressed.

Pregnenolone conversion to progesterone and dehydroepiandrosterone (DHEA) into androstenedione are catalyzed by 3βHSD. Two isoforms have been described, each encoded by a specific gene, *HSD3B1* and *HSD3B2*. Complete deficiency of 3ßHSD is a rare form of CAH, resulting in impaired synthesis of adrenal aldosterone and cortisol and gonadal testosterone and estradiol. These newborns have severe CAH and exhibit signs of mineralocorticoid and glucocorticoid deficiency in the first week of life. Mild masculinization occurs as a result of DHEA conversion to testosterone in fetal placenta and peripheral tissues by the type 1 isoform. Affected females have mild to moderate clitorimegaly, and males exhibit incomplete masculinization of the external genitalia.

Other more rare defects in the biosynthesis of cortisol can also lead to CAH conditions. These include defects in the enzyme CYP17 (P450) which catalyzes two reactions: (1) 17 α-hydroxylation of pregnenolone and (2) 17,20 lyase (side chain cleavage) of 17 hydroxypregnenolone and 17 hydroxyprogesterone. Steroidogenic acute regulatory (StAR) deficiency, also called *lipoid adrenal hyperplasia*, is a rare form of CAH and is the most severe genetic defect in steroidogenesis, resulting in death in days to weeks as a result of adrenocortical hormone deficiency. It is associated with severe glucocorticoid and mineralocorticoid deficiency due to failure to convert cholesterol to pregnenolone. The adrenal glands of affected children are large, containing very high levels of cholesterol and cholesterol esters.

Gonadal Dysgenesis

Mixed GD is the next most common DSD disorder. In general, GD disorders comprise a spectrum of anomalies ranging from complete absence of gonadal development to delayed gonadal failure. Gonadal dysgenesis involves a gonad that has not properly developed into a testis or an ovary such as a dysgenetic testis or a streak gonad.

Pure GD describes a 46XX child with streak gonads or, more commonly, a child with Turner syndrome (45XX or 45XX/46XX). An uncommon form of pure GD is called Swyer syndrome, characterized by a female phenotype, normal to tall stature, bilateral dysgenetic gonads, sexual infantilism with primary amenorrhea, and a 46XY genotype. Mutations in the *SRY* gene are reported in approximately 10–15 % of XY sex reversal cases. Gonadectomy of both streak gonads is recommended in these patients due to the high risk of tumor formation.

Partial GD refers to disorders with partial testicular development including mixed GD, dysgenetic male pseudohermaphroditism, and some forms of testicular or ovarian regression. Mixed or partial gonadal dysgenesis (45XX/46XY or 46XY) involves a streak gonad on one side and a testis, often dysgenetic, on the other side. A patient with a Y chromosome in the karyotype is at a higher risk than the general population to develop a tumor in a streak or dysgenetic gonad. Because of the 20–25 % age-related risk of malignant transformation into a dysgerminoma, surgical removal of the gonad is recommended. The patient with a 45XX/46XY karyotype and normal testis biopsy could retain his testis if it is descended or can be placed in the scrotum. This child would then need a very close follow-up of the testis by monthly self-exams for tumor formation.

46XY

46XY DSD is a heterogeneous disorder in which testes are present, but the internal duct system and/or external genitalia are incompletely masculinized. The phenotype is variable, ranging from completely female external genitalia to the mild male phenotype of isolated hypospadias or cryptorchidism. 46XY DSD can be classified into eight basic etiologic categories: (1) Leydig cell failure, (2) testosterone biosynthesis defects, (3) androgen insensitivity syndrome, (4) 5α-reductase deficiency, (5) persistent Müllerian duct syndrome, (6) testicular dysgenesis, (7) primary testicular failure (vanishing testes syndrome), and (8) exogenous hormone effects.

46XY DSD can result from Leydig cell unresponsiveness to human chorionic gonadotropin hormone (hCG) and LH. The phenotypes of these patients vary from normal female to hypoplastic external male genitalia.

Described earlier for 46XX DSD, defects in four of the steps of the steroid biosynthetic pathway from cholesterol to testosterone may also produce genital ambiguity in the male. These include the less common forms of CAH: 3βHSD deficiency, CYP17 deficiency, StAR protein deficiency, and 17βHSD deficiency. While DHEA conversion into testosterone results in masculinization in females, this same process insufficiently masculinizes affected males. Thus, male infants exhibit ambiguous genitalia with variable degrees of hypospadias, cryptorchidism, penoscrotal transposition, and a blind vaginal pouch. Males with CYP17 deficiency display a developmental spectrum from the normal female phenotype to the ambiguous hypospadiac male. The magnitude of incomplete male masculinization correlates with the severity of the block in 17α-hydroxylation. Affected males with StAR deficiency have severe testosterone deficiencies and exhibit female external genitalia with a blind vaginal pouch. No surviving 46XY patient has demonstrated testis function at puberty. The affected 46XY males with 17βHSD deficiency have external female genitalia, inguinal testes, internal male ducts, and a blind vaginal pouch. At puberty, these patients demonstrate an increase in their levels of gonadotropins, androstenedione, estrone, and testosterone. Delayed virilization occurs if testosterone levels approach the normal range.

The spectrum of androgen insensitivity syndrome (AIS) ranges from 46XY patients with complete androgen insensitivity syndrome (CAIS) to partial AIS. This syndrome is the result of mutations mainly of the steroid-binding domain of the androgen receptor resulting in receptors unable to bind androgens or receptors that bind androgens but do not function properly. This disorder occurs in approximately 1 in 40,000 live male births. The external genitalia of a child with CAIS resemble a normal female although the karyotype is XY and testes are located internally. Historically, these children have been raised as girls and most are diagnosed during surgical repair of an inguinal hernia or at puberty during an evaluation for primary amenorrhea. Management focuses on hormonal replacement, gonadectomy due to the high risk of malignancy, and possible treatment of vaginal hypoplasia. From a cross-sectional study using a self-administered validated sexual function assessment questionnaire, 90 % of women with CAIS had sexual difficulties when compared with the general female population, most commonly sexual infrequency and vaginal penetration difficulty. The timing of gonadectomy (pre- vs. postpuberty) is controversial, and endocrine, oncologic, and psychological issues should be taken into account. The incidence of malignancy associated with CAIS is 0.8 % and usually occurs after puberty, though there has been a case report of a malignant abdominal yolk sac tumor in a 17-month-old child and several reports of benign abdominal masses. The incidence of tumor formation in PAIS is much higher and early gonadectomy is recommended.

Patients born with the autosomal recessive condition, 5α-reductase deficiency, have a defect in the conversion of testosterone to DHT, causing a form of male pseudohermaphroditism. Numerous gene mutations, mainly missense mutations, have been reported. These patients are 46XY and usually have male Wolffian structures but female urogenital sinus and external genitalia. In some cohorts, they are generally assigned a female sex at birth and raised as females. However, at puberty, virilization occurs as testosterone levels increase into the adult male range, while DHT remains disproportionately low.

Anti-Müllerian hormone (AMH), or MIS, is secreted by the Sertoli cells causing apoptosis and regression of the Müllerian duct. Since the diagnosis of persistent Müllerian duct syndrome (PMDS) is often made at the time of inguinal hernia repair or orchiopexy, this syndrome is commonly referred to as hernia uteri inguinale. PMDS can occur from a failure of the testes to synthesize or secrete MIS or from a failure in the MIS receptor. It is associated with cryptorchidism and cases of seminomas and intra-abdominal testicular torsion have been reported.

Patients with dysgenetic 46XY exhibit ambiguous development of the internal genital ducts, the urogenital sinus, and the external genitalia. Dysgenetic testes can result from mutations or deletions of any of the genes involved in the testis determination cascade, namely, *SRY*, *DAX*, *WT1*, and *SOX9*. Male patients with Denys-Drash syndrome have ambiguous genitalia with streak or dysgenetic gonads, progressive nephropathy, and a predisposition to develop Wilms tumor.

Ovotesticular Disorder

Ovotesticular DSD requires expression of both ovarian and testicular tissues that is a result from sex chromosome mosaicism, chimerism, or a Y-chromosome translocation. The most common karyotype in the United States is 46XX, although 46XY or mosaicism or chimerism (46XX/46XY) can occur. Some patients with 46XX true hermaphroditism have the *SRY* gene translocated from the Y to the X chromosome. In these patients, genital ambiguity is thought to result from extensive inactivation of the *SRY*-carrying X chromosome. The gonads can be a testis on one side, an ovary on the contralateral side, an ovotestis bilaterally, or an ovotestis and either a testis or ovary on the contralateral side. The external genitalia are ambiguous with hypospadias and incomplete fusion of the labioscrotal folds. The genital duct differentiation in these patients generally follows that of the ipsilateral gonad on that side, such as a fallopian tube with an ovary and a vas deferens with a testis due to local paracrine effect of hormones.

Gender Assignment

Gender assignment in the patient with DSD can often be a difficult decision, with strongly differing viewpoints regarding the timing of gender assignment. The first is to assign and complete genital reconstruction shortly after birth, which might avoid internal conflicts with the patient or external societal conflicts as the child develops. Opponents argue that gender reassignment should be a decision of the affected individual during puberty. They maintain that neither the physician nor the family can predict future gender identity and sexual orientation for the individual. Nevertheless, the decision regarding assignment of sex for rearing should be guided by three equally important factors: the functional and anatomic abilities of the genitalia (size of phallus or vagina, fertility potential), the cause of the DSD, and the values and desires of the family.

One factor in the decision-making process that is becoming clearer is the large body of evidence to support the notion that the prenatal and postnatal hormonal milieu has an important role in predicting gender and sexual identity. Genetically female rats given testosterone shortly after birth do not exhibit typical female behavior during adulthood.

One study showed that CAH girls with excessive prenatal androgen exposure have tomboyish personalities and are more likely to have bisexual or homosexual interests than women without CAH. Among women affected by CAH from 21-OH deficiencies, there appears to be outcome differences between the more severe salt-losing form and simple masculinizing forms. Women with simple masculinizing CAH (when the deficiency is partial) reported greater satisfaction and fewer concerns with regard to their psychosexual outcomes compared to women with the more severe salt-losing form.

In general, newborns with ambiguous genitalia from CAH have a normal uterus and ovaries and should be raised as females. In cases of bilateral testicular dysgenesis where a vagina and uterus are present, female assignment may be desirable. Likewise, in cases of complete androgen insensitivity syndrome, a female orientation is correct. For most other instances of partial resistance, it is desirable to opt for male rearing. Male rearing is also appropriate when a deficit in 5α-reductase is identified since further virilization occurs during puberty. In cases where ovarian function can be preserved, female assignment is preferable for these cases of ovotesticular DSD. When a decision for female rearing is made in 46XY DSD, removal of testicular tissue is performed. If raised as males, careful follow-up is important due to the increased risk of gonadal tumors.

Newer research identifying the genetic and molecular etiologies of DSD has helped further our understanding of these complex conditions. In children born with a DSD condition, a methodical and thorough understanding of the physical exam, hormonal, radiographic, genetic, and psychological investigations is required for the proper diagnosis and management. Regardless, the decision regarding gender assignment has life-long implications and requires an open dialogue between the family and the child's caregivers.

Editor's Comment

Few diagnoses generate more profoundly difficult ethical, emotional, psychological, and physical issues for patients and their parents than that of a disorder of sexual development. For parents, the most immediate problem is gender assignment. The workup needs to be quick but thorough, before a rash and potentially regrettable decision is made. Gender assignment was traditionally made by the medical professionals involved (predominantly men) often in a paternalistic and categorical fashion, without input from the parents and without regard for issues related to gender identity or psychosocial development. For the most part, if the child had a phallus, the assignment was male, and if there was no phallus (or an inadequate phallus), the assignment was female. Many of these patients eventually suffered greatly as they entered adolescence and adulthood because of inescapable feelings of having been erroneously assigned. Today, though the decision is still very difficult, more is known about the physiology, parents are given much more of a say in the decision-making process, and most importantly, patients are treated with considerably more compassion and acceptance than they were in the past.

Care of the child with a DSD should involve a multidisciplinary team that includes pediatric urology, endocrinology, genetics, psychology, and social work. Families need a great deal of emotional support and it is always best to include them as integral members of the team. The workup should be evidence based and systematic, such that the initially overwhelming differential diagnosis can be pared down quickly and appropriately and the parents can best decide how to proceed. It cannot be overemphasized that these situations need to be handled tactfully and with the utmost empathy. Every word overheard by the parents will be scrutinized and if misinterpreted can lead to deep resentment and anger.

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Vagina

95

Peter Mattei

Vaginal anomalies are uncommon but can have a profound impact for the patient and her family. Because of the close physical and developmental association with the urinary tract, these disorders have a tendency to affect urinary function in infants and young girls, but have obvious implications for sexual and reproductive function in adolescence and young adulthood. The pediatric surgeon is the de facto gynecologist for children and will be called upon to assess the girl with vaginal anomalies and address issues both acutely and over time.

A detailed understanding of the anatomy of the female internal and external genitalia, including how this varies substantially with age, is critical. In an infant or young girl, the fallopian tubes and uterus are often surprisingly diminutive and easily dismissed as unimportant structures at laparotomy. When the salpinx herniates through a hernia sac, it can look like nothing more than a small supportive ligament or extraneous tissue. And the uterus can be barely fingertip size until just before puberty when it enlarges rather dramatically. The vagina is also small in caliber but when chronically obstructed (hydrocolpos) can become astonishingly large, sometimes extending for a distance into the abdomen. The proximal one third of the vagina is derived from Müllerian structures, while the distal two thirds are derived from ectoderm and the urogenital sinus. The boundary of the two becomes important in patients with a transverse septum at this site and in phenotypic girls with androgen insensitivity syndrome who are found to have only the external portion of a normal vagina (foreshortened vagina).

Externally, the pudenda in a child are in many respects a miniaturized version of the adult anatomy, with some important differences. The labia majora are underdeveloped, while the labia minora are contiguous with the clitoral hood and can sometimes be fused by adhesions. The urethra can be difficult to identify and is variable in location. The hymen in infants and young children is seen as a soft circumferential ring of mildly edematous tissue with a small central aperture that should normally lie just proximal to the urethra. The portion of the vagina distal to the hymen is referred to as the vestibule or the fourchette, a common location for a rectal fistula to form in girls with imperforate anus.

Physical Examination

Performing a gynecologic examination in any patient demands a comforting and sensitive approach. There should be proper instrumentation available, excellent lighting, and plenty of time available to perform an unhurried and careful examination. Infants and prepubescent girls should never endure a digital or speculum examination, and more mature girls should not, except under extraordinary circumstances, be made to undergo their first gynecologic speculum examination in the ED by untrained personnel.

Infants and young children can be examined externally in the frog-leg position with at most a lubricated cotton-tipped applicator used to gently move the hymen to see inside the vagina. A digital *rectal* examination allows palpation of the uterus and can be used to perform a bimanual examination of the lower abdomen. It is also useful to rule out foreign bodies of the vagina. If a deeper visual examination is required, a vaginoscopy (using a cystoscope under saline or a small bronchoscope) is performed under general anesthesia.

Vaginal Anomalies

Vaginal anomalies can occur in isolation but are often associated with disorders of sexual differentiation, cloacal anomalies, urogenital anomalies, or anal atresia. Vaginal agenesis is rare (1:10,000 births) and is usually suspected in infancy due to an atypical appearance of the hymen. It can also be present

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in adolescents with primary amenorrhea or pelvic pain. Patients with Mayer-Rokitansky-Küster-Hauser syndrome (Müllerian agenesis) have an absent or hypoplastic vagina, uterus, and fallopian tubes, with normal female karyotype and normal ovaries. Some patients with MRKH also have unilateral renal agenesis and, rarely, congenital heart disease. Any girl with vaginal atresia, hypoplasia, or agenesis should be evaluated with US to rule out solitary kidney and to assess the uterus and adnexa.

The goal of surgical treatment for the patient with vaginal agenesis is the restoration or creation of a functional vagina. Some patients with a rudimentary vagina and an external opening (or skin dimple) respond well to serial dilations over many years. They eventually need to learn to dilate themselves daily, so motivation and the absence of pain are important factors in the success of this method.

A second option is to create a space anterior to the rectum and line it with skin grafts. This is a complex procedure that requires a dedicated and experienced multidisciplinary team. Skin is not an ideal substitute for vaginal epithelium, which produces mucus and is more pliable, and daily dilations almost always become necessary. Eventually tissue engineering could hold promise for a better vaginal replacement, but this is not yet available. Finally, good results have been achieved in some centers with vaginal substitutes such as colon or small intestine. These are essentially pedicle grafts that can be sutured in place and dilated as necessary.

A transverse vaginal septum is the uncommon result of incomplete fusion of the Müllerian (proximal third) and urogenital sinus (distal two thirds) components of the vagina (Fig. 95.1). These are usually isolated anomalies that present with hydrometrocolpos in a teenager with cyclic abdominal pain and amenorrhea. It rarely presents in a younger girl with hydrocolpos. US or MRI usually confirm the diagnosis, though it is not uncommon to discover a transverse vaginal septum in the operation room in a girl with presumed imperforate hymen (who was not examined properly before induction of anesthesia). These are best treated by excising the central portion of the septum and approximating the mucosal edges with absorbable suture. Some will make a cruciate or double-cross incision before over sewing the edges. These septa can be 2–3 cm thick and quite vascular. Some can be located quite proximal in the vagina, making a transvaginal repair extremely difficult. In these cases, there have been case reports of laparoscopic repair. Postoperative stricture occurs somewhat frequently and requires close follow-up and serial dilations.

Imperforate hymen is more common and typically causes primary amenorrhea and abdominal pain. The physical examination is characteristic and pathognomonic, revealing a bulging, grayish, and translucent hymen (Fig. 95.2). In older girls with a large abdominal mass, the vagina can be filled with a very large volume of mucus and old blood. US reveals a fluid-filled pelvic mass representing the enlarged vagina. MRI is sometimes useful to evaluate the status of the uterus, fallopian tubes, and ovaries, which are usually normal. An uncommon variant is a double vagina (longitudinal vaginal septum in the midline), one of which is patent, while the other has an imperforate hymen. Once the diagnosis is made, hymenotomy under general anesthesia is definitive. The hymen can be simply incised vertically or with a cruciate incision or partially excised, leaving a ring of tissue circumferentially. The edge can be over sewn with absorbable suture but can also be cauterized and left alone. The vagina will return to a normal size over time.

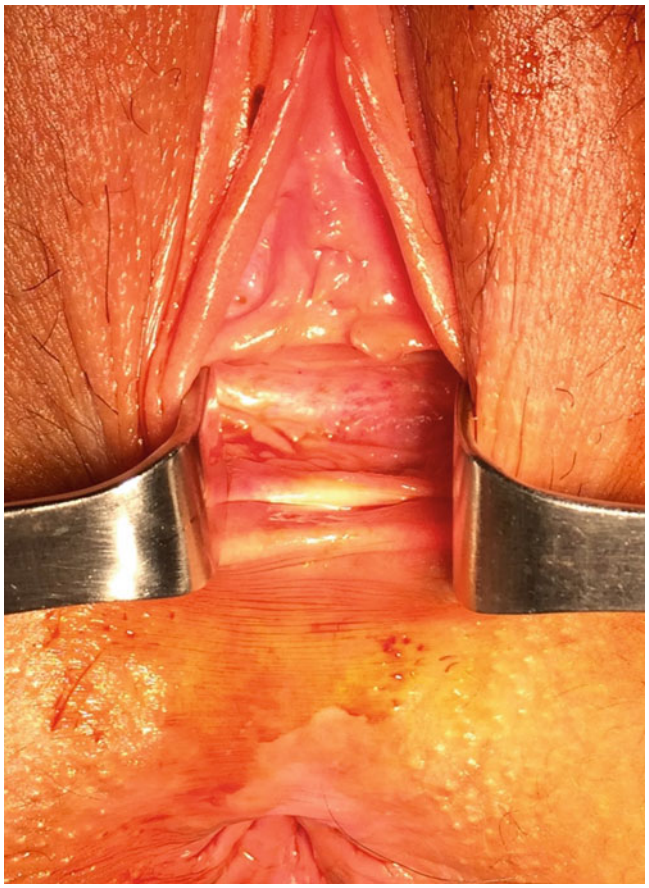

Fig. 95.1 Transverse vaginal septum in a girl with abdominal pain and primary amenorrhea. The septum was quite thick but was excised and the mucosal edges approximated with interrupted absorbable suture. These are classically located at the boundary of the upper third and lower two thirds of the vagina but are variable in location. Those located very proximal in the vagina have been repaired laparoscopically through the usually dilated upper vaginal vault

Labial adhesions are a relatively common problem in infants and very young girls (Fig. 95.3). These are sometimes noted on routine physical examination but can cause relative urinary obstruction or ballooning of the vagina with urine. The labia are seemingly fused in the midline posteriorly, which continues to a variable extent anteriorly. The line

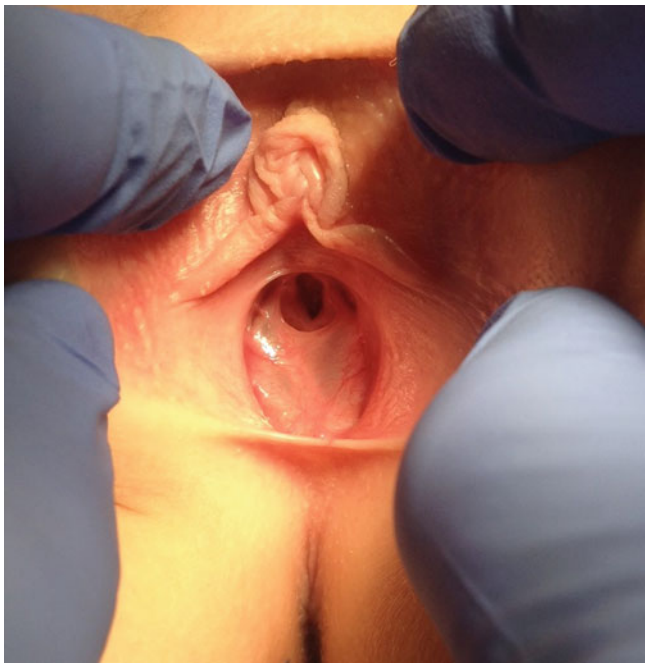

Fig. 95.2 Imperforate hymen. Note the grayish translucent membrane. In teenage girls with abdominal pain and amenorrhea, the hymen is typically bulging and tense. Hymenotomy usually allows a large amount of dark brown fluid (mucus, old blood) to drain, often under pressure (Photo courtesy of Thomas F. Kolon, MD)

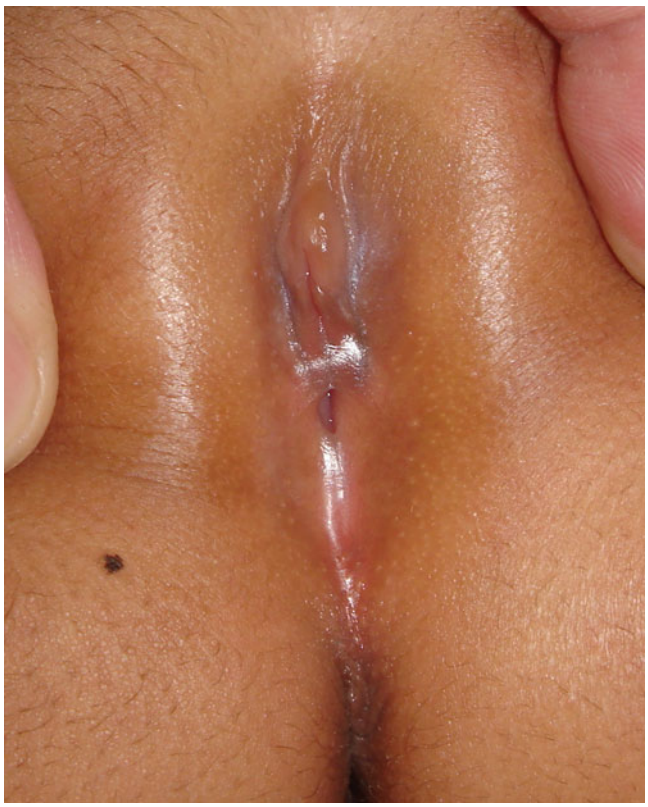

Fig. 95.3 Labial adhesions. Note the characteristic gray translucent line of fusion between the labia minora (Photo courtesy of Thomas F. Kolon, MD)

of fusion is characterized by a gray line of translucent tissue. There is thought to be a hormonal component to the persistence of labial adhesions, and as such they are usually self-limited and eventually resolve. Treatment is reserved for girls who are symptomatic. Conservative management is to apply a mild estrogen cream to the area two to three times daily, though some argue that it is massaging and emollients in the cream that help more than the estrogen itself. Surgical treatment should rarely be necessary and involves physically pulling apart the labia, trimming the tiniest superficial sliver of involved skin, and over sewing the incisions on each side with a running absorbable suture. Recurrence rates are relatively high.

A longitudinal vaginal septum creates a double-barrel vagina and is often associated with uterine didelphys. One hemivagina or both can have an imperforate hymen. Treatment of the septum is relatively straightforward. The septum can be simply excised with two long incisions, one anterior and one posterior, each leaving a small ridge of tissue that should be over sewn with running absorbable locking stitch. The appearance of the cervix (or cervixes) should be clearly documented. These girls should also eventually have a detailed US, MRI, or laparoscopy to evaluate the internal Müllerian structures and, if necessary, referred to a gynecologist with special expertise in the reconstruction of uterine anomalies.

Urethral prolapse occurs in young girls, sometimes associated with UTI or constipation with straining (Fig. 95.4). The mucosa of the urethra visibly protrudes ("doughnut sign"), sometimes rather exuberantly. On casual examination in the office setting, it is easily confused with a botryoid sarcoma. The tissue is congested and friable, and bleeding is sometimes the presenting complaint. Treatment is expectant or with the application of estrogen cream to the site two to three times daily for 1–2 weeks. Surgery involves excision of the prolapsed tissue with careful reapproximation of the mucosa and is reserved for children with pain, bleeding, obvious ischemic tissue, or urinary obstruction.

Inflammatory Disease

Crohn's disease can sometimes affect the vulva and vagina with a spectrum of lesions from ulcers to fistulae or frank tissue destruction. Treatment is with anti-inflammatory drugs, although fecal diversion is sometimes necessary. Rectovaginal fistula is a rare sequela of Crohn's disease in children. Though not in and of itself an automatic indication for diversion, these patients often have severe disease that otherwise warrants consideration of enterostomy. As with most manifestations of perianal Crohn's disease, surgical repair of a rectovaginal fistula performed in the setting of active inflammatory disease is doomed to fail. Surgical

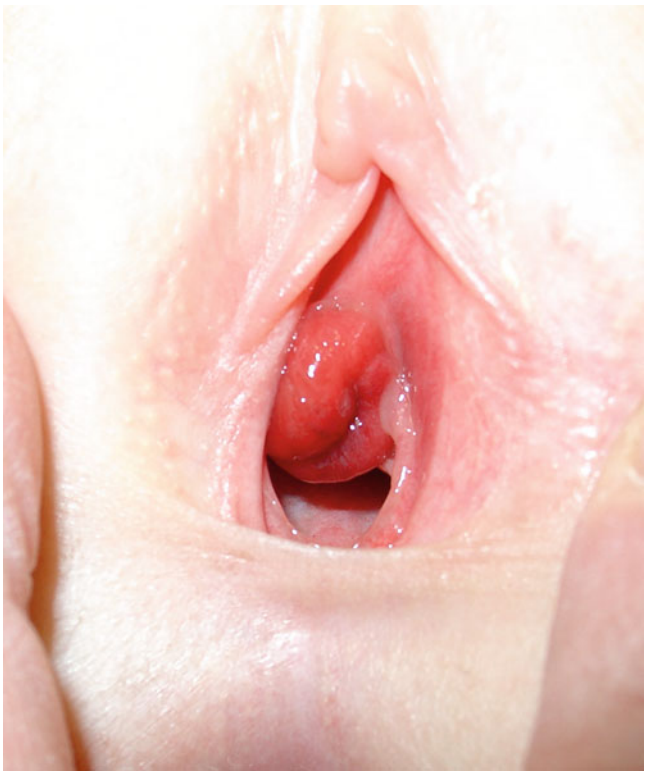

Fig. 95.4 Urethral prolapse. Girls with urethral prolapse present with pain, bleeding, dysuria, or, rarely, urinary retention. On routine examination, these are often suggestive of sarcoma botryoides

repair may be attempted in patients whose inflammatory disease has resolved but have a persistent fistula, though the fistula will usually resolve as well.

Severe acute clusters of herpetic lesions are sometimes seen, and the possibility of sexual abuse must be investigated. Likewise, perivulvar condylomata acuminata sometimes require surgical excision and warrant investigation of inappropriate sexual contact.

Tumors

Embryonal rhabdomyosarcoma of the vagina is a relatively common solid tumor of childhood. It is one of the so-called botryoid sarcomas, which refers to the characteristic cluster-of-grapes appearance of a rhabdomyosarcoma that arises within the lumen of a hollow organ. It presents as a vaginal mass that protrudes from the vagina or seems to fill the space between the labia (Fig. 95.5). It occurs most commonly in children under 3 years of age but occasionally presents in an adolescent girl.

These are usually Stage I tumors with favorable histology and respond well to standard chemotherapy consisting of vincristine, adriamycin, and cyclophosphamide (VAC). The role of the surgeon in patients is to perform an initial biopsy, which is easily done under general anesthesia, and after

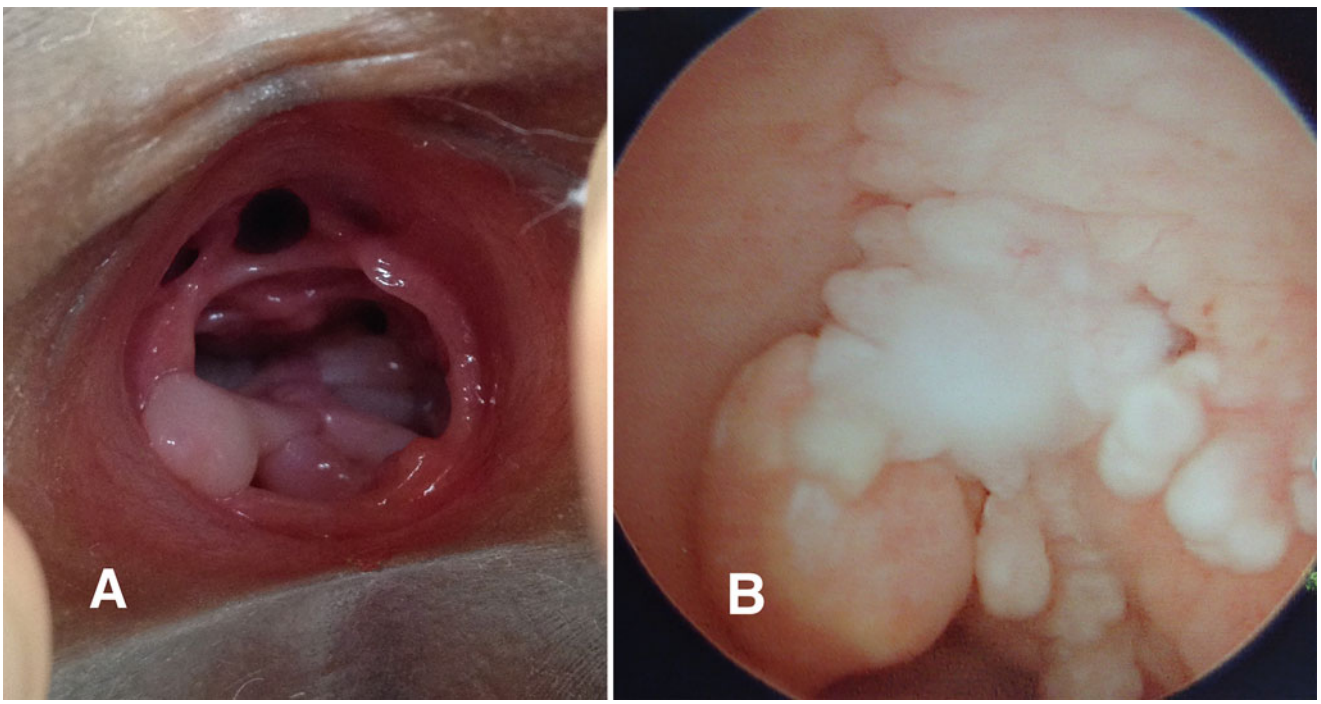

Fig. 95.5 Embryonal rhabdomyosarcoma of the vagina (sarcoma botryoides). (**a**) Note the classic "cluster of grapes" appearance on physical examination. (**b**) Appearance of sarcoma botryoides at vaginoscopy (here performed using a cystoscope under flow of saline) after chemotherapy. Though stage I rhabdomyosarcoma of the vagina will often shrink dramatically or disappear in response to chemotherapy, a mass that persists after neoadjuvant chemotherapy should be excised, preferably with a margin or normal epithelium (Photos courtesy of Thomas F. Kolon, MD)

completion of neoadjuvant chemotherapy, to perform an examination under anesthesia, usually including vaginoscopy, to confirm a complete response or to resect a small residual mass with a margin.

Other tumors occasionally arise from the vaginal or cervical epithelium including soft tissue sarcomas or endodermal sinus (yolk sac) tumors. These tumors are more aggressive than sarcoma botryoides and usually require some combination of chemotherapy, radiation, and surgery for cure. Resection of a tumor of the vagina with a margin leaves a defect that can usually be primarily repaired, as the vaginal epithelium is very forgiving, though the risk of stricture and dyspareunia as a teenager and young adult mandates follow-up with an experienced gynecologic surgeon.

Trauma

Trauma of the perineum in a girl can result in hematoma, contusion, or laceration. Straddle injury is the most common mechanism and is almost invariably accidental. Nevertheless, the possibility of intentional injury or sexual abuse must be considered. Most simple lacerations can be observed with recommendations for good hygiene and close follow-up in an office setting. Indications for surgical repair include bleeding, pain, urinary retention, obvious severe injury, or inability to fully assess the extent of injury in the office or ED. A careful examination under moderate sedation will often prevent the child from having to go to the OR.

Complex lacerations that involve disruption of underlying tissues or extend into the rectum or vagina proper should be assessed under general anesthesia. The underlying tissues and sphincter apparatus should be anatomically approximated with buried fine absorbable interrupted sutures. The skin can be closed with dermal absorbable sutures or left open to heal secondarily. Staples or permanent sutures should be avoided. Injuries that involve the urethra require Foley catheter drainage for 1–5 days depending on severity and extent. Very extensive associated rectal injuries sometimes require ostomy diversion, though this is rarely necessary.

Iatrogenic injury to the vagina can occur during ileoanal anastomosis after completion proctectomy for ulcerative colitis. The posterior wall of the vagina can be injured during the dissection or, more commonly, by suture- or stapler-related injury during the creation of the anastomosis. The result is a rectovaginal fistula that is often extremely difficult to repair, especially when staples are involved. Temporary ileostomy diversion is sometimes necessary, and large defects often require the use of an advancement flap or other complex repair strategies for definitive repair.

Injury to the vagina caused by sexual abuse is rare, certainly much less common than injury to the anus or rectum. It is the obligation of the examining physician to do a methodical and careful examination with precise documentation including photographs. A rape kit should be used, and forensic material should be collected with meticulous care, in the presence of witnesses and with assiduous attention to the rules of evidentiary chain of custody. Cultures for sexually transmitted infections and, when appropriate, a pregnancy test should be obtained. The rare intra-abdominal perforation of the vagina, usually due to the use of an implement during a sexual assault, can sometimes require laparotomy or laparoscopy for primary repair of the upper vagina and washout of the abdomen.

Foreign Body

Girls with a vaginal foreign body typically present with a malodorous mucopurulent discharge. Other symptoms might include bleeding, itching, or pain. These typically occur in toddlers and young girls. Common objects include beads and small toys, often inserted by the girl herself or a curious playmate, and tissue paper, which can accumulate little by little over time.

Most foreign bodies can be confirmed and delivered by digital rectal examination in the ED or office. Persistent or questionable foreign bodies (drainage in the absence of a clear history, question of a tumor) should be assessed by examination under anesthesia. Digital or speculum examination should never be done in a young girl; instead vaginoscopy should be performed using a cystoscope under a flow of saline. Alternatively, a small bronchoscope can be used with gentle insufflation of air into the vagina. The surgeon should be prepared to remove the foreign body or perform a biopsy if a tumor is identified instead.

Summary

The pediatric surgeon is also a pediatric gynecologist who should have the experience, confidence, and skill to assess and manage most vaginal anomalies and disorders. However, one should always consider the life-long effects of any intervention and never hesitate to call upon an experienced pediatric urologist, interventional radiologist, or adult gynecologist when the diagnosis is unclear or when difficulties arise. Preoperative US is invaluable and MRI is increasingly useful to assess the internal genitalia in young girls. Diagnostic laparoscopy should also be considered though a gynecologist who might need to follow the girl into adulthood should be present in most cases.

Suggested Reading

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Part XII

Surgical Oncology

Neuroblastoma

96

Jeremy R. Jackson and Eugene S. Kim

Neuroblastoma is an early childhood cancer derived from neural crest cells. It represents about 7 % of all childhood malignancies and is the third most common cancer in children. It can arise anywhere along the sympathetic ganglion chain from the neck to the pelvis but most often arises from the adrenal medulla. Therefore, a large majority of neuroblastoma tumors will be located within the retroperitoneum. The clinical behavior varies widely from tumors that regress or differentiate spontaneously to those that grow rapidly with disseminated metastatic disease.

Neuroblastoma is typically found in children younger than 5 years, most commonly between 1 and 2 years of age and rarely in children over 10 years of age. Children with neuroblastoma often present with a firm, fixed mass in the abdomen. Thoracic neuroblastoma is often discovered incidentally on chest radiograph while working up unrelated respiratory symptoms. Children may also present due to symptoms of metastatic disease, such as a pathologic fracture from bony metastasis or nonspecific pain from diffuse bony disease. As the majority of these tumors secrete catecholamines, hypertension is sometimes noted. Nonspecific symptoms might include fever, weight loss, and failure to thrive. Presenting symptoms and signs vary based upon the primary location and extent of disease. Children with cervical or thoracic tumors sometimes complain of dysphagia or respiratory difficulty, while tumors of the upper mediastinum or neck can produce a Horner syndrome (ptosis, miosis, anhidrosis). Children with intra-abdominal tumors may complain of abdominal pain or constipation. Pelvic tumors or tumors with spinal cord involvement can cause neurogenic urinary retention, constipation, or extremity weakness or paralysis. In rare instances, children can develop a characteristic paraneoplastic syndrome known as opsoclonus-myoclonus-ataxia syndrome ("dancing eye syndrome"), characterized by acute cerebellar ataxia, opsoclonus (rapid, random eye movements), and myoclonus (involuntary twitching of a muscle group). It is believed that this syndrome is caused by an autoimmune disorder in which tumor-targeted antibodies cross-react with Purkinje cells in the cerebellum. Another unusual and stereotypical syndrome, due to metastases to the orbits, results in "raccoon-eye syndrome" with characteristic periorbital ecchymoses that is often thought to be due to child abuse. Finally, metastases to the subcutaneous tissues, typically in newborns, can cause a "blueberry muffin" appearance of the skin.

Work-up

When children with potential neuroblastoma present to the office or emergency room, a careful history and physical exam are performed. For abdominal masses, the history is focused on the onset of symptoms, changes in bowel patterns, and abdominal girth. Thoracic lesions will often present as an incidental finding during work-up for unrelated respiratory symptoms. Often a radiograph demonstrates finely stippled tumor calcifications or displacement of adjacent structures. We further evaluate the tumor with CT with intravenous and oral contrast for abdominal and pelvic lesions or a CT with intravenous contrast for posterior mediastinal lesions. CT may also show calcifications in the tumor suspicious for neuroblastoma as well as elucidate the proximity and involvement of the tumor with nearby major vessels or the spinal canal. MRI is also a useful and increasingly popular radiation-free alternative. For neuroblastic lesions that might involve the spinal canal, MRI is far superior to CT. However, MRI may not be as readily available and in young children can require general anesthesia. At our institution, a metaiodobenzylguanidine (MIBG) scan is routinely performed at the time of diagnosis to further evaluate the

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mass and to screen for metastatic disease. MIBG scans detect sites of uptake of this chemical analogue of norepinephrine by chromaffin cells. Approximately 90 % of neuroblastomas are MIBG-avid. For tumors that are not MIBG-avid, PET scan is sometimes useful.

Most neuroblastomas secrete the catecholamines, homovanillic acid (HVA), and vanillylmandelic acid (VMA), and elevated levels can be detected in the urine in up to 90 % of patients. These levels can be used to monitor tumor activity over time and for surveillance for recurrence after treatment. MIBG scans can also be performed to follow treatment efficacy and to monitor for disease recurrence. Blood is evaluated for increased levels of LDH, ferritin, and neuron-specific enolase, which may represent advanced stage of disease and a worse prognosis.

Biopsy of the tumor is obtained early for histological confirmation of disease as well as risk stratification. In patients with localized tumors (Stage 1) that do not involve vital structures, have a negative metastatic work-up, and are otherwise deemed resectable, a primary resection of the tumor is favored over a biopsy. These children may require no further therapy than the surgical resection. Unresectable tumors at diagnosis, defined by tumors encasing or surrounding critical vessels and organs, as well as tumors which cross the midline, should be treated with neoadjuvant chemotherapy with the hopes of reducing tumor mass and shrinking disease away from critical structures, organs, and blood vessels, thereby decreasing the risk of surgical complications and morbidity. Current Children's Oncology Group (COG) guidelines recommend at least 1 g (1 cm^3) of tumor specimen for tissue banking and research purposes and in order to enroll onto COG biology protocols. Therefore, in order to safely obtain this amount of tissue, we favor biopsy through a mini-laparotomy or laparoscopy rather than a percutaneous or core needle biopsy. We typically place a permanent central line at this time if it is believed that the patient will need chemotherapy. Bone marrow biopsies are usually performed at the same time to determine involvement of bone marrow as part of the staging process.

Tumors are classified histologically as either favorable or unfavorable using the International Neuroblastoma Pathology Classification (INPC) system. This is based on the Shimada classification system, which is age-dependent and characterizes tumors based on whether the tumor is stroma-rich or stroma-poor. It also stratifies tumors based on the degree of differentiation. Using INPC, tumors are classified into three groups: ganglioneuroma, ganglioneuroblastoma, or neuroblastoma. Less-developed tumors are further characterized by a mitotic-karyorrhexis index, a high MKI bearing a worse prognosis. Tumors with favorable histology are associated with an 85 % survival rate, whereas those with unfavorable histology are associated with an approximate 40 % survival rate.

Tumor biopsy samples are also used to determine the DNA content and presence of proto-oncogenes associated with neuroblastoma. One of the most prognostically important oncogenes is *MYCN*. Approximately 25 % of primary neuroblastomas in children demonstrate *MYCN* amplification, which is defined as more than ten copies of the gene. *MYCN* amplification correlates with advanced disease, resistance to therapy, and poor prognosis especially in children older than 12 months. Tumor DNA content is also an important prognostic indicator. The DNA index (DI), which is the ratio of the number of chromosomes present to the expected diploid number, is used to assess the ploidy of a tumor. Most neuroblastomas are aneuploid (triploid or hyperdiploid) and therefore have a DI >1, which is associated with better outcomes than diploid tumors (DI = 1).

Staging and Risk Stratification

Two widely used staging systems for patients with neuroblastoma are the International Neuroblastoma Staging System (INSS) and the International Neuroblastoma Risk Group Staging System (INRGSS). The INSS is a posttreatment staging system, which requires surgical resection or surgical exploration for staging purposes. It is based upon the relationship of the tumor and its associated lymph nodes to the midline, the completeness of the resection, and the presence of metastatic disease (Table 96.1).

While generally useful over many years and multiple modifications, several limitations of the INSS have been noted. Since staging is contingent upon the extent of surgical resection and thoroughness in exploration and sampling of bilateral lymph nodes, the experience, aggressiveness, and diligence of an individual surgeon can significantly affect staging. In addition, patients who undergo expectant observation for tumor regression cannot be accurately staged using this system. To address these issues, the INRGSS was created as a pretreatment image-based staging system (Table 96.2). The INRGSS focuses on the presence of locoregional extent of disease (whether the tumor is confined to one compartment) and the presence of metastases. It relies on the radiographic identification of one or more of 20 specific image-defined risk factors (IDRF, Table 96.3), which include tumor invasion or encasement of major blood vessels, nerves, or vital organs. Tumors that are confined to single compartment (abdomen, thorax, pelvis, neck) and have no IDRF are stage L1; those with at least one IDRF are labeled L2. Patients with metastases have the additional designation of M. The INSS designation of 4S (Stage 4 Special) included infants less than a year old with metastases to the liver, skin, and bone marrow, a special group that in some cases can do well with observation alone. Under INRGSS, this group is called MS and has been modified to include infants up to 18 months of age and L1 primary tumors

Table 96.1 International neuroblastoma staging system

Stage	Description
1	Localized tumor with complete gross excision, with or without microscopic residual disease; bilateral lymph nodes negative, w/ or w/o positive nodes attached to and removed with primary tumor
2a	Localized tumor with incomplete gross excision; bilateral nonadherent lymph nodes negative
2b	Localized tumor with or without complete gross excision, with positive ipsilateral nonadherent lymph nodes and negative contralateral lymph nodes
3	Unilateral tumor extending across the midline, with or without positive lymph nodes, or localized unilateral tumor with contralateral positive lymph nodes, or midline tumor with bilateral extension or bilateral positive lymph nodes
4	Dissemination of tumor to distant lymph nodes, bone, bone marrow, liver, and/or other organs
4-S	Localized primary tumor, as defined for stage 1 or 2, with dissemination limited to the skin, liver, and/or bone marrow in infant less than 12 months

Source: Data from Brodeur GM, Seeger RC, Barrett A, et al: International criteria for diagnosis, staging, and response to treatment in patients with neuroblastoma. J Clin Oncol 1988;6:1874–1881

Table 96.2 International neuroblastoma risk group staging system

Stage	Description
L1	Localized tumor not involving vital structures as defined by the list of image-defined risk factors and confined to one body compartment
L2	Locoregional tumor with presence of one or more image-defined risk factors
M	Distant metastatic disease (except stage MS)
MS	Metastatic disease in children younger than 18 months with metastases confined to the skin, liver, and/or bone marrow

Source: Data from Monclair T, Brodeur GM, Ambros PF, et al: The International Neuroblastoma Risk Group (INRG) Staging System: An INRG Task Force Report. J Clin Oncol, 2009 10;27:298–303

Table 96.3 INRG image-defined risk factors

Location	Description
Multiple	Ipsilateral tumor extension within two body compartments
Neck	Tumor encasing carotid and/or vertebral artery and/or internal jugular vein Tumor extending to base of skull Tumor compressing the trachea
Cervicothoracic Junction	Tumor encasing brachial plexus roots Tumor encasing subclavian vessels and/or vertebral and/or carotid artery Tumor compressing the trachea
Thorax	Tumor encasing the aorta and/or major branches Tumor compressing the trachea and/or principal bronchi Lower mediastinal tumor, infiltrating the costovertebral junction between T9 and T12
Thoracoabdominal	Tumor encasing the aorta and/or vena cava
Abdomen/Pelvis	Tumor infiltrating the porta hepatis and/or the hepatoduodenal ligament Tumor encasing branches of the superior mesenteric artery at the mesenteric root Tumor encasing the origin of the celiac axis and/or of the superior mesenteric artery Tumor invading one or both renal pedicles Tumor encasing the aorta and/or vena cava Tumor encasing the iliac vessels Pelvic tumor crossing the sciatic notch
Intraspinal extension with	More than one third of the spinal canal in the axial plane is invaded and/or the perimedullary leptomeningeal spaces are not visible and/or the spinal cord signal is abnormal
Infiltration of adjacent structures	Pericardium, diaphragm, kidney, liver, duodeno-pancreatic block, and mesentery

Source: Data from Monclair T, Brodeur GM, Ambros PF, et al: The International Neuroblastoma Risk Group (INRG) Staging System: An INRG Task Force Report. J Clin Oncol, 2009 10;27:298–303

even if not resected. We currently use the INSS in our practice as it is still utilized in many Children's Oncology Group studies for risk stratification (together with stage, age, *MYCN* amplification status, histopathologic classification, and tumor ploidy). However, upcoming high-risk COG protocols will adopt the newer staging system, and the most recent intermediate-risk COG protocol has already adopted the INRGSS.

Treatment

Treatment is determined by risk stratification, and most patients are treated according to current COG protocols or institutional protocols. Chemotherapeutic treatment regimens typically utilize some combination of multiple agents, including mitotic inhibitors (vincristine), anthracyclines (doxorubicin), alkylating agents (cyclophosphamide or ifosfamide), platinum-based drugs (cisplatin, carboplatin), and topoisomerase inhibitors (topotecan or etoposide). Patients with low-risk, asymptomatic, locoregional disease without *MYCN* amplification may only require surgical resection. For localized disease, we typically attempt a gross total resection and biopsy local and regional lymph nodes whenever possible. Low-risk patients with residual disease are generally not considered at risk for recurrence. Patients with intermediate-risk disease usually require both chemotherapy and surgical resection. Surgical resection is performed with the goal of removing as much tumor as possible without damaging the function of vital structures or removing organs. For some low- or intermediate-risk patients with symptomatic or organ-threatening tumors that are poorly responsive to chemotherapy or have progressive disease, radiation therapy may be considered as an adjunct therapy.

For patients with high-risk disease, our practice is to use a multimodality treatment regimen divided into three phases: induction, consolidation, and maintenance. During *induction*, patients receive five to six cycles of chemotherapy. Peripheral blood stem cells are harvested after the second cycle of chemotherapy, while resection of the primary tumor and bulky regional metastases is performed after the fourth or fifth cycle, which is when chemotherapy has typically had its maximum effect on tumor size. During *consolidation*, patients undergo myeloablative therapy with stem cell transplantation and radiation therapy. Myeloablative therapy involves the use of a near-lethal dose of melphalan to deplete the bone marrow and eliminate residual disease. This is followed by infusion of peripheral blood stem cells harvested during the induction phase to repopulate the bone marrow. Radiation therapy directed at the primary tumor bed as well as MIBG-positive bony metastatic sites is also generally performed. *Maintenance* involves 6 months of treatment with isotretinoin (13-cisRA), which promotes the differentiation of residual disease. During this phase, patients may also be treated with immunotherapy, which commonly targets GD2, a surface disialoganglioside antigen expressed on all neuroblastoma cells. MIBG has also emerged as a novel therapeutic when combined with ^{131}I. Currently, there are protocols and compassionate care uses for MIBG therapy for patients with new diagnoses, residual disease, or recurrent disease.

Patients with 4S (or MS) disease undergo varied treatment regimens. Most of these tumors regress spontaneously, and surgical resection is often not required. About 90 % of the tumors have favorable histology, a DI>1, and no *MYCN* amplification. In general, patients who are asymptomatic with favorable biology are observed. These infants, however, can develop potentially lethal complications secondary to bulky metastatic disease and therefore may require treatment and an intervention. Severe hepatomegaly can cause respiratory compromise and renal compromise from abdominal compartment syndrome. These patients may benefit from early chemotherapy, low-dose radiation to the liver, or, in desperate situations, the creation of a Silastic pouch or silo to reduce intra-abdominal pressure.

Operative Management

After the last cycle of preoperative chemotherapy, we obtain a CT scan of the abdomen and pelvis to reassess extent of disease. We find it essential to have good PO and IV contrast to help differentiate structures and follow the course of critical blood vessels. For posterior mediastinal tumors with tumor extension into the neural foramina between T8 and T12, we recommend a preoperative spinal angiogram to document the location and sidedness of the artery of Adamkiewicz as well as critical intercostal artery feeders that supply the anterior spinal artery (Fig. 96.1). Manipulation and injury to these vessels can cause spinal cord ischemia with subsequent transient or permanent paraplegia. In addition, for posterior mediastinal tumors located in this critical zone, we utilize intraoperative neuromonitoring for both sensory (posterior columns) and motor (anterior columns) for detection and prevention of neurologic injuries.

The timing of surgery is coordinated with the oncology team. We typically operate after the 4th of 5 total cycles of chemotherapy so that any residual tumor may be treated post-resection; however, our main goal is to proceed with surgery when we feel that additional chemotherapy is unlikely to further shrink the tumor and provide additional preoperative benefit. Within a week before the scheduled operation, blood is sent for type and cross-match for packed red blood cells as well as a CBC to ensure that the patient has recovered from neutropenia. We will usually proceed with surgery with an ANC of at least 1000.

When approaching these challenging and risky tumor resections, good venous access and arterial-line monitoring

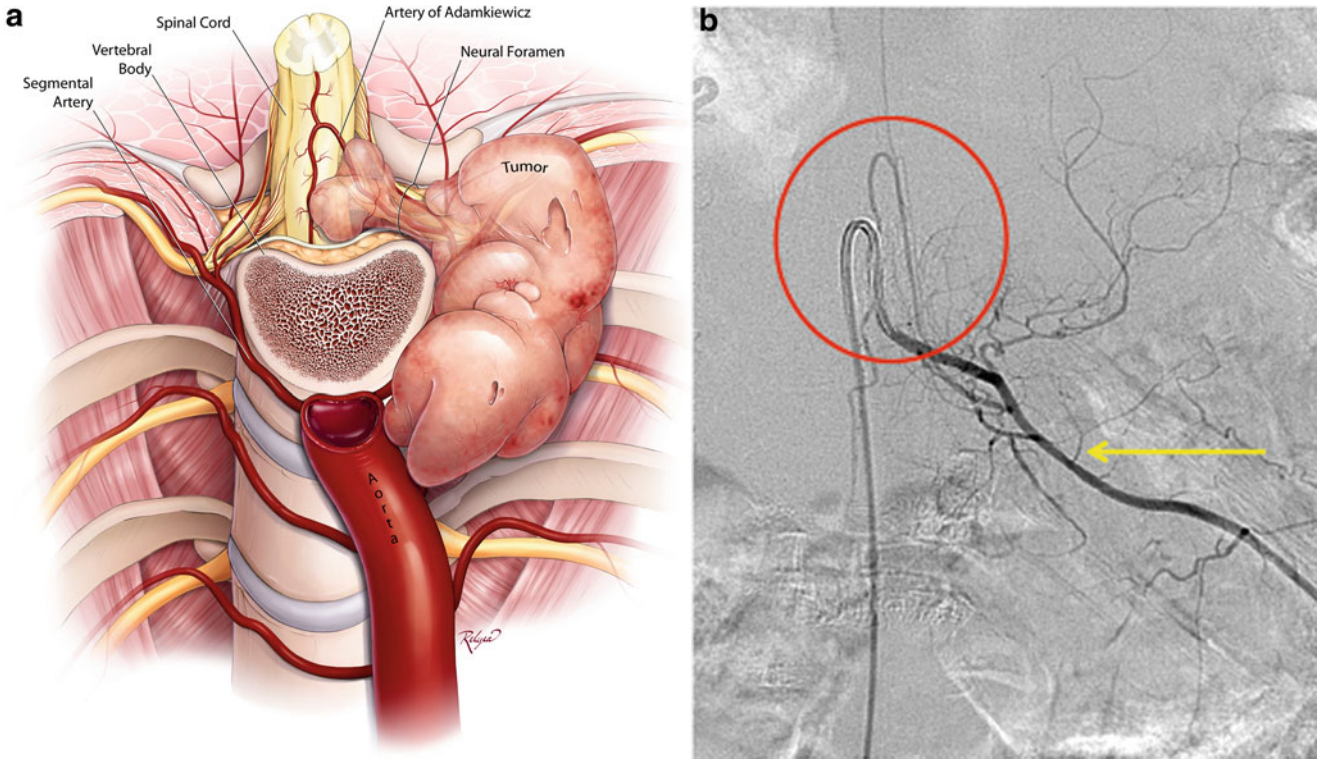

Fig. 96.1 In the *left panel* (**a**), an illustration demonstrating the relationship of a thoracic posterior mediastinal neuroblastoma to the intercostal arteries, the Artery of Adamkiewiecz, and the anterior spinal artery. Illustration by Katherine Relyea, printed with permission from Baylor College of Medicine. In the *right panel* (**b**), an image from a selective arteriogram of the left intercostal artery at T11 (*yellow arrow*). The Artery of Adamkiewicz (*red circle*) is seen making the classic hairpin turn

are essential. An epidural catheter is often utilized for intraoperative and postoperative pain management. For abdominal and pelvic tumors that involve or are in close proximity to the ureters, we will often have a ureteral stent placed just prior to the surgical resection.

While ongoing trials examine the efficacy of new chemotherapies, immunotherapies, and small molecule inhibition of new genetic targets, clinical research continues to explore the optimal management of children with neuroblastoma, including surgical considerations. When approaching a new patient with high-risk neuroblastoma, the surgeon must consider surgical biopsy options for diagnosis. Currently, all children are strongly recommended to undergo an open biopsy to obtain adequate tissue for diagnosis, cytogenetic studies, and fluorescent in situ hybridization for evaluation for histology and *MYCN* status. Additionally, adequate tissue is also mandatory for enrollment for all children who enter COG biology studies. Without submitting an adequate volume of tissue, patients must undergo treatment off-study and may not be eligible for new trials and medications.

With regards to surgical resection of neuroblastoma, there has been ongoing controversy as to the extent of tumor resection in patients with high-risk neuroblastoma. Our approach to high-risk intra-abdominal tumors is to aim for a gross total resection after induction chemotherapy has maximally reduced tumor burden. We take an aggressive approach of methodically and meticulously removing gross tumor from any major vessels or vital structures that are encountered.

As opposed to the aggressive surgical management for children with intra-abdominal high-risk neuroblastoma, there are specific subsets of patients for whom no surgical resection is required at all. Patients with 4S disease with favorable histology and no *MYCN* amplification are often treated with supportive care alone as many of these tumors will regress spontaneously. In fact, infants with perinatal identification of an adrenal mass who are younger than 6 months of age and have localized INSS stage 1 tumors that are less than 3.1 cm in diameter if solid and less than 5 cm if cystic can be safely managed with expectant observation.

Surgical management is guided by risk stratification and location of the primary tumor. *Cervical* neuroblastomas are generally of lower risk stratification, and so the goals of resection are to remove as much as possible without causing harm. Resection of the tumor is generally performed through a generous oblique or transverse collar incision to provide adequate exposure of the great vessels. Fortunately, cervical tumors do not usually encase major vessels as often as abdominal tumors, and dissection should be focused on avoiding injury to the

phrenic, vagus, and recurrent laryngeal nerves and the branches of the brachial plexus. Cervical tumor resection can result in Horner syndrome if this is not already present preoperatively.

For thoracic (posterior mediastinal) tumors, the surgical goal is gross total resection of the tumor. Most thoracic neuroblastoma tumors are low- or intermediate-risk and are therefore less aggressive. Although our goal is generally to remove at least 50 % of the tumor, we would normally attempt to remove as much as is safely possible. In many of these cases, however, the tumor is densely adherent to or abutting major vessels and structures, and so gross tumor is often purposely left behind to avoid injuries. Although less common, high-risk posterior mediastinal neuroblastoma should be approached with the goal of gross total resection. Given these surgical goals, thoracic tumors may be removed by thoracoscopic technique or through a traditional lateral thoracotomy. We make our decision based on the risk stratification of the tumor, the size, location, and the surrounding critical structures. We might use thoracoscopy for small low-risk tumors, while high-risk disease and tumors that encase critical structures usually require a thoracotomy.

Posterior mediastinal neuroblastoma is often found to have invaded neural foramina and abut or compress the spinal cord. Neurologic symptoms (extremity weakness or paralysis) are an indication for emergent management, and decompression of the spinal cord is paramount. Biopsy with immediate initiation of chemotherapy or emergent laminectomy with intraspinal tumor resection should be the first course of action prior to addressing the posterior mediastinal lesion. In the absence of neurologic symptoms, the timing of surgical resection can proceed in coordination with any necessary chemotherapy. During the thoracic resection, the goal of the surgery should be to remove as much tumor as possible and avoid intraforaminal dissection of tumor. Intraforaminal residual disease as well as asymptomatic intraspinal tumor can usually be safely followed with subsequent imaging but may sometimes be resected via laminotomy either simultaneously or in a staged fashion.

The surgical management of *abdominal* tumors is guided by risk stratification and the size and extent of the tumor. Resectable stage 1 and 2 tumors should be primarily removed at diagnosis. Unresectable tumors at diagnosis should be biopsied and treated with neoadjuvant chemotherapy.

Neuroblastoma tumors of the retroperitoneum usually arise from the adrenal gland, and as such, plans to ligate and divide the adrenal vein as well as perform an adrenalectomy along with the primary tumor should be planned. In addition, for high-risk neuroblastoma, gross total resection of the primary tumor as well as removal of involved lymph nodes is recommended. Often this will involve encasement of critical vessels, including the celiac axis, superior mesenteric artery, and the renal hilar vessels. We generally approach these retroperitoneal tumors through a subcostal approach on the affected side with the incision extending transversely at the upper epigastric region just past the midline (Fig. 96.2). This can be extended to the contralateral side as needed and extended further to a contralateral subcostal approach.

Upon entry into the peritoneum, a detailed survey of the primary tumor site and involved structures is undertaken. The liver is examined for evidence of metastatic disease with biopsy of any noted lesions. We use a self-retaining table-mounted retractor system and perform a medial mobilization of the colon on the affected side, which might in some cases include the spleen and pancreas on the left side and the liver on the right side to gain adequate exposure. After assessing the mass, our first goal in these complex resections is to remove the primary adrenal tumor. In the majority of cases, the tumor is separate from the kidney itself, and a dissection plane can be established to preserve the ipsilateral kidney. In a small percentage of cases, the tumor has invaded the kidney, in which case, a nephrectomy or partial nephrectomy might be necessary to achieve gross total resection. The primary tumor is then dissected from its lateral and posterior attachments. Superiorly, the mass can involve the diaphragm, a portion of which might need to be resected and subsequently repaired. The most difficult aspect of the case is usually the medial aspect of the tumor where it involves and often encases critical blood vessels. Depending on the affected side, proximal and distal isolation and control of the great vessels is recommended. After mobilizing the majority of the tumor, at this point in the operation, we seek to identify a safe area medially to transect the bulk primary tumor in order to provide more working space and better visualization of the remaining retroperitoneal tumor that remains as well as to provide better exposure of the visceral

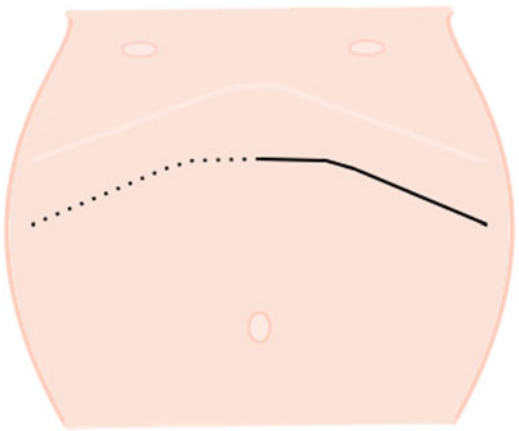

Fig. 96.2 For retroperitoneal abdominal tumors, we typically perform an incision 1–2 fingerbreadths below the costal margin on the affected side (*solid line* for a left sided tumor). If additional exposure is required, an extended incision can be made to the contralateral side (*dotted line*)

vessels. For high-risk disease, we then proceed with the meticulous and thorough resection of all remaining gross disease. During the subsequent dissection, small vessels and lymphatics are meticulously ligated using silk ties and titanium clips to help prevent and avoid chylous ascites.

For tumors that involve the aorta, inferior vena cava, or their major branches, deliberate and careful dissection of the tumor is performed. During the operation, we frequently refer back to the CT images to gain perspective and context of the tumor relative to the major blood vessels. A high-quality CT scan with intravenous contrast is essential for mapping and preoperative planning. We first gain proximal and distal control of the vessel with either a looped umbilical tape or vessel loop. If the tumor extends proximally and involves the celiac axis, we will divide the diaphragm at the aortic crus and continue to dissect along the mass proximally until normal aorta has been identified. At this point, we will isolate and control the aorta proximally at this location. Dissecting from the "known to the unknown," we use blunt dissection with a clamp to separate or bivalve the tumor from the underlying blood vessel and carry the dissection in a proximal to distal manner, longitudinally along the vessel (Fig. 96.3). Slow and deliberate blunt tumor dissection and skeletonization of the major arteries is performed along the vessel through the subadventitial plane where the tumor is most adherent to the vessel. Neoadjuvant chemotherapy will often result in a dense inflammatory process of the tumor, which can lead to a challenging and painstaking dissection. By continuing the blunt dissection from the identified vessel proximally to the tumor-encased vessel distally, a safe and complete resection can often be performed.

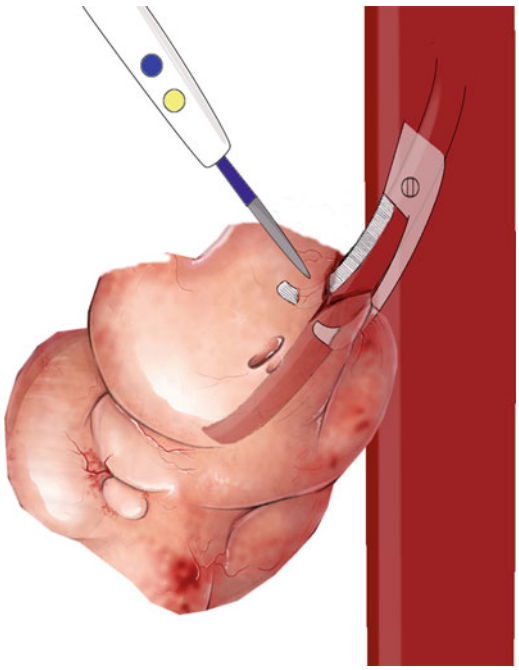

Fig. 96.3 Tumors encasing critical blood vessels may need to be bivalved in order to achieve a gross total resection. Using a clamp, blunt dissection is performed from the visualized vessel proximally in a longitudinal fashion overlying the blood vessel. The tumor is divided on the clamp with cautery to separate or bivalve the tumor from the vessel below (Illustration by Jeremy Jackson, printed with permission.)

When dissecting tumor away from an encased celiac axis, we approach the tumor from disease-free aorta proximally and carefully bivalve and dissect portions of tumor away from each branch distally in a longitudinal fashion. Careful preservation of each branch, particularly the common hepatic artery, must be performed. Similarly, resection of tumor from an encased superior mesenteric artery should proceed bluntly and longitudinally from the disease-free aorta proximally and follow the vessel distally to the major jejunal branches to achieve gross resection (Fig. 96.3). Dissection and removal of tumor from encased renal arteries and veins is critical as well and should be handled with care. Specifically, aggressive dissection of the renal artery can lead to vessel injury or spasm, leading to subsequent ischemia and loss of the organ. In addition, careful preoperative planning and notation of anomalous renal arteries and veins should be noted before undertaking a complex resection. It is important to note the course of a tumor-encased right renal artery in context to the inferior vena cava, which might also be encased in tumor. Lastly, when removing tumor from the distal aorta, we make every effort to identify and preserve the inferior mesenteric artery; however, if this is not possible, ligation of the IMA is usually well tolerated.

With intermediate-risk tumors that are unresectable at diagnosis, the surgical management can be less aggressive. Following neoadjuvant chemotherapy, we strive for gross total resection, but our threshold for minimum resection is 50 % of the total tumor. As such, in areas of dangerous dissection such as around critical vessels and organs, we would leave gross tumor behind rather than risk injury to these structures.

Like cervical tumors, *pelvic* neuroblastomas tend to be less aggressive tumors with lower risk stratification. If the primary tumor is deemed to be resectable at the time of diagnosis, every effort for a gross total resection should be made. However, more often, these pelvic tumors present as unresectable intermediate-risk masses, which often encase the iliac vessels and extend down into the pelvis and presacral region. These patients will often undergo an initial biopsy followed by neoadjuvant chemotherapy with variable response. At the time of resection, we usually approach these tumors through a low transverse incision approximately two fingerbreadths above the pubis. The incision is carried laterally to the affected side and then superiorly and obliquely in the manner of a Gibson incision. We enter the peritoneal cavity and then mobilize the colon (cecum or sigmoid) medially to gain retroperitoneal exposure to the mass. If the iliac vessels are involved, we will isolate

these vessels proximally early in the case; however, distal control and isolation are sometimes impossible due to the complete encasement of the vessels distally into the pelvis.

The subsequent pelvic tumor resection is often quite challenging, as the tumor may be densely adherent and encasing the iliac vessels in addition to involving the sacral nerve roots. Furthermore, pelvic tumors can extend deep into the narrow pelvis of children, making exposure and dissection difficult, especially with the sigmoid and rectum overlying. Due to the generally lower risk stratification of pelvic neuroblastoma, our surgical goal is to remove as much tumor as safely as possible with a threshold of removing at least 50 % of the total tumor mass. Vital structures that should be identified and preserved include the iliac vessels, the ureters, and the nerve roots from the sacrum, the injury of which may lead to risk of bladder, bowel, or erectile dysfunction. In the end, we will elect to leave residual tumors in areas adherent to critical blood vessels as well as the presacral region to avoid injury to the sacral nerve roots.

Postoperative Management

Based on the complexity of the surgical resection, operative blood loss, and any intraoperative complications, the patient may require initial postoperative care in the pediatric intensive care unit. However, the vast majority of our postoperative patients convalesce on the surgery acute care inpatient floor. Regardless of the length of surgery, we employ a fast-track management of our postoperative patients. This includes the avoidance of a nasogastric tube, limiting narcotic use while promoting the use of NSAIDs, early trial of a liquid diet and getting the patient out of bed, and ambulating as soon as tolerated. Patients are usually cleared to resume chemotherapy 1 week after surgery, as long as the patient is otherwise doing well from a surgical standpoint and tolerating a regular diet. Moreover, we typically clear patients for radiation therapy 1 month after surgery to insure good healing of all wounds.

Recurrent Disease

One of the major challenges in the care of patients with neuroblastoma is the management of recurrent disease. For low- and intermediate-risk tumors, surgical resection may play a role in the treatment of locoregional recurrent disease. For lower risk stratification patients, if the tumor recurs within 3 months after the termination of treatment, is of favorable biology, and the resection of the recurrent tumor was greater than 90 %, then chemotherapy may be avoided. Surgical resection is often followed by chemotherapy when near-complete resection is unable to be safely undertaken.

For patients with unfavorable biology, metastatic disease, or initial high-risk classification, a combination of chemotherapy, radiation therapy, MIBG therapy, and stem cell transplantation is typically utilized. With poor prognosis for these high-risk patients with recurrent disease, the surgical options for these children are generally limited.

Editor's Comment

Informed by large multinational studies sponsored by COG and SIOP, the surgical approach to children with neuroblastoma has changed in the past 10 years. In the past, parents would try to find a surgeon who was experienced and aggressive enough to offer surgical resection up front rather than "just a biopsy" or a fruitless but extravagant surgical exploration. We now know that for intermediate- and high-risk neuroblastoma, aggressive up-front surgical resection makes no difference in treatment plan or prognosis but is associated with significant morbidity. Traditional staging systems were also based on surgical findings and would vary depending on the institution and the surgeon, making comparisons between studies difficult and misleading. These concerns have largely been addressed by the INRG staging system: tumors are staged locally as L1 or L2 depending on whether there are image-defined risk factors and M if there are distant metastases. The rare L1 tumor is considered resectable and is often a low-risk tumor for which surgical resection is curative. Most children with L2 disease (and some with stage M) should have an open biopsy followed by neoadjuvant chemotherapy and delayed primary resection. Possible exceptions include posterior mediastinal tumors, which are often low-risk tumors regardless of stage and thus amenable to a >50 % resection.

Resection of lumbar and sacral paraspinal tumors should usually be done with neural monitoring to help avoid nerve root injury. Never "chase" a tumor into a neural foramen as this can create intraspinal bleeding, spinal cord compression, and paralysis. Resection of cervical and apical chest tumors almost always creates a Horner syndrome, which should be discussed with parents ahead of time and carefully documented. Thoracic tumors can sometimes be resected thoracoscopically unless very large, in which case a vertical muscle-sparing thoracotomy incision may be used. Apical chest masses can sometimes be approached quite adequately through an axillary incision. Pelvic (Zuckerkandl) tumors are a challenge, and the entire team needs to be prepared for the possibility of exsanguinating blood loss, usually from the iliac or presacral veins.

Resection of abdominal/retroperitoneal neuroblastoma can be daunting. The goal should be an aggressive attempt to achieve a gross total resection while preserving organ function and limiting serious complications (pleural effusions, chylous

ascites, chronic diarrhea from denervated bowel, renovascular hypertension). For high-risk tumors, removing at least 90 % of the tumor seems to achieve the best results, while for intermediate-risk tumors, the threshold for maximum benefit is probably lower but currently unknown. Maximal resection with minimal harm is usually a good strategy regardless of risk group and stage.

Treated neuroblastoma can usually be separated from major vascular structures using very careful dissection, frequent use of intraoperative Doppler mapping, and constant vigilance for distorted anatomy and startling surprises. High-resolution preoperative imaging is critical and should be studied in detail prior to going to the OR. Nephrectomy is considered a serious complication and should be avoided whenever possible. It might be justified if ipsilateral renal function is already minimal, if it is the only way to achieve >90 % resection of a high-risk tumor, or if the renal artery has been compromised such that hypertension is a certainty; these are all rare scenarios. Transverse abdominal incisions provide excellent exposure and heal nicely. Except under very unusual circumstances, we prefer to avoid midline incisions and almost never feel the need to use a thoracoabdominal approach. At our institution, most resections take less than 4–6 h in which case the patient can usually be cared for on the general ward using an enhanced recovery protocol (no NGT, early diet advance, minimal IV fluids, suppository on POD2) rather than in the PICU.

Open biopsy of a large abdominal mass provides adequate tissue for biological studies and the ability to control bleeding. These tumors tend to be necrotic and extremely vascular. A 2–3-cm transverse incision that can later be extended for delayed primary resection is usually adequate. An extraperitoneal approach works well but is not always feasible. After packing adjacent bowel away with moistened laparotomy pads, a generous elliptical incision is made in the capsule of the tumor, and then pieces of necrotic tumor are removed from the central portion using ringed bowel forceps, which are less likely to tear vessels than most other forceps or clamps. The bleeding can be quite brisk and difficult to control. Small children will sometimes require transfusion. The tumor cavity is then filled with hemostatic agents—oxidized cellulose, hemostatic matrix, gelfoam—whatever it takes to stop the bleeding. The capsule of the tumor will sometimes be substantial enough to hold large mattress sutures that can contain and tamponade the bleeding within the tumor.

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Wilms Tumor

97

Peter F. Ehrlich

Wilms tumor (nephroblastoma) is the most common primary malignant renal tumor of childhood. It accounts for 6 % of all pediatric tumors. Wilms tumor is the second most frequent solid organ abdominal tumor encountered in childhood. The annual incidence is 8.1 per million children, resulting in 600–700 new cases each year in North America. Outcomes for children with Wilms tumor have improved dramatically over the last 50 years with long-term survival in both North American and European trials approaching 85 %, while many of the low-stage tumors have survival rates between 99 %. The treatment strategy for children with a WT has also evolved. It is based both on traditional risk factors such as stage and histology and also on genetic markers, therapy response, and risk of late effects. The goal of modern "risk-based management" is to maintain excellent outcomes at the same time spare children with low-risk tumor intensive chemotherapy and radiation with their long-term side effects but to intensify therapy for high-risk tumors to decrease recurrence rates (Table 97.1). Risk-based therapy requires a multidisciplinary team that includes oncologists, radiologist, surgeons, radiation oncologists, pathologists, social workers, and nurses. Within the multidisciplinary treatment team, the surgeon plays a critical role in diagnosis and staging and his or her technical skills and judgment direct therapy and impact outcome.

Presentation

Most children with WT will present with an asymptomatic abdominal mass usually detected by a parent or pediatrician on routine examination. The child may also present with hematuria (a sign that there may be tumor in the ureter) or abdominal pain due to tumor bleeding or capsular rupture. The differential diagnosis of an abdominal mass is extensive and includes neoplastic and nonneoplastic lesions (Table 97.2). WT is the most frequent tumor of renal origin, but other possible renal tumors include clear cell sarcoma, rhabdoid tumors, renal cell carcinoma, and mesoblastic nephroma.

The mean age at diagnosis is 3 years with most children presenting between the ages of 1 and 4 years. Wilms tumor is rare over 10 years and under 6 months of age. The mass is usually discovered incidentally either by a parent when dressing or giving the child a bath or at a routine visit to the pediatrician. Twenty percent of children with WT have hematuria, 10 % have coagulopathy, and 20–25 % present with hypertension due to activation of the renin-angiotensin system. Fever, anorexia, and weight loss occur in 10 %. In rare instances, tumor rupture and bleeding can cause an acute abdomen. Between 5 and 10 % of tumors are bilateral, and bilateral tumors can either be synchronous or metachronous. Most bilateral tumors are de novo, but children with syndromes such as WAGR (Wilms tumor, aniridia. genital urinary malformations, mental retardation) and Beckwith-Wiedemann syndrome (visceromegaly, macroglossia, omphalocele, hypoglycemia) are more likely to have bilateral tumors.

One classic but still sometimes helpful clinical observation to help distinguish between WT and neuroblastoma is that children with neuroblastoma often look ill due to release of metabolically active tumor peptides. In contrast, children with WT are usually otherwise healthy appearing and well nourished. In 15–30 %, congenital anomalies (aniridia, genitor urinary malformations, hemihypertrophy, signs of overgrowth) are reported. The syndromes associated with the highest risk of developing WT include WAGR, BW, and Denys-Drash (nephropathy, renal failure, male pseudohermaphroditism, Wilms tumor). Other associations with Wilms tumor include hemihypertrophy, Klippel-Trenaunay-Weber, Perlman syndrome, and genitourinary malformations.

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Table 97.1 Wilms tumor: conceptual framework for risk-based therapy

	Potential for late effects	
Relapse-free survival	Low	Moderate to high
Excellent (≥85 %)	Stage I/II FHWT, LOH–	Stage I/II CCSK Stage III FHWT, LOH–
Good (75–84 %)		Stage IV FHWT, LOH– Stage II AHWT Stage III CCSK
Unsatisfactory (<75 %)	Stage I/II FHWT, LOH+ Stage I AHWT Stage I–IV RCC	Stage III/IV FHWT, LOH+ Stage III/IV AHWT Stage V WT Stage IV CCSK Stage I–IV MRT Relapsed FHWT

FHWT Familial histology Wilms tumor, *AHWT* anaplastic histology Wilms tumor, *LOH* loss of heterozygosity, *CCSK* clear cell sarcoma of the kidney, *MRT* malignant rhabdoid tumor

Table 97.2 Differential diagnosis of solid abdominal neoplastic lesions

(A) Common neoplastic lesions of the abdomen
Liver
Hepatoblastoma
Hepatocellular carcinoma
Spleen
Hematological disorder
Intestine
Lymphoma (Burkitt's)
Ovary
Germ cell tumor
Adrenal
Neuroblastoma
Retroperitoneum
Sarcoma
Germ cell tumor
Neuroblastoma
(B) Renal tumors
Wilms tumor
Clear cell sarcoma
Adenocarcinoma
Rhabdoid tumor of the kidney
Cellular, classic, or mixed mesoplastic nephroma
Angiomyolipoma
Cystic nephroma or cystic partially differentiated nephroblastoma
Metanephric tumor (adenoma, adenofibroma, stromal tumor)
Ossifying renal tumor of infancy
Diffuse hyperplastic perilobar nephroblastomatosis
Nephrogenic rest
Oncocytic renal neoplasms following neuroblastoma
Papillary renal cell carcinoma
Renal medullary carcinoma
Renal tumors associated with TFE3 or TFEB translocations

Imaging

Once the clinical diagnosis of an abdominal mass is entertained, the next step is to determine the origin of the mass and the extent of the tumor (Fig. 97.1). WT can extend through the renal vein up to the right atrium or down through the ureter (Fig. 97.2). The common sites of metastatic spread include the lungs and the liver; therefore, abdominal and pulmonary imaging is needed. Ultrasound is a good screening tool to determine if it is renal or extra renal in origin. A color Doppler US or properly phased CT scan should be used routinely at diagnosis to identify tumor in the renal vein, inferior vena cava, or right atrium. About 4 % of WT present with IVC or atria involvement and 11 % with renal vein involvement. Caval thrombosis has caused mortality when an unrecognized thrombus embolized during nephrectomy. US is not as sensitive as other techniques for detection of bilateral Wilms tumor or nephrogenic rests**.**

A CT or MRI will confirm the renal origin of the mass and determine whether there are bilateral tumors. Early generations of CT missed 7–10 % of bilateral lesions, and it was always mandated to explore the contralateral side prior to doing a nephrectomy. With modern helical CT scans, only 0.25 % of bilateral tumors are missed, all of which are less than 1 cm. Thus, the new surgical recommendations do not include a formal exploration of the contralateral kidney prior to nephrectomy. CT can also help to identify renal and IVC tumor thrombus. CT may not be able to distinguish a hyperplastic nephrogenic rest or WT from a sclerotic nephrogenic rest. MRI is helpful but to date has not been shown to be superior to CT scanning in standard assessments. Although positron-emission tomography (PET) appears to be useful in some malignancies, its role is yet to be defined. The most

common site of metastasis for renal tumors is the lung, and a chest CT will also need to be performed to assist with staging. A CT of the brain should be performed if the renal tumor pathology is clear cell sarcoma as theses tumors can spread to the brain. If the mass turns out to be a rhabdoid tumor, a bone scan or PET should be performed.

Prognostic Factors

There are several prognostic factors that influence the outcome of children with WT. These include histology, stage, molecular markers, age, and tumor weight. Histology and stage remain the most important. A child less than 2 years of age with a stage I tumor that weighs less than 550 g has a lower risk than other patients.

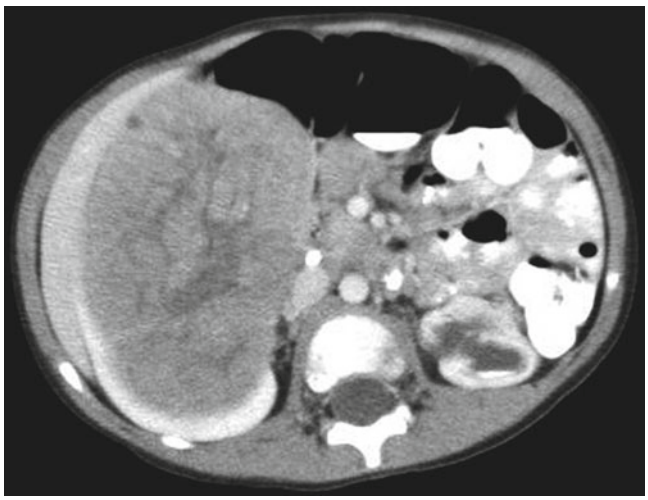

Fig. 97.1 A computed tomography scan of a large righted Wilms tumor

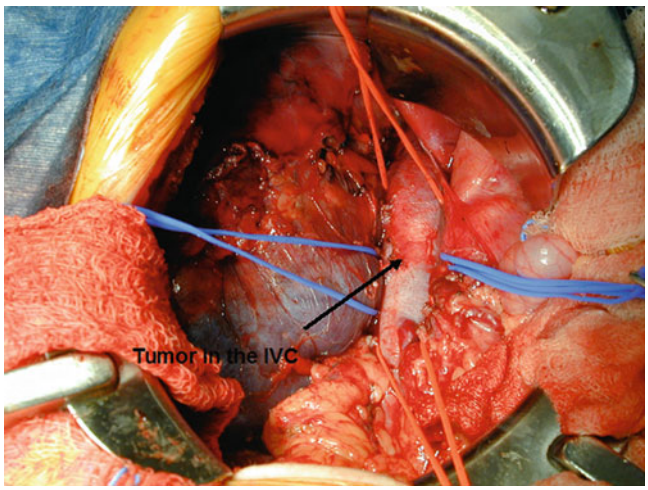

Fig. 97.2 An intraoperative picture of a Wilms tumor extending into the inferior vena cava. The inferior vena cava is isolated by vessel loops

Histology

The common renal tumors a pediatric surgeon will encounter are WT, renal cell carcinoma (RCC), clear cell sarcoma of the kidney (CCSK), rhabdoid tumor of the kidney (RTK), and mesoblastic nephroma. CCSK and RTK tumors were originally thought to be variants of WT but are now recognized as separate entities requiring different treatments. Mesoblastic nephroma is a benign hamartoma of the kidney. It is the most common neonatal and infant renal neoplasm (children less than 1). However, it is important to remember that 20 % of infant and neonatal renal tumors are WT. A surgeon operating on a neonate with a renal tumor should therefore assume it is a malignant tumor and perform a cancer operation. The risk of RCC increases with the age of the child. It is often under-recognized that RCC is the second most common renal tumor in children under the age of 21.

Histologically, Wilms tumors are classified as either *favorable* or *unfavorable*. Favorable tumors consist of blastemal, stromal, and epithelial elements (Fig. 97.3). Unfavorable tumors are anaplastic (Fig. 97.4). Patients with favorable histology have a better overall survival by stage than any other group of WT patients. Unfavorable histology is found in about 10 % of WT. Anaplasia is a marker of resistance to treatment, not of tumor aggressiveness; therefore, it is important that the pathologist notes the distribution of anaplasia as either diffuse or focal. Focal anaplasia has a better prognosis and is treated differently than a child with diffuse anaplasia. It is also important to note that anaplasia cannot be diagnosed by a core or needle biopsy.

Stage

The tumor stage is determined by the results of the imaging studies and both the surgical and pathologic findings at nephrectomy (Table 97.3). The staging system has been gradually revised as features that correlate with prognosis that have been defined. Patients will receive a local stage as well as an overall disease stage, so that a child can have a local stage I tumor but can be stage IV due to pulmonary metastasis. Therapy will be different than for a child with a local stage III tumor and pulmonary metastasis. Bilateral tumors ("stage V") are each locally staged separately.

Molecular Markers

Loss of heterozygosity refers to loss of genetic material and allelic uniqueness. LOH may be found on chromosomes 11p, 16q, or 1p in children with WT and is associated with poorer outcome independent of stage or histology than those without LOH; however, recently recommended augmented

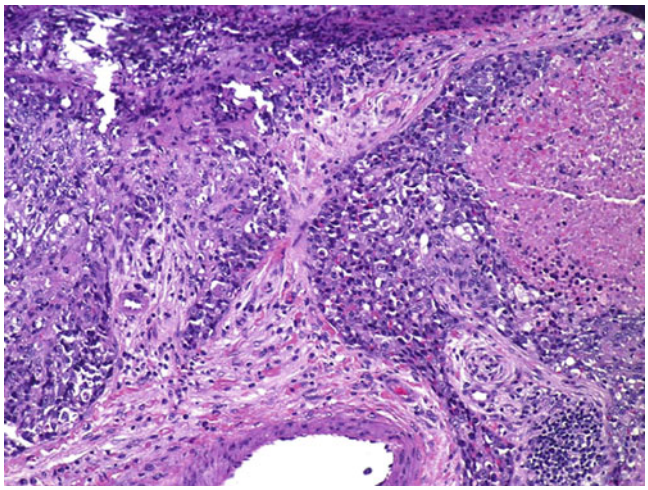

Fig. 97.3 A high-power H and E stained micrograph of favorable histology Wilms tumor

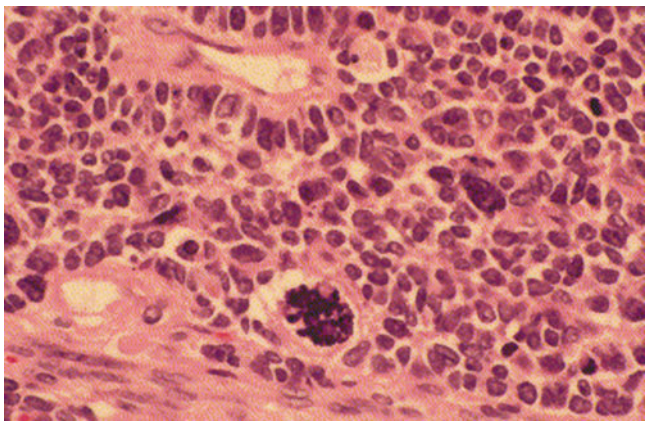

Fig. 97.4 A high-power H and E stained micrograph of unfavorable histology (anaplastic)

therapy for patients with LOH has resulted in significantly improved overall and event-free survival across all stages.

Patients with relapsed WT have a poor prognosis. Advanced stage, unfavorable histology, age >24 months, or combined LOH at 1p and 16q account for one third of children who relapse. Gain of genetic material on chromosome 1q has been found retrospectively to be very strong predictors of relapse. In future studies, this will be test prospectively with treatment stratification based on the presence or absence of 1q gain.

Surgical Management

The operative procedure is very important to the staging and treatment of a child with WT. There are several key things to note in the operative record. First, upon entering the abdomen, the presence of any tumor rupture must be documented. Preoperative tumor rupture mandates whole-abdomen radiation therapy. The second is to document whether the tumor was violated, spilled, or ruptured during the operation. To achieve good outcomes, treatment needs to be altered if this occurs. Although surgeons were previously asked to determine whether the spill was "local" or "diffuse," these terms are very subjective, and data show that if *any* spill has occurred, undertreatment increased the risk of local relapse. When all spills are treated as stage III tumors, excellent oncologic outcomes are maintained.

The approach recommended by the Children's Oncology Group (COG) for a child with a unilateral renal tumor is primary radical nephroureterectomy and lymph node sampling. The Société Internationale d'Oncologie Pédiatrique (SIOP), on the other hand, recommends preoperative chemotherapy followed by radical nephrectomy and lymph node sampling. Pre- or intraoperative biopsies prior to removing the kidney are unnecessary and should be avoided in a child with a potential WT as this upstages the tumor to stage III and mandates increased chemotherapy and flank radiation. A transverse abdominal or a chevron incision should be used for good transabdominal exposure. Retroperitoneal incisions often result in failure to properly determine the tumor extent, and the surgeon more often fails to sample lymph nodes. For very large tumors or those that come off the superior pole and extend up to the diaphragm, a thoracic extension of the incision through the eighth or ninth rib space helps with exposure. Complete exploration of the abdomen should be done to look for liver metastasis, peritoneal seeding, signs of preoperative rupture, and ascites. Routine exploration of the contralateral kidney is not necessary if imaging is satisfactory and does not suggest a bilateral process. If the initial imaging studies are suggestive of a possible lesion on the contralateral kidney, the contralateral kidney should be formally explored to rule out bilateral involvement. This should be done *prior* to nephrectomy—bilateral tumors should be biopsied, and if positive, nephrectomy should *not* be performed.

The most common mistake made by an operating surgeon is failure to sample lymph nodes. Lymph node status is critical to staging and determining therapy. If the tumor is stage I and LNs are negative, the child may not require chemotherapy. Alternatively, if LNs are positive, the child has stage III disease and would require three-drug chemotherapy and flank radiation. A second mistake is doing an extensive resection of other organs such as the liver, bowel, or pancreas. Most WT do not invade other organs and are very responsive to chemotherapy. There is almost never the need to do a liver or bowel resection to remove the kidney. These extra procedures do not improve the oncologic survival and are associated with increased complications. Exceptions are the adrenal gland, especially for upper-pole tumors, and the diaphragm, a small portion of which can be resected at the time of nephrectomy if the tumor is adherent.

I place a bump under the child on the side of the tumor as this helps with exposure. There are also specific anatomic

Table 97.3 Children oncology group Wilms tumor staging

Stage I
The tumor is limited to the kidney and has been completely resected
The tumor was not ruptured or biopsied prior to removal
No penetration of the renal capsule or involvement of renal sinus vessels
Stage II
The tumor extends beyond the capsule of the kidney but was completely resected with no evidence of tumor at or beyond the margins of resection
There is penetration of the renal capsule
There is invasion of the renal sinus vessels
Stage III
Gross or microscopic residual tumor remains postoperatively including: inoperable tumor, positive surgical margins, tumor spillage surfaces, regional lymph node metastases, positive peritoneal cytology, or transected tumor thrombus
The tumor was ruptured or biopsied prior to removal
Stage IV
Hematogenous metastases or lymph node metastases outside the abdomen (the lung, liver, bone, brain)
Stage V
Bilateral renal involvement is present at diagnosis, and each side may be considered to have a stage

considerations depending on which side the tumor is located. The right renal vein is short and easier to tear, and the right adrenal vein may be adherent to the tumor mass. To help with exposing the vein and the vena cava, the hepatic flexure is mobilized, and a Kocher maneuver is performed. On the left, the renal vein crosses over the aorta, and the gonadal and adrenal veins enter the left renal vein directly. The tumor may also be densely adherent to the duodenum or superior mesenteric artery, and injuries have been reported. Mobilizing the spleen and pancreas superior and medially will facilitate exposure for left-sided tumors. If the adrenal gland is adherent to the tumor, it is best to remove it with the kidney to avoid tumor spillage.

Once the abdomen has been assessed, I begin to mobilize the kidney. The bowel is reflected medially to expose the kidney. These tumors can be very large, and preliminary ligation of the renal artery and vein should not be pursued if technically difficult or dangerous. In these cases, I will identify the ureter and divide it as distally as possible. Then I will mobilize the kidney laterally, inferiorly, and superiorly, coming to the hilum last so that the kidney is on a pedicle.

When the renal vein is exposed and controlled, the vein and IVC should be palpated to rule out extension of the tumor into the wall or the lumen of the vein. If tumor extension is present, this should be removed en bloc with the kidney. Tumor that extends into the renal vein and cava is considered stage II if it can be removed en bloc. Transection of the tumor thrombus or bringing it out piecemeal is considered a tumor spill. This will make the tumor a stage III and therefore should be avoided. I will often do a partial occlusion of the inferior vena cava to assist in removing the tumor in one piece. Note should be made of whether tumor penetrates the vessel wall or is attached to the intima. If the tumor extends to the intrahepatic portion of the IVC or higher, the primary tumor should just be biopsied and treated with chemotherapy before attempting resection. This approach will often achieve significant shrinkage of the intravascular thrombus facilitating subsequent surgical removal. This reduces significant complications by over 25 % and does not influence oncologic outcomes. Some WT are very soft, and if during the dissection the tumor capsule is violated or ruptured, postoperative radiation therapy is indicated.

Stage IV Tumors

A child can have a local stage I or II tumor and pulmonary metastases, making them disease stage IV. A common misconception is that children who have pulmonary metastatic disease should be treated with preoperative chemotherapy. This is *false*. If the primary tumor is resectable, it should be removed because flank radiation can be avoided if the local tumor is truly a stage I or II. In addition, reduction of tumor burden up front might enhance chemotherapy effectiveness.

When Is a Tumor Unresectable?

There are four main reasons a tumor might be considered initially unresectable: (1) tumor thrombus extends above the level of the hepatic veins; (2) the tumor involves contiguous structures whereby the only means of removing the tumor is to remove the other structure (excluding the adrenal gland); (3) in the surgeon's judgment, a nephrectomy would result in significant or unnecessary morbidity, risk of death, diffuse tumor spill, or residual tumor; or (4) there is extensive pulmonary compromise from a massive tumor or widespread pulmonary disease, making the patient a high-risk surgical

candidate. A relative contraindication to up-front resection might be tumor diameter of 12 cm or greater, which we have shown to be at higher risk of intraoperative tumor rupture.

Children with tumors that are considered unresectable should receive neoadjuvant chemotherapy to decrease subsequent operative risk. Pretreatment with chemotherapy in most cases can reduce tumor bulk and make it resectable. The maximum response to chemotherapy typically occurs by week 6; therefore, radiographic reevaluation should be performed at this point. However, keep in mind that this approach does not result in improved survival rates but can result in the loss of important staging information. It is recommended that all patients be considered for initial exploration to assess operability.

Laparoscopy

The role of laparoscopic surgery for Wilms tumor is yet to be defined. The laparoscopic surgeon must perform the same operation as the open operation. The main benefit of laparoscopic surgery is a smaller incision and potentially less pain. WT tends to be very large and cannot be morselized and put into a bag brought out through a small incision as crucial staging data will be lost. Most are being converted to open, or the incision is ultimately as large as an open incision might have been. There is also an increase in intraoperative tumor spill, and the lymph nodes tend not to be sampled.

Unilateral Partial Nephrectomy

The renal failure rate in children with unilateral WT 40 years after surgery is 1 %. In those without a syndrome, it is less than 0.5 %. The main long-term morbidities from WT therapy are due to radiation therapy and additional chemotherapy such as doxorubicin—not renal failure. In COG studies, there is no role for partial nephrectomy in children with two normal kidneys. Some surgeons still attempt partial nephrectomy, but over 2/3 of these children are found to have positive margins, resulting in more intense chemotherapy and the addition of radiation therapy. In addition, it is very common that LNs are not sampled.

If a child has a single kidney or is at risk for metachronous tumors, then a renal-sparing approach should be considered. These include patients with aniridia, BWS, DDS, WAGR, and idiopathic hemihypertrophy.

Lymph Node Documentation and Tumor Spillage

The presence or absence of disease in hilar and regional lymph nodes is extremely important for accurate staging. Children with positive lymph nodes are classified as stage III and receive abdominal radiation and more intensive chemotherapy. Thus, routine lymph node sampling from the renal hilum as well as the pericaval or para-aortic areas must be done. Survival for children with WT drops to 40 % if they relapse. Studies have highlighted two key factors that affect relapse: (1) failure to biopsy lymph nodes, which increases local relapse greater than when lymph node involvement is documented in biopsied nodes, and (2) tumor spillage, which significantly increases local relapse even when correcting for histology, age, and lymph node involvement. Failure to sample lymph nodes occurs 10–12 % of the time and is a major technical error noted in Wilms tumor surgery.

"Surgery only" is the treatment for children with WT whose tumor is stage I and weighs less the 550 g in a child less than 2 years old. Survival in this group is nearly 99 %. Because of the significant risk of short- and long-term complications from chemotherapy in children under 2 years of age, avoiding chemotherapy is beneficial. However, children can only receive this therapy if the nodes were sampled and are negative.

Nephroblastomatosis (Nephrogenic Rests

Nephroblastomatosis or nephrogenic rests (NRs) are defined as "persistent metanephric tissue after the 36th week of life" (Fig. 97.5). Rests are remnants of embryonic renal tissue that are considered precursor lesions to Wilms tumors. Nephrogenesis in the normal kidney is usually complete by 34–36 weeks gestation. Nephrogenic rests are found in the kidney in a perilobar, intralobar, or panlobar location. A surgeon might come across a rest within a kidney that contains a WT. This is a marker for an increased risk of developing a metachronous tumor in the other kidney. A second and often more difficult scenario is when a rest is an independent renal lesion. These children can also develop de novo Wilms tumors within the rest itself and must be followed carefully.

It can be difficult to distinguish a rest from a WT. Nephrogenic rests are classified based on the rest category present and their growth phase. One type is diffuse hyperplastic perilobar nephrogenic rests (DHPLNs). The growth phase is divided into incipient or dormant nephrogenic rests, hyperplastic nephrogenic rests, and regressing or sclerosing nephrogenic rests. Those that form a thick rind around the kidney, DHPLN, are the least difficult to identify. The rests that cause the greatest diagnostic obstacle are those that are actively proliferating. These are very difficult to distinguish from a WT. Hyperplastic NR can produce masses as large as a typical Wilms tumor. Neoplastic induction of NR can occur and is the biggest challenge for the surgeon managing these patients. Pathologic distinction between NR and WT is difficult. Incisional biopsies are of no value. What is critical is to examine the juncture between the lesion and the surrounding renal parenchyma. Most hyperplastic NR lacks a pseudocap-

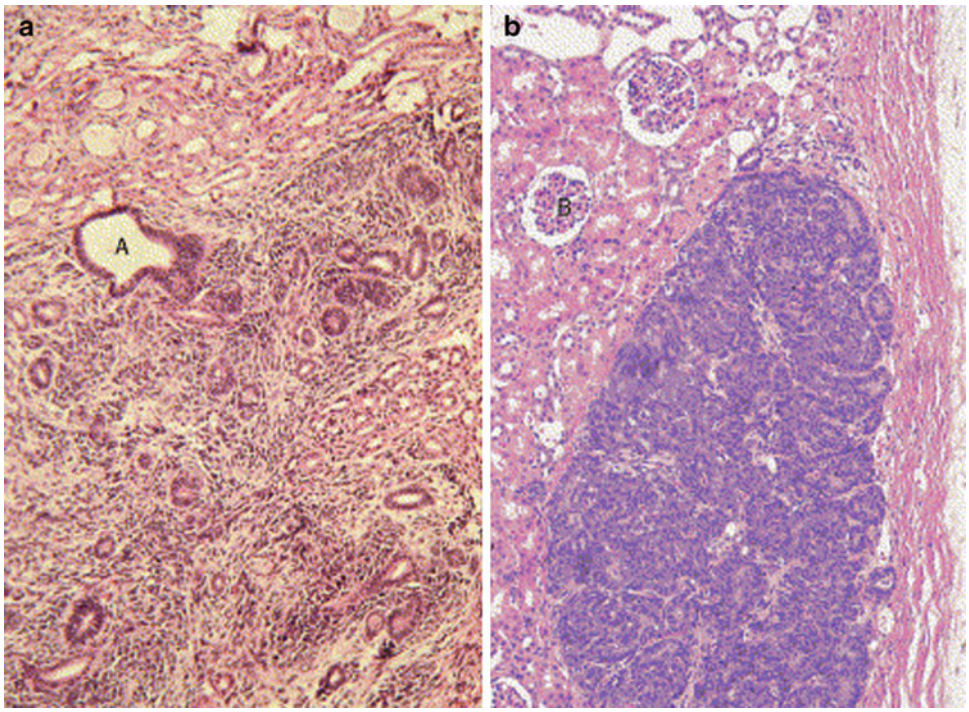

Fig. 97.5 Nephrogenic rests

sule at the periphery, while most Wilms tumors will have this feature. The prevalence of NR in unilateral Wilms tumor is 41 %, in bilateral 90 %, and in metachronous 94 %. Serial imaging is recommended in children with WT with nephroblastomatosis. The hallmark of neoplastic transformation of benign nephroblastomatosis appears to be renal enlargement. US is the most cost-effective screening tool, but T1-weighted MRI is the best way to make the diagnosis.

Intravascular Extension

Vascular invasion of the renal vein, IVC, and right atrium presents special surgical challenges. Primary resection of extension when the tumor extended beyond the interior portion of the hepatic vena is associated with high operative morbidity. In these circumstances, preoperative chemotherapy decreases the size and extent of the tumor thrombus thereby facilitating subsequent excision. Tumor that extends into the renal vein and cava may simply extend as a floating attachment. Control of the renal vein and cava above and below the tumor with vessel loops is necessary. The tumor should not be transected. Stitches can then be placed on either side of the renal vein. This will help with vascular control and limit bleeding.

The tumor and kidney should be completely mobilized prior to removing vascular thrombus. A venotomy is then done, and the tumor pulled out of the vein. A Foley balloon technique can also be used to pull out the tumor. In other instances, the tumor may be fixed to the vascular lumen. Extraction is more difficult and a larger venotomy may be required. A similar technique to remove plaque for a carotid endarterectomy is helpful to lift the tumor off the vein wall. If after preoperative chemotherapy the tumor still extends above the hepatic veins, cardiopulmonary bypass is needed to remove the vascular extent of the tumor.

Bilateral Wilms Tumors

Current therapy for children with bilateral Wilms tumors is focused on sparing renal parenchyma. These include children who present with BWT and those with unilateral tumors who are at high risk for a metachronous tumor. Approximately 9 % of children with synchronous bilateral Wilms tumor eventually develop renal failure. The cause of renal failure in about ¾ is bilateral nephrectomy for persistent or recurrent tumor in the remaining kidney after initial nephrectomy. Therefore, avoiding total nephrectomy at initial surgery is advised. Initial therapy for a child with bilateral WT is three-drug chemotherapy. Extensive algorithms have been developed to help direct therapy for children with BWT and can be found on the COG website at www.childrensoncologygroup.org. It is strongly recommended that when you encounter a patient with BWT that you review the therapy guidelines, as they are regularly revised, and contact one of the surgical experts listed for BWT.

After initial chemotherapy, the patient is evaluated by repeat imaging at 6 weeks (Fig. 97.6). If imaging suggests a partial resection is feasible, then surgery should be performed. It is important to also examine lymph nodes at that time, as each kidney would be treated differently with respect

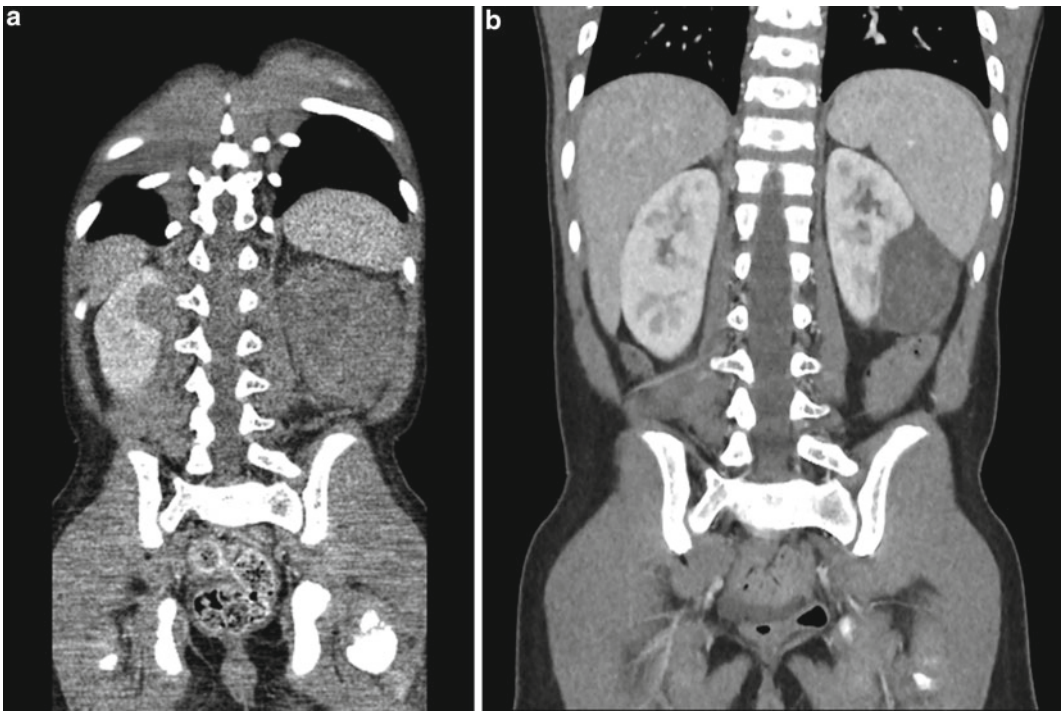

Fig. 97.6 (**a**) A CT scan of child at presentation with bilateral Wilms tumor showing a very large right-sided tumor and a smaller left-sided one. (**b**) The small child after four rounds of chemotherapy showing excellent response to the chemotherapy

to radiation therapy. If at 6 weeks there has been no response, bilateral open biopsies are recommended. No response could mean that the one or both of the tumors are anaplastic and require different chemotherapy or that the chemotherapy has caused rhabdomyomous change, which is a good prognostic sign but means the tumor will not shrink in size further, and one should proceed with definitive surgery. Continuing chemotherapy beyond 12 weeks will not improve survival or result in increased renal tissue salvage; it also often leads to significant short- and long-term toxicity.

There are no validated guidelines for partial nephrectomy in children with WT. Most come from adult surgery with RCC tumors. These include leaving 50 % of the renal tissue, no tumor in the hilum, and no vascular involvement. However, WT tends to compress the normal kidney, and more is actually present than appears. The hilum can also be split using a lateral partial nephrectomy incision and tumor removed from the hilum. Consultation with an experienced WT surgeon may help determine whether a partial nephrectomy can be performed.

There are several renal preservation techniques described including vascular clamping, cooling, mannitol, and extracorporeal resection. In the small child, the major reason for intraoperative loss of a kidney is venous or arterial thrombosis. In the young child with BWT, I do not use vascular occlusion. I do a minimal mobilization, and I am very careful not to put the kidney on traction. I then use intraoperative ultrasound to distinguish normal kidney from tumor. This helps me determine resectability and also lowers the risk of a positive margin. Achieving negative margins is ideal; however, I will accept a positive margin in a child with favorable histology WT and treat with radiotherapy (the outcomes are equivalent) if this avoids a total nephrectomy. If the pathology is anaplasia, one cannot leave positive margins as this negatively impacts survival. Enucleation of the tumor is reserved for children with favorable histology BWT if removing a margin of renal tissue would compromise the vascular supply to the kidney, such as a tumor located centrally near the hilum. Children with BWT who require bilateral nephrectomies can be considered for renal transplantation after therapy is completed but due to immunosuppression will be at risk of tumor reactivation and the associated risks of renal transplantation.

Horseshoe Kidney

Children with horseshoe kidney should be treated as a unilateral tumor not a bilateral or single kidney. Resection presents unique challenges. Children with a horseshoe kidney and WT must be carefully imaged prior to any surgery. The ureters and blood supply to the kidney must be identified and isolated. Exposure and mobilization of the kidney (the isth-

mus and the ipsilateral ureter) on the side of the tumor are carried out as if one is performing a unilateral resection. The ipsilateral portion of the kidney and the isthmus should be removed. As with other unilateral procedures, the lymph node groups are sampled for staging purposes.

Lung Metastasis

Patients with lung metastasis in North America have been treated with adjuvant chemotherapy and 1200 cGy radiation to both lung fields. Prior studies suggested that pulmonary radiotherapy might not be needed in all children with lung lesions, and this has been confirmed in a more recent study. These are children whose lung lesions completely respond to three-drug chemotherapy at 6 weeks. In these children, it is safe to avoid pulmonary radiotherapy. There are three times a surgeon might be asked to intervene in a child with a pulmonary lesion: (1) at diagnosis for a single small lesion in a child whose primary tumor is stage I, in which case the child may be eligible for surgery alone (or less toxic chemotherapy); (2) after the first round of chemotherapy if lesions shrink but do not go away completely, in which case it would be valuable to assess the histology of the lesion prior giving radiotherapy; and (3) when tumor remains after both chemotherapy and radiotherapy, in which case surgical resection would be for cure.

Editor's Comment

Total nephroureterectomy for Wilms tumor is usually straightforward but can present challenges. In Europe, standard treatment guidelines include preoperative tumor shrinkage with neoadjuvant chemotherapy and delayed nephrectomy, whereas the standard for unilateral tumors in the USA is up-front nephrectomy and lymph node sampling followed by adjuvant chemotherapy. The principal advantage of the former approach is a minimal risk of intraoperative rupture (the operation is certainly much easier after the tumor has been treated), but the downside is that all children are treated with an intensive three-drug chemotherapy regimen. The European approach also creates a dilemma related to diagnostic confirmation—biopsy always results in tumor spillage, while treating patients without tissue exposes children with benign lesions to chemotherapy and risks undertreating those with anaplasia. Nevertheless, a neoadjuvant approach is used here for: tumors that have ruptured, extremely large tumors that are metastatic or inoperable, and tumors with intracaval tumor thrombus that extends above the hepatic veins or into the right atrium and bilateral tumors.

For tumors with intracaval tumor thrombus extending above the hepatic veins, chemotherapy will usually cause tumor thrombus to shrink back toward the primary, allowing control of the IVC above the tumor and removal at the time of the nephrectomy. Tumors that do not retract are either poor responders or adherent the wall of the vessel. In these situations, it is recommended to have a cardiac surgeon perform a sternotomy and place the child on bypass. This allows for resection and reconstruction of the retrohepatic cava as well as atriotomy for removal of intracardiac tumor. Occasionally, the top of the thrombus can be pulled down below the hepatic veins by manual traction on a kidney that has been completely mobilized and only attached by the renal vein. In these cases, we will have the cardiac team on standby.

In the past, patients with a renal mass and lung lesions would sometimes be offered thoracoscopic lung biopsy and neoadjuvant chemotherapy, but we know now that that is not usually the best option. These patients are best served with up-front total nephrectomy and lymph node sampling as though they had no lung disease. Finally, while it is true that even very large Wilms tumors rarely invade local structures, a possible exception is the posterior aspect of the diaphragm, where the tumor can be quite adherent and which is a common location for recurrence. In these cases, it is probably best to excise a portion of the diaphragm with the tumor.

Patients with bilateral Wilms tumors are treated at our institution without a biopsy and after neoadjuvant chemotherapy are prepared for bilateral partial nephrectomy. These are difficult and sometimes bloody operations. We will occasionally use two separate incisions, each started lateral to the rectus muscles. Intraoperative US is helpful to identify the extent of the lesions. We will try to preserve at least half of a kidney; anything less than about a third is probably not worth the effort or the risks. We always try to achieve capsular approximation with absorbable mattress sutures, usually with liberal use of hemostatic agents including oxidized cellulose, and we almost never feel the need to leave a drain. If capsular apposition is impossible, it is acceptable to cover the exposed parenchyma with Gerota's fascia or omentum. Overall, the outcomes have been excellent, and the morbidity is quite low.

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Adrenal Tumors

98

Daniel von Allmen

When one considers adrenal tumors in children, neuroblastoma is usually the first thought. However, there are several other neoplastic processes that can involve the adrenal gland in children and run the gamut from aggressive malignancies with a very poor prognosis to benign processes with an excellent prognosis. They might be completely asymptomatic or express a broad variety of endocrine behaviors. Although heterogeneous by nature, they share the fact that surgery is the primary mode of therapy.

Adrenocortical Tumors

Adrenocortical carcinoma (ACC) and adrenocortical adenomas are very rare in children, accounting for less than 0.2 % of all pediatric malignancies. ACC is more common in girls than boys and has a somewhat bimodal age distribution, with a peak less than 2 years of age and a second peak near the end of the first decade of life. For reasons that are somewhat unclear but most likely based on genetic predisposition, the incidence of adrenocortical tumors is ten times higher in Brazil than in the USA. By combining data on this uncommon tumor, investigators from the Children's Oncology Group and from Brazil are joining forces to improve our understanding of the disease.

A significant number of patients with adrenocortical tumors have a p53 mutation. More than half of patients in the USA with ACC have germ-line mutations in the p53 DNA-binding domains (exons 4–8), while a single mutation in exon 10 of the *TP53* gene is consistently observed in patients from Brazil. A genetic predisposition can be associated with specific syndromes: ACC is 100 times more frequent in patients with Li-Fraumeni syndrome, which is characterized by a p53 mutation, than in the normal population. Similarly, ACC has been associated with Beckwith-Wiedemann syndrome, characterized by LOH for IGF-2, another recognized genetic risk factor.

Although ACC presents as an asymptomatic mass in about 10 % of cases, it frequently presents with evidence of hormonal stimulation. Though true precocious puberty is rare, it is not uncommon for children with ACC to present with virilization, characterized by an increase in the size of the genitals, pubic hair, deepening voice and hirsutism, or signs of cortisol excess, including acne, hypertension, moon face, centripetal fat, weight gain, and a buffalo hump.

The workup for a patient presenting with any of these findings includes imaging and laboratory studies. Ultrasound is usually the first imaging study because it is relatively inexpensive and usually rapidly obtained. The presence of a mass suggestive of an adrenal lesion then leads to more sophisticated imaging such as CT or MRI. The laboratory workup includes urine for 17-ketosteroids and the androgen dehydroepiandrosterone sulfate (DHEA-S). Plasma is sent for cortisol, DHEA-S, testosterone, renin activity, deoxycortisol, 17-hydroxyprogesterone, aldosterone, and androstenedione.

Treatment

The treatment of any adrenal mass is primarily surgical. Adrenal masses identified in the face of abnormal clinical and laboratory findings require surgical resection. While small, well-circumscribed lesions are sometimes amenable to the laparoscopic approach, larger lesions and those with evidence of invasion into surrounding structures mandate an open exploration with aggressive attempts at resection. Patients with larger tumors (stage II) should also undergo a formal retroperitoneal lymph node dissection on the side of the tumor using published templates. Tumor extending up the right adrenal vein and inferior vena cava is sometimes an indication for obtaining intrapericardial control of the inferior vena cava or cardiopulmonary bypass to allow for resection of the

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venous extension in continuity with the primary tumor (Fig. 98.1). Distinguishing between adenoma and carcinoma can be difficult, but infiltration of surrounding tissues suggests malignancy and, given the absence of effective chemotherapy, dictates aggressive attempts at resection. This includes partial gastrectomy or splenectomy for invasive or adherent left-sided tumors and nonanatomic liver resections on the right.

Staging of adrenal tumors is surgical and is based on the size of the tumor and degree of resection (Table 98.1). Distinguishing between malignant carcinoma and benign adenoma in children can be very difficult. The histopathologic distinction is based on mitotic index, extent of tumor necrosis, presence of atypical mitoses, and nuclear grade (Table 98.2). The clinical behavior of the tumor also provides an indication of the aggressiveness of the tumor.

Unfortunately, there is little in the way of effective medical therapy for adrenocortical carcinoma. Mitotane is an adrenolytic insecticide that can be used in either low doses to inhibit steroid synthesis or in higher doses to destroy adrenocortical cells. The response rate to the drug is 20–30 %, but there has been no change in overall mortality. Evaluation of the efficacy of neoadjuvant chemotherapy in stage III and IV patients is ongoing. Study patients are treated with cisplatin, etoposide, and doxorubicin, both before and after definitive surgery, followed by an 8-month course of mitotane.

The overall survival for ACC is between 50 and 75 %. There is a sharp distinction based on stage with a greater than 90 % survival for patients with stage I disease and less than 10 % survival for patients with stage IV disease. Younger patients (less than 4 years old) have a higher incidence of low stage disease and therefore a higher survival rate. Local recurrence occurs in 30–50 % of stage II and III tumors and the outcome for stage III and IV disease remains very poor.

Pheochromocytoma

Pheochromocytomas arise from the chromaffin cells of the adrenal medulla. Paragangliomas are extra-adrenal manifestations of the same process and typically arise within the sympathetic ganglia. Both are characterized by synthesis of catecholamines including epinephrine, norepinephrine, and dopamine. Pheochromocytomas are rare tumors that usually present between the ages of 6 and 15 years, and, unlike ACC, they are slightly more common in boys. Although pheochromocytomas are seen in association with hereditary syndromes including MEN-2A, MEN-2B, von Hippel-Lindau, and NF-1, most tumors are sporadic and do not share the same chromosomal abnormalities as the familial variants. In patients with MEN-2, abnormalities of the RET proto-oncogene are common.

Eighty-five percent of pheochromocytomas occur in the adrenal gland, while the remainder arise in other areas associated with sympathetic tissues such as the sympathetic ganglia near the renal hilum and the organ of Zuckerkandl. Thirty percent of patients have multiple tumors.

Most children with pheochromocytoma have signs and symptoms of sustained hypertension rather than the paroxysmal hypertension more commonly seen in adults. Central nervous system manifestations, including mental status changes, visual changes, and decreasing school performance have all been described. Headaches, palpitations, sweating, and anxiety are also commonly reported. Other than hypertension, the physical findings are usually limited.

The diagnosis can be confirmed by measuring elevated catecholamines, metanephrines, vanillylmandelic acid (VMA), and homovanillic acid (HVA) in urine that is collected for 24 h. The radiologic workup includes CT or MRI of the abdomen, which typically reveals a smooth, well-circumscribed lesion less than 5 cm in diameter. A nuclear

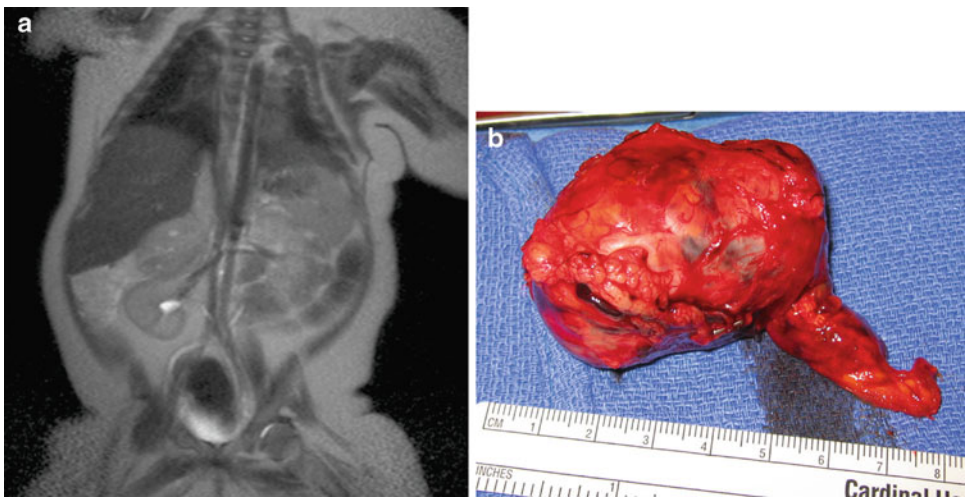

Fig. 98.1 A five-month-old with right adrenal tumor. (**a**) MRI sagittal view showing extension of tumor up to the vena cava to the level of the diaphragm; (**b**) resected tumor specimen with caval extension removed in continuity with adrenal mass

Table 98.1 Staging for adrenocortical tumors

I. Small tumors totally excised (<100 g and <200 cm^3) with normal postoperative hormone levels
II. Completely resected large tumors (≥100 g and ≥200 cm^3) with normal postoperative hormone levels
III. Unresectable, gross, or microscopic residual disease
Tumor spillage
Patients with stage I and II tumors who fail to normalize hormone levels after surgery
Patients with retroperitoneal lymph node involvement
IV. Presence of distant metastasis

Table 98.2 Histologic grading, modified Weiss criteria for pediatric adrenocortical tumors

Diagnosis	Mitotic index	Confluent necrosis	Atypical mitosis	Nuclear pleomorphism
Adrenocortical adenoma	0–5	Absent	Absent	Mild-moderate
ACC-low grade	6–20	Present	Present	Marked
ACC-high grade	>20	–	–	–

Source: Bugg MF, et al. Am J Clin Path. 1994;101(5):625–29. © 1994 American Journal of Clinical Pathology; © 1994 American Society for Clinical Pathology

Mitotic index, Mitotic figures/high power field

medicine $^{[131]}$I-metaiodobenzylguanidine (MIBG) scan is helpful in identifying multiple lesions. The preoperative workup should include an echocardiogram to look for left ventricular hypertrophy due to chronic hypertension. In some patients, congestive heart failure can be the presenting sign.

Treatment

The primary treatment for pheochromocytoma is surgical resection. Classically, patients have been prepared for operation with alpha-blockade and volume loading to counteract the chronic vasoconstriction induced by catecholamine excess. During the operation, the anesthesiologist must be prepared for rapid changes in blood pressure such as spiking hypertension when the tumor is manipulated and rapid loss of alpha stimulation leading to hypotension when the adrenal vein is ligated. Adrenalectomy is usually curative, and the tumors are often relatively small and well circumscribed, making them amenable to a laparoscopic approach. Bilateral tumors are sometimes amenable to partial adrenalectomies, leaving residual functional adrenal gland on one or both sides. On the other hand, if bilateral adrenalectomy is necessary, lifelong replacement with glucocorticoids and mineralocorticoids becomes necessary.

Obviously, associated paragangliomas should be completely resected. Less than 10 % of tumors are malignant. Malignant tumors can be treated with $^{[131]}$I-MIBG, octreotide, or tumor chemoembolization, but the prognosis is poor with unresectable or metastatic disease.

Editor's Comment

Many of the adrenal masses encountered in children can be resected laparoscopically, including pheochromocytomas, most ganglioneuromas, and even some small neuroblastomas. The size of the mass might be a limiting factor depending on the experience of the surgeon. Tumors for which spillage is potentially disastrous, such as adrenocortical carcinomas, should probably not be approached using a minimally invasive approach. In most cases a transabdominal laparoscopic approach with the patient in essentially a lateral thoracotomy position can be used for either right or left adrenal lesions. The majority of the operation can be performed using blunt dissection, dividing small vessels with the harmonic scalpel or hook cautery. Control of the adrenal vein can be particularly hazardous, especially on the right where it is very short and enters directly into the IVC. It is easily torn by overly aggressive dissection but once identified can be clipped near its origin and divided.

Newborns with incidentally identified adrenal masses have neuroblastoma or adrenal hemorrhage. These are difficult to differentiate, but the distinction is usually irrelevant, because either lesion, if small, can be safely observed. Resection is rarely necessary but sometimes demanded by anxious parents or dictated by growth of the mass. Careful surveillance with serial US appears to be safe.

Adrenal ganglioneuromas are often found incidentally in teenagers who undergo CT or MRI for unrelated symptoms or as part of a trauma evaluation. The vast majority of these lesions are benign and could theoretically be safely observed indefinitely; however, because a very small percentage of

these will turn out to harbor a tiny neuroblastoma (ganglioneuroblastoma), resection is usually recommended. In fact, although most "incidentalomas" in children are benign, size and imaging characteristics do not necessarily predict the likelihood of malignancy. In practice then, a pediatric surgeon is asked to resect almost every adrenal mass identified in a child beyond the newborn period. Fortunately, these lesions can almost always be removed laparoscopically.

All but the smallest adrenocortical carcinomas should be resected using an open approach through a generous incision in order to make every effort to avoid breach of the capsule and even the slightest degree of tumor spillage. These tumors are unresponsive to chemotherapy, and therefore complete resection offers the greatest (and often the only) chance for cure. Spillage upstages the tumor and can significantly diminish survival. The tumor capsule is usually very delicate and tears easily. A meticulous and very gentle "no-touch" approach is imperative. Locally invasive tumors should be resected en bloc, including portions of the adjacent spleen, liver, stomach, or diaphragm if necessary to achieve negative margins. All patients should undergo an extensive ipsilateral retroperitoneal lymph node dissection for staging purposes. Unlike the case with Wilms tumor, adrenocortical carcinomas with tumor thrombus extension into the IVC or atrium almost never shrink in response to neoadjuvant chemotherapy. If, even after complete mobilization of the primary tumor, the thrombus cannot be pulled down into the infrahepatic IVC to allow placement of a vascular clamp above it, cavotomy with or with atriotomy on cardiopulmonary bypass must be used.

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Rhabdomyosarcoma

99

Carlos R. Alvarez-Allende and Roshni Dasgupta

Rhabdomyosarcoma (RMS) is a malignant tumor of mesenchymal origin and is the most common pediatric soft tissue sarcoma, accounting for approximately 5 % of childhood cancers. It is the third most common extracranial solid tumor in the pediatric population preceded by neuroblastoma and Wilms tumor with an estimated 350 new cases each year in the United States. Epidemiologically, there is a male predominance and a bimodal age of distribution with the first between 2 and 6 years and a second between 10 and 18 years. This correlates with the incidence of the two primary histological types of the disease. Embryonal rhabdomyosarcoma (ERMS) is more common between birth and early childhood, and alveolar rhabdomyosarcoma (ARMS) is generally noted in later childhood and adolescence.

RMS can arise in one of multiple different sites in the body, the most common being the head and neck (35 %), followed by genitourinary and extremity primaries. Although the vast majority of cases are sporadic, RMS has also been associated with various genetic syndromes. RMS is the most common pediatric cancer in Li-Fraumeni syndrome, which has been linked to a germ-line mutation of the tumor suppressor gene p53 and activation of the RAS oncogene. Patients with this condition often present with RMS at an early age and develop other malignancies including premenopausal breast cancer, acute leukemia, soft tissue and bone sarcoma, and adrenocortical carcinoma. Other syndromes associated with RMS include neurofibromatosis type 1, Beckwith-Wiedemann syndrome, Noonan syndrome, Costello syndrome, and hereditary retinoblastoma.

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Histology and Tumor Biology

RMS is thought to originate from skeletal muscle stem cells and pluripotent mesenchymal stem cells. Approximately 70 % of RMS cases are embryonal, which is further subdivided into typical, dense, botryoid, and spindle cell patterns. The botryoid and spindle cell patterns portend a better prognosis. Spindle cell histology is commonly found in paratesticular lesions, while botryoid tumors are located within hollow viscera such as the vagina, bladder, and biliary tree. Histologically, ERMS is characterized by regions of loose myxoid mesenchymal tissues alternating with densely cellular regions and rhabdomyoblasts in various stages of differentiation. In contrast, sheets of primitive cells with scant cytoplasm and angulated, ovoid nucleus characterize dense subtype ERMS without myogenic differentiation. ERMS tumors regardless of pattern demonstrate loss of heterozygosity in the locus 11p15.5 prompting overexpression of IGF2 due to paternal allele duplication.

The ARMS subtype usually carries a worse prognosis than ERMS and is subdivided into the classical and solid patterns. By definition more than 50 % of the specimen must be alveolar in order to be classified as such. Classic ARMS cells contain eosinophilic cytoplasm arranged in nests separated by fibrous septae with islands of tumor cells. In contrast, the solid pattern lacks dividing septae and is characterized by sheets of monomorphic cells with round nuclei.

Newer techniques in molecular biology have led to the association of ARMS with a chromosomal translocation that fuses the DNA-binding domain of PAX3 (chromosome 2) or PAX7 (chromosome 1) with the carboxyl terminus of FOXO1, encoded by *FOXO1* on chromosome 13. Molecular diagnosis of fusion status is done by either RT-PCR or fluorescence in situ hybridization (FISH). PAX-FOXO1 fusion status is found in approximately 80 % of ARMS and is associated with decreased failure-free survival (FFS) when compared with ERMS and fusion-negative ARMS. Expression of the PAX3-FOXO1 transcription factor is seen in 60 % of ARMS cases compared to 20 % of PAX7-FOXO1 and has been associated with decreased

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overall survival in intermediate-risk patients. The 20 % of ARMS cases that do not express fusion status are known as fusion negative, and these have been shown to clinically behave similarly to ERMS cases showing the same loss of heterozygosity at locus 11p15.5 with comparable OS and FFS. In addition, myogenin expression is also associated with alveolar histology and carries a worse prognosis, but still remains imprecise in risk stratification. In the future, it is likely the histologic distinctions between ERMS and ARMS will likely be replaced by fusion-negative and fusion-positive tumors.

Diagnosis

Initial presentation of a patient with RMS is usually an asymptomatic mass. Depending on the location of the primary, patients may present with signs and symptoms related to mass effect or complications secondary of the tumor. Histological subtype also varies according to primary tumor site. ARMS is more commonly seen in the trunk and extremities, and ERMS is more prevalent in the head and neck.

Evaluation of the patient with suspected RMS should include a comprehensive laboratory workup including complete blood count, liver function tests, renal function tests, electrolytes, and urinalysis. Imaging studies should include CT scan or MRI of the primary tumor site to assess the true size and involvement of surrounding structures or vital organs (Table 99.1). Pretreatment imaging of the primary tumor is essential to determine if resection is possible without significant morbidity or if there is need for neoadjuvant treatment prior to resection.

Clinical and radiographic evaluation of regional lymph nodes should be done in the pretreatment stage as this guides staging and therapeutic interventions. Surgical lymph node sampling, preferably by sentinel lymph node biopsy, should be undertaken with all soft tissue tumors particularly those located on the extremities or trunk. Positive lymph nodes in the regional basin extend the radiation treatment fields to the affected areas. Positive lymph nodes distant to the regional basin are considered metastatic disease.

The use of ^{18}F-fluorodeoxyglucose-positron emission tomography (FDG-PET) in the pediatric RMS population has been limited. Although some studies have suggested better identification of nodal, bone, and bone marrow involvement in the pretreatment stage, it has yet to supplant the need for actual tissue sampling.

Metastatic workup traditionally includes bone scan and bone marrow aspirate, chest CT for both lung nodules and thoracic node disease, and lumbar puncture for cerebrospinal fluid collection in parameningeal tumors, though recently some have questioned the need for such an extensive and invasive workup, particularly in patients with low-risk disease. These patients have a very low rate of metastatic disease noting that many patients have unnecessary bone marrow biopsies and bone scans.

Table 99.1 Workup for RMS patients

Patients	Diagnostic study
All patients	CBC with differential Renal and liver function tests Urinalysis Chest X-ray MRI or CT primary site Biopsy
Intermediate risk[a] High risk[a]	Chest CT Bone marrow aspirate Bone scan
Clinically involved lymph nodes	Lymph node sampling
Extremity RMS	Sentinel lymph node biopsy
Parameningeal RMS	CSF cytology

[a]Consider PET-CT scan in patients with possible lung, bone, or nodal involvement

Staging

Staging of RMS is done in its pretreatment phase and is based only on preoperative physical examination and imaging studies. Site, size and invasiveness of tumor, clinical nodal status, and the presence or absence of metastatic disease determine staging, which is a modified TNM classification system (Table 99.2).

Clinical Group

Grouping of patients with RMS is done after surgical resection and pathologic analysis. Residual disease after surgical resection is one of the most important prognostic factors in RMS. Patients are grouped based on pathologic evaluation of specimens evaluating margin of resection, nodal involvement, and evidence of tumor metastasis (Table 99.3). It is used in conjunction with the pretreatment TNM staging system to determine risk assessment, prognosis, and plan of treatment.

Risk Stratification

The Soft Tissue Sarcoma Committee of the Children's Oncology Group (STS-COG) developed the risk stratification system for RMS. The system uses the pretreatment TNM staging and the clinical group classification to distribute patients in the low-, intermediate-, and high-risk tiers (Table 99.4).

Table 99.2 TNM pretreatment staging

Stage	Sites	T	Size	N	M
1	Orbit, head and neck[α], genitourinary[β]	T_1 or T_2	A or b	N_0 or N_1 or N_x	M_0
2	Bladder/prostate, extremity, cranial parameningeal, others[γ]	T_1 or T_2	A	N_0 or N_x	M_0
3	Bladder/prostate, extremity, cranial, parameningeal, others[γ]	T_1 or T_2	A b	N_1 N_0 or N_1 or N_x	M_0 M_0
4	Any	T_1 or T_2	A or b	N_0 or N_1	M_1

Sites: α, no parameningeal involvement; β, no bladder or prostate involvement; γ, trunk, retroperitoneum, thoracic
Size: a, ≤5 cm in diameter; b, >5 cm in diameter; T, tumor; T_1, confined to site of origin; T_2, extends into surrounding tissue; N, nodes; N_0, no lymph node involvement; N_1, clinically involved lymph nodes; N_x, unknown lymph node status; M, metastasis; M_0, no metastasis; M_1, metastasis present

Table 99.3 Clinical group classification

Group	Definition
Group I	Complete resection of localized disease
Group II	Regional resection
IIA	Regional resection Inadequate microscopic margins
IIB	Regional resection Lymph node disease Adequate microscopic margins
IIC	Regional resection Lymph node disease Inadequate microscopic margins
Group III	Incomplete resection Biopsy only
Group IV	Distant metastatic disease

Treatment

The standard of care in the treatment of patients with RMS is a multimodal approach that includes surgical resection, systemic chemotherapy, and radiotherapy. Cure rates for RMS improved dramatically from 25 % in the 1970s to more than 70 % in the 1990s. Current studies aim to improve or maintain the high FFS of low-risk patients while reducing intensity and duration of therapy.

Surgical Resection

Masses thought to be malignant should undergo open biopsy, taking care to obtain adequate tissue samples for diagnosis. If at presentation the mass is resectable with adequate margins and without significant morbidity, resection should be considered as the primary procedure. For metastatic disease or areas not amenable to gross surgical resection, open biopsy should be performed. Core needle biopsies are not recommended due to sampling error and inadequate quantity of tissue.

Once the diagnosis of RMS is confirmed pathologically, the mainstay of surgical treatment is complete and a wide resection of the mass has a circumferential margin of at least 0.5 cm. Morbid or disfiguring procedures should not be performed. Complete marginal resection is particularly difficult in the head and neck region and retroperitoneum. All margins of the specimen should be marked to allow for precise evaluation of margins. In the event of residual disease, microscopic or gross, the surgical bed should be marked with clips to guide future radiotherapy. Piecemeal removal of tumor is considered to be clinical group II even if all gross disease is removed.

Pretreatment re-excision (PRE) should be considered in instances where surgical margins were not clear, a non-oncologic procedure was performed, or only a biopsy was performed. PRE consists of wide local re-excision with the goal of achieving negative margins of disease prior to start of adjuvant therapy; it is most commonly performed in extremity and trunk RMS but should be done whenever technically possible. Patients who undergo PRE and are categorized as group I have the same outcome as patients with negative margins on initial presentation. There is no role for tumor debulking in RMS patients with the possible exception of patients younger than 10 years of age who have metastatic ERMS; in this subgroup, debulking appears to improve FFS compared to biopsy only.

Nodal Sampling

Lymph node involvement in patients with RMS is an independent poor prognostic factor. Regional lymph node disease is present initially in approximately 25 % of patients with extremity RMS. Suspicious nodal involvement on physical exam and pretreatment imaging should be confirmed pathologically by lymph node biopsy. Sentinel lymph node biopsy for extremity and trunk RMS is recommended. We use both radioisotope and the injection of blue dye in our patients. The initial subcutaneous injection of the radioisotope is done in the nuclear medicine suite by the surgeon in four quadrants around the primary tumor. This procedure is done under local anesthetic in older patients but often requires general anesthesia in younger children. We have found the use of CT lym-

Table 99.4 Risk stratification

Risk	Stage	Group	Histology
Low, subset 1	1 or 2 1	I or II III orbit	ERMS ERMS
Low, subset 2	1 3	III non-orbit I or II	ERMS ERMS
Intermediate	2 or 3 1, 2, or 3	II or III I, II, or III	ERMS ARMS
High	4	IV	ERMS or ARMS

ERMS embryonal rhabdomyosarcoma, *ARMS* alveolar rhabdomyosarcoma

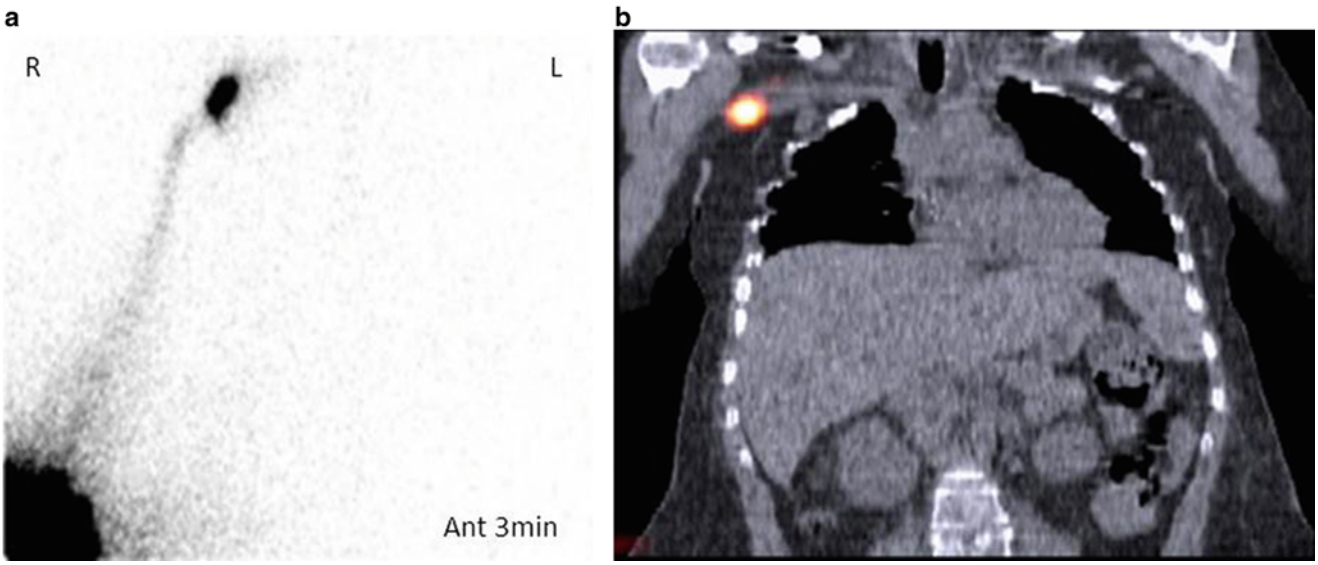

Fig. 99.1 Comparison of (**a**) lymphoscintigraphy and (**b**) CT lymphoscintigraphy

phoscintigraphy is helpful for anatomical localization of the draining nodal basin and accurate identification of the sentinel node (Fig. 99.1). The patients are then transported to the operating room and injected with isosulfan blue dye and a gamma probe is used to direct our procedure. Nodes are removed and deemed as sentinel nodes, with all nodes greater than 10 % of the highest count removed in the localized region. The nodes are sent fresh to pathology, where a specific protocol, including 100 μm sectioning, is utilized to identify lymph node metastases. We have noted minimal postoperative complications from this protocol and have identified lymph node metastases in patients that had negative cross-sectional and PET scan imaging.

Patients older than 10 years of age with paratesticular tumors have a 40 % incidence of nodal disease and therefore require pathologic evaluation of lymph nodes regardless if clinically or radiologically negative. This can be done open or laparoscopically depending on surgeon experience and comfort. Overall 5-year survival increases in this subgroup from about 65 % to approximately 85 % in patients who undergo lymph node dissection.

Second-Look Operation

Second-look operations (SLO) should be considered during or after adjuvant therapy. As with primary resection, the goal of SLO is complete removal of disease without compromising function. Better results are seen in the extremity and trunk. SLO also plays a role in recurrent RMS with re-excision increasing 5-year survival from about 10 % to 35–40 % compared to those who did not undergo second-look surgery.

Radiotherapy

External beam radiotherapy is an essential part of the multimodal approach in the treatment of RMS. XRT is indicated

in clinical groups II, II, and IV. Dosage and timing of RT is based on anatomic site, extent of residual disease, and lymph node involvement. Initiation of RT ranges from 6 to 12 weeks after the beginning of chemotherapy, except in patients with parameningeal RMS with intracranial extension in whom starting earlier XRT confers better local control. XRT dosing ranges from 41.4 Gy for group IIA patients up to 50.4 Gy for group III patients. Current COG studies are evaluating dose reduction of RT in low-risk RMS patients in order to achieve comparable local control with reduced long-term morbidity.

Systemic Therapy

The mainstay of chemotherapy in RMS patients is a combination of vincristine, actinomycin-D, and cyclophosphamide (VAC) regardless of risk stratification. Low-risk, subset-A RMS patients have an FFS of 90–95 % after 43 weeks on VAC chemotherapy. Current research aims to decrease the exposure of the low-risk population to alkylator chemotherapeutic agents in order to avoid side effects such as secondary malignancy and sterility. A VAC backbone is also used in intermediate-risk patients. High-risk patients continue to be one of the most challenging to treat. VAC chemotherapy remains the standard of care in this subgroup. Current studies aim to add monoclonal antibodies to the therapy regime of these patients.

Metastatic Disease

RMS metastasizes through both hematogenous and lymphatic routes. Metastatic disease is associated with a very poor prognosis: no improvement is noted in the FFS or OS despite the various multiple treatment strategies employed. Patients with progressive or recurrent RMS have a 5-year survival of 15–20 %. New treatment strategies include the addition of bevacizumab and temsirolimus, an mTOR pathway inhibitor, to the VAC chemotherapy backbone.

Outcomes

Multiple factors dictate the prognosis and outcomes of patients with RMS. Favorable prognostic factors include age less than 10, tumor size less than 5 cm, embryonal histology, favorable primary tumor site (orbit, non-parameningeal head and neck, bladder, prostate), and nonmetastatic disease. Complete gross surgical removal at the time of diagnosis has also been shown to be a positive prognostic factor.

Patients with completely resected disease (group I) have an overall good prognosis, with a 5-year survival of greater than 90 %. In patients with regional disease (group II), the overall long-term survival is 85 %; however, the presence of alveolar histology, residual tumor, and nodal involvement is associated with worse prognosis. Metastatic disease (group IV) is seen in approximately 15 % of patients at initial diagnosis and is associated with a 3-year FFS of approximately 25 % despite multimodal therapy (Table 99.5).

Editor's Comment

Rhabdomyosarcoma arises from a mesodermal pluripotent cell but does not necessarily develop within skeletal muscle. Unlike most other cancers, the approach to treatment and the prognosis of rhabdomyosarcomas vary greatly depending on the site of origin, with certain sites being considered favorable and others unfavorable. This characterization mostly correlates with the histologic subtype—tumors that arise in favorable sites are usually embryonal, while those from unfavorable sites are typically alveolar. So important is the site of origin that it is a primary factor in determining tumor stage. Rhabdomyosarcomas that arise within hollow organs such as the bladder, nasal cavity, or biliary tree are often described as botryoid ("cluster of grapes"), which is a type of embryonal rhabdomyosarcoma and associated with the best prognosis. Age is also an important prognostic factor but mostly because it correlates with histology and site of origin: in general, children under 1 year of age or older than 10 have a worse prognosis.

Like other small round blue cell tumors (lymphoma, Ewing's/PNET, neuroblastoma), rhabdomyosarcomas have a tendency to metastasize to the bone marrow, which is why bone marrow biopsy is usually performed as part of the initial workup. Tumors in favorable sites are treated with biopsy and neoadjuvant chemotherapy with little need for more than a limited surgical exploration to confirm the absence of residual tumor. Complete resection with a margin is rarely needed. Unfavorable tumors, on the other hand, require elaborate attempts at local control with either aggressive surgery or, if surgical resection is not feasible or safe, external beam radiation. Multiple operative attempts to render the patient free of tumor might be reasonable in certain situations.

For certain sites, such as an extremity or the trunk, sentinel lymph node biopsy might be requested. The technique is straightforward and starts with lymphoscintigraphy. We no longer use injection of blue dye. Often two lymph nodes are identified, sometimes in different nodal regions (popliteal and inguinal), both of which need to be excised. At second- or

Table 99.5 RMS overall survival

Risk stratification	Overall survival (%)
Low	90
Intermediate	60–80
High	20–40

third-look operations for resection, the previous scar and all tissue planes violated at the previous operation must be excised with a margin, which can result in a significant soft tissue defect. Entering the previous site increases the risk of recurrence but can be difficult to avoid even with preoperative high-resolution three-dimensional imaging. An ideal margin is 1–2 cm, but if the tumor is adjacent to vital structures or the bone, a negative tissue fascia plane is acceptable.

Botryoid tumors arising from the vagina should be biopsied and treated with chemotherapy. Mutilating surgery is almost never indicated and the prognosis is usually excellent. Biliary rhabdomyosarcoma also carries a relatively good prognosis, especially if it is of the botryoid variety. Biopsy can be performed by common duct exploration or through the cystic duct after cholecystectomy. At planned reoperation, we have used choledochoscopy to confirm the absence of residual tumor after chemotherapy. Depending on the stage and extent of disease, some of these patients will also require liver resection or the addition of radiation therapy. Extremity tumors often occur in adolescents, are usually alveolar, and carry a guarded prognosis. Although therapy to control the primary tumor must be aggressive, limb salvage should be considered if at all possible.

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Non-rhabdomyosarcoma Soft-Tissue Sarcoma

100

Andrea Hayes-Jordan

In this chapter, we will focus on non-rhabdomyosarcoma soft-tissue sarcoma (NRSTS). Approximately 8 % of childhood malignancies are soft-tissue sarcomas and roughly half are NRSTS. There are over 50 histologic types of NRSTS, the genetic patterns of which are poorly understood. When surgical resection is feasible, about 60 % of patients are expected to achieve long-term survival with or without radiation therapy. Patient outcome is largely based on age, the presence of metastases at diagnosis, size and depth of the lesion, and margin status.

General Principles

To understand the role of surgical resection, it is important to think of this large number of soft-tissue sarcomas in two categories, chemosensitive and chemo-insensitive sarcomas (Table 100.1) and, within these two categories, low- and high-grade malignancies.

Histologic grade of NRSTS helps predict outcome. Grade 1 refers to tumors with low malignant potential and a mitotic activity less than 5 per high-powered field. NRSTSs with tumor necrosis less than 15 % and mitotic activity of 5 to per 10 HPF are considered grade 2, while specific histologic subtypes with known aggressive behavior and any sarcoma with tumor necrosis of more than 15 % or mitotic activity of more than 10 HPF are considered grade 3. This is per the pediatric oncology (POG) grading system.

The current standard chemotherapy regimen for NRSTS is a combination of adriamycin and ifosfamide. Chemosensitive NRSTSs are expected to decrease in size in response to chemotherapy in approximately 50 % of patients. If chemosensitive tumors are unresectable at the time of presentation, these can likely be successfully treated with chemotherapy to decrease the size of the tumor and allow a neurovascular- and organ-sparing surgical resection. This approach also often allows a limb-sparing operative resection to be possible in the extremity. In chemo-insensitive NRSTSs (Table 100.1), chemotherapy is ineffective approximately 80 % of the time or more, and therefore aggressive surgical resection, combined with radiation, is the desired approach. Chemo-insensitive NRSTS may necessitate amputation. If located in the abdomen or on the trunk, complete resectable with negative margins is often not possible without substantial organ sacrifice. Neoadjuvant chemotherapy alone fails to improve survival for large (>8 cm) high-to-intermediate-grade NRSTS in adults. For patients with chemoresistant, chemosensitive histologies but of smaller size (<5 cm) and low grade and even high-risk patients unwilling or unable to receive chemotherapy, a course of radiation therapy prior to surgical resection of the primary tumor is a widely accepted standard.

In patients with surgically resected NRSTS, factors that negatively impact event-free survival include positive surgical margins, tumor size ≥5 cm, tumor invasiveness, histologic grade, and intra-abdominal primary site. The likelihood of local recurrence is increased by intra-abdominal primary site, positive surgical margins, and the omission of radiation therapy, while distant recurrences are predicted by the biology of the tumor: tumor size >5 cm, invasiveness, and high-grade histology. Children and adolescents with initially unresectable NRSTS are a subgroup at particularly high risk. These are large tumors, >5 cm, that involve critical neurovascular structures of the extremity, trunk, abdomen, or pelvis. In these patients, the estimated 5-year overall survival is 50–60 %, the EFS is 33 %, and the post-relapse survival is poor, about 20 % despite multimodality therapy.

Low-risk patients have tumors less than 5 cm and low histologic grade and are generally treated with surgery alone, whether R0 or R1 resection margins are achieved. Patients in this group who receive no chemotherapy and no radiation therapy have essentially 100 % overall survival at 2 years, and although they have a 90 % disease-free survival, all can be salvaged with further resection.

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Table 100.1 Chemosensitive versus chemo-insensitive non-rhabdomyosarcoma soft-tissue sarcoma

Chemotherapy sensitive	Chemotherapy insensitive
Synovial sarcoma	Alveolar soft part sarcoma
Undifferentiated sarcoma	Epithelioid sarcoma
Fibrosarcoma	Clear cell sarcoma
Angiosarcoma	Malignant fibrous histiocytoma
Mesenchymal chondrosarcoma	Hemangiopericytoma
Embryonal sarcoma of the liver	Solitary fibrous tumor
Liposarcoma (A)	Malignant peripheral nerve sheath
	Extraskeletal myxoid sarcoma

Chemosensitive tumors that are surgically unresectable have ~50 % 5-year survival compared to ~15 % 5-year survival for chemo-insensitive tumors which are surgically unresectable

Current recommendations are the following: (1) large, >5 cm, chemosensitive tumors should be treated with neoadjuvant adriamycin and ifosfamide; (2) resectable tumors (R0) <5 cm should be surgically resected at diagnosis; (3) small, <5 cm, low-grade tumors with negative (R0 or R1) resection margins can be treated with surgical resection alone and chemotherapy and radiation therapy omitted; (4) large, unresectable, chemo-insensitive NRSTS patients should be enrolled on a clinical trial, as their outcomes are predictably dismal.

Contrary to previous belief, surgical resection can safely be performed after neoadjuvant radiation. Optimal timing of surgery after radiation is now recommended 4–5 weeks after the completion of radiation, compared to the previous recommendation of 6–8 weeks after radiation. Earlier surgical intervention after radiation allows the surgeon to use the inflammatory "planes" for dissection and reduces postoperative wound complications.

Presentation and Workup

Patients usually present with a painless mass, sometimes identified after a recent episode of trauma. Children with an extremity or trunk mass >5 cm in diameter should have an MRI followed by core-needle or open biopsy. If NRSTS is identified and non-mutilating limb-sparing surgical excision is feasible, resection should be considered. If margins are microscopically positive, postoperative radiotherapy should be given in high-grade tumors and tumors larger than 5 cm. Low-grade tumors that are <5 cm can be re-excised or just watched closely. If surgical excision is not feasible without amputation or severe morbidity, regardless of size, preoperative chemotherapy and radiotherapy should be administered. If surgical excision is feasible but R1 resection is anticipated, the type of radiotherapy whether pre- or postoperative brachytherapy, proton-beam therapy, or external beam should be discussed with the radiation oncologist with the goal to avoid the growth plate in younger patients who are still growing. In tumors <5 cm, complete surgical excision with negative microscopic margins is the goal. In the case of unexpected malignant pathology, primary re-excision is recommended. For all NRSTS, negative microscopic margins should be the goal, though there is no consistent reliable evidence as to the optimal width of the margins.

NRSTS has a low propensity to metastasize to lymph nodes. Sentinel lymph node biopsy although recommended for rhabdomyosarcoma to evaluate normal-appearing lymph nodes is only recommended in histologic subtypes of NRSTS that have high risk of lymph node metastasis, including epithelioid sarcoma and clear cell sarcoma, both of which have an incidence of lymph node metastasis of up to 30 %. Synovial sarcoma metastasizes to the lymph nodes approximately 15 % of the time.

Chest CT is a necessary part of the workup as lung metastasis occurs in approximately 30 % of patients with NRSTS. Since NRSTSs are relatively chemo-insensitive, surgical resection of lung metastasis is recommended. Thoracotomy is the recommended approach in order to palpate the lung for any tumors that may have been missed on imaging.

Infantile Fibrosarcoma

In addition to chemosensitivity, age is a prognostic indicator. Patients less than one year of age have an excellent prognosis, whereas the adolescents and young adults have a worse prognosis compared to younger patients or older adults. Large reviews reveal the overall 5-year survival estimate for children less than one year of age is 90–95 %, compared to 30–40 % in those 15–21 years of age. Patients between 1 and 15 years have an intermediate survival of approximately 60 %. Survival after relapse is poor in all age groups less than 18 years except those less than one year of age. The 5-year estimate of post-relapse survival in patients between birth and one year of age is 80 % compared to the 15–25-year-old patient in which survival is roughly 20 % at 5 years. This includes patients who received various types of chemotherapy, but in whom surgical excision

was completed for lesions ≤5 cm and for most patients with lesions >5 cm, a gross total resection was achieved.

Patients less than one year of age have infantile fibrosarcoma (IF). This is a very rare form of NRSTS that occurs mostly during the first year of life but can be present up to year 4. It presents as a rapidly occurring mass in the trunk or extremities that can erode bone and usually reaches a large size. By definition, IF must have a specific translocation: *t*(12;15)(p13;q25) leading to fusion of ETV6 (TEL), a member of the ets family of transcription factors, on chromosome 12p13 and NTRK3 (TRKC), which encodes a receptor tyrosine kinase for neurotrophin on chromosome 15q25. Other cytogenetic abnormalities include trisomy 11; random gains of chromosomes 8, 11, 17, and 20; deletion of the long arm of 17; and a *t*(12;13) translocation. The helix–loop–helix dimerization domain of ETV6 fuses to the protein tyrosine kinase domain of NTRK3. The fusion protein results in ligand-independent chimeric protein tyrosine kinase activity with autophosphorylation. This leads to constitutive activation of Ras-MAPK and P13K-AKT pathways via insulin receptor substrate-1, which is tyrosine phosphorylated, and through the activation of c-Src. The fusion protein also associates with TGF-betaII receptor, which can be oncogenic by leading to inhibition of TGF-beta receptor signals that mediate tumor suppression.

Identical genetic findings have been reported in the cellular variant of congenital mesoblastic nephroma, a microscopically similar tumor of the kidney, and in secretory carcinoma of breast and acute myeloid leukemia, implying oncogenesis by lineage-independent activation of kinase-related signaling pathways.

Synovial Sarcoma

Synovial sarcoma (SS), undifferentiated sarcoma, and malignant peripheral nerve sheath tumor (MPNST) are the most common pediatric NRSTS. Undifferentiated or unclassified NRSTS is a new histologic designation that is treated similarly surgically to synovial sarcoma. SS is the most common NRSTS of childhood. It is characterized by a very specific fusion gene of X and 18 [*t*(X;18) (p11.2;g11.2)]. Its etiology is unknown. In evaluating the three largest reviews of pediatric SS, common principles are evident: for children 0 to 16 years and tumors <5 cm, 5-year OS is between 70 and 90 %. In this group, the addition of chemotherapy does not correlate with survival. In patients 17–30 years, the addition of chemotherapy does correlate with metastasis-free survival. In patients with SS tumors >5 cm that are deep and invasive, without metastasis, OS is 50–75 % and chemotherapy responsiveness is 50–60 %. Roughly half of synovial sarcoma patients had a response to chemotherapy. It is clear that for SS, survival does not depend on surgical margins but depends on local invasiveness and size, EFS varying between 50 and 60 % for tumors >5 cm and 90–95 % for those >5 cm.

Malignant Peripheral Nerve Sheath Tumor

Malignant peripheral nerve sheath tumors (MPNST), also called schwannoma or neurofibrosarcoma, usually arise in proximity to nerve sheaths. MPNST develop in a preexisting neurofibroma in approximately 40 % of patients, particularly those with neurofibromatosis type 1. Five-year OS is approximately 50 % and progression-free survival is 35–40 %. Poor prognostic variables include the absence of NF1 and tumor. The overall response of patients who receive neoadjuvant chemotherapy is 40–50 %. Some partial responses are seen in patients with initially unresectable disease because of neurovascular involvement. Neoadjuvant radiotherapy is expected to maintain or achieve local control in 50–60 % of patients. Neither chemotherapy nor radiotherapy has any significant impact on outcome, suggesting that MPNST is a chemoinsensitive sarcoma, though interestingly while 50–60 % of patients without NF1 have a response to chemotherapy, only 5–10 % patients with NF1 have a response to chemotherapy. Complete surgical resection is therefore important for successful treatment: 5-year OS is 80–90 % in patients who undergo complete surgical resection, about 75 % for complete surgical resection with radiation therapy, 70 % for incomplete resection with radiation therapy, about 50 % for radiation therapy alone, 35 % for incomplete surgical resection without radiation therapy, and 30–35 % for those who receive no local treatment. Complete surgical resection and major response to chemotherapy confer the best prognosis.

Desmoplastic Small Round Cell Tumor

The most common abdominal sarcoma in children is DSRCT. This is a rare tumor, first described in 1989; however, the site of origin is unknown. It presents with either a solitary omental mass that is adherent to pelvic structures or dozens to hundreds of intra-abdominal peritoneum-based tumors. The appearance is similar to carcinomatosis. Parenchymal liver and lung metastases may also be present in advanced stages. In can also be seen in the bone as the primary site

The diagnosis is made by identifying Ewing's sarcoma/Wilms' tumor fusion protein with an (11;22) translocation at biopsy. Although the number and extent of tumors on imaging at presentation may seem impossible to surgically resect, after 4 or 5 months of chemotherapy, complete resection is usually possible and is a required component of treatment. Neoadjuvant and adjuvant chemotherapies, as well as adjuvant radiation therapy, are also recommended to improve survival.

As in carcinomatosis, a treatment option in patients with sarcomatosis from DSRCT is hyperthermic intraperitoneal chemotherapy (HIPEC). In pediatric and young adult patients with DSRCT, HIPEC has shown promise as a safe and effective strategy. It is most effective in the absence of metastatic disease, either in the liver or elsewhere. If extra-abdominal

disease has been eliminated on imaging by chemotherapy, complete surgical resection of the abdominal metastases should be attempted. Debulking may prolong survival somewhat, but complete resection is recommended. This often takes an entire day in the operating room. With 100 % surgical resection, survival at 5 years can be prolonged from 15 to 60–70 %. Studies thus far show promising results for HIPEC, but more studies are needed to validate the technique. HIPEC is not the present standard of care, therefore, at the least, complete surgical extirpation is recommended.

Editor's Comment

There is a considerable variety of benign and malignant soft-tissue tumors seen in children. They can arise from almost any tissue type and in any part of the body. Some malignant soft-tissue tumors respond well to therapy and have a very good prognosis, while some that are technically benign can be locally invasive and extremely difficult to eradicate. They are overall quite rare, and because they are easily confused with garden-variety benign tumors (lipoma) or dismissed as traumatic lesions, the diagnosis is often a surprise or delayed. They are also often treated improperly at first, leading to unnecessary or disfiguring surgery.

Any soft-tissue mass in a child should be considered potentially malignant. In practical terms, this means that one should adhere to certain surgical principles so as to avoid spread of the tumor and the eventual need to remove more tissue than would otherwise have been necessary. Tumors that are small and easily excised with a margin of normal tissue without creating large soft-tissue defects or causing injury to neurovascular structures or normal organs should be excised up front. Larger tumors should be biopsied first. The incision and the tissue planes traversed should be planned carefully so that if a subsequent wide excision becomes necessary, one can incorporate the scar. For extremity lesions, this usually means a longitudinal incision. If frozen-section biopsy confirms the presence of a benign lesion, surgical extirpation is usually the only treatment needed. Some can be simply enucleated while others require a more aggressive approach. Desmoid tumors and inflammatory myofibroblastic tumors are known to sometimes respond to anti-inflammatory drugs or COX-2 inhibitors, but surgical resection is still standard.

For most malignant tumors, neoadjuvant chemotherapy can be used to shrink the tumor and render it resectable or at least minimize the amount of surrounding normal tissue that needs to be excised to achieve tumor-free margins. For most soft-tissue sarcomas, the prognosis is the same whether the tumor is resected up front or after chemotherapy, as long as the entire mass is ultimately excised with a margin. When a tumor needs to be re-excised after a biopsy or ill-advised attempt at resection, traditional teaching mandates that the resection plane must stay clear of all previous surgical planes. This entails making an elliptical incision around the previous scar and then staying outside of the postoperative seroma by at least 1–2 cm. Preoperative planning with high-resolution three-dimensional imaging is critical to achieving this goal. If the previous operative site is entered, the risk of subsequent recurrence is much higher. It is especially problematic when the previous operation was associated with significant bleeding or a hematoma, in which case previously uninvolved compartments might now be considered contaminated.

Though likely someday to be supplanted by PET scanning, sentinel lymph node biopsy is being used at some centers to assess the likelihood of metastasis and to guide therapy, especially for some of the more aggressive sarcomas (rhabdomyosarcoma, synovial cell sarcoma). Formal lymph node dissection is rarely indicated. Resection of metastases is also rarely indicated except for the unusual situation in which there are a small number of isolated lung nodules. Because of the many variations in approach to soft-tissue tumors, it is best to consult with a pediatric oncologist before any planned operative procedure. One should always be thinking about the next step in order to avoid making an avoidable and disfiguring error. There are also nationally recognized experts (COG) who can answer questions and give advice regarding the optimal approach to the surgical management of these complex disorders.

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Sacrococcygeal Teratoma

101

William H. Peranteau

SCT is the most common extra-gonadal germ cell tumor and the most common congenital neoplasm in fetuses and neonates. It has an incidence of 1 in 35,000 to 40,000 live births with a fourfold increased incidence in females. Advances in antenatal imaging have led to the prenatal detection of most SCTs. If not detected prenatally, the majority of SCTs will be diagnosed at birth. Only a small subset of SCTs (<10 %) will be missed at birth and diagnosed later in life. SCTs are believed to originate from Hensen's node in the developing embryo and arise from the three germ cell layers. Although the majority of SCTs contain mature elements, some also contain immature cellular features or rarely frankly malignant elements (yolk sac tumor most commonly but also embryonal carcinoma). Associated congenital anomalies are noted in 18 % of patients with musculoskeletal and central nervous system defects being the most common.

SCTs can be classified according to two main criteria that have significant implications on clinical management and outcome. An SCT may be cystic, solid, or a mixture of cystic and solid. Tumors with large solid components tend to be more vascular and are sometimes associated with high-output cardiac failure in utero with subsequent hydrops fetalis and fetal demise. Similarly, these tumors tend to have an increased risk of bleeding from tumor rupture, which can occur prenatally, at birth, or at the time of surgical resection. SCTs can also be classified according to the relative extent of the intra- and extra-pelvic components of the tumor (Fig. 101.1). Type I (tumor is primarily external with only a small presacral component) is the most common (45 %). Types II through IV represent 35%, 10%, and 10% of SCTs and have progressively more internal components with type IV containing no visible external component.

Management of SCTs requires surgical resection. The majority of SCTs are benign and resectable after birth. Overall survival in patients with SCTs varies from >90 % for small nonvascular tumors to approximately 50 % for large (>10 cm) predominantly vascular tumors diagnosed prenatally. Fetal interventions are possible for a small subset of patients with high-risk tumors. Long-term outcome is favorable in patients with benign tumors who undergo complete resection. However, long-term follow-up is required for all patients to monitor for tumor recurrence and postoperative urologic and anorectal sequelae.

Diagnosis

SCTs are frequently detected by prenatal ultrasound and can be detected as early as 18–19 weeks' gestation. They present as a solid, cystic, or mixed solid/cystic mass originating in the presacral area. Ultrafast fetal MRI is also used in dedicated centers to evaluate fetuses with suspected SCT (Fig. 101.2). MRI complements fetal ultrasonography and provides a better assessment of the cephalad extent of type II and III tumors. It also provides a better assessment of the effects of the tumor on surrounding structures like the colon, urinary tract and vaginal dilation, hip dislocation, and intraspinal extension of the tumor. After birth, most SCTs are readily evident on physical examination. Rectal examination provides useful information regarding the degree of intrapelvic extension of the tumor, especially in tumors not prenatally diagnosed. In clinically stable infants, a postnatal CT or MRI confirms the extent of the SCT. An MRI has the additional benefit of providing information regarding possible intraspinal extension of the tumor. A plain x-ray can also help identify sacral defects and tumor calcifications. Additional postnatal imaging is unnecessary in prenatally diagnosed infants with a large SCT that is tenuous or causing clinical instability.

Less than 10 % of SCTs are completely internal and therefore only found later in life, most commonly between 4 months and 4 years of age if no prenatal diagnosis was made. These patients might present with constipation, bladder compression, anal stenosis, and a perirectal mass noted on rectal exam.

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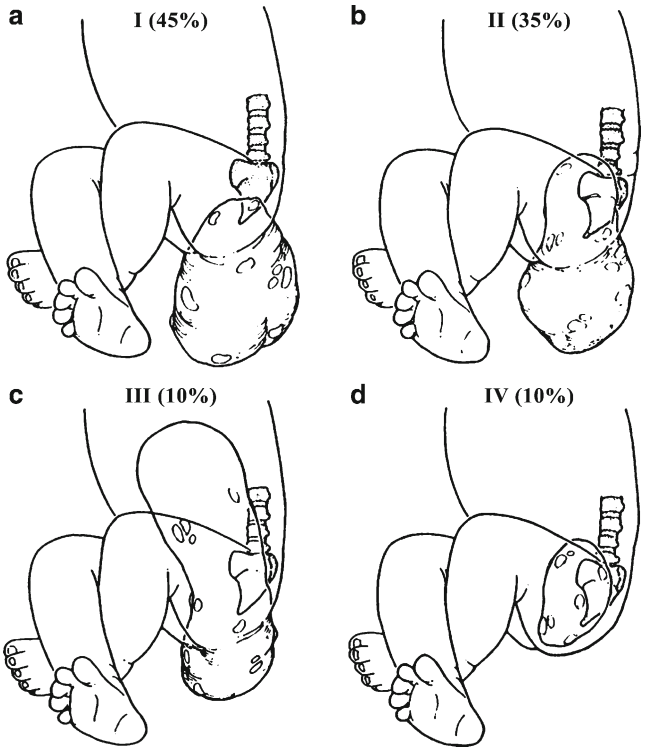

Fig. 101.1 Altman classification of SCT. (From Grosfeld JL, Billmire DF. Teratomas in infancy and childhood. Curr Probl Cancer. 1985;9(9):1–53. Reprinted with permission from Elsevier)

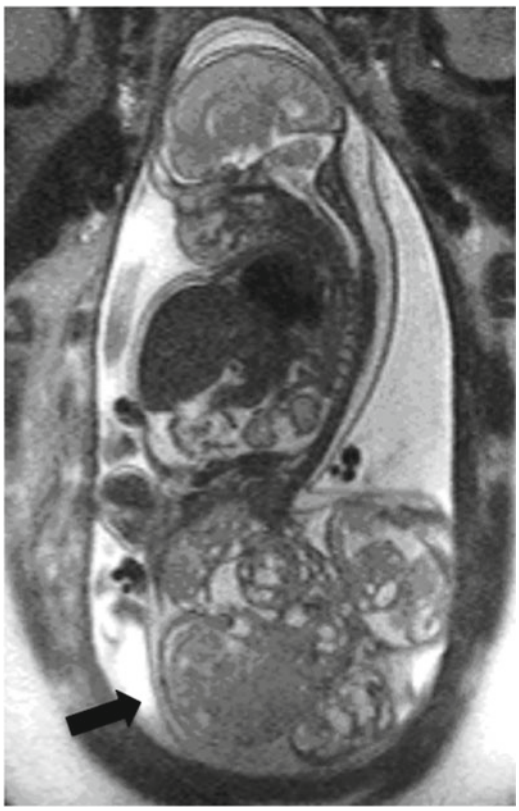

Fig. 101.2 Ultrafast fetal MRI of fetus with SCT. 22-week gestation fetus with large predominantly solid type I SCT (*arrow*)

Patients presenting later in life have a higher incidence of malignancy and require a full metastatic workup including serum tumor markers (alpha fetal protein, β-HCG) and a CT scan of the chest/abdomen/pelvis.

Surgical Management

Management of an infant with an SCT at the time of birth focuses on the initial neonatal resuscitative efforts common to all infants (airway, breathing, circulation) with the additional concern of handling of the SCT. Large predominantly solid tumors with a significant vascular supply are at increased risk for tumor rupture and potentially catastrophic bleeding prenatally, at the time of birth or postnatally (Fig. 101.3). Thus, fetuses with external tumors that are >5 cm or have a significant solid component are delivered by cesarean delivery and manipulation of the tumor prior to surgical resection is minimized. After adequate intravenous access is obtained, a full set of preoperative labs are sent including a CBC and type and cross-match in anticipation of surgery. Prior to resection, serum AFP and β-HCG levels are obtained. If the patient is stable, time is allowed for the infant to transition to postnatal life and obtain additional imaging studies prior to surgical resection, which is planned for during the first week of life.

Complete surgical excision of the SCT is the treatment of choice. The type of tumor dictates the surgical approach. Specifically, type I and II tumors can frequently be resected by a posterior approach with the patient in the prone position. Type III and IV tumors often require an anterior intra-abdominal approach followed by a posterior approach if complete transabdominal resection is not possible. Regardless of the approach, a number of basic goals apply to the surgical procedure: (1) complete resection of the tumor without damage to surrounding structures, (2) removal of the coccyx, (3) reconstruction of the pelvic floor and anorectal sphincter, and (4) an acceptable cosmetic appearance. Adherence to a few basic principles is instrumental to accomplishing these goals (Fig. 101.4). After placement of a Foley catheter and positioning the patient prone in a jack-knife position for a posterior approach, the incision should be performed to allow for the development of large skin flaps. Excess skin can be removed after the tumor is excised to allow for the best cosmetic appearance. Attention should be paid to staying close to the tumor capsule during dissection, which will allow for preservation of attenuated muscle fibers to be used to reconstruct the pelvic floor and anorectal sphincter. The surgeon must identify and always be cognizant of the position of the anus and rectum as they are often displaced and closely opposed by the SCT. The placement of a Hegar dilator in the anus during tumor dissection often aids

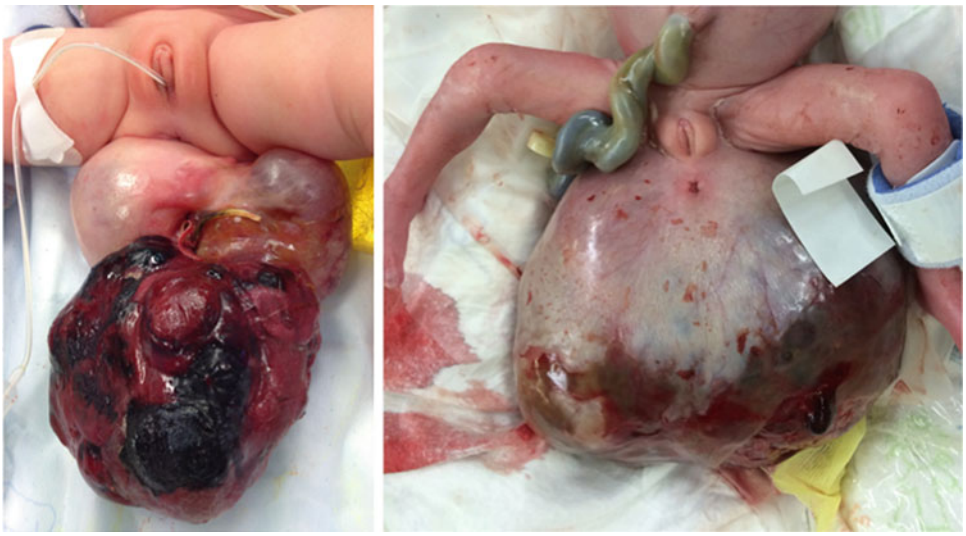

Fig. 101.3 Large type I SCTs in which tumor rupture and hemorrhage into the tumor were noted at the time of birth

in the identification of the anorectum and helps to avoid damage to the bowel during dissection. For tumors with a large intrapelvic component, similar attention must be paid to the position of the ureters. The coccyx is identified and usually approached from the posterior. Care is taken to stay on the anterior surface of coccyx during its circumferential dissection at the sacrococcygeal joint to avoid injury to the vascular supply to the tumor, which usually originates from the middle sacral artery or branches from the hypogastric arteries. The vascular supply to the tumor is ligated after the coccyx is transected at the sacrococcygeal joint.

In challenging cases involving a vascular tumor with a large intrapelvic component, attempts to control the vascular supply to the tumor through a transabdominal approach prior to significant dissection of the tumor should be considered. The tumor and coccyx are ideally resected as a single specimen, after which the pelvic floor and anorectal sphincter are reconstructed and the skin is closed with or without a subcutaneous drain depending on the amount of empty space.

Postoperative Management

In the immediate postoperative period, the patient is positioned to minimize pressure on the wound and is monitored closely for bleeding and wound dehiscence or infection. Urinary retention requiring a Foley catheter or intermittent catheterizations may also be seen postoperatively especially in cases with a large intrapelvic component.

All patients with a SCT require long-term follow-up. The overall risk of recurrence is between 10 and 15 %. Recurrence occurs at a median of 10–16 months after initial resection. Recurrences can occur with mature, immature, and malignant tumors although there is a greater incidence of recurrence in those with malignant tumors at the time of initial resection. About half of recurrences are malignant recurrences independent of the initial histology. Recurrences can also be associated with metastasis to other organs including the spine, liver, lungs, and mediastinum.

Risk factors for recurrence include spillage of tumor parenchyma during resection, incomplete resection, and primary immature and malignant histology. Failure to remove the coccyx at the initial operation is also associated with an increased risk of recurrence. Management of recurrence involves surgical re-excision with or without chemotherapy. Malignant yolk sac tumors are highly sensitive to platinum-based chemotherapy. Given the higher risk of recurrence with malignant elements, a common question is the need for chemotherapy following initial tumor resection when malignant elements are noted on histology. Although consultation with an oncologist is warranted, frequently no chemotherapy is recommended and standard postoperative management is recommended if the tumor has been completely excised especially if only a microscopic focus of yolk sac tumor is noted. Overall survival of patients with recurrent SCT is 65 % compared to an overall survival of >90 % following complete resection without recurrence.

Given the risk of recurrence, we see patients every 3 months for the first 3 years and then every 6 months for the next 2 years after resection. An AFP level is checked and rectal examination performed. If the AFP level has not returned to normal by 9 months or is elevated compared to postoperative levels at the time of discharge or a mass is appreciated on rectal examination, repeat imaging with an MRI or CT is performed. If recurrence is noted, a full metastatic workup including a CT or MRI of the chest, abdomen, and pelvis and laboratory studies are required. In addition to the risk of recurrence, an infant with an SCT has an increased risk for persistent urologic and anorectal complications, specifically, severe chronic constipation and fecal incontinence in up to

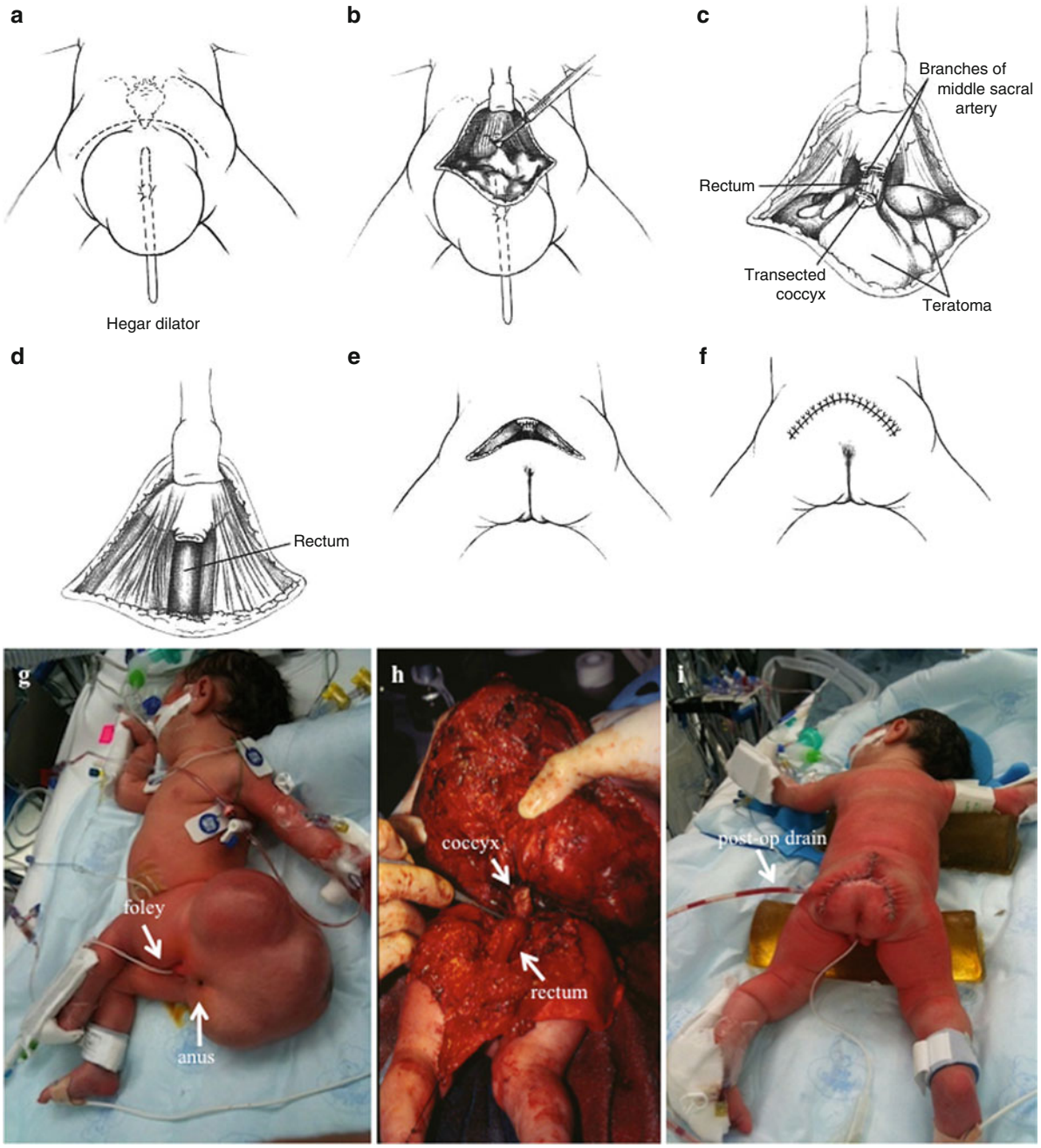

Fig. 101.4 Principles to the posterior approach to SCT resection. (**a**) Prone positioning of the infant with placement of a Hegar dilator into the rectum to facilitate its identification during tumor resection. (**b**) An inverted V posterior incision with adequate skin flaps facilitates access to the tumor and coccyx. (**c**) The coccyx is transected at the sacrococcygeal joint. After transection, the middle sacral vessels are identified anterior (deep) to the coccyx and ligated. (**d**) The tumor has been dissected from the rectum and separated from the often-attenuated muscles of the pelvic floor. Staying on the tumor capsule during dissection aides in preserving the muscles of the pelvic floor. The underlying rectum and pelvic muscles can be visualized. (**e**) Anatomic reconstruction of the anorectal muscles is performed. (**f**) Final skin closure. (**g**, **h**) Preop, intraop, and postop pictures of resection of a type I SCT in a newborn (**a**–**f**, adapted from Grosfeld JL, ed. Pediatric surgery. 6th ed. Philadelphia, PA: Mosby; 2006, p. 561. Reprinted with permission from Elsevier)

60 % of patients and urologic sequelae including neurogenic bladder, vesicoureteral reflux, and urinary incontinence in up to 45 % of patients. These complications are associated with obstructive consequences of a large intrapelvic tumor and are rare in patients with a type I tumor (Fig. 101.5).

Currarino Triad

The Currarino triad consists of (1) anal stenosis, (2) sacral bony defect, and (3) a presacral mass. The presacral mass is (a) a teratoma, (b) an enteric duplication cyst, (c) a dermoid

Urologic complications

33% incidence overall

- Neurogenic bladder (27%)
- Vesicoureteral reflux (11%)
- Urinary incontinence (16%)

Anorectal complications

29% incidence overall

- Severe chronic constipation (29%)
- Fecal incontinence (9%)

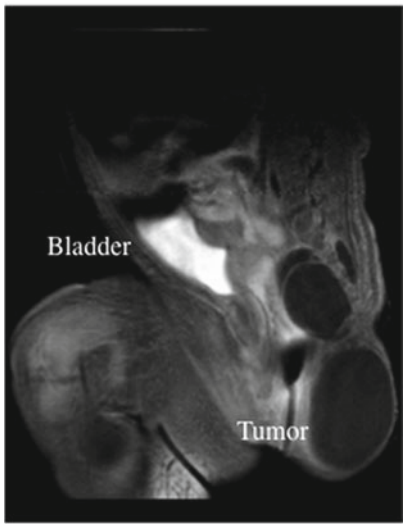

Fig. 101.5 Postoperative urologic and anorectal complications. A high incidence of postoperative urologic and anorectal complications has been seen following surgical resection of SCTs with large intrapelvic components. Numbers represent those found in the study by Partridge et al., J Pediatr Surg 2014;49:139–143 in which no patients with a type I SCT had postoperative urologic or anorectal complications. Compression of the rectum and/or bladder by the intrapelvic tumor as shown in the MRI image is believed to contribute to urologic and anorectal dysfunction

cyst, or (d) a meningocele. Teratoma is the most common presacral mass found in Currarino triad. A significant number (~20 %) of patients with Currarino triad will have a tethered spinal cord. Resection of the presacral mass (dermoid cyst, enteric duplication cyst, teratoma) or repair of the meningocele is required. At the time of teratoma resection (usually done from the posterior approach), repair of the anal stenosis should also be performed. In contrast, a meningocele is repaired first and the anal stenosis addressed at a later date to avoid contamination and meningitis during the meningocele repair.

High-Risk Fetal SCT

Large fetal SCTs present a formidable challenge because of their unpredictable growth and risk of complications including high-output cardiac failure and associated hydrops, premature labor secondary to the volume effects of the tumor or polyhydramnios, spontaneous hemorrhage into the tumor, tumor rupture, and the maternal mirror syndrome in which the mother develops preeclampsia and edema "mirroring" fetal hydrops. Depending on the gestational age of the fetus, prenatal interventions are sometimes appropriate to consider (Fig. 101.6). Amnioreduction and SCT cyst aspiration have been performed for maternal discomfort, preterm labor, and prevention of tumor rupture at delivery. When the SCT is solid, it has a significant external component (type I or II) and there is ultrasonographic and echocardiographic evidence of impending high-output heart failure as indicated by signs of hydrops (ascites, skin/scalp edema, pleural effusions, pericardial effusions), an elevated cardiac/thoracic ratio (normal: <0.33), a dilated inferior vena cava (normal: 2.9–4.1 mm in fetuses 21–28 weeks' gestation), increased placental thickness (normal = gestational age in weeks ± 10 mm), increased aortic velocity (normal: 184 ± 20 mL/kg/min), or elevated fetal combined cardiac output (normal: 553 ± 153 mL/kg/min) in fetuses <28 weeks' gestation; fetal debulking is an option at select fetal surgery centers. Prior to fetal debulking, the absence of maternal risk factors for anesthesia or surgery, a singleton pregnancy with a normal karyotype, and the absence of other significant fetal-associated anomalies must be confirmed. The development of maternal mirror syndrome is a contraindication to fetal intervention and mandates immediate delivery. Alternatively, in fetuses beyond 27–28 weeks' gestation, the progressive or precipitous development of high-output cardiac failure and evidence of fetal distress or preterm labor are indications for early delivery by cesarean delivery or EXIT procedure. Tumor debulking is performed immediately after delivery or at the time of the EXIT procedure to prevent progression of heart failure. Reoperation within the first few weeks of life after the infant has stabilized is necessary to achieve complete tumor resection in cases of fetal or neonatal debulking.

Editor's Comment

Nearly all sacrococcygeal teratomas are identified by antenatal ultrasound. Predominantly cystic SCTs can usually be safely observed to term, but aspiration of fluid is sometimes indicated for very large cysts that could cause premature labor. Tumors that are predominantly solid are usually well vascularized, tend to grow rapidly, and are associated with hydrops and fetal demise. If lung maturity can be achieved, early delivery is indicated. If hydrops develops too early in gestation for delivery, in utero resection has been performed with variable success. In cases associated with concomitant

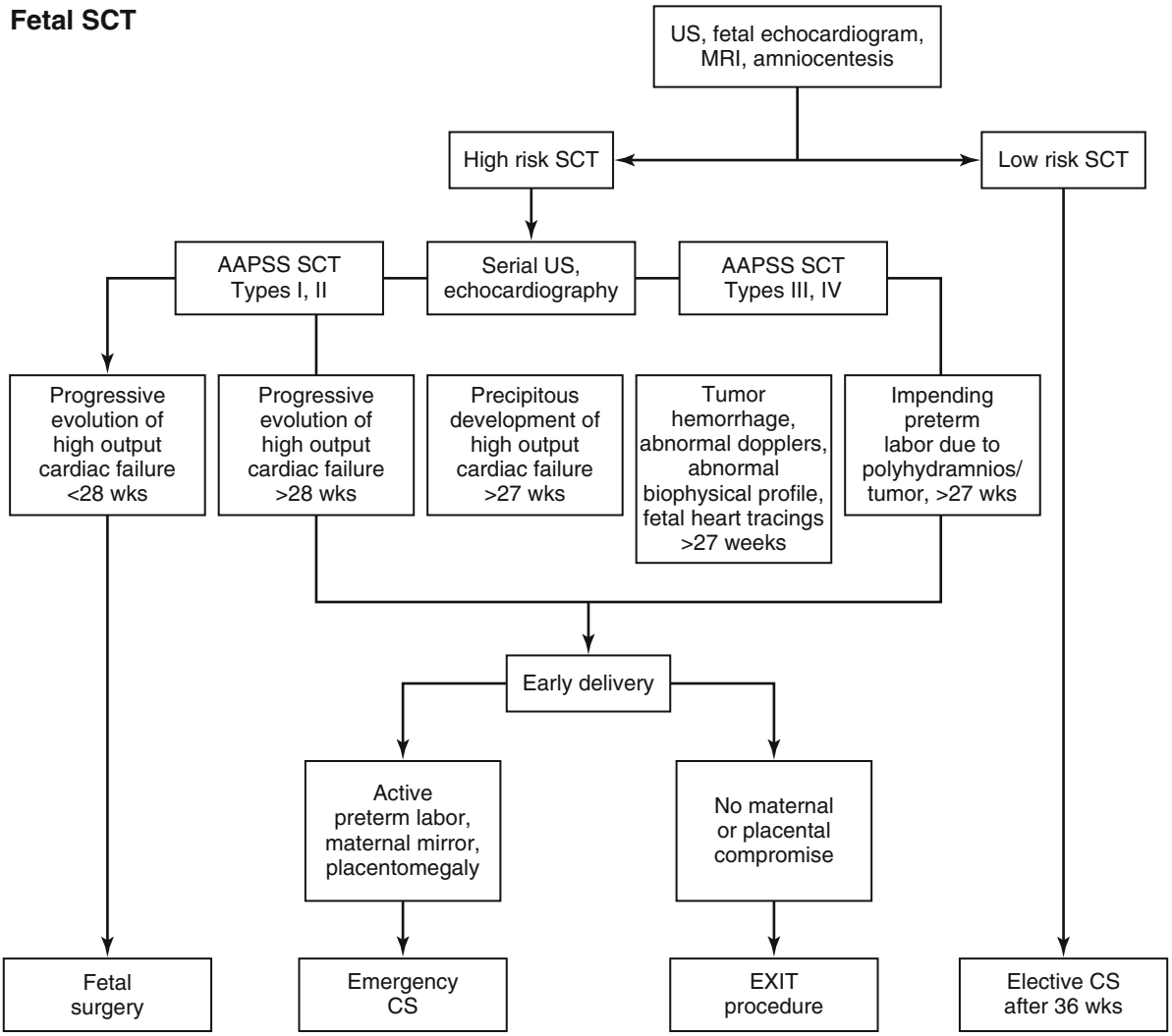

Fig. 101.6 Algorithm for prenatal management of SCT. (From Roybal et al., J Pediatr Surg. 2011;46:1325–1332. Reprinted with permission from Elsevier)

fetal anomalies, maternal mirror syndrome or early severe hydrops, delivery might be the only option.

Managing an infant with a large SCT at birth is challenging. The tumor can weigh as much or more than the baby and its blood flow can be greater. After rapid resuscitation, the operation might need to be started rather urgently. Hemorrhage is a devastating complication and can be difficult to prevent and nearly impossible to control once it occurs. Some have attempted to wrap the tumor tightly with an elastic bandage until the operation can be undertaken, but the benefit of this maneuver is unknown. Many surgeons start with a transabdominal approach in an attempt to control the blood supply of the tumor by ligating the middle sacral artery before proceeding with a posterior resection.

Type IV (abdominopelvic) SCTs typically present late and have a higher rate of malignant transformation. The diagnosis should be considered in toddlers who develop a change in bowel habits. The tumor can usually be detected by careful digital rectal examination and confirmed by MRI of the pelvis. Tumor markers (AFP, HCG) must be sent and a thorough metastatic workup performed. Surgical resection with coccygectomy is the mainstay of therapy, but this can be a difficult operation—too low for a transabdominal approach and too high for a perineal approach. A combined approach is often necessary, in which case the transabdominal operation is performed first in order to control the blood supply and mobilize a portion of the tumor.

Although yolk sac tumors that arise within SCTs in young children are usually chemosensitive, malignant germ cell tumors that arise in the sacral region in otherwise healthy adolescents can be very difficult to treat. They are infiltrative and sometimes locally invasive, extremely difficult to resect in their entirety, and poorly responsive to chemotherapy or radiation. It is sometimes necessary to perform multiple

operations to eradicate all residual and recurrent tumor. It is not known if these tumors arise de novo or within a small SCT. Coccygectomy should be performed in all cases and is well tolerated.

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Ovarian Tumors

102

Kirk W. Reichard

Ovarian pathology can present in a variety of ways including abdominal pain, abdominal mass, abnormal vaginal bleeding or menstrual irregularity, precocious puberty, and on routine antenatal ultrasound. Because the ovary is composed of epithelial, sex cord-stromal, and germ cell elements, many different neoplastic and nonneoplastic conditions may develop. Fortunately, the majority of ovarian lesions in children are benign. Therefore, a rational differential diagnosis and treatment plan can be developed based on the patient's age, presenting symptoms, and the appearance on diagnostic imaging.

Most girls with suspected ovarian pathology will undergo pelvic ultrasound examination as the initial diagnostic study. Cystic lesions can be readily identified and the fluid characterized as simple or complex, with debris and septa that suggest either hemorrhage or torsion. A color-Doppler flow study should be performed if torsion is suspected, to confirm the presence of arterial and venous blood flow within the ovary. Occasionally, a twisted pedicle may also be seen. However, many authors have reported that blood flow is present in many ovaries that are found to be torsed at surgery. Therefore, blood flow does NOT exclude torsion, which remains a clinical diagnosis. US can also identify fat and calcifications that are found in teratomas. Large, poorly circumscribed, complex masses with areas of necrosis or hemorrhage are suspicious for malignancy.

Further diagnostic imaging is indicated for patients with complex cystic or solid lesions. Compared with US, CT provides better delineation of the soft tissue components of the mass, including fat and calcification, is valuable in detecting evidence of metastases in the liver or lymph nodes, and, as the initial modality in patients who present with abdominal pain, can help to rule out other pathologies. However, it is worth remembering that small, simple ovarian cysts are normal in preadolescents and adolescents. In the absence of rupture, hemorrhage, or excessively large size, they are unlikely to cause pain. In many institutions, MRI is becoming the modality of choice for the imaging of pelvic organs. It is more specific in characterizing soft tissue and fluid components, can show evidence of torsion or PID, and avoids the risks associated with ionizing radiation.

Many neoplastic and nonneoplastic ovarian masses are hormonally active. Functional cysts and sex cord-stromal tumors occasionally produce sufficient estrogen to cause precocious puberty and gonadotropin suppression in premenarchal girls. Rarely a sex cord (Sertoli-Leydig cell) tumor may produce testosterone, leading to virilization. Germ cell tumors may also secrete certain tumor markers. Alpha-fetoprotein is normally secreted by certain embryonic and fetal tissue and is markedly elevated in patients with yolk sac (endodermal sinus) tumor as well as embryonal carcinoma. However, levels of AFP are normally well over 10,000 ng/dL in newborns and do not fall to normal levels for 6–8 months (Table 102.1). AFP has a serum half-life of 5–7 days and can be used to determine adequacy of treatment as well as a harbinger of recurrence. The β-subunit of human chorionic gonadotropin (βHCG) is secreted by various germ cell tumors, including choriocarcinoma and embryonal carcinoma. It has a short half-life and so its level falls much more quickly than AFP after complete resection of tumor. CA-125 is a valuable marker in epithelial tumors, but has somewhat limited use in children. Some hormonally inactive tumors produce high levels of LDH based purely on bulky disease.

Purely Cystic Lesions

Functional cysts are nonneoplastic cysts. They arise from ovarian follicles in response to endogenous or exogenous gonadotropins and can often be found incidentally on imaging studies of the pelvis. These cysts usually resolve spontaneously and can be managed expectantly.

In the fetal and neonatal period, follicular cysts develop in response to maternal gonadotropins and occur more commonly

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Table 102.1 Average normal serum AFP in infants

Age	*n*	Mean ± SD (ng/mL)
Premature	11	134,734 ± 41,444
Newborn	55	48,406 ± 34,718
Newborn—2 weeks	16	33,113 ± 32,503
2 weeks to 1 month	43	9,452 ± 12,610
1 month	12	2,654 ± 3,080
2 months	40	323 ± 278
3 months	5	88 ± 87
4 months	31	74 ± 56
5 months	6	46.5 ± 19
6 months	9	12.5 ± 9.8
7 months	5	9.7 ± 7.1
8 months	3	8.5 ± 5.5

Imaging
- Ultrasound with color Doppler
- Abdomen and pelvis CT scan with contrast
- or
- MRI, if readily available

Laboratory data
- Serum tumor markers
  - AFP, βHCG, CA-125
- Hormones (if precocious puberty or masculinization)
  - Estradiol, LH, FSH, GnRH, testosterone
- Others

LDH

Source: Reprinted with permission from Wu JT, et al. Serum AFP levels in normal infants. Pediatr Res. 1981;15:50

in pregnancies complicated by diabetes, preeclampsia, or Rh disease. Neoplastic cystic lesions are quite rare in this age group. Non-echogenic, simple cysts that are asymptomatic and measure less than 5 cm can safely be observed with serial pelvic ultrasound, with resolution expected within the first 3–6 months of life. Cysts that are 5 cm or larger are thought by many to be at increased risk for torsion. These cysts can be percutaneously aspirated or drained and unroofed laparoscopically or at laparotomy, although there is a risk of recurrence. Occasionally, large fetal cysts are aspirated in an attempt to prevent antenatal torsion. Complex cysts or large simple cysts that persist for greater than 3–6 months should be managed surgically with ovarian sparing techniques whenever possible, although some of these lesions will prove to be ovaries that have undergone antenatal torsion.

In premenarchal and adolescent girls, functional cysts are very common. Follicular cysts develop before ovulation and can continue to grow if ovulation does not occur. Corpus luteum cysts develop after ovulation and can spontaneously hemorrhage. As long as normal blood flow can be demonstrated on Doppler examination in a patient without ongoing abdominal pain, simple and hemorrhagic cysts that measure less than 5 cm are typically observed, generally resolving in 8–12 weeks. Cysts that are symptomatic, larger than 5–7 cm, or complex but not obviously hemorrhagic should be managed with cyst excision, taking care to spare the ovary. Aspiration, simple unroofing, and marsupialization are less likely to cause ovarian damage, but are associated with higher recurrence rates. The lining of the cyst must be removed. Occasionally, adnexal Müllerian remnants can develop into large cysts that preoperatively may be indistinguishable from ovarian cysts and can also be prone to torsion.

Ovarian Torsion

Girls who present with the acute onset of severe pelvic pain must be evaluated promptly for ovarian torsion. These patients usually present with associated nausea and vomiting that starts with the pain, and some will have a fever. Doppler US is the diagnostic modality of choice. However, blood flow does NOT rule out torsion. Underlying pathology, such as a functional cyst or teratoma, is found in the majority of patients with ovarian torsion, although nearly a quarter occur in otherwise normal ovaries. Torsion is less common in the setting of a malignancy, but torsion by no means rules it out with certainty. Occasionally, acute hemorrhage into a functional cyst may mimic the clinical findings of torsion and should be treated similarly if ultrasound findings are. While the traditional treatment for an ovary that appears completely necrotic after detorsion has been oophorectomy, recently many have challenged this approach, calling instead for detorsion and, in some cases, oophoropexy. Associated pathology, such as cysts or teratomas, should be treated with ovarian sparing excision, if technically feasible. Malignancy is an unusual cause of torsion in this age group. Nevertheless, if underlying neoplastic pathology is strongly suspected (larger than 10 cm, elevated markers) or if a large amount of grossly necrotic tissue is present, oophorectomy is still an acceptable option. The ipsilateral tube should be preserved if possible. In any case, a repeat pelvic US should be performed 2–3 months later to exclude previously unsuspected pathology. Torsion of the contralateral ovary is rare, particularly if a pathologic lesion is found on the first side. Contralateral oophoropexy is not routinely recommended unless there is evidence for laxity of the ovarian suspensory ligaments.

Mixed and Solid Masses

Unlike purely cystic lesions, mixed or solid neoplasms of the ovary are more likely to be malignant. Nevertheless, most are still benign, particularly in younger girls. Malignant tumors more frequently present as an asymptomatic mass or with chronic pain and abdominal swelling. They are thought to undergo torsion less often than benign lesions, but can present with acute pain from hemorrhage. Solid masses in the perinatal period are extraordinarily rare.

Table 102.2 Children's oncology group ovarian germ cell tumor staging and risk-based therapy

Stage	Extent of disease	Treatment (COG, AGCT 0132)
I	Limited to the ovary or ovaries; peritoneal washings negative for malignant cells	Surgery only (low risk)
	No clinical, radiographic, or histologic evidence of disease beyond the ovaries	
	Tumor markers normal after appropriate postsurgical half-life decline	
	The presence of gliomatosis peritonei[a] does not upstage patient	
II	Microscopic residual or positive lymph nodes (≤2 cm as measured by a pathologist). Peritoneal washings negative for malignant cells	PEB × 3 (intermediate risk)
	Tumor markers positive or negative	
	The presence of gliomatosis peritonei[a] does not upstage patient	
III	Lymph with malignant metastatic nodule (>2 cm as measured by a pathologist). Gross residual or biopsy only	PEB × 3 (intermediate risk)
	Contiguous visceral involvement (omentum, intestines, bladder)	
	Peritoneal washings positive for malignant cells	
	Tumor markers positive or negative	
IV	Distant metastases, including the liver	PEB × 4 (high risk)

PEB compressed-dose cisplatin, etoposide, and bleomycin
[a]Peritoneal nodules composed entirely of mature glial tissue and having no malignant elements

Germ cell tumors make up nearly two thirds of all ovarian masses in children and adolescents, although sex cord-stromal tumors are relatively more common in young girls. In older adolescents and young adults, epithelial tumors begin to become more prominent, although they are usually benign or of low malignant potential (e.g., mucinous and serous adenomas). Invasive adenocarcinoma is quite rare in the pediatric age group.

Staging of pediatric ovarian masses has traditionally followed the International Federation of Gynecology and Obstetrics (FIGO) system used in adults, which was developed mainly for patients with epithelial tumors (Table 102.2). The Children's Oncology Group (COG) has developed a staging system for patients with germ cell tumors that is used in all current clinical protocols. Both staging systems depend upon a standardized operative technique, which should be followed in all patients with complex mixed or solid masses. Given the different biological behavior in pediatric tumors and the desire to preserve fertility in young girls and adolescents, the operative approach to staging in children has become more conservative than that traditionally prescribed for adults (Table 102.3).

A midline laparotomy is generally employed, although a transverse mid-hypogastric incision may be appropriate, especially in younger girls. Laparoscopic approaches have been described, but because of the increased risk of spillage and subsequent upstaging of the tumor, it should only be considered when the lesion is small or the risk for malignancy is low. Immediately upon entering the abdomen, any free peritoneal fluid should be aspirated and sent for cytology. If no fluid is apparent, saline washings should be obtained. The contralateral ovary is then carefully inspected. A normal-appearing ovary should *not* be bivalved or randomly biopsied, but suspicious nodules should be excised for histopathologic analysis. Pelvic and retroperitoneal lymph nodes should be inspected visually and by palpation and any enlarged or suspicious nodes should be removed. It is unnecessary to perform omentectomy for germ cell tumors unless the omentum is adherent to the tumor or when there is obvious tumor extension or nodularity. Any peritoneal nodules should be biopsied. The remainder of the intra-abdominal viscera should be inspected for tumor spread, and suspicious areas biopsied. Attention should then be turned to the primary tumor. The vast majority of pediatric ovarian tumors are adequately treated with unilateral oophorectomy, preserving of the fallopian tube if it is free of gross disease. Bilateral tumors are quite uncommon, and so bilateral oophorectomy and hysterectomy are rarely indicated, especially at the first operation.

Germ Cell Tumors

The majority of ovarian neoplasms in children and adolescents are germ cell tumors, and the ovary is one of the most common sites for a germ cell tumor to develop, second only to the sacrococcygeal region when all age groups are considered. The specific type of tumor depends upon the pathway and degree of differentiation that the neoplastic primordial germ cells take (Fig. 102.1). Undifferentiated cells produce germinomas. Extraembryonic differentiation leads to choriocarcinoma and yolk sac (endodermal sinus) tumors. Embryonal carcinomas develop from partial embryonic differentiation, while more complete embryonic differentiation yields mature and immature teratomas.

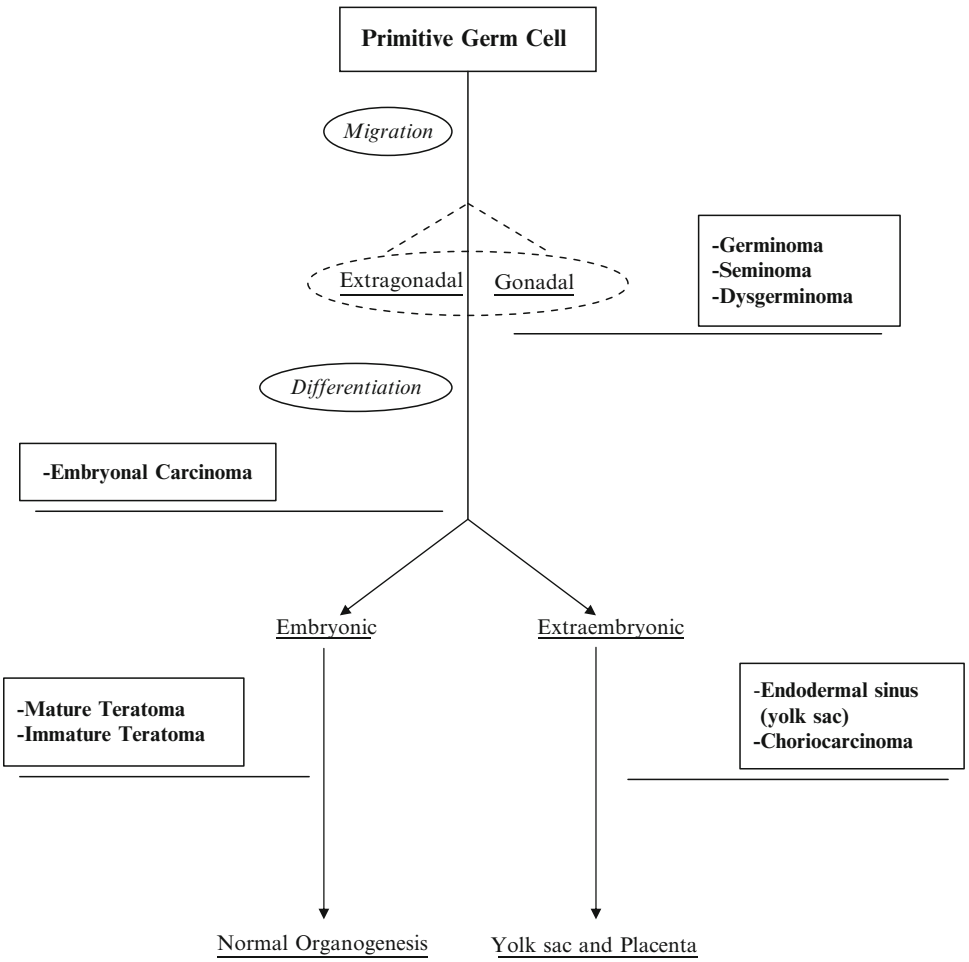

Fig. 102.1 Schematic diagram of the differentiation of the primordial germ cell and points where mutations or altered growth patterns lead to the various germ cell tumors encountered in clinical practice

Table 102.3 Operative staging recommendations for suspected ovarian malignancy

Laparotomy
Collect peritoneal fluid/peritoneal washings
Inspect and palpate normal ovary (only biopsy suspicious lesions)
Inspect for tumor extension
Omentum—omentectomy if involved
Peritoneal surfaces—biopsy suspicious lesions
Other organs—resection only if no functional consequence
Search for enlarged lymph nodes—biopsy and debulk when possible
Tumor resection—unilateral oophorectomy, with salpingectomy if there is tubal involvement, preserving fertility if possible

Teratomas

Mixed cystic lesions are usually benign in children and adolescents, with teratomas by far the most common. Teratomas contain elements from all three embryonic tissue layers: ectoderm, mesoderm, and endoderm. One or more may predominate, and not all need be present in the same tumor, but there must be embryonic tissue elements in an ectopic location. Fat and organized calcifications, such as the teeth or bone, are typically seen on preoperative imaging. They are often predominantly comprised of cysts, which may contain simple fluid or a significant amount of protein and cellular debris. Benign teratomas are further classified as mature (more common) or immature, based upon the degree of cellular differentiation and presence of immature neural (glial) elements. The level of maturity is graded on a scale of 1–4, in ascending order of immaturity and likelihood of malignant potential. Patients with lesions that are grade 2 and above are typically treated with adjuvant chemotherapy. Patients with both mature and immature teratomas may be found to have plaques of glial tissue studding the peritoneal surfaces at laparotomy. These should be biopsied, but are not considered malignant, do not affect staging, and do not need to be completely removed.

Germ cell tumors, usually endodermal sinus or yolk sac, can rarely be seen arising within a teratoma and should be suspected in patients with significantly elevated preoperative AFP level. It should be noted, however, that the embryonic tissue in benign teratomas can produce modest elevations in AFP. Although quite unusual, any tissue type found in a tera-

toma can undergo malignant degeneration, giving rise to adenocarcinomas, sarcomas, or Wilms tumor, among others. The postoperative therapy for these malignant tumors is guided by the histology and stage of the malignant component.

The operative approach should include the elements of the staging procedure described above. Teratomas must be resected intact. It is inappropriate to drain the fluid intraoperatively, as one might for a simple cyst. Although controversial, complete resection of the tumor with the affected ovary is the standard approach for unilateral disease. Enucleation of a mature teratoma with ovarian preservation leads to a marginally higher recurrence rate, but some authors advocate this approach for smaller, well-circumscribed tumors. Enucleation should clearly be attempted in patients with bilateral disease and those who have already had one ovary removed.

Patients with mature teratomas sometimes develop recurrence, including occasional reports of germ cell tumor, whether treated with oophorectomy or cystectomy. Therefore it is recommended that they undergo post-op monitoring with serum AFP and US, obtained at 6–12-month intervals for 3–5 years.

Malignant Germ Cell Tumors

Germ cell tumors are the most common malignant ovarian neoplasm in childhood. Among this group, yolk sac tumor, also known as endodermal sinus tumor, prevails in most series. It is an aggressively malignant tumor and, in the vast majority of cases, is characterized by markedly elevated AFP levels.

Germinomas are somewhat less common in girls, but when combined with seminoma (which is the same cell type in males) and dysgerminoma (their extra-gonadal counterpart), they are the most common histological type in children overall. These tumors frequently present in association with other cell types, so-called mixed germ cell tumors. Germinomas can become quite large before presentation, and although these tumors are generally not hormonally active, they usually produce high levels of lactate dehydrogenase (LDH).

Embryonal carcinoma and choriocarcinoma are relatively less common germ cell malignancies. Both can produce isosexual precocious puberty or menstrual disturbances due to secretion of βHCG. Choriocarcinoma is particularly aggressive and can occur in various forms during pregnancy.

The general treatment approach is similar in all malignant germ cell tumors. Complete evaluation of tumor extent as outlined above is the first goal, as accurate staging guides subsequent therapy. To preserve fertility, unilateral oophorectomy or salpingo-oophorectomy is preferred whenever feasible. However, if tumor is identified in the contralateral ovary, bilateral oophorectomy is required. More extensive disease should be debulked, but neoadjuvant therapy followed by delayed resection is a reasonable course for advanced local disease.

The treatment of malignant germ cell tumors has been revolutionized by the advent of platinum-based chemotherapy, which is now the mainstay. The current COG protocol calls for surgery alone with careful surveillance for patients with stage I (low-risk) ovarian tumors. Recurrence is effectively treated with surgical resection and chemotherapy. Patients with stage II and III (intermediate-risk) tumors receive compressed-dose cisplatin, etoposide, and bleomycin (PEB) therapy. Patients with advanced disease may respond to standard PEB regimens. High-dose therapy combined with stem cell transplantation is utilized for unresponsive or recurrent disease.

Sex Cord-Stromal Tumors

Sex cord-stromal tumors arise from pre-committed mesenchymal cells destined to become granulosa-theca cells in the ovary and Sertoli-Leydig cells in the testes. As a group, they are the second most common category of ovarian neoplasm in children and are nearly equal in incidence with germ cell tumors in younger girls. Patients with these hormonally active tumors typically present with precocious puberty. In younger girls, granulosa-theca cell tumors are more prevalent and cause true precocious puberty, whereas Sertoli-Leydig cell tumors predominate in older girls and generally produce virilization due to the secretion of testosterone.

Surgical staging guidelines are the same as for the germ cell tumors. Most patients with sex cord-stromal tumors present with stage 1 disease and carry a favorable prognosis, responding well to unilateral oophorectomy alone. More advanced lesions tend to be quite aggressive and require multimodal therapy, including radiation therapy in patients with granulosa-theca cell lesions.

Epithelial Tumors

Tumors that arise from the surface epithelial cells are the least common ovarian neoplasm in children and adolescents, but become the predominant tumor type in adult women. Most of these are benign mucinous or serous tumors that respond well to local surgical therapy. Malignant epithelial neoplasms differ from their adult counterpart in several ways, including a higher incidence of the mucinous cell type and higher incidence of tumors with borderline or low malignant potential, which make up a third of malignancies in adolescents.

Epithelial tumors are hormonally inactive and can present with very large tumors and bulky disease. They may also present with pain from torsion or hemorrhage. Most of these

neoplasms elaborate CA-125, which, though not as specific as the other ovarian tumor markers, can be used as a diagnostic tool and as a measure of response to therapy.

After a proper staging laparotomy, ovarian epithelial malignancies are staged according to the FIGO staging system. Locoregional spread is more common in these tumors and has a much greater impact on the extent of surgery. Tumors isolated to one or both ovaries without capsular invasion can be treated with unilateral or bilateral salpingo-oophorectomy. Patients with more locally advanced disease require total abdominal hysterectomy and bilateral salpingo-oophorectomy. Cytoreduction is a key component to therapy. Adjuvant platinum-based chemotherapy is employed in nearly all cases. Borderline or low malignant potential tumors are usually treated with surgery alone, sparing fertility in many cases. Recurrences generally respond well to further surgery resection.

Ovarian tumors present in a variety of clinical scenarios and represent a wide-ranging differential diagnosis (Table 102.4). The age of the patient, presenting symptoms, and appearance on imaging can help refine the diagnostic possibilities and therapeutic strategies. Functional cysts can generally be monitored unless they are large and symptomatic or have debris or septations on imaging. Teratomas are the most common benign ovarian neoplasm in children and can usually be managed with conservative resection that preserves fertility. Malignant lesions are derived from a variety of cell types and exhibit heterogeneous behavior. A careful preoperative evaluation and thorough intraoperative staging are the cornerstone of successful treatment, the ultimate goal of which is not only cure, but preservation of fertility.

Editor's Comment

Most of the diagnostic and treatment paradigms that we apply in the care of children with ovarian tumors are still based on the now somewhat dated concepts that were developed for women with epithelial ovarian cancer. Although there are some similarities, the biology of germ cell tumors is usually very different than that of epithelial cancers and therefore they should be approached differently. The unique psychosocial needs of adolescents and the importance of preserving sexual function and fertility are also factors to be considered. Nevertheless, based on the results of clinical trials and the experience of many pediatric surgical oncologists, these protocols are gradually being updated and appropriately individualized.

As a rule, every ovarian mass in a young girl should be assumed to be malignant until proven otherwise. This even applies to large ovarian cysts (larger than 8 cm or growing rapidly) and mature teratomas, which though benign can contain immature (glial) elements that can seed the peritoneum (gliomatosis peritonei) or harbor a malignancy. In addition, a benign neoplasm (mucinous cystadenoma) can look just like a simple benign cyst but is associated with a risk of recurrence if incompletely excised or if its contents are spilled. Consequently, when treating a young patient with

Table 102.4 Differential diagnosis and management strategy

Purely cystic Functional cysts Follicular (neonatal and premenarchal) Corpus luteum (premenarchal) Müllerian remnants (e.g., para-tubal)	If symptomatic, complex, or large: laparoscopic/open drainage with resection of lining and preservation of ovarian function (consider pexy) If asymptomatic and less than 5 cm: nonoperative management with serial US to confirm resolution
Torsion Acute onset of pain (with abnormal ovary on ultrasound) May have underlying pathology (functional cyst, teratoma, malignancy) Hemorrhagic cysts (may be difficult to differentiate by ultrasound)	Urgent exploration and detorsion Inspect contralateral side Resection if Underlying pathology suspected (think about staging) Large amount of necrotic tissue Pexy Ipsilateral if preserving Contralateral only of ligaments are lax
Complex/solid Germ cell neoplasms Teratomas (mature, immature) Malignant GCTs (endodermal sinus tumor, germinoma, embryonal carcinoma, and choriocarcinoma) Sex cord/stromal tumors Epithelial neoplasms Benign (cystadenomas) Malignant (mucinous or serous adenocarcinomas) Borderline/low malignant potential	Obtain CT or MRI to look for intra-abdominal spread Send tumor markers (AFP, βHCG, LDH, CA-125) Laparoscopy/minilaparotomy ONLY for benign lesions Malignant or uncertain lesions require formal staging laparotomy Large, bulky, and unresectable lesions can be biopsied initially, followed by neoadjuvant chemotherapy

an ovarian mass, surgical intervention should be undertaken without excessive delay, serum tumor markers (AFP, βHCG) should be sent as part of the preoperative workup in all cases, and the surgical approach must not put the patient at risk for spillage and subsequent upstaging of the tumor. This sometimes makes it difficult to consider a minimally invasive approach, which greatly increases the risk of spillage. As a general rule, laparoscopy should be used only in cases in which spillage is thought to be unlikely (small mature teratoma) or harmless (thin-walled simple cyst). When in doubt, it is recommended that a Pfannenstiel (or lower midline incision for large tumors) be used and that precautions be taken to avoid even microscopic spillage. Tumors should be removed *en bloc* and with meticulous technique. To avoid a big incision when dealing with a large cyst, many surgeons will drain the cyst prior to performing the resection. This is technically considered spillage regardless of what precautions are taken. Nevertheless, there is ongoing debate as to the best way to balance the need to avoid harm (tumor spread) and the desire to minimize scarring.

Despite a lack of supportive data, traditional gynecologic oncology guidelines often recommend ipsilateral salpingo-oophorectomy in all patients with an ovarian tumor. For most tumor types seen in girls, however, this is probably excessive. The approach recommended for young women with an ovarian mass is to preserve the fallopian tube unless it is directly involved with tumor and, when possible, to preserve part of the cortex of the ovary, which is where the ova reside. When the nature of the mass is not known, one can remove the entire mass using an ovary-sparing technique and send it for frozen-section analysis before deciding whether the ovary needs to be removed. When there is obvious metastatic disease, spillage is less of an issue and cyst drainage or incisional biopsy is acceptable. Although surgical oncologists generally cringe at the concept of "tumor debulking," ovarian cancer is one of the few tumors for which reducing the gross volume of tumor is palliative and, in some cases, might also improve survival. Inspection and selective biopsy of suspicious iliac and para-aortic lymph nodes should be performed as part of the staging process, but formal lymph node dissection is unlikely to be therapeutic and is associated with significant risks.

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Testicular Tumors

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Gregory E. Tasian and Thomas F. Kolon

Tumors of the testicle account for 1–2 % of all pediatric solid tumors (1 in 100,000 boys less than age 15 years). Testicular tumors are more common in whites during infancy and rare in black or Asian children. Although the presentation and initial surgical treatment are similar for most testicular masses regardless of age, the diseases are different. We therefore conceptualize them as two separate groups: the germ cell and stromal tumors classically defined as "pediatric" testicular tumors and the germ cell tumors that occur in adolescents and young adults.

Pediatric Testicular Tumors

The majority of pediatric patients with a testicular neoplasm will present before the age of 2 years. A painless scrotal mass is the most common initial complaint. Other disorders that must be excluded are epididymo-orchitis, hernia/hydrocele, and acute testicular torsion. Spermatic cord torsion can present as a painless mass in a newborn with few signs of inflammation if the event occurred prenatally. Boys referred for precocious puberty or with a history of a disorder of sex development (DSD) must also be carefully evaluated for a testicular tumor. DSD patients with hypomasculinization or testicular dysgenesis on histology are of greatest risk. A thorough history and physical examination are needed with special attention to the contralateral gonad as well since bilateral testicular tumors are rarely present. A scrotal ultrasound (SCRUS) is mandatory to evaluate the mass and adjacent testicular parenchyma. This is especially helpful for preoperative preparation if a testis-sparing approach is being considered. SCRUS is also recommended if the testicle cannot be adequately palpated as with a large, tense hydrocele.

Testicular tumors can appear as solid or cystic lesions on SCRUS. While there are no definitive features that distinguish benign from malignant tumors, cystic lesions suggest benign entities such as a simple cyst, cystic dysplasia, teratoma, or cystic granulosa cell tumor. Focal (not diffuse bilateral) testicular microlithiasis has been reported in association with yolk sac tumors.

Prior to surgical exploration, serum tumor marker levels should be measured. Alpha-fetoprotein (AFP) is the only tumor marker necessary in prepubertal children since cell types associated with elevations in lactate dehydrogenase (LDH) or human chorionic gonadotropin (hCG) such as choriocarcinoma, seminoma, and embryonal carcinoma are not seen in the prepubertal age group. Preoperative tumor marker levels and likely tumor histology will help dictate additional imaging. The combination of normal serum AFP and benign features on SCRUS helps to identify potential candidates for a testis-sparing surgical approach. Of note, AFP levels will be naturally elevated in infant boys because AFP synthesis continues after birth. Normal adult AFP levels (<10 mg/mL) are not reached until about 8 months of age. Children under 6 months of age or with an elevated AFP should have a metastatic workup, including a CT scan of the abdomen and pelvis and chest X-ray or CT of the chest.

Primary testicular tumors in children are of germ cell or stromal origin. Germ cell tumors include yolk sac tumor, teratoma, and epidermoid cyst. Stromal tumors include Leydig cell tumor, Sertoli cell tumor, juvenile granulosa cell tumor, and mixed gonadal stromal tumor. In the prepubertal boy, yolk sac tumor and teratoma account for the majority of neoplasms. In addition, the incidence of benign lesions is much higher (40–75 %) in children than in adults.

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Yolk sac tumor represents the most common malignant neoplasm in children, the majority of whom will have an elevated serum AFP at presentation. The AFP level may not be useful to distinguish a yolk sac tumor from other scrotal pathologies in the first year of life due to the expected increased level. The pathognomonic histologic finding in yolk sac tumor is Schiller-Duval bodies. Staining can also demonstrate the presence of AFP.

Teratoma is possibly the most common testicular tumor in children, but the incidence is likely significantly underreported due to its benign nature. These tumors are composed of tissues derived from all three germ cell layers (endoderm, mesoderm, ectoderm) in various stages of maturation. In the prepubertal age group, teratoma is invariably benign; however, they are malignant neoplasms in postpubertal children and adolescents. *Epidermoid cyst* is also a benign testicular lesion described as epithelium-lined cysts filled with keratin. Although once thought of as a monodermal teratoma, it is now considered a non-teratomatous benign mass.

Stromal testicular tumors are extremely rare. *Leydig cell tumor* (5–10 % of prepubertal tumors) behaves in a benign fashion in prepubertal boys and is often associated with precocious puberty or gynecomastia. Reinke crystals, a characteristic histologic feature of Leydig cell tumor, are seen in 40 % of tumors. The rare *Sertoli cell tumor* is hormonally inactive in boys. Sertoli cell tumor is generally benign, but a malignant diagnosis is affixed if mitoses are present histologically or if metastases are seen. *Juvenile granulosa cell tumor* is also rare and usually presents within the first 6 months of age. It is a hormonally inactive lesion and can be seen in patients with DSD or abnormal Y chromosome. Orchiectomy has most often been employed, but due to its benign nature, partial orchiectomy can also be considered. *Gonadoblastoma* is the most common tumor seen in DSD. It occurs in the streak gonad primarily but the undescended dysgenetic testis is also at risk. A streak gonadoblastoma may undergo malignant degeneration into a *dysgerminoma*, and any germ cell component of a streak or a dysgenetic testis may degenerate into seminoma or nonseminomatous tumor.

Surgery

Surgical removal of the tumor is the standard of care and often the only treatment necessary. Both radical orchiectomy and testis-sparing partial orchiectomy should always be done through an inguinal incision. The incision is generally made along Langer's lines just above and parallel to the ipsilateral inguinal ligament, between the lateral edge of the pubic symphysis and the anterior superior iliac spine. The external oblique fascia is incised along the direction of its fibers beyond the external inguinal ring in order to deliver the testicle without difficulty or rupture. The ilioinguinal nerve is identified along the anterior surface of the spermatic cord and should be dissected away from the cord structures. The spermatic cord should be mobilized from surrounding tissues and encircled with a quarter-inch Penrose drain. Prior to delivering the testicle, the operative field is isolated with sterile surgical towels and the Penrose is used as a gentle tourniquet.

During a radical orchiectomy, a high ligation of the cord is performed. The use of nonabsorbable sutures facilitates intra-abdominal identification of the cord structures if a retroperitoneal lymph node dissection is performed. The external oblique fascia is then approximated with absorbable suture and skin edges approximated using a subcuticular closure with fine absorbable monofilament.

The child older than 6 months with an elevated AFP is presumed to have a yolk sac tumor and is recommended to undergo radical orchiectomy. Those with a normal AFP level and a well-circumscribed mass on US with potential for testicular preservation should undergo inguinal exploration with excisional biopsy and frozen-section analysis after vascular control of the inguinal cord. If pathology reveals a malignant lesion, then radical orchiectomy should be performed. If the frozen section reveals a benign lesion, such as teratoma, epidermoid tumor or Leydig cell tumor, a partial orchiectomy, with complete excision of the tumor, can be performed. After tumor resection, the tunica albuginea can be closed with an absorbable suture and the testicle replaced in the scrotum. Lesions that are encapsulated or well circumscribed are more amenable to a parenchyma-sparing approach than an infiltrating lesion. If sufficient normal parenchyma remains after excisional biopsy (documented normal histology by biopsy), it should be preserved. Of note, since pubertal teratoma is considered malignant, the presence of postpubertal changes within the normal parenchyma mandates that a radical orchiectomy be performed. Orchiectomy alone is required for all streak gonads or dysgenetic testes remaining undescended in any DSD child with a Y chromosome.

The staging (Table 103.1) and management of testicular tumors in children generally parallels that in adults. In fact, the recommendations in cases of scrotal violation have included hemiscrotectomy or the excision of the scrotal scar at the time of retroperitoneal lymph node dissection (RPLND). Due to the lack of evidence supporting a less aggressive approach, no conclusive recommendations are available for the pediatric patient.

Post-Orchiectomy Treatment

The majority of patients with a yolk sac tumor will present with a lesion localized to the testicle and need no further therapy. After removal of a yolk sac tumor, serum AFP levels should be followed serially. The half-life of AFP is 5–7 days. Failure of serum AFP to normalize following surgery suggests the presence of residual or metastatic disease.

Table 103.1 Nonseminoma testicular germ cell tumor—clinical staging (from Children's Oncology Group)

Stage I	Limited to testis; complete resection, no evidence of disease beyond the testis by tumor markers, radiologic scans, or pathology
Stage II	Trans-scrotal orchiectomy, microscopic disease in the scrotum or high in spermatic cord (>0.5 cm), RP lymph node <2 cm, tumor markers fail to normalize or increase
Stage III	Gross residual disease, RP lymph node >2 cm in boys younger than 10 years
Stage IV	Distant metastases, including the liver, brain, bone, and lung

In the case of metastatic or recurrent disease, excellent results have been achieved with platinum-based chemotherapy. In the rare patient with a yolk sac tumor and normal preoperative AFP levels, recurrent disease can be very difficult to detect and these patients might benefit from empiric RPLND. Follow-up for the patient with stage I yolk sac tumor should include monthly serum AFP, chest X-ray every 2 months for 2 years, and CT scan of the abdomen and pelvis every 3 months for the second year.

Adjuvant chemotherapy and radiation are recommended for metastatic Sertoli cell tumor, though the results are generally dismal. RPLND is rarely necessary in children and is covered further in the postpubertal tumor section. Unlike testicular germ cell tumors in adolescents and adults, pediatric testicular tumors spread hematogenously (predominantly to the lung) more often than through lymphatic metastasis to the retroperitoneum. Given the potential for metastasis, surveillance is also needed with Sertoli cell tumor and possibly with mixed gonadal stromal tumor, although this has not been strictly defined. No specific follow-up is needed for prepubertal teratoma, epidermoid cyst, juvenile granulosa cell tumor, or Leydig cell tumor.

Following a testis-sparing procedure, preservation of adequate testicular volume should be confirmed by physical examination and US. After a radical orchiectomy, it is important to discuss the option of testicular prosthesis with the patient and his family (generally more applicable for implantation after puberty). Parents must also be warned about the potential for hypogonadism and the need for hormone replacement as the boy gets older.

Postpubertal Testicular Germ Cell Tumors

The median age of testicular germ cell tumors is 33 years. Testicular germ cell tumors are rare before 15 years; however 7 %, approximately 600 cases per year, occur in adolescents and young adults younger than 20 years each year in the United States. It is thus important that the pediatric surgeon and urologist are familiar with the evaluation and treatment of young men who may present to a pediatric hospital with a testicular germ cell tumor.

Boys and young men eventually diagnosed with a testicular germ cell tumor often present with a painless enlarged testis. Symptoms due to metastases outside the retroperitoneum (cough, seizures) or signs caused by elevated tumor markers (gynecomastia from hCG) are very uncommon. The initial evaluation of a child or adolescent with a testicular mass includes scrotal ultrasound, serum chemistries, tumor markers (hCG, AFP, LDH), and a chest X-ray.

Clinical Evaluation

On SCRUS, a germ cell tumor will usually appear as a hypoechoic, occasionally cystic, and non-hypervascular mass. Nonseminomas can produce elevated AFP, hCG, or LDH, but these are all sometimes within normal ranges. AFP is not elevated in seminomas—an elevated AFP with 100 % pure seminoma on pathology indicates an undetected nonseminomatous component, which impacts adjuvant, but not initial management. When physical examination, SCRUS, and serum studies indicate that a testicular tumor is present, the standard surgical intervention is a radical inguinal orchiectomy.

Testicular germ cell tumors are classified as seminoma or nonseminoma. Nonseminomas include *embryonal carcinoma*, *choriocarcinoma*, *teratocarcinoma*, *yolk sac tumor*, and *teratoma*. From this point forward in the management of a patient with a testicular germ cell tumor, the pathology from the orchiectomy dictates the subsequent management. Because AFP is not elevated in seminoma, any AFP elevation in patients with pure seminoma on orchiectomy should be treated as having a nonseminoma.

Staging

In addition to the tumor characteristics from the orchiectomy specimen, cross-sectional imaging is necessary to accurately stage the disease. Knowledge of the histology can guide the appropriate imaging selection. All patients with testicular cancer should have a CT of the abdomen and pelvis with intravenous contrast and further imaging dictated by the histology of the tumor and the findings on the abdominal CT. Because testicular germ cell tumors spread lymphatically in a predictable sequence (choriocarcinoma is a notable exception), a chest CT is not mandatory for seminomas in the setting of a normal chest X-ray and the absence of retroperitoneal disease. For nonseminomas, brain, chest, and bone imaging should be obtained as clinically indicated.

Post-Orchiectomy Management

There are often multiple clinical options available following orchiectomy, which makes a multidisciplinary approach critical for patients with testicular cancer. Each option has benefits and risks, such as radiation exposure for surveillance regimens, toxicity and risk of secondary malignancy for chemotherapy, and surgical morbidity for RPLND. A complete overview of the algorithm for treating patients with seminoma and nonseminoma germ cell tumors is available on the National Comprehensive Cancer Network (NCCN) guidelines website: http://www.tri-kobe.org/nccn/guideline/urological/english/testicular.pdf.

Seminoma

The relapse rate for patients with stage I seminoma on a surveillance protocol following primary orchiectomy is approximately 18 %, with larger primary tumors associated with a higher risk of recurrence. Formerly, adjuvant radiation was the standard of care for patients with stage I testicular seminoma; however, surveillance is also an option, as is single-agent carboplatin, which has been shown to have a decreased relapse rate compared to surveillance and has minimal toxicity. Higher stage seminoma is treated with radiation or combination BEP chemotherapy (bleomycin, etoposide, cisplatin).

Nonseminoma

Monitoring tumor markers is critical following orchiectomy, which should decrease according to their half-life (~5 days for AFP, ~3 days for hCG). Should tumor markers not normalize in patients with stage I nonseminoma, three cycles of BEP are indicated. For patients with stage IA nonseminoma in whom tumor markers normalize, surveillance and RPLND are options. Primary chemotherapy with one or two cycles of BEP is an option for patients with no metastatic disease (stage I) but with more advanced tumor characteristics. Patients with lymph node metastases are treated with RPLND, three cycles of BEP or four cycles of EP, with more aggressive (large embryonal carcinoma component) and multifocal metastases favoring primary chemotherapy. In patients who undergo primary chemotherapy, RPLND is indicated when there are residual masses >1 cm and tumor markers have normalized. In patients who undergo primary RPLND, the need for adjuvant chemotherapy is dictated by the pathology.

Editor's Comment

A pediatric general surgeon might encounter a testicular mass unexpectedly during inguinal hernia repair, hydrocelectomy, or orchidopexy; it is therefore important to understand the basic principles of the care of a child with a testicular tumor. Failure to do so could result in tumor spread or necessitate a hemiscrotectomy or orchiectomy that might otherwise have been avoided. As a general rule, a testicular mass should never be approached through a scrotal incision or percutaneous trans-scrotal biopsy. This should only be done through an inguinal incision, usually made somewhat larger than a typical inguinal hernia incision and always involving opening the external ring so that the testis can be delivered into the wound without rupture. If a testicular mass is discovered incidentally intraoperatively, the testis should be delivered through the inguinal incision and carefully inspected. A call should be made immediately to either an experienced pediatric urologic oncologist or to one of the national experts designated by the Children's Oncology Group for an intraoperative consultation. At this point, depending on the circumstances and availability of expertise, the decision might be to remove the testis, to control the spermatic cord with a tourniquet and perform a biopsy for frozen-section analysis, or to place the testis back in its anatomic position in anticipation of a more definitive operation in the near future. The same approach should be used with paratesticular tumors, which can also be malignant and are treated using a very similar approach.

A painless testicular mass is presumed to be malignant until proven otherwise. The next step should always include scrotal US and measurement of tumor markers (AFP, hCG). Boys with gynecomastia should also be examined very carefully for the rare hormonally active testicular tumor, but routine scrotal US is not cost-effective. Metastatic workup for testicular tumors includes a chest X-ray and abdominal CT scan and for paratesticular rhabdomyosarcoma includes a bone marrow biopsy.

A small testicular teratoma or epidermoid cyst in a prepubescent child can usually be easily excised with a small margin of normal parenchyma. Testicle-sparing surgery might also be recommended for Leydig cell tumors. For most other lesions, an incisional or excision biopsy with frozen-section diagnosis can usually help with decision making regarding orchiectomy. If orchiectomy is recommended, this should include a radical orchiectomy with high ligation of the spermatic cord. If the tumor is truly a surprise, it is usually best to consult the parents, intraoperatively if necessary, before an orchiectomy is performed. While it is usually considered better to have removed a testis for what was felt to be a possible malignancy than to preserve one that ultimately harbors a cancer, the decision should not be made lightly, especially since it would be difficult to justify the loss of an otherwise normal testis for a small benign lesion that could easily have been simply enucleated. Difficulty also arises in the rare situation of a testicular hematoma that is thought to possibly represent a ruptured testicular tumor. This is an extremely rare occurrence, but intraoperative biopsy should be performed if there is a pathologist available.

Retroperitoneal lymph node dissection for staging purposes in boys with testicular cancer is rarely necessary anymore, having been replaced for the most part by medical imaging. The

morbidity from an extensive dissection can be significant. It is also sometimes requested in boys who have persistent tumor marker elevation but normal imaging after orchiectomy. We are occasionally asked to biopsy a suspicious node after the completion of therapy because of concerns about recurrence. If feasible, this should be performed laparoscopically.

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Liver Tumors

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Rebecka L. Meyers

A new liver lesion in a child might turn out to be one of the several possible congenital or acquired hepatic lesions (Table 104.1). For many nonneoplastic lesions, the key to the diagnosis lies in identifying the underlying medical condition. One might expect to see a bacterial hepatic abscess in a child with chronic granulomatous disease, a fatty deposit in the liver of a child with hyperlipidemia, or an inspissated bile lake in a child with biliary atresia. Congenital liver cysts are rare and represent a spectrum that includes large simple cysts, intrahepatic choledochal cyst, and ciliated hepatic foregut cyst. Hydatid cysts will usually have a distinctive radiographic appearance. A small congenital liver cyst can safely be observed. If large and symptomatic, excision might be indicated to relieve pain, prevent rupture, and guard against reported possibility of malignant transformation in ciliated foregut cysts of the liver.

Although rare, pediatric liver neoplasia accounts for about 1.5 % of all pediatric tumors with an incidence that has been increasing. Age at presentation is often the key to the differential diagnosis. In newborns the most common tumor is benign infantile hepatic hemangioma. Malignant hepatoblastoma is most commonly diagnosed between ages 4 months and 4 years. Benign tumors in toddlers include mesenchymal hamartoma and focal nodular hyperplasia. Hepatocellular carcinoma and hepatocellular adenoma are seen in older children. Other tumors are more rare (Table 104.2). Although the most common benign tumors often show classic radiographic features, imaging is not always a reliable way to differentiate benign from malignant tumors. Because of their multicystic nature, mesenchymal hamartoma can sometimes be mistaken for nonneoplastic cystic disease such as amoebic or hydatid cysts (Fig. 104.1).

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Benign Liver Tumors

The most common benign liver tumors generally have characteristic radiographic features (Table 104.3). Mesenchymal hamartomas have multiple complex cysts separated by thick vascular septa. The key to differentiation from amoebic or hydatid cysts is the presence of the hyperenhancing thick vascular septa. Focal nodular hyperplasia (FNH) is usually a well-demarcated and hyperenhancing lesion with a characteristic central stellate scar. Although this central fibrosis or scar is considered pathognomonic, frequently FNH does not have a central scar. More recently hepatobiliary phase MRI especially with the use of hepatocyte specific contrast agents such as Eovist, has been shown to differentiate FNH from hepatocellular adenoma. An infantile hemangioma typically demonstrates bright peripheral enhancement and may be focal, multifocal, or diffuse.

Infantile Hepatic Hemangioma

Infantile hepatic hemangioma is the most common benign tumor of the liver in infancy. Many of these lesions are discovered incidentally and are localized and small enough to be of no clinical significance. Symptoms sometimes seen with larger lesions include abdominal distention, hepatomegaly, congestive heart failure, vomiting, anemia, thrombocytopenia and consumptive coagulopathy, jaundice secondary to biliary obstruction, and associated cutaneous or visceral hemangiomas. Sometimes a large rapidly growing lesion can be life threatening, with intractable high-output cardiac failure due to intrahepatic arteriovenous shunting and massive hepatomegaly. Although these findings can be confused with Kasabach–Merritt syndrome (KMS), in infantile hemangioma of the liver, they are usually a result of intrahepatic high flow vascular shunting and congestive heart failure. True KMS is more commonly seen with a different and very rare lesion in infants, kaposiform hemangioendothelioma, which can occur any-

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Table 104.1 Differential diagnosis of liver lesions in children

Malignant tumors	Benign or premalignant tumors	Other/nonneoplastic masses
Hepatoblastoma (HB)	Infantile hepatic hemangioma	Vascular malformations
Transitional type tumors: Tumors with features of both HB and HCC (HC-NOS)	Mesenchymal hamartoma	Hemangioma
Hepatocellular carcinoma (HCC)	Hepatocellular adenoma	Arteriovenous shunts
Fibrolamellar hepatocellular carcinoma (FL-HCC)	Bile duct adenoma	Congenital and acquired cysts:
Sarcomas:	Nodules:	Simple
Biliary rhabdomyosarcoma	Focal nodular hyperplasia (FNH)	Polycystic liver disease
Undifferentiated embryonal sarcoma of the liver (UESL)	Macroregenerative nodules:	Choledochal cyst
Angiosarcoma	Nodular regenerative hyperplasia (NRH)	Inspissated bile lake/biliary atresia
Rhabdoid tumor	Large regenerative hyperplasia (LRN)	Parasitic cysts
Nested epithelial stromal tumor	Dysplastic nodules	Amoebic
Cholangiocarcinoma	Inflammatory myofibroblastic tumor (IMT)	Hydatid
Hemangioendothelioma (epithelioid or retroperitoneal kaposiform)	Teratoma	Abscess
Metastatic:		Bacterial (chronic granulomatous disease)
Wilms, neuroblastoma, colorectal, carcinoid,		Fungal
lymphoma, germ cell, desmoplastic SRBCT		Hematoma
Hepatic involvement hematologic malignancy		Fatty liver
Acute myeloid leukemia (AML)		Geographic distribution of fat deposition
Megakaryoblastic leukemia (M7)		
Hemophagocytic lymphohistiocytosis (HLH)		
Langerhans cell histiocytosis (LCH)		

Table 104.2 Age at presentation, most common malignant and benign liver tumors

Age group	Malignant	Benign
Infant/toddler	Hepatoblastoma (HB), 43 %	Infantile hepatic hemangioma, 14 %
	Rhabdoid tumor, 1 %	Mesenchymal hamartoma, 6 %
	Others, 1 %	Others, 1 %
School age/adolescent	Hepatocellular carcinoma (HCC) including FL-HCC[a] and HC-NOS[b], 23 %	Focal nodular hyperplasia and others Nodules, 3 %
	Sarcomas and others, 7 %	Hepatic adenoma and others, 1 %

[a]Fibrolamellar hepatocellular carcinoma (FL-HCC)

[b]Hepatocellular-not otherwise specified (HC-NOS) includes transitional-type tumors with features of both HB and HCC

where in the body especially in the extremities and chest wall. In the rare retroperitoneal location, this very vascular invasive tumor may not respect anatomic boundaries (Fig. 104.2). Multidrug chemotherapy regimens are sometimes required in aggressive forms of kaposiform hemangioendothelioma.

The diagnosis of infantile hepatic hemangioma is usually straightforward and based on the combination of clinical symptoms and radiographic appearance on ultrasound and CT scan. Contrast-enhanced CT shows an area of diminished density, and after bolus injection of intravenous contrast, there is enhancement from the periphery toward the center of the lesion and, after a short delay, there essentially is complete isodense filling of the lesion and liver. Tumors are traditionally subcategorized as focal, multifocal, or diffuse (Fig. 104.2). Angiography might be necessary in infants with multifocal or diffuse tumors and refractory symptoms of intrahepatic shunting in whom embolization is considered.

If a definitive diagnosis of simple infantile hepatic hemangioma can be made radiographically, biopsy is not necessary and management can be noninvasive because spontaneous regression occurs in most cases, especially in infants with focal tumors. The historic initial medical treatment with corticosteroids has been nearly universally replaced with propranolol as first line therapy. Congestive heart failure is treated with digitalis, diuretics, and meticulous fluid management. Anemia and coagulopathy are treated with corrective blood product replacement therapy. Historically, both success and complete failure have been reported variously with many other treatments including epsilon-aminocaproic acid, tranexamic acid, low-molecular-

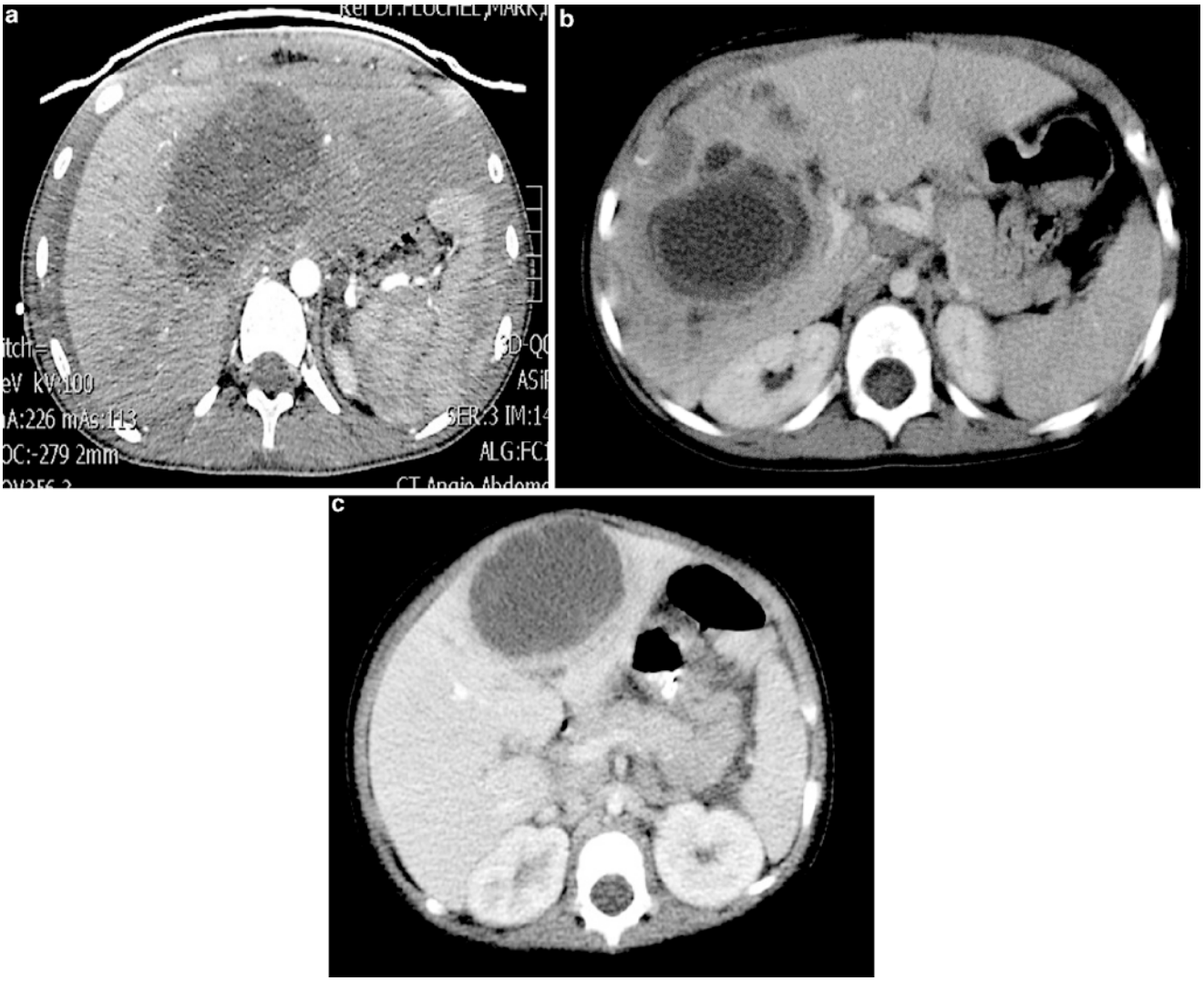

Fig. 104.1 Liver masses with possible cystic component: (**a**) undifferentiated embryonal sarcoma may present with rupture and hematoma; (**b**) mesenchymal hamartoma is multicystic with thick vascular septae; (**c**) amoebic abscess

Table 104.3 Distinguishing characteristics on radiographic imaging of the most common benign liver tumors

Benign liver tumor	Distinctive imaging characteristics
Mesenchymal hamartoma	Complex multicystic mass with thick vascular septa separating the cysts
Focal nodular hyperplasia	Hyperenhancing lesion with fibrous central scar on CT; hyperintense on MR hepatobiliary phase in gadobenate dimeglumine (Gd-BOPTA)-enhanced scan
Infantile hepatic hemangioma	Very bright peripheral contrast enhancement with central area of water attenuation; focal/multifocal/diffuse
Hepatocellular adenoma	Isointense or less intense on MR hepatobiliary phase in gadobenate dimeglumine (Gd-BOPTA)-enhanced scan

weight heparin, vincristine, cyclophosphamide, interferon 2-alpha, AGM-1470, and newer-generation antiangiogenic drugs such as bevacizumab and sorafenib. Recent studies have shown that the large tumors can produce antibodies to TSH and screening to rule out secondary hypothyroidism is recommended. Reports demonstrate resolution of the hypothyroidism after liver transplantation in cases that fail medical management.

In infants who fail medical management, symptomatic solitary tumors can be treated by excision or embolization. Although potentially hazardous, hepatic arterial embolization can be lifesaving because it reduces intrahepatic arteriovenous shunting. There have been reports of orthotopic liver transplantation for cases in which the lesion is extensive and no other options exist. A treatment algorithm has been published by the vascular tumor study

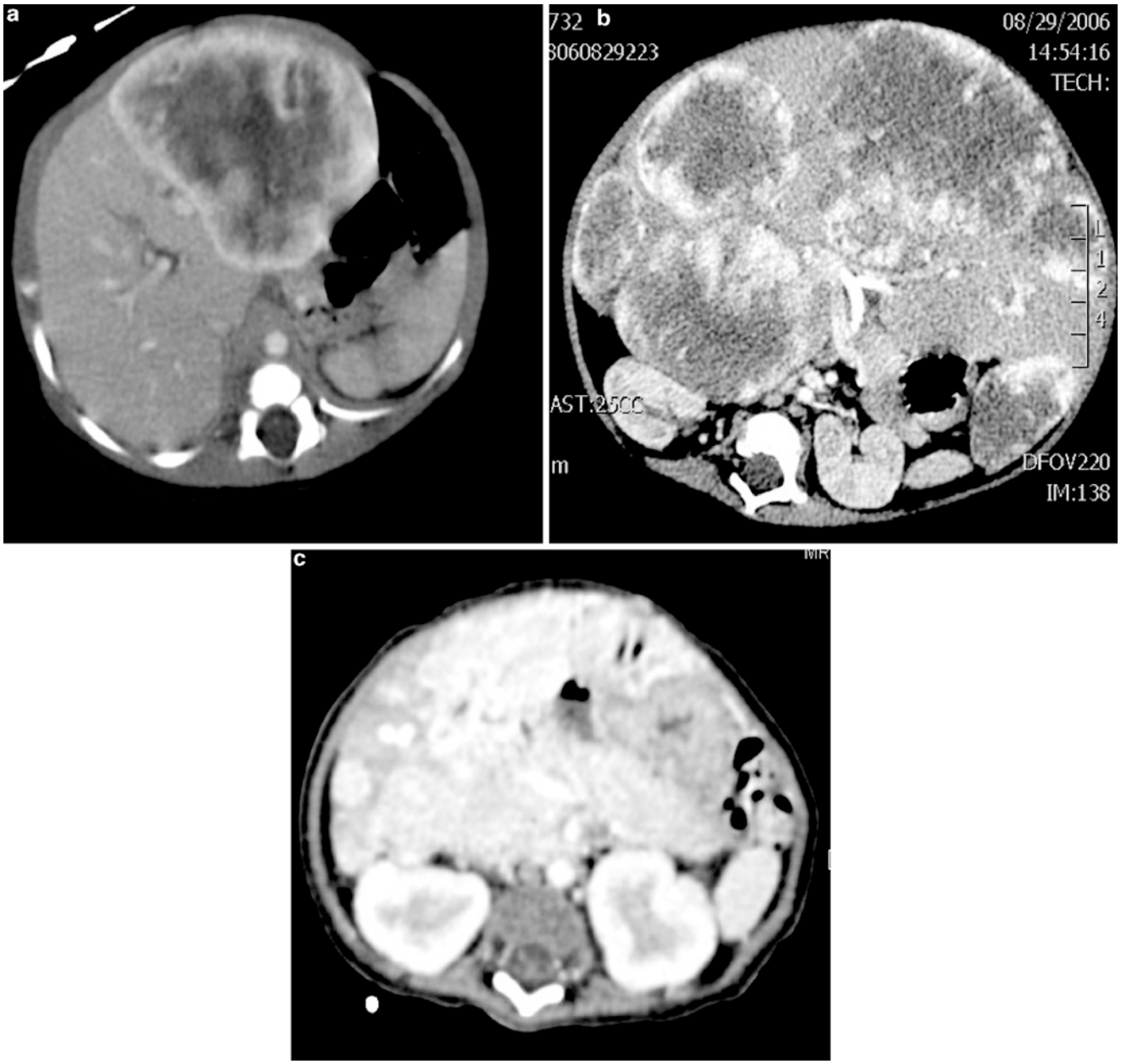

Fig. 104.2 Vascular liver lesions. (**a**) Focal infantile hepatic hemangioma; (**b**) multifocal/diffuse infantile hepatic hemangioma; (**c**) very rare tumor, retroperitoneal kaposiform hemangioendothelioma: Infant with invasive vascular tumor involving the liver, retroperitoneum, pancreas, and base of mesentery who presented with heart failure, thrombocytopenia, and compression of portal triad

group at Boston Children's Hospital and stratifies treatment based upon whether or not the tumor is solitary, multifocal, or diffuse.

Mesenchymal Hamartoma

Although mesenchymal hamartoma of the liver is the second most common benign liver tumor in children, its biology and pathogenesis are poorly understood. Historically, mesenchymal hamartoma has been described in the literature by various names including pseudocystic mesenchymal tumor, hepatic and giant cell lymphangioma, cystic hamartoma, bile cell fibroadenoma, hamartoma, and cavernous lymphangiomatoid tumor. Children with mesenchymal hamartoma typically present with abdominal swelling before 2 years of age. Before the widespread use of sophisticated diagnostic imaging, many of these tumors became very large, eventually presenting with mass effect such as vena cava compression, feeding difficulties, and respiratory distress. With the widespread use of ultrasound and CT, these tumors are now usually detected early as a palpable mass in an otherwise asymptomatic child. The alpha-fetoprotein (AFP) level is occasionally elevated in this tumor confounding the differentiation from hepatoblastoma.

Mesenchymal hamartoma is more common in the right lobe of the liver. On US one sees multiple echogenic cysts, but if the cysts are small, the entire tumor might appear as an echogenic mass. The CT typically shows a well-circumscribed, multilocular, multicystic mass that contains low-density cysts separated by solid septae and stroma. The stroma and septae can be vascular and occasionally show contrast enhancement similar to that seen in infantile hemangioma. When the cysts are small and the lesion appears solid, biopsy might be required to eliminate the diagnosis of malignant neoplasm. The tumor tends to increase in size during the first several months of life and subsequently either stabilizes, continues to grow, or undergoes spontaneous regression. Traditionally, the surgical treatment has been complete tumor excision, either nonanatomically with a rim of normal tissue or as an anatomic hepatic lobectomy. If the tumor is unresectable, the surgical options include enucleation and marsupialization. There are historic reports of nonoperative expectant management. Caution is warranted however because increasingly these tumors are recognized to be on a genetic continuum with undifferentiated embryonal sarcoma of the liver (UESL).

Focal Nodular Hyperplasia

FNH may be diagnosed at any age, from newborns to the elderly. In children, it usually is diagnosed between 2 and 5 years of age. It is a benign epithelial tumor that has been referred to by various names in the literature including benign hepatoma, solitary hyperplastic nodule, focal cirrhosis, cholangiohepatoma, and even mixed adenoma. Focal nodular hyperplasia is a well-circumscribed, lobulated lesion whose typical architecture on gross examination consists of bile ducts and a central stellate scar containing blood vessels that supply the hyperplastic process. Usually, there is no real capsule, but often the fibrous tissue surrounds the lesions, which can be single or multiple and vary in size from a few millimeters to more than 20 cm in diameter. Microscopically, the proliferating cells are practically identical to the surrounding hepatocytes.

Like other benign liver tumors, small lesions are usually incidentally found. Larger lesions may produce mass symptoms such as abdominal pain. The diagnosis of FNH is suggested by the appearance on US or CT of a well-demarcated, hyperechoic, and homogenous lesion. Although approximately 50 % of tumors will have normal accumulation of ^{99m}Tc sulfur colloid on liver scintigraphy, this finding is not specific as some of these children will turn out to have hepatoblastoma or hepatocellular carcinoma. In fact, although a radiographic "central stellate scar" is a characteristic finding, the radiographic appearance of FNH can be quite variable (Fig. 104.3). Recent advances in MRI technology suggest that imaging with MRI using hepatocyte specific contrast agents like Eovist may definitively diagnose the lesion as FNH; if doubt remains percutaneous biopsy may be needed. If biopsy does not definitively confirm the diagnosis, excision might become necessary to definitively rule out HCC. Complete surgical resection of radiographically or biopsy-

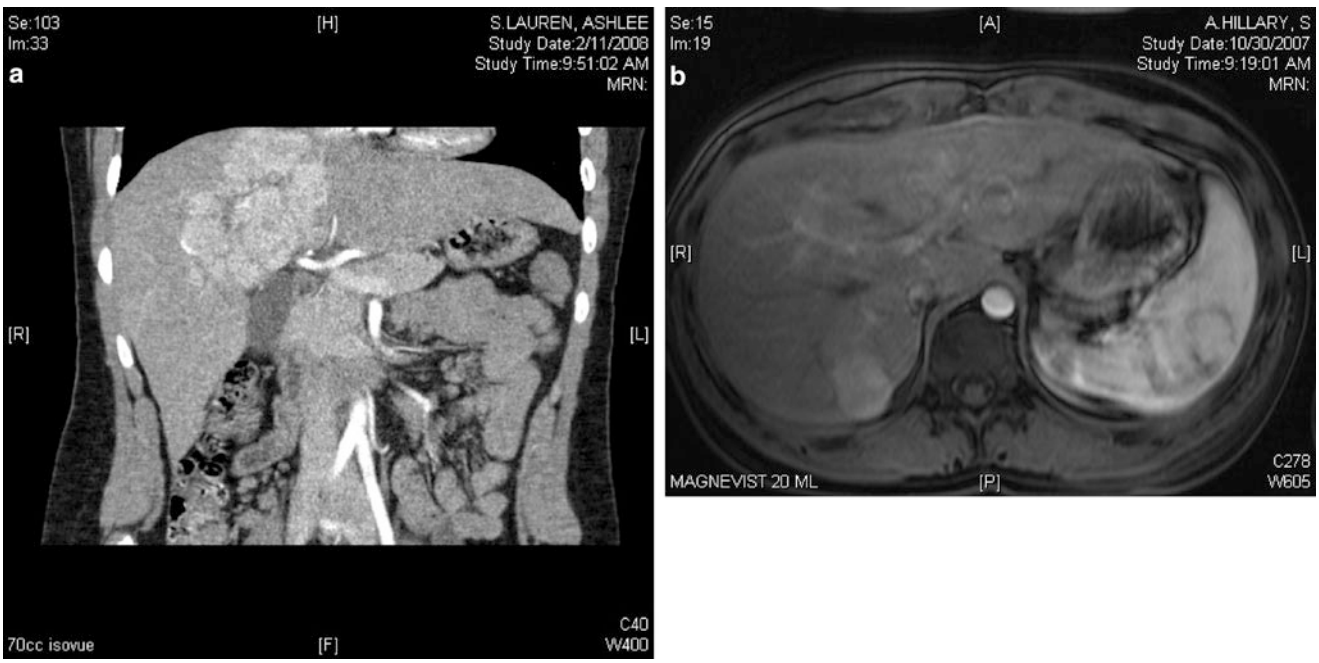

Fig. 104.3 Focal nodular hyperplasia (FNH): Though typically a hyperenhancing lesion with a central scar, these are examples of atypical appearing lesions: (**a**) hypervascular with unusual nest of dilated vessels encasing the tumor; and (**b**) this posterior right lobe FNH was not visible and isodense on CT and MRI T1 and T2; it is seen here only after gadolinium contrast enhancement

proven FNH is not mandatory in asymptomatic patients. Because spontaneous regression has not been reported, symptomatic patients will require either surgical excision or percutaneous ablative therapy.

Macroregenerative Nodules

Nodular regenerative hyperplasia (NRH) is comprised of macroregenerative nodules in a non-cirrhotic liver. This is a rare entity of unknown etiology that in children has been associated with a variety of other diseases and drugs. In about half of the children, there is some component of associated portal hypertension. Radiographically the nodular appearance may look like neoplasia and open wedge biopsy is occasionally required to definitively rule out malignancy. Prognosis in the absence of portal hypertension is good and complications are rare. Some pathologists feel that NRH and large regenerative nodules (LRNs) are distinct types of hepatocellular nodules with terminology that has historically often been used interchangeably in the literature. NRH and LRN may have different predisposing factors and imaging findings. The differentiation might be important if there is a suspicion of malignant degeneration of the nodule in which case biopsy is necessary.

Hepatocellular Adenoma

Most common in young women, especially in response to birth control hormonal therapy, hepatocellular adenomas can rupture and bleed. HCAs can also be seen in children with the APC mutation and in children with glycogen storage disease. Larger studies correlating genetic and histopathologic features have led to categorization of these lesions into three distinct subgroups: inflammatory HCA, hepatocyte nuclear factor 1-mutated HCA, and B-catenin-mutated HCA. The latter group has a greater propensity for developing HCC. Treatment depends on subtype and surgery is more likely to be needed with some genetic subtypes. Distinguishing HCA from FNH is sometimes still a challenge. Apart from the special circumstance of glycogen storage disease, surgical excision is recommended for lesions >5 cm, dysplastic foci, enlarging size, features of malignant change on imaging, B-catenin activation, or male gender.

Teratoma

True hepatic teratoma is extremely rare. Twenty-four cases have been reported in the literature, 18 in children less than 3 years old, but about half are malignant. The characteristic histological finding is the predominance of hepatic tissue in the resected specimen.

Malignant Liver Tumors

Age and serum AFP level are the most important first considerations in the differential diagnosis (Table 104.2). In infants and toddlers, most malignant tumors are hepatoblastoma (HB) and present as an asymptomatic right upper quadrant or epigastric abdominal mass. Some have fatigue, fever, pain, anorexia, and weight loss. Rarely, they present with abdominal pain and hemorrhage after traumatic or spontaneous rupture of the tumor. Nonspecific symptoms of inanition or respiratory failure appear insidiously as the disease enters its advanced stages. As the cancer grows, the pain in the abdomen progresses to shoulder or back pain and becomes more pronounced. The child might also develop progressive anorexia and vomiting and appear thin and sickly. Tumor growth compresses the normal hepatic architecture causing ascites, due to occlusion of the portal or hepatic veins; GI bleeding or splenomegaly, due to portal vein occlusion; or jaundice, scleral icterus, and pruritus, due to obstruction of the biliary tree. Symptoms are more common in older children, in whom the most common primary malignant liver tumor is hepatocellular carcinoma (HCC), primarily because it commonly presents at an advanced stage. Presentation with jaundice secondary to biliary obstruction is more common with biliary rhabdomyosarcoma.

Although the exact cause of liver cancer is unknown, there are a number of conditions that are associated with an increased risk for developing HB or HCC: Beckwith–Wiedemann syndrome, prematurity, and FAP for HB and chronic inflammation, cirrhosis, or metabolic liver disease for HCC. Most HBs occur in children <4 years, and most HCCs occur in adolescents. Children of intermediate age between 5 and 10 years are at increased risk of having a tumor with hybrid characteristics of both HB and HCC. The new international consensus classification of liver tumors refers to these tumors as hepatocellular neoplasm -not otherwise specified (HC-NOS). This ill-defined category includes tumors with a fairly uniform histology of an aggressive "transitional-type cell." Alternatively, and more commonly, there may be a heterogeneous admixture of different histologic patterns where some areas of the tumor resemble HB and other HCCs.

Diagnosis

Routine laboratory investigation should include CBC, liver panel (albumin, transaminases, glutamyl transferase, alkaline phosphatase, total and conjugated bilirubin), lactate dehydrogenase (LDH), tumor markers (AFP, βHCG, ferritin, CEA, catecholamines), and viral titers (hepatitis A, B, and C, EBV). The most important tumor marker is the serum AFP, which is elevated in 90 % of children with HB and

about 50 % of children with HCC; however an increased AFP is not pathognomonic of a malignant liver tumor. HB with AFP <100 IU/mL at diagnosis appears to be biologically more aggressive and carry a worse prognosis. Rarely, a well-differentiated, fetal-type, favorable prognosis HB will not express AFP. Moreover, AFP levels must be interpreted with caution because AFP is normally elevated in neonates up to 6 months of age and is sometimes slightly elevated with other tumors, as well as after hepatic damage or during regeneration of liver parenchyma. There are many reports of both infantile hepatic hemangioma and mesenchymal hamartoma in children with high AFP levels. Beware that a false low AFP level may sometimes occur due to lab error, in which the presence of extremely high AFP overwhelms the assay technique and generates an erroneously low result (the "hook effect"). Other tumor markers that can be useful include βHCG, elevated in germ cell tumors; ferritin, elevated in HCC and metastatic neuroblastoma; CEA, elevated in HCC and metastatic colorectal carcinoma; LDH, elevated in many malignant tumors; catecholamines, elevated in metastatic neuroblastoma; hepatitis C, in HCC; and EBV viral titers, in lymphoproliferative disorders.

Biopsy

While biopsy is possible by percutaneous, laparoscopic, or open technique, ultrasound or CT-guided percutaneous biopsy by coaxial technique is the most common approach to liver tumor biopsy. Multiple cores of tumor are desirable to yield a sufficient amount of tissue for diagnosis and biologic and genetic testing. Recommendations are for six or more cores of viable tumor and one core of adjacent normal liver—two cores minimum for diagnosis with an additional 4 cores frozen for biology and genetic testing for risk stratification. The additional core of adjacent normal liver along with the 4 cores for biologic testing should be frozen for analysis of underlying liver disease in HCC and for germline mutation analysis in HB. A final important concept, the needle biopsy tract, should pass through the liver that will ultimately be resected at the time of future definitive resection. It is highly recommend that the surgeon discuss the above with their interventional radiologist, oncologist, and pathologist, before biopsy is done. When doubt exists about the ability to achieve these goals percutaneously, laparoscopic or open biopsy should be performed.

Imaging

Appropriate high-quality radiographic imaging remains essential although it is difficult to establish the diagnosis based on imaging alone. Both HB and HCC are usually large, solid, and relatively heterogeneous. Multifocality is possible in both but more common in HCC. Both HB and HCC may show calcification, venous invasion, and lung metastasis. Non-lung metastasis (bone) and lymph node involvement are rare in HB and favor a diagnosis of HCC or rhabdoid tumor. After US localizes the tumor to the liver, definitive imaging should be triphasic contrast-enhanced abdominal CT or MRI with hepatocyte-specific contrast agents such as Eovist. High-quality images in the venous phase of contrast are of paramount importance because these venous contrast phase images usually maximize the visualization of tumor margins and are best for assessment of portal and hepatic venous involvement. PET-CT may be helpful in situations of occult tumor persistence or relapse, although beware of possible false positive results.

PRETEXT and Segmental Anatomy

The radiographic evaluation of the tumor at diagnosis is used to assign the tumor a PRETEXT (pretreatment extent of tumor) group and PRETEXT Annotation Factors. Devised by the International Society of Pediatric Oncology Liver Tumor Study Group (SIOPEL) in the early 1990s, PRETEXT has been used by the European study group for risk stratification for many years. The Children's Oncology Group adopted the PRETEXT nomenclature to define surgical resectability and risk group stratification in its current protocol AHEP-0731. American pediatric surgical oncologists and radiologists need to become familiar with this system as it has become the international language of pediatric malignant liver tumors.

Using the Brisbane liver anatomy nomenclature of Hemiliver => Section => Segment, (Fig. 104.4) PRETEXT defines contiguous tumor-free liver "sections." At diagnosis we assign a PRETEXT group; after neoadjuvant chemotherapy, we assign "POST-TEXT" (posttreatment extent of tumor) groups: group I, three adjacent sections free of tumor; II, two adjacent sections free of tumor (or one section in each hemiliver); III, one section free of tumor (or two sections in one hemiliver and one nonadjacent section in the other); and IV, no tumor-free sections (Fig. 104.5). PRETEXT annotation factors have been recently expanded and now include tumor involvement of: V, retrohepatic vena cava or all three hepatic veins; P, main portal or both right and left portal branches; E, extrahepatic contiguous growth (the diaphragm, stomach, etc.); F, multifocal tumors; R, tumor rupture before diagnosis; C, caudate lobe; N, lymph node; and M, distant metastases (mostly the lungs, otherwise specify) (Fig. 104.6). Chest CT is an essential part of the initial radiographic evaluation to rule out metastatic pulmonary disease. About 20 % of children with HBL and 50 % of those with HCC have lung metastasis at diagnosis (Fig. 104.6).

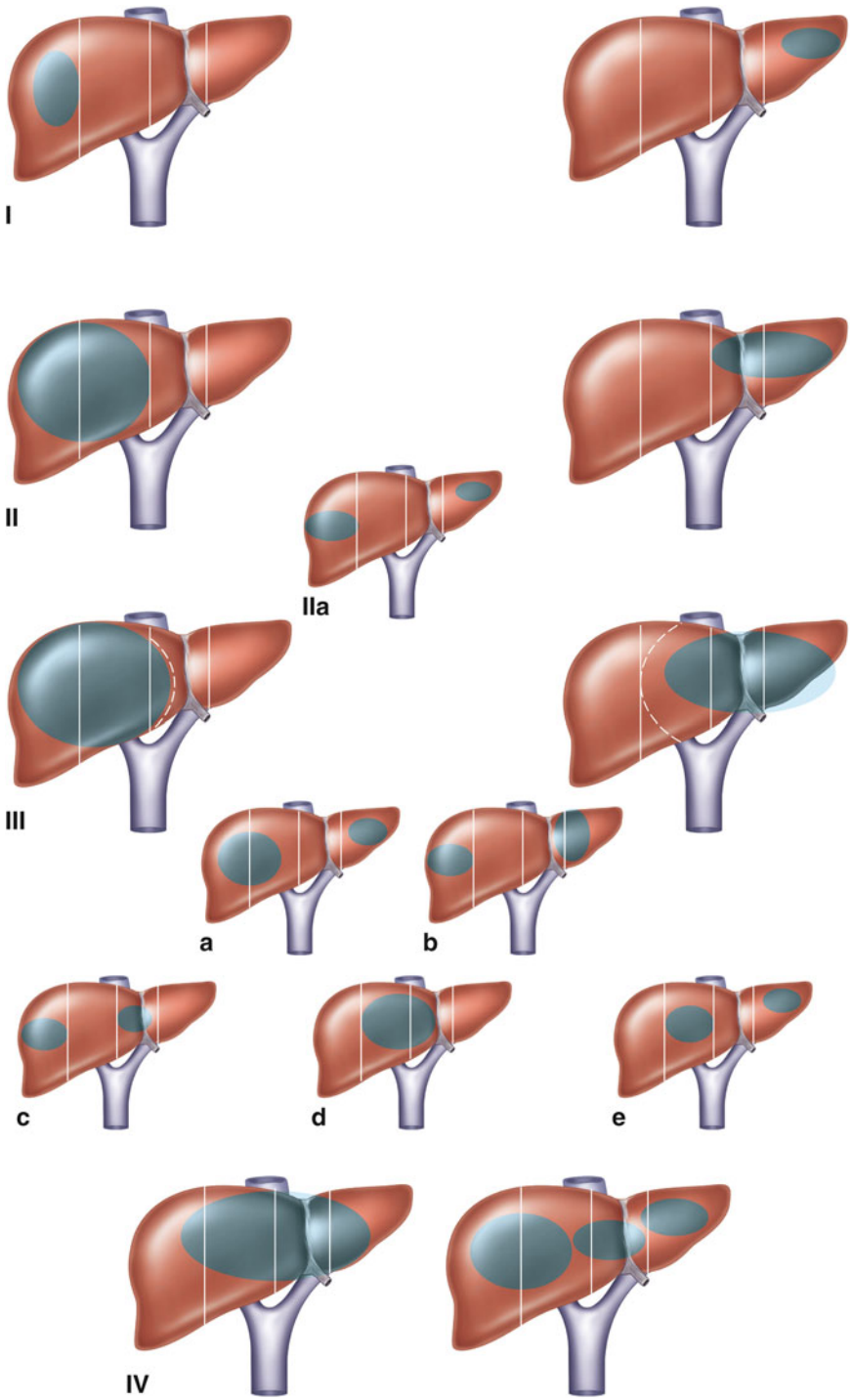

Fig. 104.4 PRETEXT denotes pretreatment extent of disease. POST-TEXT denotes posttreatment extent of disease. The tumor group describes the intraparenchymal extent of tumor: I (three contiguous sections tumor-free), II (two contiguous sections tumor-free), III (one contiguous sections tumor-free), or IV (no contiguous sections tumor-free). In addition, any group may have one or more PRETEXT annotation factors: V, ingrowth vena cava, all three hepatic veins; P, ingrowth portal vein, portal bifurcation; E, contiguous extrahepatic tumor; F, multifocal tumor; R, tumor rupture prior to diagnosis; C, caudate; N, lymph node involvement; M, metastasis, distant extrahepatic tumor. Tumors with positive PRETEXT annotation factors (VPEFRCNM) define increased risk and are not recommended for resection at diagnosis

Treatment

If radiographic imaging is suspicious for malignancy, either a biopsy or definitive surgical resection can be performed (Fig. 104.7). The European/SIOPEL standard is biopsy followed by neoadjuvant chemotherapy for all PRETEXT groups. In an attempt to reduce chemotherapy toxicity, the Children's Oncology Group (COG) advocates definitive resection of PRETEXT I and II tumors at diagnosis, while PRETEXT III and IV are treated with biopsy and neoadjuvant chemotherapy. Postoperative chemotherapy is given to all patients except a small subset of HB patients with a favorable histologic type known as "pure fetal" histology.

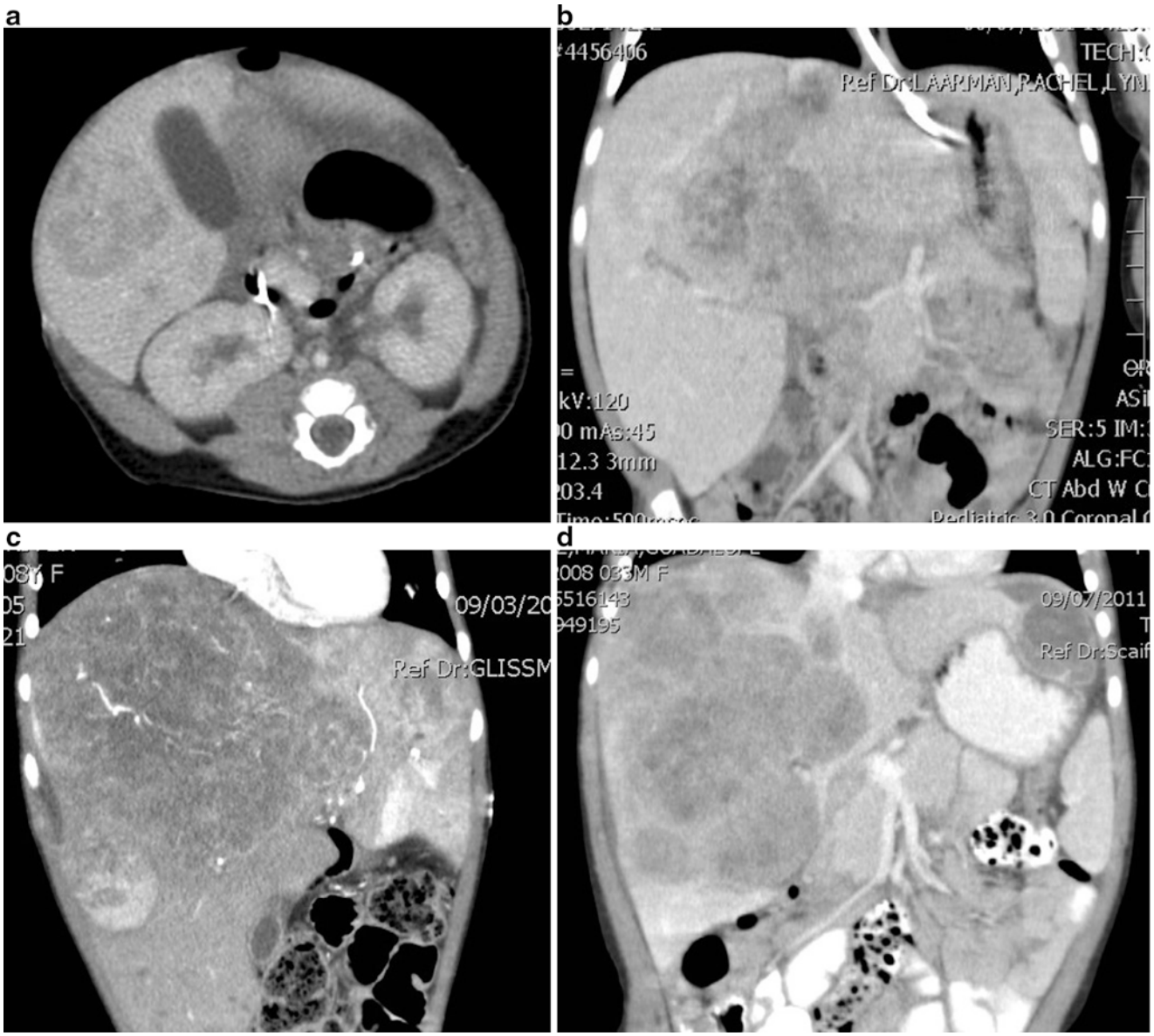

Fig. 104.5 PRETEXT examples. (**a**) PRETEXT II tumor of the right hemiliver; (**b**) Central PRETEXT IIId tumor with encasement portal vein at bifurcation (+P); (**c**) PRETEXT IV tumor with encasement of all three hepatic veins (+V); (**d**) PRETEXT IV tumor with multifocality (+F)

Surgical Technique

An excellent knowledge of the liver anatomy shown (Fig. 104.8) is essential in planning any liver resection because atypical, nonanatomic, or wedge resections are *not* recommended. Division between the upper and lower Couinaud segments is marked by the bifurcation of the right and left of the portal veins. Vertical margins between right posterior, right anterior, left medial, and left lateral sections are marked by the major hepatic veins and umbilical fissure. If the tumor appears radiographically unresectable at diagnosis, the first POST-TEXT assessment should be obtained about 2 weeks after the second cycle of chemotherapy as much of chemotherapy response often occurs in response to the first two cycles of chemotherapy. A PRETEXT I tumor can be resected with a segmentectomy, PRETEXT/POST-TEXT II with a hemi-hepatectomy, POST-TEXT III with an extended hemi-hepatectomy or a central liver resection, and POST-TEXT IV or POST-TEXT III with +V +P (bilateral major vascular invasion) by a liver transplant or extreme resection. Tumor resectability obviously depends upon surgical expertise, and the resection/transplant of the most advanced liver tumors is probably best done at a center with technical expertise and experience in liver resection and transplantation.

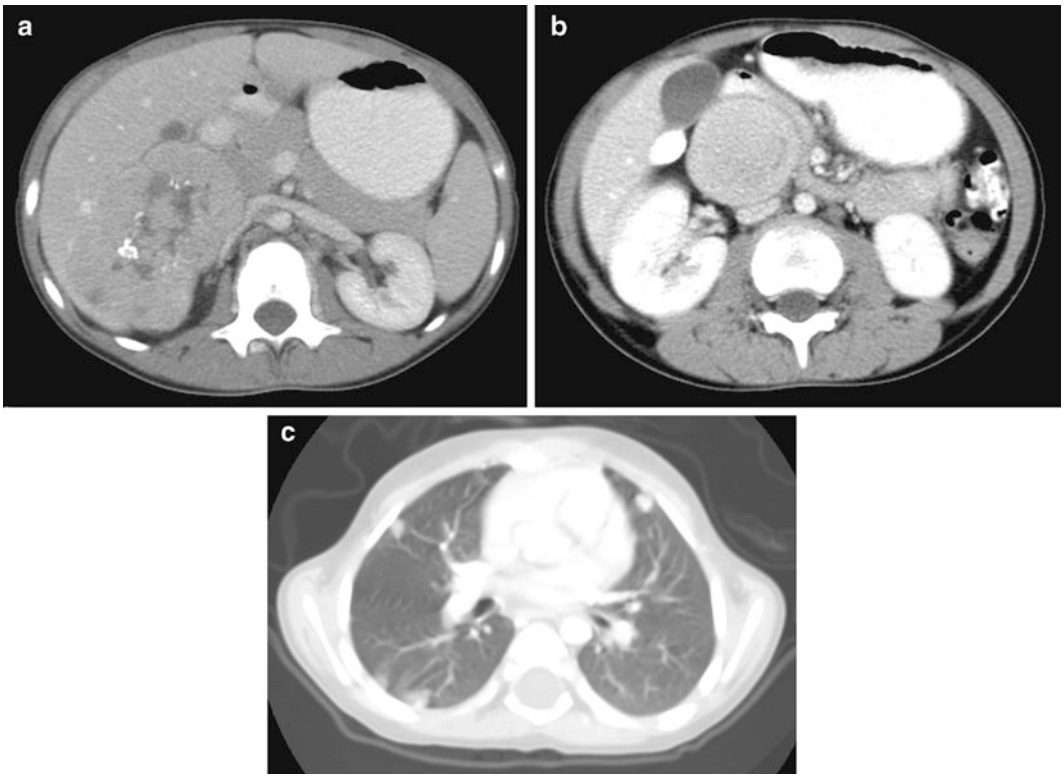

Fig. 104.6 Hepatocellular carcinoma (HCC): (**a**) PRETEXT II (involves right anterior and posterior sections); (**b**) large metastatic retroperitoneal lymph node obstructing duodenum; and (**c**) multiple metastatic lung nodules bilaterally

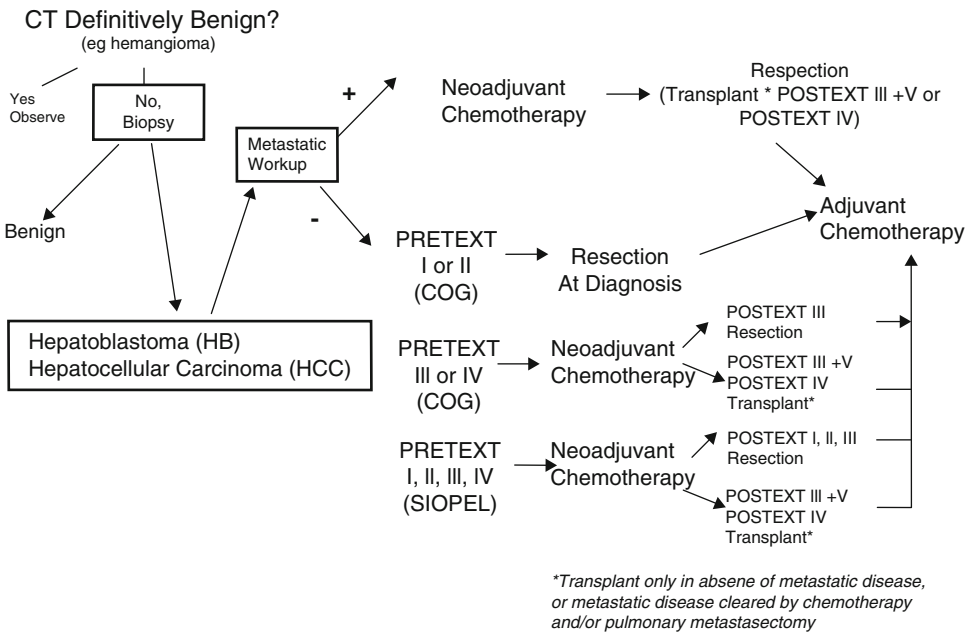

Fig. 104.7 Pediatric malignant liver tumor … simplified treatment algorithm. Note that in COG, neoadjuvant chemotherapy is recommended for all patients with positive PRETEXT annotation factors (VPEFRCNM, see Fig. 104.4 for definitions)

Specialized equipment that can be helpful includes ultrasonic CUSA-type dissector, Ligasure, water knife (Hydrojet, ERBE), argon or infrared beam coagulator, and especially intraoperative ultrasonography. Intraoperative US can help to define the deep intraparenchymal extent of the tumor in large or multifocal tumors. The size of the desired tumor-free resection margin depends upon the context and timing of the resection. Surgical margin of 1 cm is desirable when the resection is done before chemotherapy or in a tumor with limited or no chemotherapy response

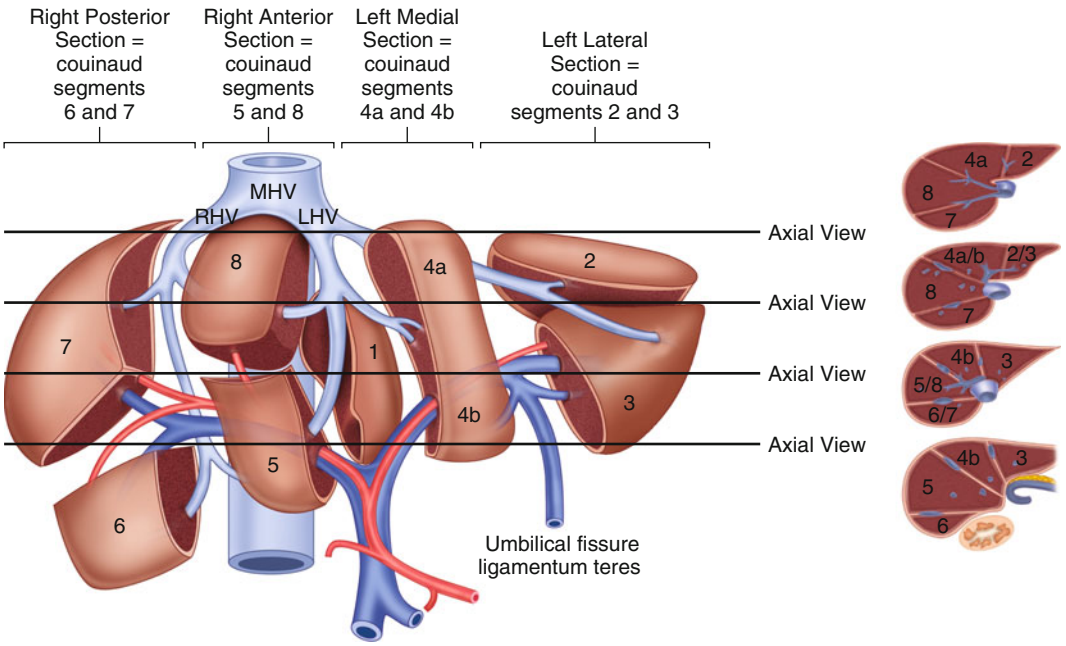

Fig. 104.8 Brisbane liver terminology. Hemiliver > Liver Section > Couinaud segment

(such as HCC). Alternatively, if the resection is being done after chemotherapy in a tumor with documented excellent response to chemotherapy, then a simple microscopic negative margin is acceptable.

The procedure begins with mobilization of the liver with meticulous hemostasis and anatomic definition of the extent of the tumor, of any satellite lesions, and of any suspicious areas of vascular involvement. Excisional biopsy of lymph nodes from the hepatoduodenal ligament, or any other areas or enlargement, should be performed in every case. Portal vein and hepatic artery inflow, and suprahepatic cava outflow, are fully defined prior to any parenchymal dissection. Ligation of the portal, arterial, and hepatic venous branches to the tumor usually precedes parenchymal dissection (in difficult situations hepatic veins can be secured toward the end of parenchymal resection and accessed through liver parenchyma), but this is done only after the surgeon is certain that the remaining inflow and outflow vessel branches are safe and secure from harm. Parenchymal dissection is then done along the line of demarcating ischemia.

Whatever technique or tool (CUSA, stapler, ligasure, clips, cautery, etc.) is used for parenchymal dissection, it is important to minimize blood loss with meticulous technique. Blood loss can also be minimized by slight Trendelenburg position and maintenance of a low CVP during the parenchymal dissection. Intermittent vascular inflow occlusion with Pringle maneuver, outflow occlusion with suprahepatic venous clamping, or both can safely be applied for short periods. Warm ischemia in short intervals limited to 10–15 min with intervening 5–10 min periods of perfusion and recovery is much better tolerated than uninterrupted longer periods of occlusion. During and after dissection of the parenchyma, various techniques of local hemostasis can be applied.

Non-anatomic resection, incomplete tumor resection, increased surgical blood loss, surgical complications, and macroscopic residual have all been associated with worse outcome. Whenever there is any doubt, and particularly when one suspects macroscopic residual, the surgeon should biopsy and re-resect the margin by taking an extra slice or, if necessary, an additional segment of liver. Sometimes the actual margin can be difficult to interpret because of a thick eschar of burned tissue at the margin from the use of high-voltage electrocautery. Cautery artifact may in part explain the observation that in a few patients in the SIOPEL studies, where resection is done after chemotherapy, a microscopic positive margin was not associated with worse prognosis. An alternative explanation is that microscopic residual in a chemosensitive tumor may succumb to postoperative chemotherapy. A third possibility can be seen with CUSA resection where the resection margin in vacuumed away and thus not available for pathologic evaluation in its entirety. Regardless of the cause, it should be stressed that while microscopic positive foci at the resection margin may, in select cases of HB, but never HCC, still be compatible with survival, it should never be the goal of a thorough and complete liver resection. Complete surgical resection is the cornerstone of cure for liver tumors, and, if the ability to obtain a resection free margin cannot be anticipated with a high degree of confidence, referral for liver transplantation, or resection by a more experienced liver surgeon, is preferred. Complex resection of extensive tumors should be carried out in centers that

have a facility for liver transplant, where surgical expertise, as well as willingness to embark on more radical surgery with a transplantation "safety net" is likely to be greater.

Hepatoblastoma

An embryonal tumor in the classic sense of incomplete differentiation, 90 % of HB are manifest by the age of 4, several have been present at birth and there is a hypothesized association with prematurity. The incidence of HB is 0.7–1 case per one million population per year in children in Western countries and has been increasing by about 3 % per year. There is an increased risk of HB in children with Beckwith–Wiedemann syndrome (BWS), hemihypertrophy, and familial adenomatous polyposis (FAP). Additional screening for cases in FAP kindreds is recommended by testing for germline mutations in the APC tumor suppressor gene. Additional biologic markers might include trisomy 2, 8, and 20, alternations in gene copy number translocation of the NOTCH2 gene on chromosome 1, and a host of increasingly well-defined aberrations in a number of genetic signaling pathways including Wnt, Notch, Hedgehog, MAPK, PI3/AKT, hepatocyte growth factor, insulin-like growth factor II, MYC signaling, p53, epigenetic changes, and microRNAs.

Definitive diagnosis of hepatoblastoma is made by biopsy or resection. Of the five histologic subtypes—fetal, embryonal, mixed epithelial, mesenchymal/macrotrabecular, and small cell undifferentiated—fetal carries the most favorable prognosis and small cell undifferentiated the worst. Even if unresectable at diagnosis, most hepatoblastomas are unifocal and chemosensitive, especially to the platinum-derived drugs. Since the routine addition of cisplatin in the late 1980s and the increased use of liver transplantation and intensified chemotherapy regimens in the last decade, overall survival in hepatoblastoma has increased dramatically. Today cisplatin and doxorubicin remain the backbone of the various different chemotherapy regimens of the major multicenter study groups in Europe, America, and Japan. The best outcomes to date have been achieved in the most recent studies: (a) metastatic patients overall survival of 79 % in SIOPEL-4 and (b) nonmetastatic patients overall survival of 94 % in AHEP-0731. Because of these recent advances, it is highly recommended that as many patients as possible be enrolled on current therapeutic trials.

Cure from hepatoblastoma is not considered possible without a complete gross resection of the primary tumor at some point during the treatment regimen. There are two principal strategies (Fig. 104.9). COG advocates for tumor resection at diagnosis whenever prudent and possible, arguing that toxicity is reduced by avoidance of unnecessary neoadjuvant chemotherapy and that some tumors become resistant to prolonged courses of chemotherapy and the highest survival rates have historically been observed in patients with initially resected tumors (although these tumors also tend to be the smaller and more favorable). COG surgical guidelines advocate definitive surgical resection at diagnosis for localized, unifocal PRETEXT I and II tumors followed by chemotherapy. When the tumor is large, is multifocal, or shows radiographic evidence of portal or hepatic venous invasion or pulmonary metastatic lesions, the chance of curative resection might be improved by neoadjuvant chemotherapy and delayed primary resection. Alternatively, SIOPEL has historically discouraged resection of any tumor at diagnosis favoring neoadjuvant chemotherapy in all patients with the argument that the chemotherapy renders most tumors smaller, better demarcated, and more likely to be completely resected. This approach argues that the increased toxicity of neoadjuvant chemotherapy will be offset by the benefit of improved resectability.

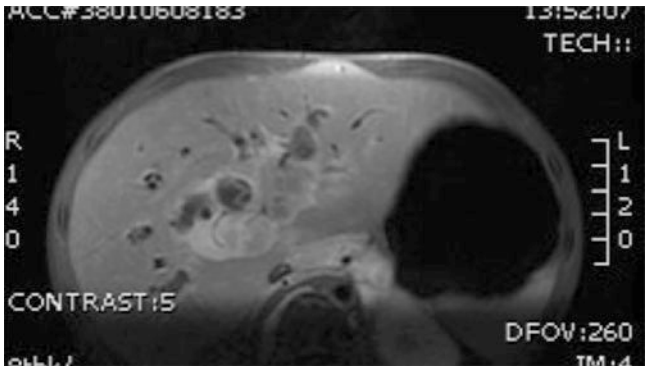

Fig. 104.9 Hilar biliary rhabdomyosarcoma on MRCP showing biliary obstruction at diagnosis

The role of pulmonary metastasectomy for HB has yet to be clearly defined, although it appears that surgical resection of lung deposits that persist at the completion of protocol chemotherapy might increase the chance of cure. The role for metastasectomy is more controversial in the setting of later pulmonary relapse.

Hepatocellular Carcinoma

Because hepatocellular carcinoma is relatively chemoresistant, it still carries a poor prognosis and a dismal 15 % cure rate that has not improved much over the past decades. Complete surgical resection or transplantation for localized disease is often the only hope. Tumors are commonly multifocal and carry a high risk of local relapse even after definitive resection with negative margins. In contrast to reports in the adult literature, the fibrolamellar histologic variant has a similar outcome to other types of childhood HCC. Children with resectable tumors confined to the liver at diagnosis have a better prognosis irrespective of histologic subtype, whereas

outcome remains poor for children who present with advanced stage disease. Metastatic relapse is more common after transplantation for HCC, and therefore liver transplantation is restricted to patients whose tumor has always been clearly localized to the liver. The Milan criteria for liver transplant in adults with HCC (fewer than three nodules, largest nodule less than 5 cm) do not seem to apply to children and transplant has been increasingly encouraged for tumors confined to the liver.

For unresectable patients, new treatment modalities are the target of investigation with some early promising results and include dose-compressed chemotherapy, adjuvant anti-angiogenic therapy, transarterial chemoembolization (TACE) with either doxorubicin or radioactive yttrium eluting beads, and percutaneous ablations. The hallmark of increased risk for HCC in adults is underlying cirrhosis. Curiously, however, relatively fewer children with HCC have underlying cirrhosis compared to about 70 % of adults. Cirrhosis in children may be due to biliary atresia, the PFIC familial cholestatic syndromes, hepatitis B or C, or neonatal hepatitis. Other risk factors for HCC in childhood include type 1 glycogen storage disease, tyrosinemia, hemochromatosis, Fanconi's anemia, alpha-1 antitrypsin deficiency, autoimmune hepatitis, and primary sclerosing cholangitis. The fibrolamellar variant of HCC (FL-HCC) is rarely associated with cirrhosis, rarely produces alpha-fetoprotein, and tends to affect primarily adolescents and young adults.

Hepatic Sarcomas

Primary hepatic sarcomas are rare. Outcome depends primarily on tumor histology, sensitivity to chemotherapy and/or radiotherapy, and the ability to achieve complete tumor resection.

Biliary Rhabdomyosarcoma

The classic presentation of biliary rhabdomyosarcoma is in young children (average 3½ years) with jaundice and abdominal pain, often associated with distension, vomiting, and fever (Fig. 104.9). Histology is exclusively either embryonal or botryoid, both of which are associated with a favorable prognosis. Gross total resection is rare, but the tumor is often both chemo- and radiation sensitive and long-term survival is seen in 60–70 % of patients. Surgical intervention has two goals: to establish an accurate diagnosis and to determine the local-regional extent of disease. Although chemotherapy is generally effective at relief of the associated biliary obstruction, it is sometimes often too late. Patients remain at high risk of death from biliary sepsis during the first 2 months of their disease and empiric broad-spectrum antibiotic coverage is of paramount importance in febrile patients.

Angiosarcoma

We have seen rare cases that support the sporadic case reports in the literature of malignant transformation of infantile hemangioma to angiosarcoma. Histologic verification of malignancy can be difficult and this rare entity must be suspected if an infantile hemangioma shows unusual progression. Relatively chemoresistant, prognosis is generally poor. Early recognition and transplant in the absence of preexisting metastatic disease can be life-saving.

Undifferentiated Sarcoma of the Liver

Undifferentiated embryonal sarcoma of the liver (UESL) is a rare childhood hepatic tumor and has historically been considered an aggressive neoplasm with an unfavorable prognosis. It is increasingly recognized that UESL may develop from mesenchymal hamartoma and differentiating the two lesions can sometimes be quite challenging. Survival has improved with multimodal approaches, designed for patients with soft tissue sarcomas at other sites, including conservative surgery at diagnosis, multiagent chemotherapy, and second-look operation in cases of residual disease. Using these techniques, several small series have reported survival in up to 70 % of children.

Rhabdoid Tumor

Malignant rhabdoid tumor of the liver is a rare and aggressive tumor of toddlers and school-age children that sometimes presents with spontaneous rupture. These rare tumors are often chemoresistant and fatal, although a recent case report suggests the potential for cure with multimodal therapy including ifosfamide, vincristine, and actinomycin D.

Metastatic Liver Tumors

Unlike the large body of literature concerning liver resection for metastatic colorectal tumors in adults, there is little published data that addresses the treatment of metastatic tumors in the liver from abdominal solid tumors in childhood. Results of small series that have included neuroblastoma, Wilms tumor, osteogenic sarcoma, gastric epithelial, and desmoplastic small round cell tumor show that most of these patients die of progressive disease or develop local recurrence. The overall prognosis in these patients remains poor and the decision to perform hepatic metastasectomy should be made with caution. The treatment approach should not, however, be uniformly nihilistic, because not all liver lesions in children with abdominal solid tumors turn out to be metastatic disease. Both nodular regenerative hyperplasia and focal nodular hyperplasia have been reported to mimic hepatic metastasis in children. Definitive diagnosis requires biopsy or resection.

Editor's Comment

Hepatoblastoma is uncommon but in many cases potentially curable. Given the importance of complete surgical excision and the intricacies of modern pediatric oncologic care, these children are best cared for where surgical and oncological expertise and transplantation capability are available. Complete resection of the primary tumor is critical, and salvage rates after a failed resection attempt or with recurrence after resection are not very good, even with transplantation. Therefore, it is important to approach these patients with a thoughtful plan and with early involvement of a pediatric liver specialty surgeon.

The surgical approach is relatively straightforward: if the tumor is safely resectable with an adequate margin up front, then it should be resected; but if the tumor is not safely resectable with a 1-cm margin up front, the tumor should be biopsied and the patient treated with neoadjuvant chemotherapy. After two and then after four cycles of chemotherapy, the patient is reimaged, and if at any point it is considered resectable, then it should be resected. If it is still not resectable even after four cycles, the option of transplantation should be discussed. If it is clear that the tumor will not be resectable even after neoadjuvant chemotherapy, then liver transplantation as the primary surgical therapy should be considered.

The decision about resection is made more difficult when it is thought that a nontraditional type of resection is necessary (extended lobectomy, central hepatic resection, reconstruction of the vena cava), in which case it is an option at some centers to have a liver speciality surgeon perform the resection. It is important to involve these surgeons early whenever there is the possibility of difficult or dangerous resection as intraoperative challenges might arise during hepatic resection and an urgent last-minute phone call for help is usually a poor backup strategy.

Intraoperative assessment of margins can be difficult when the lesion is deep or small. Preoperative imaging therefore needs to be of excellent quality, studied in detail ahead of time, and available for review in the operating room. This should include CT or MR angiography to map out every vessel within and around the liver. If the anatomic landscape is still confusing, intraoperative US should be available. Margin recommendations depend upon tumor type, timing of resection, and quality of the chemotherapy response. As a general rule, 1 cm is needed before chemotherapy or in a chemoresistant tumor like HCC, but microscopically negative is acceptable after chemotherapy with a documented good chemotherapy response.

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Musculoskeletal Tumors

105

Mark A. Seeley and John P. Dormans

A thorough history and physical examination is imperative in formulating a differential diagnosis when a musculoskeletal tumor is suspected. Information gleaned from both the patient and family will be helpful in proceeding with the workup. All aspects of the history will provide a clue to establishing a diagnosis (Table 105.1).

The presence or absence of pain is a key piece of information. Although not always true, patients with malignant lesions will tend to have a history of pain, while benign lesions are generally found incidentally unless associated with a pathologic fracture. It is important to characterize the pain profile with regard to its onset, duration, quality, progression, and severity. Useful tools in quantifying pain include a pain scale (0–10), recording the percentage of waking hours the pain is present and determining exacerbating or ameliorating factors. Night pain is a red flag that should prompt further investigation. Pain that is worse at night and improves markedly with NSAIDs is a classic presentation for an *osteoid osteoma*. Pain with weight bearing can be a sign of a bone lesion at risk for fracture, the presence of which should be ruled out with a radiograph. Constitutional symptoms are also important to document in the history. Some tumors, such as *Ewing sarcoma* or *eosinophilic granuloma*, can mimic infection and present with fever, chills, and increased WBC and CRP.

It is important to document how long a mass has been present, its size progression, and any change in consistency. Lesions that change in size can be indicative of a vascular lesion or a ganglion cyst. A family history of masses, deformities, or short height can indicate inherited disorders, such as multiple hereditary exostoses or neurofibromatosis.

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The musculoskeletal exam should not only focus on the region of interest but should include muscle strength testing of affected and non-affected extremities, neurovascular status, range of motion of the joints above and below the affected region, and a visual and physical exam of the entire body. It is important to look for coast-of-California spots or café-au-lait skin lesions, the presence of more than three of which is suggestive of McCune-Albright disease. The skin should be inspected for any overlying change, such as erythema or vascular engorgement from hyperemia, which may be associated with a primary bone sarcoma. A thorough regional lymph node examination should be performed when a soft tissue mass is found. Certain soft tissue tumors have a predilection for metastasizing via the lymphatic system (Table 105.2). When dealing with soft tissue tumors, the size, location, consistency, and mobility of a mass characterize the lesion and help formulate the differential diagnosis. Is the mass soft and mobile like a lipoma, or hard and nonmobile, adherent to local tissue? Is the mass fluctuant and does it transilluminate like a *ganglion cyst*? It is very important to differentiate whether the mass is superficial or deep to the fascia. Deep soft tissue masses larger than 5 cm are considered sarcomas until proven otherwise. Is the mass tender? Are there any other masses? Observing the child walks barefoot helps to evaluate for the presence of a gait abnormality, suggesting the possibility of a spine or lower extremity lesion. Leg length discrepancies and angular deformities should be evaluated and could represent physeal injury or tethering from an exostosis in the setting of multiple hereditary exostoses.

The more the musculoskeletal examination routine can be built into a game with younger children, the easier it will be to perform. For most of the examination, the child can be sitting comfortably on a parent's lap. Examining and testing normal, non-painful body parts prior to the tender areas allow you not only to gain the confidence of younger patients but also collect this information prior to a potential refusal to participate further.

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Table 105.1 Differential diagnosis of benign and malignant pediatric musculoskeletal tumors, classified by tissue of origin

Origin	Benign	Malignant
Bone	Osteoid osteoma Osteoblastoma	Osteosarcoma
Cartilage	Osteochondroma Chondroblastoma Chondromyxoid fibroma Enchondroma Periosteal chondroma	Chondrosarcoma
Fibrous tissue	Non-ossifying fibroma Fibrous dysplasia Osteofibrous dysplasia Desmoplastic fibroma	Malignant fibrous histiocytoma (MFH) of bone
Miscellaneous	Unicameral bone cysts Aneurysmal bone cysts Giant cell tumor Langerhans cell Histiocytosis	Ewing sarcoma Leukemia Lymphoma of bone
Metastatic tumors		Neuroblastoma Retinoblastoma Hepatoblastoma
Bone lesions that can mimic tumors	Osteomyelitis Tuberculosis Avulsion fractures	
Vascular tumors	Hemangioma Vascular malformations	
Nerve origin	Neurilemmoma Neurofibroma	Malignant peripheral nerve sheath tumor (MPNST)
Fibrous origin	Fibromatosis	Fibrosarcoma
Muscular origin		Rhabdomyosarcoma
Miscellaneous	Ganglion Synovial cyst	Synovial sarcoma Primitive neuroectodermal tumors (PNET) Soft tissue Ewing sarcoma
Soft tissue lesions that can mimic tumors	Abscess Hematoma Heterotopic ossification Granuloma annulare	

Table 105.2 Soft tissue sarcomas with lymph node metastases

Epithelioid sarcoma
Synovial sarcoma
Angiosarcoma
Rhabdomyosarcoma
Clear cell sarcoma

Diagnosis

Plain radiographs provide vital information for diagnosing both bone and soft tissue tumors and should be obtained at the initiation of workup. This should consist of at least two orthogonal views centered over the lesion. When evaluating a radiograph of a bone lesion and trying to narrow down the differential diagnosis, it is useful to ask the following five questions: (1) What is the age of the patient? (2) Where is the lesion? (3) What is the lesion doing to the bone? (4) What is the bone doing to the lesion? (5) What is the periosteal response (Fig. 105.1)? The first two questions regarding age and location are important as various bone lesions appear in classic locations in certain age groups (Fig. 105.2, Table 105.3). *Chondroblastoma* often presents as a discrete, round, lytic lesion located in the epiphysis of a skeletally immature patient. In the skeletally mature patient, a lesion that extends into the epiphysis might be a *giant cell tumor*.

The local effect of the lesion and the host bone's ability to contain the lesion can also provide clues as to the diagnosis. As such, the radiographic features between malignant and benign bone lesions differ markedly. *Osteogenic sarcoma* often presents as a locally aggressive, permeative metaphyseal lesion, with destruction of normal bone anatomy and marked reaction by surrounding bone (Fig. 105.3). Benign lesions, on the other hand, are typically more discrete, with narrow zones of transition between tumor and host bone and present in certain classic patterns (Figs. 105.4 and 105.5). Finally, the periosteal response to a well-contained, slowly growing benign lesion is a mature and solid cortical thickening, while the response to an aggressive lesion such as *Ewing sarcoma* is

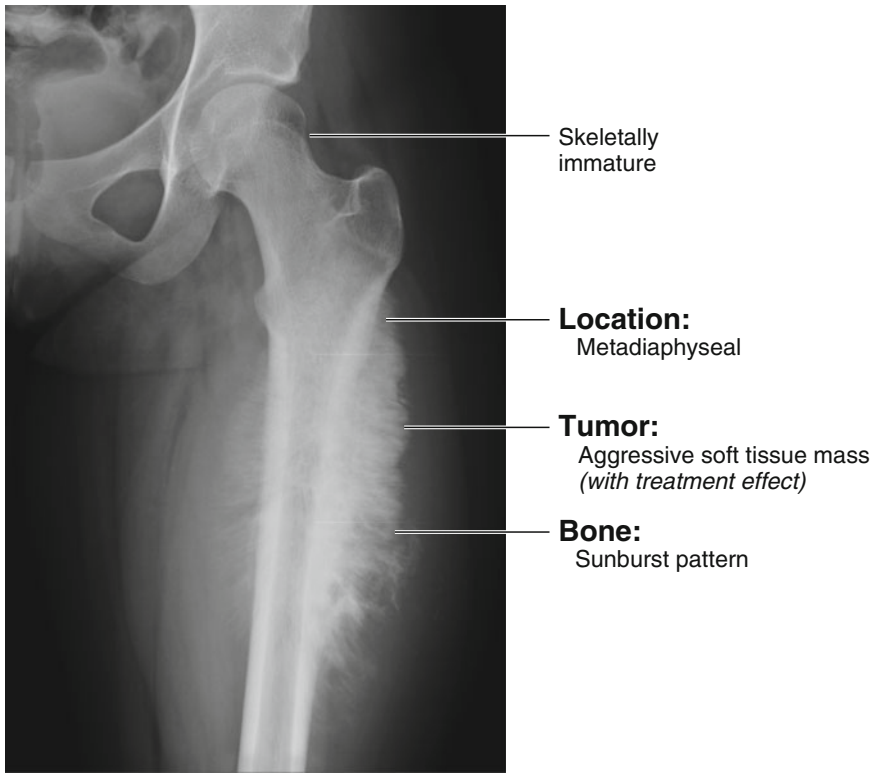

Fig. 105.1 AP radiographic of a 15-year-old female with a proximal femoral osteosarcoma. When evaluating the radiographic, the reviewer should ask the following questions: (1) What is the age of the patient? (2) Where is the lesion? (3) What is the lesion doing to the bone? (4) What is the bone doing to the lesion? (5) What is the periosteal response?

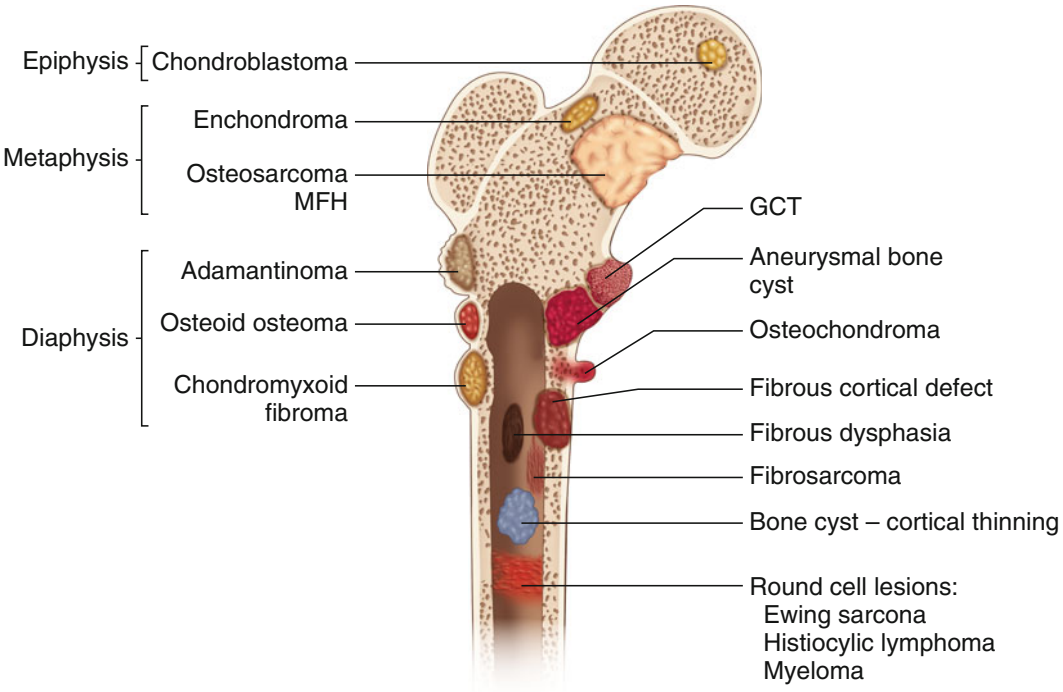

Fig. 105.2 Differential diagnosis of bone tumors according to common locations

more likely to be interrupted and poorly consolidated, having the classic appearance of "hair on end," "sunburst," or "onion skin" calcification patterns (Fig. 105.1).

More advanced imaging is required when the diagnosis cannot be established based on clinical and radiographic examination. This could include ultrasound, CT, MRI, or positron emission tomography scans. US is noninvasive but has limited utility for bone tumors—it can be used to characterize an equivocal soft tissue mass in a young child to avoid sedation for more advanced imaging (*ganglion cyst*, *Baker cyst*).

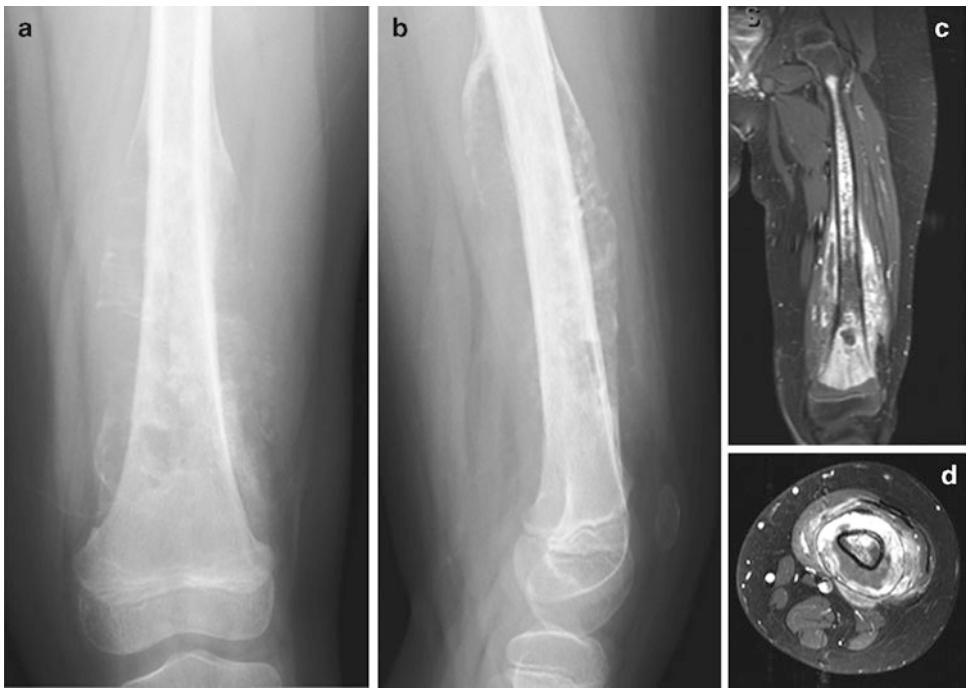

Fig. 105.3 **a,b** Anterior-posterior and lateral radiographs of osteogenic sarcoma distal femur. **c** Coronal view of the osteogenic sarcoma showing the soft tissue extension and extent of intramedullary involvement. **d** Axial MRI showing close proximity, but not involvement, of the neurovascular structures to the tumor

Table 105.3 Bone tumor locations

Epiphysis	Chondroblastoma
	ABC
	Giant cell tumor
	Infection
Diaphysis	Fibrous dysplasia
	Osteofibrous dysplasia/adamantinoma
	Eosinophilic granuloma/LCH
	Lymphoma/leukemia
	Ewing sarcoma
Cortex	Osteoid osteoma
	Non-ossifying fibroma
	Chondromyxoid fibroma
	Osteofibrous dysplasia/adamantinoma
Spine	Osteoid osteoma
	Osteoblastoma
	Aneurysmal bone cyst
	Eosinophilic granuloma

CT is useful in differentiating a benign lesion from a low-grade malignant cartilage lesion. CT provides a detailed evaluation of the bony architecture of the extremity and is the preferred method of evaluation for osseous anatomy (osteoid osteoma). In contrast, MRI is extremely useful for evaluating most bone and soft tissue neoplasms. MRI can be used to detect an associated soft tissue mass from a bone lesion, the proximity of the lesion to neurovascular structures, the extent of bone marrow involvement, and the presence of skip lesions. When using MRI to evaluate a soft tissue mass, it is helpful to use gadolinium, which enhances visibility and helps delineate the tumor borders. PET scans assess soft tissue and bone neoplasms by objectively evaluating the tissue metabolism and physiology. PET scans use radiolabeled fluorodeoxyglucose (FDG), which is injected intravenously and becomes trapped within cells. Aggressive tumors have a higher rate of glycolysis than less aggressive lesions and therefore have higher accumulations of FDG. Many sarcoma centers are using combined PET-CT for pretherapy staging, assessment of the response to therapy, and post-therapy surveillance.

Benign Bone Tumors

Many patients with asymptomatic benign bone tumors can be observed. This is particularly true of lesions that have a natural history of improving without intervention, such as unicameral bone cysts. Enlisting the help of an experienced musculoskeletal radiologist can corroborate the diagnosis and therefore prevent unnecessary biopsies of benign "no-touch" lesions (eosinophilic granuloma, small non-ossifying fibromas). If the lesion is painful or the size and location portend a risk of fracture, curettage and bone grafting might be indicated and is the treatment of choice for symptomatic benign lesions such as *non-ossifying fibromas*, some *unicameral bone cysts*, and *fibrous dysplasia*.

Locally aggressive benign lesions, such as *chondroblastoma*, *giant cell tumors*, *chondromyxoid fibroma*, and *aneurysmal bone cysts* (Fig. 105.4), should be treated with an extended curettage using a burr, an adjuvant such as phenol or

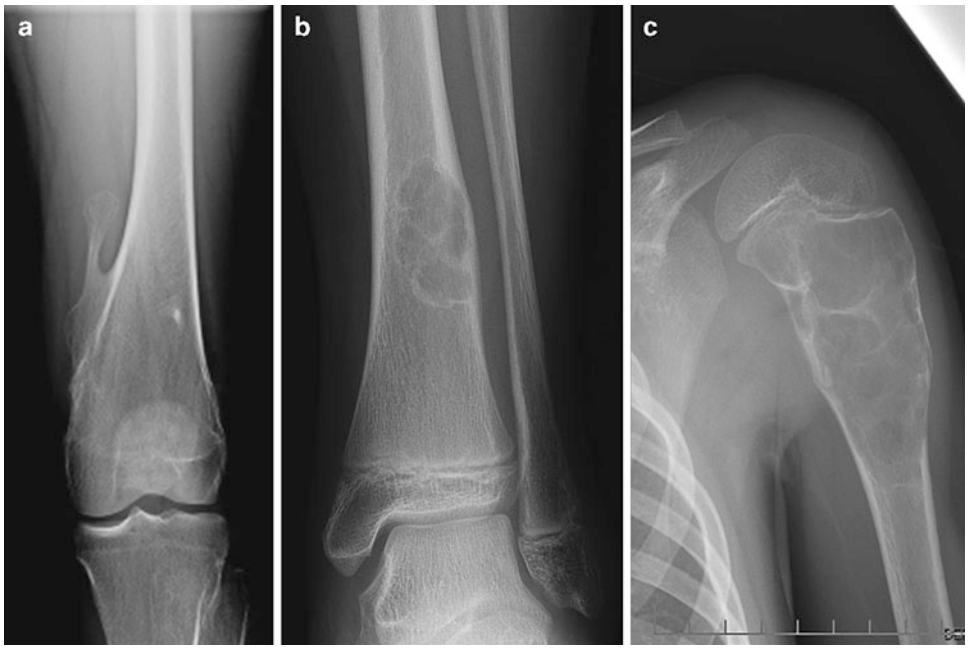

Fig. 105.4 Benign bone tumors. **a** Pedunculated osteochondroma medial distal femur. **b** Non-ossifying fibroma of the distal tibia. **c** Large unicameral bone cyst of the proximal humerus. Note the proximity of the lesion to the growth plate

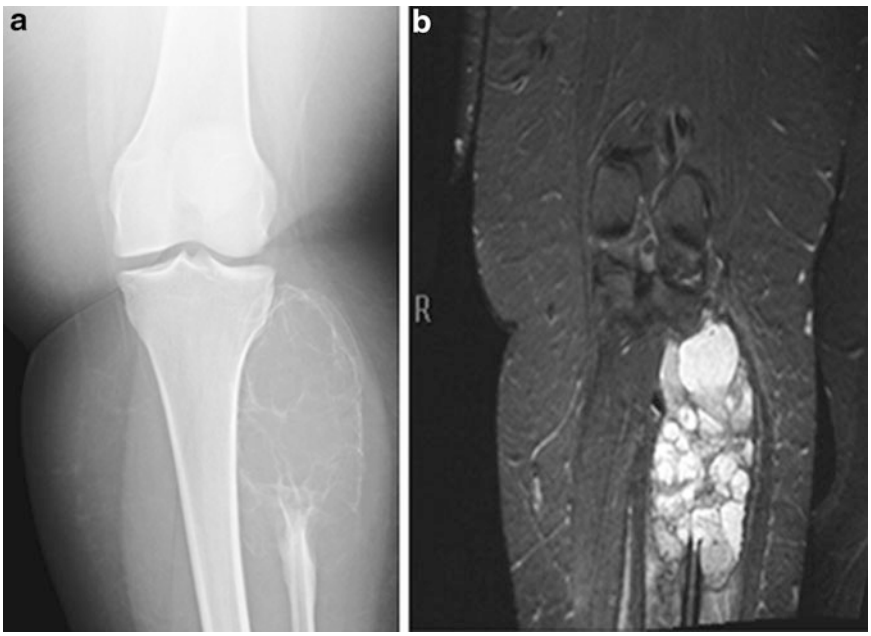

Fig. 105.5 Benign aggressive bone tumor. **a** AP radiograph of an aneurysmal bone cyst of the proximal fibula. Note the expansile bone cyst with multiple loculations. **b** MRI of the same bone lesion demonstrates a multiloculated cyst with fluid-fluid levels typically seen with aneurysmal bone cysts

cautery and bone grafting. When treating ABCs, in particular those that are large and aggressive, it is useful to remember that *telangiectatic osteosarcoma* is in the differential diagnosis and to communicate this to the pathologist. The specific surgical treatment of some benign bone tumors depends on the lesion and location: patients with osteoid osteomas whose symptoms are not controlled by NSAIDs can be treated with radiofrequency ablation or surgical excision if the lesion is located in an area where radiation is not feasible.

Bone Sarcomas

The preoperative workup for suspected bone sarcomas includes a staging workup and a biopsy. Anterior-posterior and lateral radiographs are often diagnostic, at least in establishing the presence of a malignant process, but further studies are almost always needed. An MRI shows the extent of bone involvement and soft tissue extension and is very useful in planning the approach for biopsy or excision

(Fig. 105.3). The relationship of the tumor to neurovascular structures also helps determine the feasibility of a limb-sparing approach. A bone scan is performed to look for skip lesions, multifocal disease, and metastases. Depending on the most likely diagnosis, a CT scan of the lungs is sometimes indicated to rule out the presence of lung metastases.

To make a definitive diagnosis and guide treatment, it is necessary to perform a tissue biopsy for a suspected sarcoma. The biopsy should preferably be performed by a surgeon with experience in dealing with bone tumors and who will be able to follow the patient through to the definitive stages of therapy. As the biopsy tract is always eventually excised at the time of definitive surgery, it is important to plan the incision such that it can be part of a future limb-sparing incision. In cases where the biopsy must be performed by someone other than the tumor surgeon, it is a good idea to consult with that surgeon to assure that the biopsy incision is in the same location as the incision of the final procedure. Biopsy incisions should be parallel to the long axis of the limb or body part, except some of those that are made around the pelvis or shoulder girdle (Fig. 105.6). The biopsy tract should dissect through one muscle plane and should avoid contamination of neurovascular structures or multiple compartments. This allows better preservation of tissues during the final procedure and is a prerequisite for allowing a limb-sparing operation. Careful hemostasis and meticulous closure are important. If a patient has an aggressive bone lesion, it is important to support the extremity to avoid a pathologic fracture. A pathologic fracture would risk contamination of adjacent structures by hematoma, which may eliminate the possibility of limb salvage or increase the risk of local recurrence.

An intraoperative incisional biopsy with hand-carried frozen section ensures that adequate tissue is obtained to make a diagnosis and has an accuracy of more than 90 %. Personally carrying the specimen to the pathologist and conveying the clinical information leading up to the differential diagnosis eliminate errors and miscommunication. Working with an experienced musculoskeletal pathologist is key to obtaining a correct diagnosis. Based on the results of the frozen section analysis, central venous access and bone marrow biopsy are often done during the same general anesthetic (Fig. 105.7). Ultimately, cytogenetic tests that identify characteristic marker proteins and translocations for certain sarcomas aid greatly in establishing an accurate diagnosis (Table 105.4).

Most patients with a bone or soft tissue sarcoma receive neoadjuvant chemotherapy prior to final resection. Though the response to chemotherapy varies, it usually shrinks the tumor, which in most cases allows for a more limited resection and preservation of limb function. It also targets the microscopic disease that is thought to be present in most patients and predisposes to metastases and local recurrence. Chemotherapy-induced tumor necrosis in the specimen of more than 90 % portends a better prognosis. After chemotherapy, preoperative planning must include new radiographs and another MRI.

Prior to the routine use of chemotherapy in the 1970s, survival rates for patients with osteogenic sarcoma were around 20 %, and the majority of patients were treated with amputation. With neoadjuvant chemotherapy, survival rates in the pediatric population today approach 70 %, limb-sparing surgery can safely be done in 80 % of cases, and local recurrence rates are down to 5 to 7 %.

Surgical Technique

The most important goal of definitive surgery for a bone sarcoma is wide resection of the tumor with negative margins. The art and science of the surgery includes the ability to obtain safe local control while preserving function whenever feasible. A wide resection of the tumor entails removing the tumor with the pseudocapsule, reactive tissue (satellite lesions) and a margin of normal tissue. What constitutes a "negative margin" depends on the tissue involved: for muscle and cancellous bone, 2 to 3 cm is considered adequate, while a single fascial layer or a physis is likely a sufficient barrier to tumor progression in most cases. The local recurrence rate after wide resection is 2 to 4 %. Intralesional excision (going into the pseudocapsule and tumor) and marginal excision (through the reactive zone with potential satellite lesions) can and probably do leave tumor cells behind and are therefore not appropriate when removing skeletal sarcomas.

The extent of resection is planned on the basis of the preoperative MRI. The entire tumor is excised, taking great care during the dissection to never violate the margin of the tumor or contaminate the field (Fig. 105.7). After resection, an intraoperative frozen section is done from the resected tumor bed to evaluate for adequate margins. The final answer regarding margins, ultimate diagnosis, and the extent of tumor necrosis will not be available for several days due to specimen processing.

Reconstruction after resection can be done with allograft, metallic prosthesis, allograft-prosthesis composite, magnetic expansile endoprostheses, or free vascularized fibula grafts (Fig. 105.8). If possible, attempts to save the physis will allow for future growth of the limb. When the physis cannot be saved in a child with the potential for further growth, the use of a modular or extendable prosthesis should be considered. These children often undergo multiple procedures over several years to allow lengthening of the reconstructed limb. The risk of complications for these procedures is high and much time is invested in the limb. In the very young child, amputation is sometimes preferable. It entails a single operation and

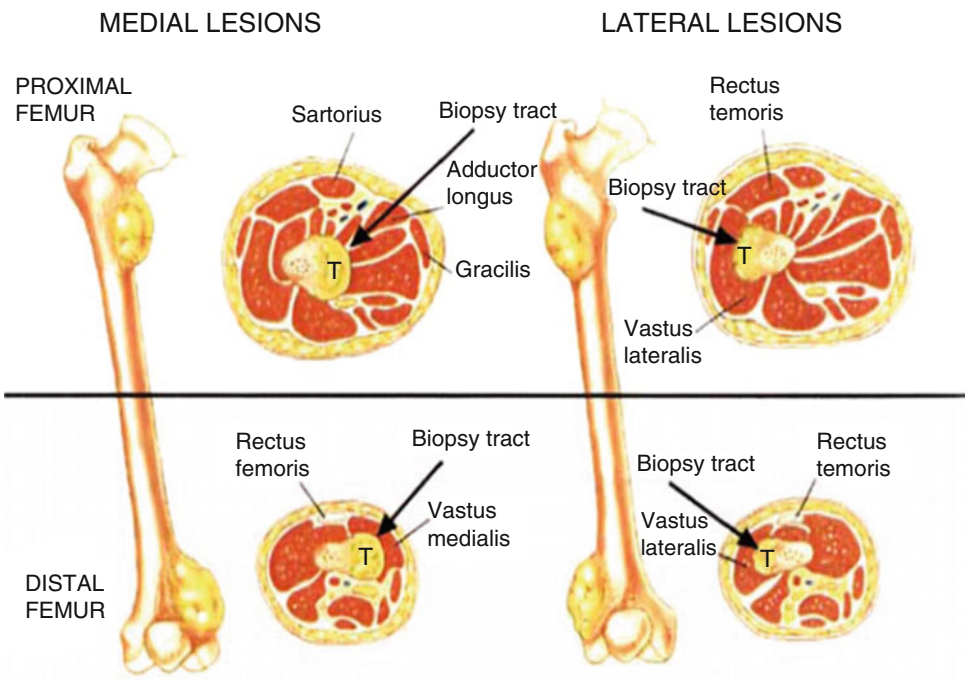

Fig. 105.6 Biopsy tract and proximal and distal femur. A distinction is made between lateral and medial lesions (adapted with permission from Bickels et al. Biopsy of Musculoskeletal Tumors, Clin Orthop 368, 212–219, 1999)

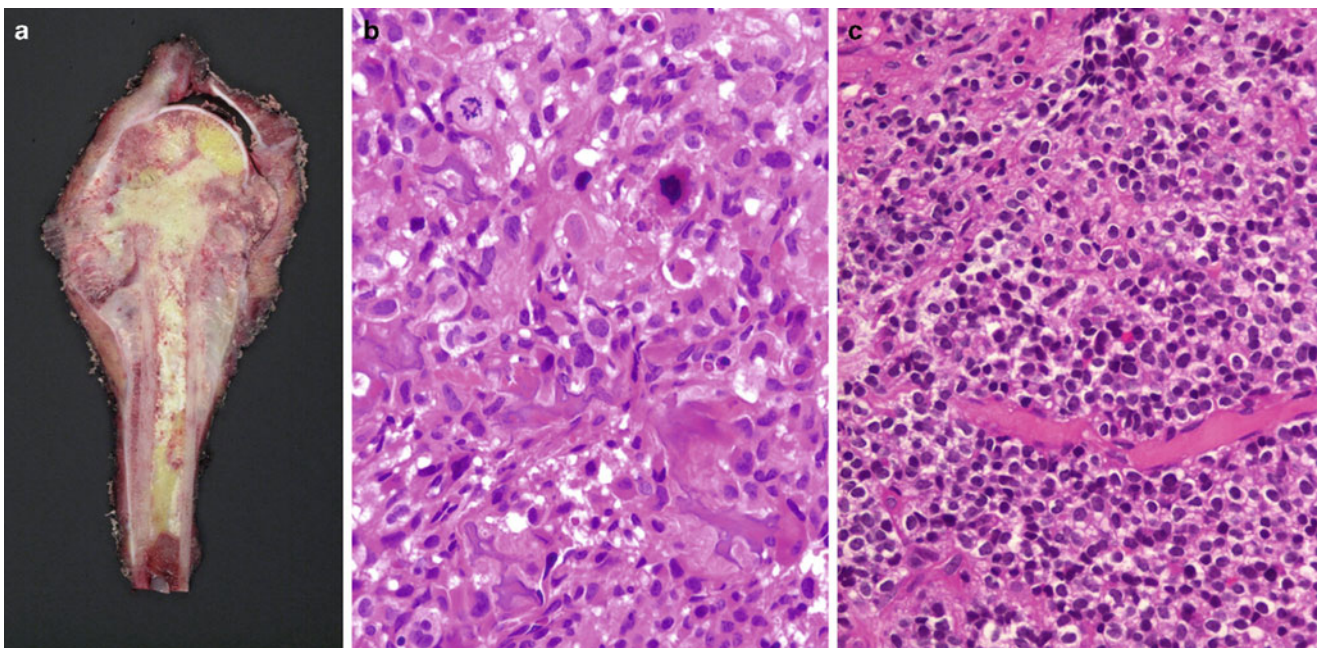

Fig. 105.7 **(a)** Gross anatomy of a resected osteosarcoma proximal humerus. Pathology evaluation demonstrated 50 % viable tumor after neoadjuvant chemotherapy. **(b)** Histopathology of osteogenic sarcoma demonstrating pleomorphic spindle cells and osteoid production. **(c)** Ewing sarcoma histopathology demonstrating sheets of monomorphic blue cells

avoids the multiple return trips to the operating room, as well as the interruptions in life, potential complications, and periods of rehabilitation associated with each procedure.

In select patients a rotationplasty can be performed (Fig. 105.9). This surgical procedure involves resecting the tumor en bloc and rotating the distal tibia and foot 180° prior to reattaching to the proximal femur. This provides a more functional limb than an above-the-knee amputation and is indicated for active patients who can accept the unusual cosmetic appearance of the rotationoplasty. Quality-of-life studies have not been able to show a significant quantitative difference between patients who undergo limb-sparing surgery or amputation, although it is likely that there are qualitative differences that have yet to be fully defined.

Table 105.4 Chromosomal translocations and associated fusion genes that are characteristics of specific sarcomas. These aid in the identification of tumors and will likely be the way all tumors are identified in the future

Chromosomal translocation	Fusion gene	Tumor
t(x;17)(q22;q13)	TFE3, ASPL	Alveolar soft part sarcoma
t(2;12)(q35;q14)	PAX3-FKHR	Rhabdomyosarcoma (alveolar)
t(x;18)(p11;q11)	SYT-SSX1 or SSX2	Synovial sarcoma
t(11;22)(q24;q12)	EWS-FLI1	Ewing sarcoma
t(17;22)(q22;q13)	COL1A1-PDGFB1	Dermatofibrosarcoma protuberans
t(12;22)(q13;q12)	ATF1-EWS	Clear cell sarcoma
t(11;22)	EWS-WT1	Desmoplastic small round cell sarcoma
t(12;16)	CHOP-TLS	Myxoid liposarcoma

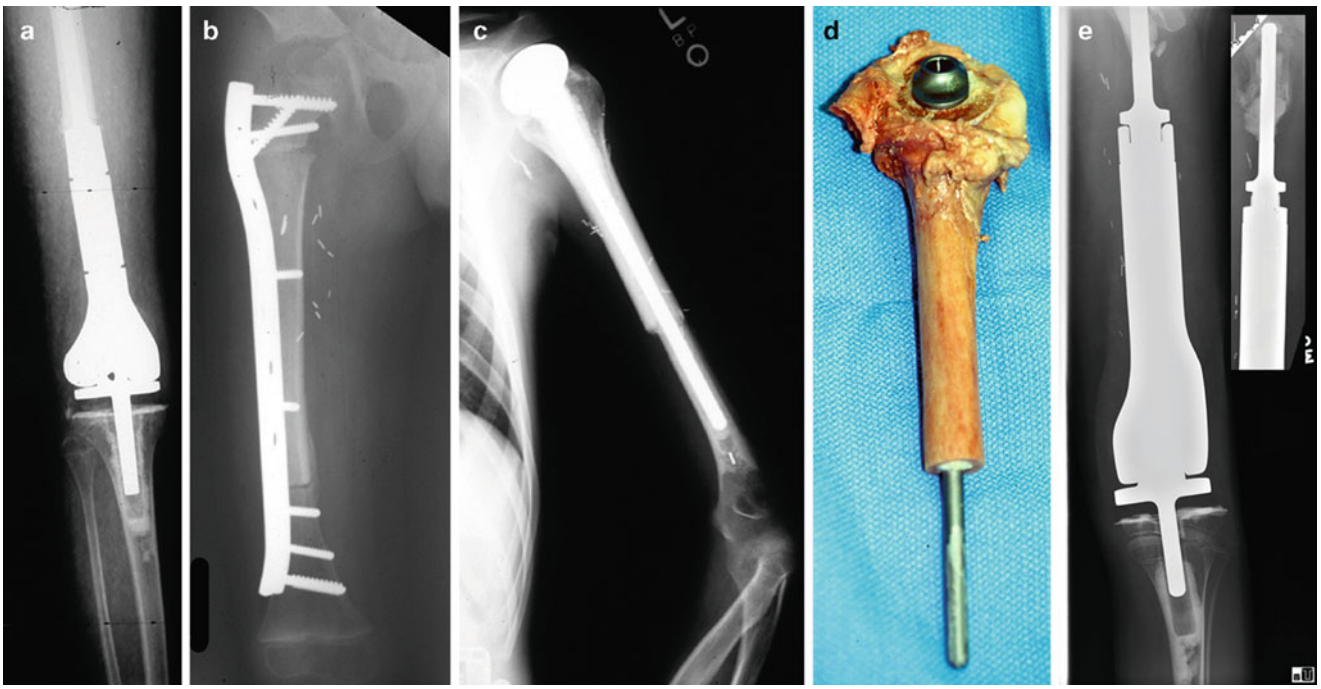

Fig. 105.8 Limb-sparing reconstructive options. **(a)** An endoprosthetic reconstruction. **(b)** An allograft intercalary reconstruction after resection of a diaphyseal Ewing sarcoma. **(c, d)** An allograft prosthetic composite (APC) reconstruction for a proximal humerus osteosarcoma enables improved soft tissue reconstruction. **(e)** An expandable growing endoprosthesis, with the inserted picture showing lengthening mechanism, can be used for skeletally immature patients with substantial growth left

Postoperative Care

Postoperative questions generally surround immobilization/weight-bearing status, antibiotics, and pain control. Postoperatively, the involved extremity can be expected to swell. It is therefore imperative that non-circumferential occlusive dressings be used to minimize the risk of compartment syndrome in the immediate postoperative period. In addition, the extremity should be supported through braces or splints until muscular control can be regained or bone healing occurs to prevent further injury. Prophylactic antibiotics are usually continued until drains are removed. Physical therapy, with attention to range of motion, is started early in the postoperative period. As the dissections required for tumor excision are sometimes extensive, it is recommended to use a multi-team approach with anesthesia, nursing, and physical and occupational therapy to maximize patient comfort in the postoperative period. If the procedure is amenable to regional blocks, these should be used; otherwise, patient-controlled analgesia is the preferred method of pain control postoperatively. Chemotherapy can usually be restarted after about 7–10 days as long as the wound is healing and it is medically deemed appropriate.

Careful monitoring for early postoperative complications such as infection and wound dehiscence is important, as these are somewhat more common due to exposure to chemotherapy and poor nutritional status. Postoperative joint contractures are also a concern, although early aggressive rehabilitation helps maintain range of motion. Long-term complications are not uncommon and depend on the type of surgery performed. They include endoprosthetic loosening, hardware failure, adjacent joint wear, allograft nonunion,

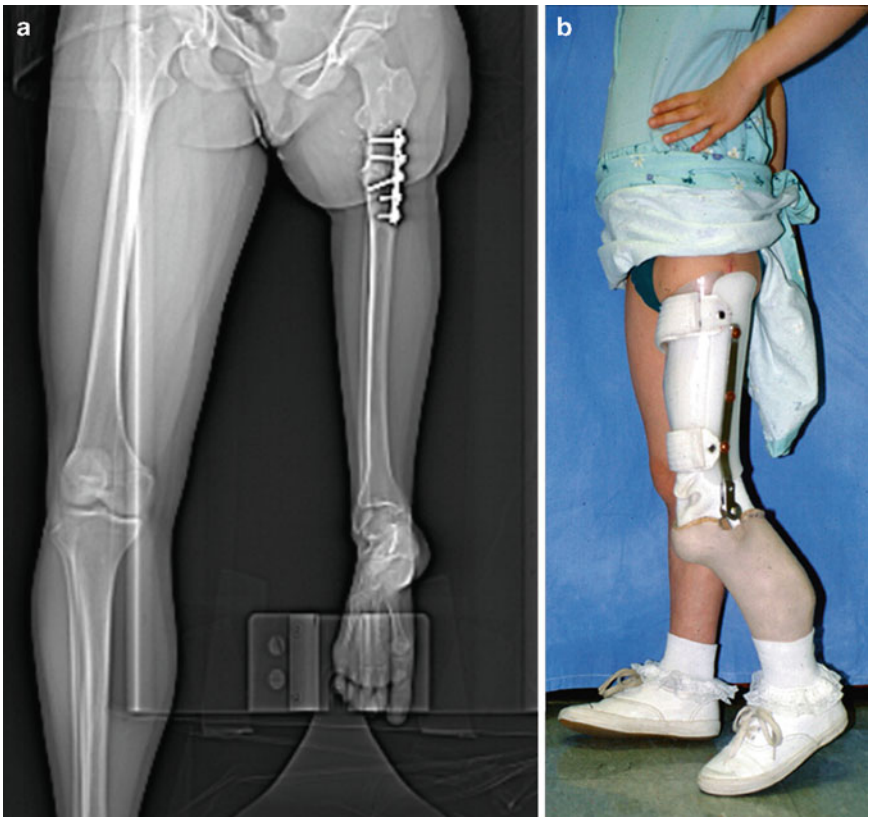

Fig. 105.9 Rotationplasty: **(a)** Scout view from a CT scan showing the rotationoplasty reconstruction on the left. After resection of the tumor of the distal femur, the distal tibia is rotated 180° and attached to the proximal femur. **(b)** Clinical picture of a patient having undergone a rotationplasty. Note how the ankle now essentially works as a knee within the prosthesis

allograft resorption, and late infection. The incidence of long-term complications depends on the initial tumor location, the type of reconstruction performed, and the patient's activity level. Children treated with amputation are at risk for terminal limb bone overgrowth.

Soft Tissue Sarcomas

Any deep (subfascial) mass larger than 5 cm is considered a sarcoma until proven otherwise. The preoperative workup for suspected soft tissue sarcomas is similar to that of bone sarcomas and includes an MRI, bone scan, chest CT, and incisional biopsy. Soft tissue sarcomas are usually treated with wide surgical resection. After resection of the primary tumor, plastic surgery expertise is sometimes needed for local reconstruction and wound closure.

Chemotherapy is more effective for certain soft tissue tumors, such as *rhabdomyosarcoma* or *infantile fibrosarcoma*. Although the specific indications for chemotherapy are complex and controversial, it is more likely to be offered to patients with chemosensitive tumors that are likely to recur and when there is metastatic disease. It is usually not indicated for sarcomas smaller than 5 cm and for superficial tumors that can be completely resected and are associated with a low risk of recurrence.

Some soft tissue tumors have a tendency to metastasize to lymph nodes, which makes a huge difference in the treatment strategy, especially with regard to chemotherapy. After careful physical examination, biopsy of clinically suspicious local and regional lymph nodes is indicated. For certain specific tumors (*rhabdomyosarcoma*, *synovial cell sarcoma*), sentinel lymph node biopsy should be used for staging purposes. Radiotherapy is occasionally indicated for local control of the primary tumor, particularly in cases where clear margins are not obtainable.

Unplanned Resections

What do you do if you find an unexpected malignancy when excising what you thought was a benign lesion? It is probably best to avoid this situation by obtaining an MRI prior to going to the operating room and to obtain intraoperative frozen sections on any suspicious tissues encountered during a procedure. The information provided by MRI is easier to interpret in the absence of postoperative change and scarring and generally accurate in differentiating benign from malignant soft tissue tumors.

Nevertheless, if for some reason you find yourself in this predicament, the most important thing is to recognize that the lesion is not a benign lesion and to *change* the operative plan. For any suspicious lesion, it is best to use a longitudinal

incision, in case it turns out to be malignant. Start with obtaining a frozen section prior to attempting excision. If an immediate diagnosis is not available, convert the surgery from an excision to an incisional biopsy. Obtain tissue for diagnosis, achieve hemostasis, and perform a water-tight closure over a drain placed in line with the longitudinal incision. Complete the indicated radiographic workup (MRI, bone scan, chest CT) while waiting for the final pathology results. About 60 % of patients who undergo an unplanned sarcoma excision will have residual tumor present. This is why a second procedure to re-excise the tumor bed is recommended in cases where a presumed benign lesion turns out to be a sarcoma after final pathology.

Summary

The field of musculoskeletal oncology comprises a complex group of pathologic processes. The specific treatment depends on the type of bone lesion, the location, and patient's symptoms. For optimal care, these rare cases should be cared for at a musculoskeletal center adequately equipped in dealing with the pediatric tumor patient. At the very least, a verbal consultation prior to proceeding with an incisional biopsy can help avoid a situation in which the ultimate treatment plan is compromised by mistakes in early diagnostic care. Increasing general awareness of the basic principles of surgical musculoskeletal oncology will help provide the best care for this patient group.

Editor's Comment

Most children and their parents with a soft tissue mass or bone tumor associate it with trauma. Whether local trauma can cause a musculoskeletal tumor to form seems unlikely, but it is useful to recall that "every child falls every day." What is important is that we do not assume a mass or bony lump is just a bruise or simply related to an injury. Any large hematoma, especially one elicited by seemingly minor trauma, could be due to rupture of a soft tissue sarcoma. A follow-up US or MRI should be performed within 2 to 3 weeks to be sure that it is resolving as expected for a simple hematoma. Likewise, a fracture that occurs with minor trauma should be considered a pathologic fracture until proven otherwise. It is still surprisingly common for a child with a sarcoma to have the diagnosis confirmed many weeks or months after initial presentation with a lump that was attributed to an injury. One should have a low threshold to obtain a radiograph for a bony lesion or US for a soft tissue mass and always insist on a follow-up visit within 2 to 4 weeks.

A small soft tissue sarcoma can often appear quite innocuous. Except for some obviously benign masses (lipoma, epidermal inclusion cyst), most soft tissue masses should be evaluated by US or MRI prior to attempting a resection or biopsy, especially if they are larger than a few centimeters in diameter. Though an operation is not necessarily the wrong thing to do, the manner in which it is performed can make all the difference to a child whose mass later turns out to be malignant. This includes longitudinal incisions on the extremities; limiting the dissection to single muscle compartment; avoiding unnecessary dissection in adjacent planes; maintaining meticulous hemostasis to avoid a postoperative hematoma, which can increase the spread of the tumor; and staying clear of neurovascular structures. One must always think ahead to the next operation that might need to be performed. When re-excising a mass that has been previously operated on, it is important to excise all tissue that has been touched by the other surgeon en bloc with a margin of normal tissue and without violating the previous planes of dissection or entering the seroma or hematoma that might still be present. These resections can lead to formidable residual wounds that require the assistance of a plastic surgeon.

Sentinel lymph node biopsy is requested for certain musculoskeletal tumors. The technique is straightforward and is fairly well standardized. Whether a formal lymph node dissection should be performed in the event of a positive sentinel node is more controversial and should be based on the specific histology of the tumor and the clinical situation.

Osteogenic sarcoma is one of the few neoplasms for which surgical resection of metastatic lung lesions can improve survival. Patients with fewer than about ten lung nodules on chest CT should be considered for an attempt to resect of all palpable nodules. This can be done through staged bilateral thoracotomies or median sternotomy. Thoracoscopy does not allow one to be thorough since tactile assessment of the lungs is not possible. Thoracotomy is standard, and some feel that sternotomy fails to allow adequate access to all portions of the lung, especially the left lower lobe. Additional benefits of sternotomy include less postoperative pain, the need for only one operation, and more rapid physical rehabilitation. The principal shortcoming is the scar, which is often hypertrophied and unsightly. Regardless of the approach, each lung needs to be excluded from ventilation while it is being inspected in order to increase the sensitivity of the examination. It is unlikely to be of any benefit to remove more than ten nodules, but the exact upper limit is not known.

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Part XIII

Skin and Soft Tissues

Benign Skin Lesions

106

Michael D. Rollins II and Sheryll L. Vanderhooft

Virtually every child has a number of benign growths on the skin. Parents of children who ask their pediatrician to look at a growth are usually concerned that the lesion may be cancerous or precancerous. Many papules and nodules that arise in children have characteristic clinical features that allow a diagnosis to be made without the aid of histological or radiographic evaluation. However, some lesions are nonspecific in appearance and therefore require a biopsy to make a diagnosis. In some situations, obtaining an imaging study is desirable before a biopsy is performed. This is especially true for lesions along the midline of the face, scalp, or back, as they will sometimes have connections to the brain or spinal cord and care must be taken to avoid biopsy of any midline lesion until such a communication is ruled out, usually by CT or MRI.

More than 75 % of soft tissue tumors that present between birth and 12 months of age are benign. There are several features of a cutaneous neoplasm that heighten the concern about malignancy. These include onset during the neonatal period, rapid or progressive growth, skin ulceration, fixation to or location deep to the fascia, and a firm mass greater than 3 cm in diameter. In the absence of any of these findings, there is a greater than 99 % chance that the lesion will prove to be benign.

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Cutaneous Lesions

Verrucae

Human papillomaviruses (HPV) infect epithelial tissues of the skin and mucous membranes and clinically manifest as warts (verrucae). Infection occurs by skin-to-skin contact, with maceration or sites of trauma predisposing patients to inoculation. The incubation period of these viruses ranges from 2 to 6 months. The virus induces epidermal proliferation, causing rough-surfaced papules and plaques, often with superficial thrombosed capillaries. The natural history of warts is a spontaneous resolution once a host immune response occurs. However, this can take several years. On average, 75 % of warts in children will spontaneously resolve within 3 years, even if no treatment is attempted.

In children old enough to comply with therapy, reasonable first-line therapies for common, plantar, and palmar warts include salicylic acid, liquid nitrogen cryotherapy, or cantharidin blistering. For patients with facial lesions, topical agents such as 5-FU, tretinoin, or imiquimod may be useful. Topical or intralesional immunotherapy for recalcitrant lesions might be effective with less scarring. This type of treatment is often best accomplished with the help of an experienced dermatologist. When selecting a method of treatment, the extent and location of the lesions, age of the child, and willingness of the child to participate in treatment should be considered. The least painful methods should be used initially, reserving more destructive therapies for recalcitrant lesions and lesions for which cosmesis is less important.

Calcinosis Cutis

Cutaneous calcification arises secondary to trauma or in association with metabolic diseases (parathyroid neoplasms, hypervitaminosis D, renal disease) and connective tissue diseases (CREST syndrome, dermatomyositis). It may be a focal

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process or more widespread. Calcinosis cutis presents as hard nodules with chalky material within them. The clinical differential diagnosis includes osteoma cutis and the treatment of choice is usually surgical removal.

Keloids

Keloids are benign fibrous growths present in scar tissue that form due to an exaggerated connective tissue response to dermal injury. Keloids differ from hypertrophic scars in that they extend beyond the margin of the original scar. These lesions may be asymptomatic or frequently they are pruritic, tender or cause sharp, shooting pains. Keloids do not spontaneously resolve and may continue to enlarge.

Management consists of potent topical steroidmassage, intralesional steroid injections, or topical silicone gel. Intralesional corticosteroids are first-line therapy for keloids with up to 70 % of patients responding, although recurrence rates are high. Triamcinolone (5–40 mg/mL) is injected into the bulk of the keloid using just enough to make the keloid blanch. Injections may be repeated at monthly intervals using increasing concentrations of triamcinolone. Do not exceed 40 mg of the drug per visit due to the risk of atrophy and hypopigmentation. Surgical revision of a keloid may be considered, but recurrence is common.

Pyogenic Granuloma

Pyogenic granulomas are solitary polypoid lesions that often occur after a history of trauma or local irritation. They are associated with capillary proliferation and are commonly found on the skin as red, raised, and occasionally bleeding lesions (Fig. 106.1). They are sometimes associated with profuse and difficult to control bleeding. The lesion typically develops over a few days to weeks, and treatment may be indicated for cosmesis or if the lesion bleeds easily with minor trauma. Treatment strategies include topical silver nitrate, liquid nitrogen, or ligature of the polyp neck. Most commonly these are shaved off and the base cauterized. Rarely is more extensive surgical excision required.

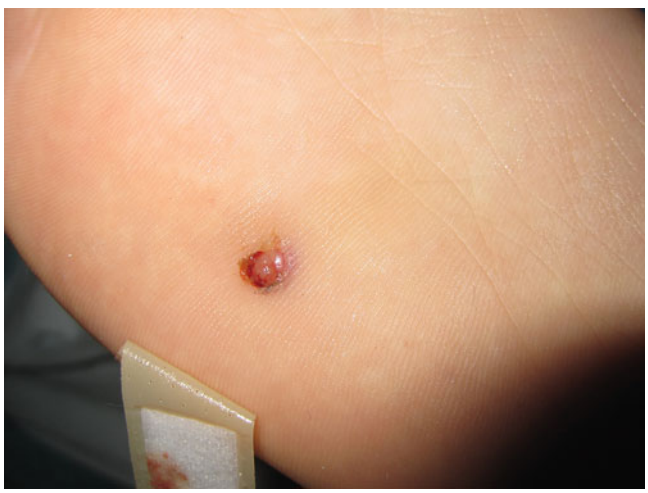

Fig. 106.1 Pyogenic granuloma overlying the heel

Dermatofibroma

Dermatofibromas are benign neoplasms of dermal connective tissue that vary tremendously in appearance. Some dermatofibromas present as small, firm, reddish-brown, sclerotic papules, less than 1 cm in size, that exhibit dimpling of the overlying skin when they are squeezed (Fig. 106.2). Others present as dome-shaped pink, red, or reddish-brown tumors. Dermatofibromas are freely movable over the subcutaneous fat. They may grow slowly and then remain stable for years. They are found most commonly on the anterior surface of the lower extremities. No treatment is required unless the lesion is symptomatic, has recently changed in size or color, or is bleeding. If the lesion protrudes above the skin surface and exposed to repetitive trauma, excision could be considered. Progressively enlarging lesions should be excised due to the rare development of dermatofibrosarcoma protuberans.

Neurofibroma

Neurofibromas are benign neoplasms of nerve tissue that may appear as solitary lesions in otherwise healthy individuals or as multiple lesions in association with neurofibromatosis. They appear initially in early childhood or adolescence as firm, polypoid, irregular nodules which gradually increase in size. In patients with neurofibromatosis, lesions may increase in number. Neurofibromas occur anywhere on the cutaneous surface, but palms and soles tend to be spared. When moderate digital pressure is applied to the surface of a small neurofibroma, it may invaginate into the dermis, which is referred to as "buttonholing." Although most neurofibromas are intradermal lesions, large plexiform lesions may occur in the subcutaneous layer.

Surgical excision is performed on tumors that are disfiguring, interfere with function, or are subject to irritation, trauma, or infection. It is important to evaluate any patient with a neurofibroma for the characteristic skin findings of neurofibromatosis type 1, which includes the presence of six or more café-au-lait macules, two or more neurofibromas of any type or one plexiform neurofibroma, and freckling in the axillary or inguinal regions. If these classic skin lesions are identified, the patient should be referred to a medical geneticist.

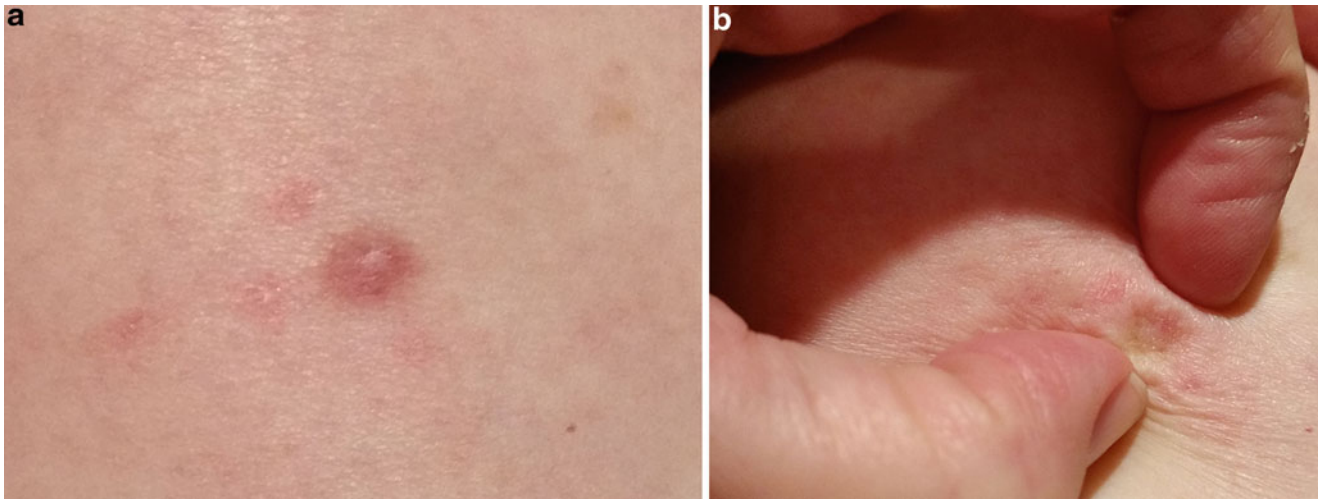

Fig. 106.2 (**a**) Small, firm, reddish-brown, sclerotic papule characteristic of a dermatofibroma. (b) The "dimple sign" seen when compressing a dermatofibroma

Subcutaneous Lesions

Lipoma

Lipomas and lipoblastomas arise from subcutaneous fat. They are soft, mobile, and nontender subcutaneous nodules with a lobular and somewhat rubbery texture. They can be difficult to differentiate from deep hemangiomas or lymphangiomas. They arise anywhere on the body, but most commonly, they are found on the neck, shoulders, back, and abdomen. Lipomas are benign and generally asymptomatic and can be left untreated unless they become uncomfortable, are growing, or are cosmetically unacceptable. Radiographic imaging should be considered for lesions located in the deeper soft tissue of the extremities, the neck, or the paraspinous region.

Complete surgical excision is typically curative. It is usually possible to differentiate lipomas from the surrounding fat intraoperatively because they have a firmer consistency. Lipoblastoma should be considered in the differential diagnosis of a rapidly enlarging subcutaneous mass in children less than 3 years of age. Although lipoblastoma is a benign lesion, it recurs up to 25 % of the time and long-term follow-up is recommended.

Granuloma Annulare

Although granuloma annulare is an idiopathic inflammatory process involving the dermal collagen and not a neoplasm, the firmness of the lesions often raises the concern about malignancy. The cutaneous type presents most commonly in children and young adults as localized firm aggregates of flesh-colored or reddish-brown papules that coalesce into annular plaques, often with central clearing (Fig. 106.3).

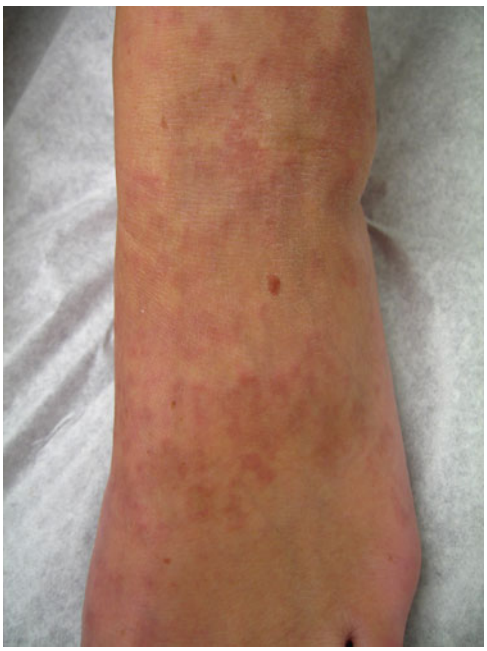

Fig. 106.3 Granuloma annulare affecting the dorsal surface of the foot and ankle

There is a subcutaneous variant that presents in healthy young children as a firm, painless, nonmobile, lobular mass usually on the lower extremity, which often raises the concern about malignancy.

Spontaneous resolution occurs within several years in the majority of patients. Reassurance, therefore, is an important aspect of management and expectant observation is a reasonable approach. Symptomatic lesions may be treated with topical or intralesional steroids with varying success. Occasionally, an incisional biopsy is required to confirm the diagnosis in the subcutaneous type although clinical presentation along with MRI findings may be sufficient to support observation.

Infantile Myofibroma

Infantile myofibromatosis is a neoplasm derived from myofibroblasts and is the most common fibrous tumor of infancy. The tumors are rubbery, firm, rounded dermal and subcutaneous nodules that may be present at birth or appear in early infancy. They may be reddish-brown or purple and range from 1 to 7 cm in diameter (Fig. 106.4). The condition occurs in two forms, solitary (more common) and multicentric. The solitary form more commonly affects the trunk, head, and neck. It is more common in males and is characterized by one tumor involving the skin or soft tissue that regresses spontaneously within 1–2 years with less than 10 % recurrence. The multicentric form is more common in females and is characterized by several tumors involving the skin, soft tissue, viscera, or bone. It also follows a benign course in most circumstances with spontaneous resolution in a few years. However, the condition may be fatal in infants with extensive visceral involvement, especially the lung. Biopsy of the cutaneous tumors is essential to exclude soft tissue sarcoma, fibrosarcoma, and rhabdomyosarcoma. Although these tumors have a high rate of spontaneous regression, visceral myofibromas that affect the function should be surgically excised. Recurrence is unusual but should be managed by re-excision. All children with myofibromas should be evaluated for bone and visceral involvement with imaging studies.

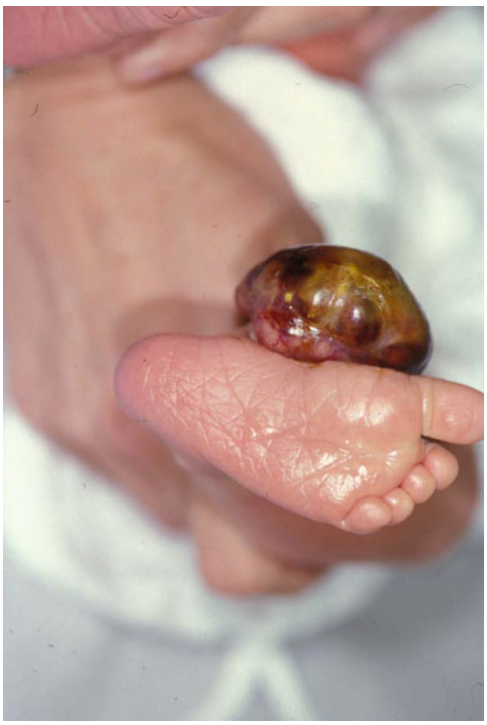

Fig. 106.4 Infantile myofibroma in a newborn

Cysts

Epidermoid Cyst

Epidermoid cysts, also called epidermal inclusion cysts, are the most common type of cutaneous cysts. They arise from occluded pilosebaceous units or from traumatic implantation of epidermal cells into the dermis. They are often erroneously referred to as "sebaceous cysts." The cyst wall consists of normal epidermis that produces keratin, and they grow slowly as keratin accumulates within them. They present as elevated, round, flesh-colored, or somewhat yellow papules or nodules, often with a discernible overlying punctum, and are freely movable. When they rupture, the keratin that is released has a cheesy consistency and a sour odor. Although epidermoid cysts typically appear after puberty, they are not unusual in young children. They arise most commonly on the face, scalp, neck, back, and scrotum. Another relatively common location in toddlers is within the umbilical scar.

Removal of the entire epidermal lining of the cyst is necessary to prevent recurrence. If the cyst ruptures when it is being removed, care must be taken to irrigate all of the keratin out of the wound to prevent the formation of a foreign body granuloma. Epidermoid cysts can become infected, which makes excision more difficult and the final cosmetic result less acceptable. It is best to treat these with antibiotics with or without drainage and delayed excision until all signs of the acute infection have resolved.

Dermoid Cyst

Dermoid cysts arise primarily along lines of embryonic fusion. They are most commonly located along the lateral third of the eyebrow, forehead, and scalp (Fig. 106.5). Another common location is the midline lower neck and sternal notch. Dermoids are usually round, soft, and fixed to deep tissue or underlying periosteum. They usually present as a painless mass 1–2 cm in diameter but can grow larger if left untreated. They contain keratin and some may also contain hair, bone, tooth, or nerve tissue. Dermoids in the head often cause a saucer-shaped indentation in the outer table of the skull, which may be apparent on skull radiograph. Cysts arising near the medial canthus of the eye, along the nose or along suture lines of the skull, can have an intracranial extension, and therefore radiographic imaging with CT or MRI is recommended before attempting surgical removal.

Definitive treatment is surgical excision. Incisions on the scalp should follow lines of tension. An incision just above or below (never in) and parallel to the eyebrow should be used for improved cosmesis in dermoids located at the lateral eyebrow.

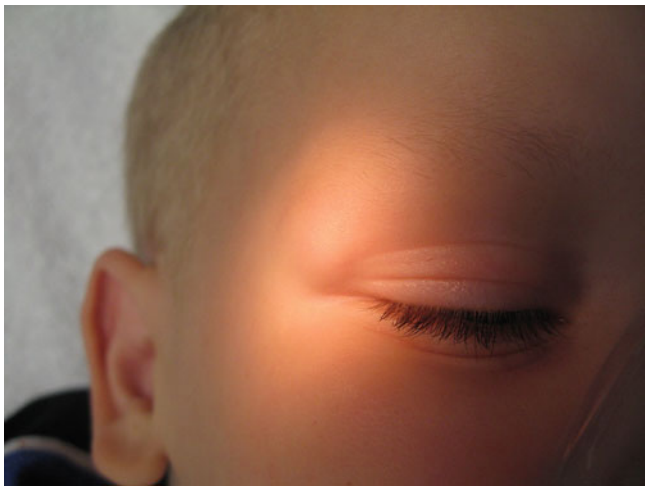

Fig. 106.5 Dermoid cyst located along the lateral third of the eyebrow

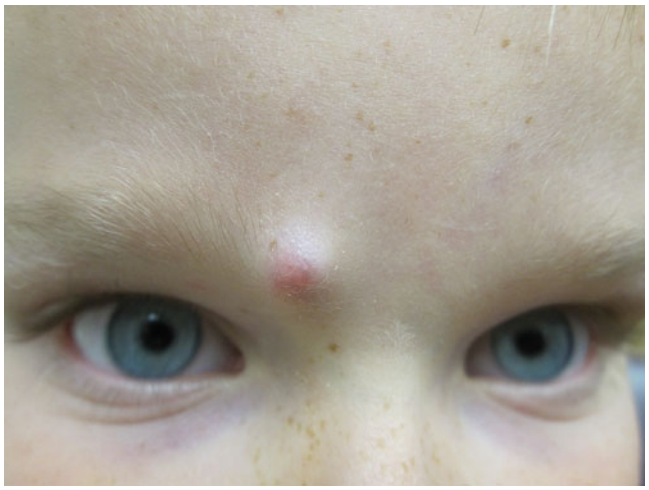

Fig. 106.6 In contrast to a dermoid cyst which is commonly located along the lateral eyebrow and is soft, a pilomatricoma has a rock-hard consistency and often discoloration of the overlying skin

Pilomatricoma

Pilomatricomas (calcifying epithelioma of Malherbe) are benign tumors of hair follicle origin. They present as slow-growing solitary papules or nodules with a rock-hard consistency in the subcutaneous fat just below the dermis (Fig. 106.6). The overlying skin may have a yellow, red, or blue hue. These nodules occur almost exclusively in children and young adults with more than half located on the head and neck. The tumors are usually asymptomatic but may become inflamed and tender. The clinical differential diagnosis includes epidermoid cyst, other cystic lesions, and calcinosis or osteoma cutis. Surgical excision is the treatment of choice for these tumors and should include the small area of overlying dermis. Recurrence rates are low.

Ingrown Toenail

Ingrown toenails most commonly affect the great toe and occur when the lateral nail plate pierces the lateral nail fold and enters the dermis. Predisposing factors include poorly fitting shoes, excessive trimming of the lateral nail plate, and trauma. Treatment of ingrown toenails depends on the severity of the lesion. Patients should be educated about proper nail trimming, which includes allowing the lateral nail plate to grow beyond the lateral nail fold and trimming the nail horizontally. Mild to moderate lesions may be treated by soaking the affected foot in warm water three times per day and pushing the lateral nail fold away from the nail plate. A small cotton wedge may be placed under the lateral nail plate to relieve pressure.

For more severe lesions in which there is significant pain, erythema, or pustular discharge, treatment involves removing the lateral portion of the nail. This may be accomplished using a digital nerve block or, more commonly, under general anesthesia. A straight hemostat or sharp scissor is inserted under the nail to separate it from the nail bed, and the lateral nail fold is excised. A curette should be used to remove granulation tissue. Following excision, dilute hydrogen peroxide should be used to clean the site 2–3 times daily followed by application of bacitracin ointment. The intraoperative application of electrocautery, 10 % NaOH, or other strong sclerosant to the adjacent germinal matrix to accomplish a chemical matrixectomy prior to curettage may reduce recurrence rates.

Foreign Bodies

Children are often referred for various nodular and cystic lesions that are usually removed in order to relieve parental anxiety and obtain a definitive diagnosis. One should keep in mind that lesions that are tender or show signs of inflammation may represent a local reaction to a foreign body. The history is frequently suggestive, but plain radiographs or ultrasonography should be performed for documentation and to help guide surgical intervention. Removal of soft tissue foreign bodies may occasionally be performed in the ED with sedation and local anesthesia but is usually best accomplished in the OR. Intraoperative fluoroscopy or US is helpful for localization and to ensure that all fragments have been removed. Depending on the nature of the wound, the skin may either be left open to granulate or loosely closed. Postoperative radiographic documentation of complete removal of the foreign body is imperative, as a retained foreign body cancause significant discomfort, recurrent infection, and the need for multiple procedures.

Lymph Nodes

Enlarged lymph nodes may cause great concern to parents and primary care providers. These are most commonly secondary to infectious or otherwise nonspecific processes although malignancy must be considered. The interview should help the surgeon distinguish infectious from noninfectious causes. Questions should focus on how long the node has been present, if there has been any change in size, and if it is causing any symptoms. Presence of constitutional symptoms including fevers, chills, night sweats, and weight loss (more than 10 % body weight) should be sought. In addition, orthopnea or the recent onset of dyspnea suggests a mediastinal component. Other pertinent aspects of the history are recent foreign travel and exposure to cats.

Certain characteristics on physical exam may suggest a benign versus a malignant process, although it is impossible to determine based on exam alone. Physical examination should focus not only on the involved lymph node but also on identification of a local infectious process near the enlarged lymph node, an examination of all major nodal basins, and an abdominal examination to evaluate for hepatosplenomegaly or an abdominal mass. Lymphadenopathy present in only one region suggests local causes. An obvious infection near the anatomically drained area may be present but often there is no clinical evidence of an inoculation site.

Generalized lymphadenopathy is the enlargement of more than two noncontiguous lymph node regions and is generally the result of systemic disease. A node that is smaller than 1 cm and asymptomatic may safely be observed. If the node is tender, has overlying skin changes, or is fluctuant, it is likely infectious, and a trial of antibiotics or drainage should be considered. Asymptomatic lymph nodes greater than 2 cm, symptomatic lymph nodes greater than 1 cm, and nodes that are getting progressively larger, are firm or fixed, or are located in the supraclavicular region are worrisome and should be biopsied or excised. Prior to excision, a CBC, erythrocyte sedimentation rate, chest x-ray, cat-scratch (Bartonella henselae) titers, Epstein–Barr virus titer, or monospot test should be obtained. In certain situations, a PPD or HIV test may be indicated.

When excision of a lymph node is required, one must be careful not to injure adjacent structures, especially peripheral nerves. The incision should be made along the lines of tension in the skin. Mobilization of the lymph node should be almost exclusively by blunt dissection in a plane immediately adjacent to the capsule of the node and the vascular pedicle cauterized or ligated only when clearly visualized and separated from adjacent structures. If the lymph node is part of a matted group of nodes, then an incisional biopsy large enough for diagnosis is all that is required. If there is a suspicion for lymphoma, the specimen should be sent fresh to pathology. Cultures should be performed if an infectious process is suspected.

Cervical Lymphadenitis

Cervical lymphadenitis is common in childhood and is usually caused by a viral upper respiratory illness. Cervical lymphadenitis caused by viral or bacterial infection may be acute or subacute and may present with unilateral or bilateral involvement. Lymph node enlargement caused by a viral upper respiratory illness is typically small, rubbery, mobile, and discrete without erythema. They may be minimally tender. Although the clinical course is self-limited, the enlarged lymph nodes may persist for several weeks.

Children occasionally have enlarged nodes that do not appear to be acutely infected. The nodes may be less erythematous or have no erythema and are less tender than those in acute bacterial adenitis. In the absence of a history or physical exam that suggests a malignant process, the child should be evaluated for tuberculosis, atypical mycobacterial infection, and cat-scratch disease. Most children should receive a 2-week course of an oral antistaphylococcal antibiotic with repeat examinations by the same physician to assess response to therapy. An oral antibiotic effective against methicillin-resistant staphylococcus may be a reasonable choice depending on the prevalence of the organism in the hospital or region. A single dominant lymph node present for longer than 4–6 weeks, which has not responded to appropriate antibiotic therapy, should probably be completely excised, cultured, and submitted for histologic exam to rule out neoplasm.

Atypical mycobacteria are now the most common causative agents of mycobacterial lymphadenitis. These are characterized as acid-fast bacilli using light microscopy. Atypical (or nontuberculous) mycobacterial adenitis is generally considered a local infectious process in immunocompetent hosts. It is not contagious and the portal of entry in an otherwise healthy child is thought to be the oropharynx. The common clinical presentation is in a child between 1 and 5 years of age with focal, unilateral involvement of the jugulodigastric, preauricular, or submandibular nodal group. The involved nodal group is usually minimally tender, firm, and rubbery to palpation, is well circumscribed, and may be adherent to underlying structures. The involved lymph nodes may enlarge over weeks to months without prominent systemic symptoms. Skin testing with tuberculin PPD may yield an intermediate reaction due to cross-reactivity. The treatment of choice is complete surgical excision with primary wound closure. Some would advocate a prolonged course of clarithromycin in addition to surgical excision. If complete excision is not possible, curettage is the next best option although recurrence of the infection and the development of a chronic draining sinus are possible sequelae. There is some evidence that observation alone may be effective after the diagnosis is confirmed by fine needle aspiration, though resolution of the lymphadenitis may take up to 12 months.

Cat-scratch disease is a common cause of lymphadenitis in children. The causative organism is Bartonella henselae. Most cases can be directly related to contact with a cat, and the usual site of inoculation is a limb. The disease begins as a superficial infection or pustule forming in 3–5 days and is followed by regional adenopathy in 1–2 weeks, although adenopathy may occur as long as 60 days following the event. Although the diagnosis can often be made by history alone, commercially available tests to detect antibodies against *B. henselae* or PCR will usually confirm the diagnosis. Although early systemic symptoms of fever, malaise, myalgia, and anorexia are common, the disease usually follows a benign, self-limiting course with resolution of lymphadenopathy in 6–8 weeks even without specific treatment. Excisional biopsy may be warranted if a draining sinus tract develops or if the diagnosis is uncertain.

Normal lymph nodes in most regions are usually less than 1 cm in their longest diameter. Exceptions are the epitrochlear region (less than 0.5 cm in diameter) and the inguinal region (less than 1.5 cm in diameter). Although concern for malignancy in unexplained peripheral lymphadenopathy is high, the actual prevalence of neoplasia in peripheral lymph node biopsies is generally fairly low. Supraclavicular lymphadenopathy, however, is associated with a higher rate of malignancy. Right-sided nodes are associated with cancer of the mediastinal lymph nodes, whereas left-sided nodes suggest intra-abdominal malignancy and lymphoma. Axillary lymphadenopathy is commonly the result of infections or trauma of the arm, thoracic wall, or breast. Inguinal lymphadenopathy in children is usually not associated with a specific etiology unless the nodes are very large (>3 cm). Palpable epitrochlear nodes are often pathologic in children. The differential diagnosis includes infections of the forearm or hand, leukemia, lymphoma, and atypical mycobacterial infections.

Vascular Lesions

Hemangioma

Infantile hemangiomas are the most common tumor of infancy, occurring in 10–12 % of infants. They are vascular tumors that grow by endothelial proliferation and generally occur within the first few weeks of life. They are classified as superficial (epidermal and dermal involvement), deep (subcutaneous), and mixed depending on the depth of soft tissue involvement. They are usually well-circumscribed lesions that may be flesh colored, bright red, or blue. Growth is characterized by two phases: a rapid proliferative phase (birth to 12 months) followed by a much slower involutive phase (2–10 years). Hemangiomas typically double in size during the first 2 months of life, with the average lesion achieving 80 % of its final size by 5 months.

Complications are associated with extensive size, involvement of vital structures, bleeding, ulceration, secondary infection, platelet trapping (Kasabach–Merritt syndrome), and associated abnormalities. The Kasabach–Merritt phenomenon occurs with the more invasive kaposiform hemangioendothelioma or tufted angioma. Worrisome lesions include lumbosacral lesions, large facial lesions, periocular lesions, lesions in the beard distribution on the face, and occasionally multiple lesions. Lumbosacral lesions can be associated with genitourinary anomalies and spinal dysraphism. Large facial hemangiomas can occur as part of the PHACES syndrome (posterior fossa malformations, hemangiomas, arterial anomaly, coarctation of the aorta and cardiac defects, eye abnormalities, and occasionally sternal defects). Eyelid and periocular hemangiomas represent ophthalmologic emergencies because of potential visual impairment from pressure on the globe or visual obstruction. Lesions that are prone to ulceration include those on the lip, axillae, neck, and buttock. Hemangiomas occurring in the beard distribution of the face (Fig. 106.7) can be associated with airway involvement with hemangioma. Multiple papular small hemangiomas can be seen in association with visceral hemangiomas involving the liver, gastrointestinal tract, lungs, brain, and other organs. High-output cardiac failure can develop with large liver hemangiomas. Lesions that pose significant cosmetic concerns, such as those involving the lip, nasal tip, and ear, may require early medical intervention in an attempt to halt growth and prevent permanent deformation.

Most hemangiomas can simply be observed. Regression is complete in half of children by age 5, in 70 % of children by age 7, and in the remainder by age 10. In the involuted phase,

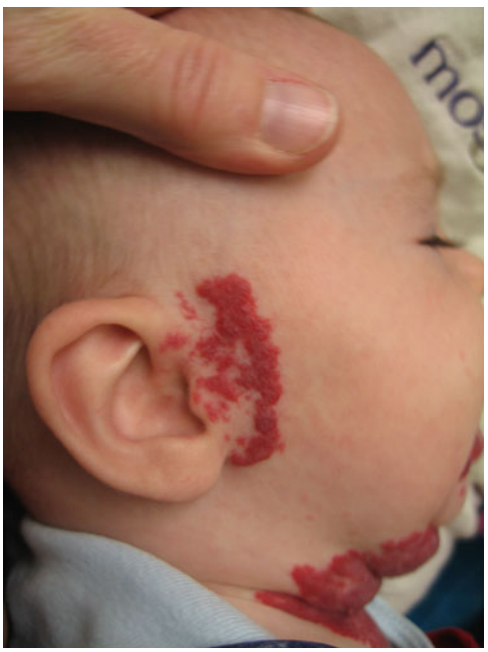

Fig. 106.7 Beard distribution of an infantile hemangioma as well as facial involvement

nearly normal skin is restored in approximately 50 % of children. Yellow pulsed-dye laser treatment may halt progression of growth of early hemangiomas and should be considered for all facial hemangiomas. Propranolol or corticosteroids (intralesional or systemic) are recommended for large hemangiomas, those that cannot safely be excised, and those that compromise vital structures and function. Vincristine may be considered for steroid-unresponsive hemangiomas. Surgical excision is recommended for lesions that have not completely involuted, skin ulceration, recurrent bleeding, or if the location of the lesion poses significant health concerns.

Vascular Malformations

Vascular malformations are localized or diffuse lesions that result from errors of embryonic development and may affect any segment of the vascular system, including arterial, venous, capillary, and lymphatic vessels. Most vascular malformations are sporadic with an overall prevalence of 1–1.5 %. Lesions are categorized as slow-flow or fast-flow anomalies. Lymphatic malformations are slow-flow vascular anomalies best characterized as microcystic, macrocystic, or mixed. They most commonly appear as ballotable masses with normal overlying skin, although a blue hue may be present with large underlying cysts.

Lymphatic malformations are generally evident at birth or before age 2. Radiologic documentation is best performed by MRI although ultrasound may be useful to characterize the flow within the malformation and confirm the presence of macrocysts. Malformations are commonly located in the axilla/chest, cervicofacial region, mediastinum, retroperitoneum, buttock (Fig. 106.8), extremities, and anogenital areas. The two main complications of lymphatic malformations are intralesional bleeding and infection. Analgesia, rest, and time are sufficient therapy for intralesional bleeding. Infection may result in cellulitis requiring prolonged intravenous antibiotics.

The two strategies available for treating lymphatic anomalies are sclerotherapy and surgical resection. Macrocystic lesions are more amenable to treatment with sclerotherapy. Commonly used agents include hypertonic saline, sodium tetradecyl sulfate, absolute ethanol, and doxycycline. OK-432, a treated strain of *Strep. pyogenes*, is an investigational agent which has had excellent reported success. Side effects of sclerosants include local necrosis, blistering, and local neuropathy. Complete clinical resolution has been reported in 60–100 %. In some cases, especially lesions that are predominantly microcystic, surgical resection might be the only way to cure lymphatic malformations, but this can be difficult due to extent of the lesion and incorporation of vital structures. Staged resections may be necessary for large lesions. Recurrence is common after resection and reported in 40 % of lesions following incomplete resection and 15–20 % after macroscopically complete excision.

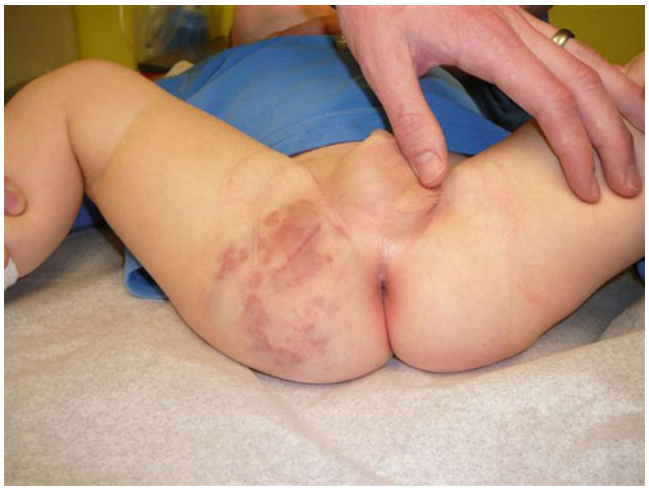

Fig. 106.8 A mixed lymphatic and vascular malformation involving the buttock

Venous malformations are the most common of all vascular anomalies and are frequently misdiagnosed as hemangiomas. The typical appearance is a blue, soft, and compressible mass. They demonstrate proportional growth with the growth of the child. Most venous malformations are solitary, but multiple cutaneous or visceral lesions can occur. Phlebothrombosis is common and can be painful. If large and located on the extremity, they may cause limb length discrepancies, painful hemarthrosis, and degenerative arthritis. These anomalies are best imaged by MRI.

Treatment options include sclerotherapy and surgical resection. For small cutaneous malformations, injection with 1 % sodium tetradecyl sulfate is often successful. However, recanalization can occur leading to recurrence. Excision of a venous malformation is usually successful for small, well-localized lesions. Sclerotherapy may be useful 24–72 h prior to resection in order to shrink the lesion and decrease intraoperative bleeding.

Non-melanocytic Nevi

Epidermal Nevi

Epidermal nevi present as yellowish-brown, velvety, granular, or warty plaques (Fig. 106.9). They may occur as single or multiple lesions and typically have a linear or whorled configuration, following the lines of Blaschko. Epidermal nevi may be present at birth, but they most often appear during early childhood and evolve until puberty. They may arise anywhere on the cutaneous surface and may also involve the oral mucosa and ocular conjunctiva. Most epidermal nevi measure several centimeters or less in length but can extend

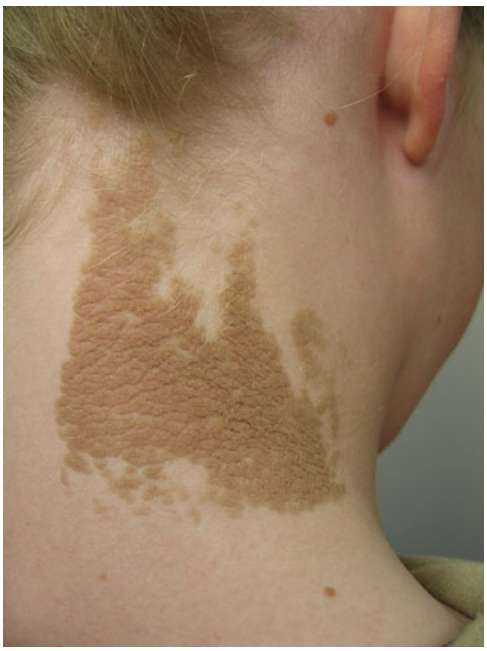

Fig. 106.9 Epidermal nevus

along an entire limb or traverse the chest, abdomen, or back. Malignant degeneration (basal cell carcinoma, squamous cell carcinoma) of epidermal nevi is rare. Epidermal nevi may be generalized and associated with abnormalities of the skeletal, ocular, genitourinary, central nervous, and cardiovascular systems, commonly referred to as the epidermal nevus syndrome.

Treatment of these lesions is unnecessary unless the nevus results in cosmetic disfigurement. Topical therapies can help smooth the epidermal nevi but need to be used long term to maintain the effect. Full-thickness surgical excision is curative for a completely developed epidermal nevus; however, excision of a lesion that has not completely evolved may lead to recurrence. Surgical excision therefore should be delayed if possible until puberty.

Nevus Sebaceus of Jadassohn

Nevus sebaceus is a collection of normal sebaceous glands. It presents at birth as a solitary well-circumscribed round or oval hairless yellowish-orange plaque, often with a lobular texture. The predominant sites of involvement are the scalp, face, and neck. A nevus sebaceus usually grows in proportion to the child's growth but is usually less than 2–3 cm in diameter. With the onset of puberty, the sebaceous glands within the nevus become functional, which causes thickening of the plaque. Secondary neoplasias arise in 10–15 % of these lesions, typically in adulthood, and are most commonly benign tumors of epidermal appendage origin. Malignant degeneration (basal cell carcinoma, squamous cell carcinoma) is uncommon and estimated to occur in less than 1 %. Changes of the nevus sebaceus that should prompt consideration of a biopsy include friability, focal nodularity, or rapid enlargement. Periodic evaluation for changes during infancy, early childhood, and into adulthood is recommended. Management includes biopsy of any changing area or full-thickness excision if the lesion is bothersome. Prophylactic excision before puberty is no longer routinely recommended.

Becker's Nevus

Becker's nevi are epidermal nevi that present initially as a hyperpigmented patch, predominantly in males during childhood or adolescence. The lesion commonly develops hypertrichosis limited to the area of pigmentation. It is usually a large lesion, 10–20 cm in diameter, and frequently located over the back, shoulder, or upper arm. Becker's nevus is characterized by increased androgen receptor sensitivity, which explains why it is seen predominantly in males. It is a benign lesion and therefore surgical excision is not necessary. Treatment of the pigmentation and hypertrichosis may be attempted with lasers. Shaving, depilatories, and electrolysis also can address the issue of hair overgrowth.

Postoperative Care

After surgery, routine follow-up is essential to assess wound healing and discuss pathology results. Lesions not excised on the first visit should be evaluated on serial office visits by the same examiner. Enlarged lymph nodes may require repeat examination every 2–3 weeks for up to 8 weeks, whereas nevi may need to be followed for up to a year. The surgeon should be thoughtful and sensitive when dealing with these minor skin lesions, as parental anxiety is often high.

Editor's Comment

The paraspinal region of the back is for some reason a common place for subcutaneous lesions such as lipomas, lymphangiomas, and fibromas to arise in infants and young children. Typically near or below the tip of the scapula, these tend to be large, flat lesions with indistinct borders and a high risk of recurrence after surgical excision. US or MRI is useful to determine their true extent and to help with surgical planning. It is also helpful to delay excision until the child is more than a year of age when the dissection planes within the fat are somewhat easier to delineate. These will sometimes turn out to be due to nodular fasciitis, an inflammatory lesion that causes the fascia of the paraspinous muscles to thicken and fibrose. Excision usually leaves the muscle without investing

fascia, which is functionally not an issue. In the end, these lesions are all benign and mostly of cosmetic concern; therefore, the least invasive operation with the best cosmetic result should be the goal.

Other uncommon but challenging skin lesions occasionally seen in a typical pediatric surgical outpatient practice include tick bites and myiasis. Tick bites create a lot of anxiety in some parts of the country because of concerns about Lyme disease, but surgeons are sometimes asked to assess a child who has had a tick removed in such a way that the mouth parts are left imbedded in the skin. This can cause an intense foreign body reaction or even a local vasculitis. If the lesion persists after a 2-week period of observation, surgical excision is sometimes necessary. Cutaneous myiasis is due to growth within the skin of the larva of the botfly, which is indigenous to parts of Central and South America. The dermal lesion is typically red, raised, and itchy with a small central breathing pore through which a serosanguinous discharge (feces) is intermittently seen. Patients will sometimes also describe the feeling that something is wriggling within the lesion. The larva will eventually come out on its own and the course is benign, but few patients or parents in the US will tolerate such an approach. The application of petrolatum can suffocate the larva, but surgical extraction under local or general anesthesia is usually the best option. The pore is enlarged with a small incision and the breathing tube of the larva is grasped and used to pull the larva from its burrow.

For dermoid cysts that are located within a slight concavity of the skull, it is important to remove the underlying periosteum to prevent recurrence. US or MRI should be performed first to rule out a lesion that traverses the skull, in which case a neurosurgeon should be consulted. It is tempting to attempt retrieval of a foreign body of the foot in the office or ED, but this is often a frustrating exercise that can push the foreign body deeper. The foot has many intersecting subcutaneous fibrous septae that are difficult to navigate, can allow the foreign body to hide, and can make the practitioner appear to be incompetent. Unless the foreign body is directly visible, it is always best to perform the extraction in the operating room, under general anesthesia, and, if the foreign body is radiopaque, under fluoroscopic or US guidance. When dealing with any foreign body extraction, it is important to warn the parents about the possibility of a retained foreign body and carefully document that the foreign body has been completely extracted, usually with a follow-up radiograph. Always insist on a follow-up visit so that you can be sure that the wound has healed well with no evidence of infection or foreign body. These situations are often highly charged, both emotionally and legally.

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Nevi and Malignant Melanoma

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Rebecca L. Farmer and Ahmed M. Afifi

The discovery of a pigmented skin lesion on a child can be a distressing event for everyone involved, including the parents, the child, and the pediatric surgeon. A great deal of time and effort can be spent determining the best approach for managing these lesions, and often there are many concerns that must be addressed before deciding upon a management plan. The possibility that a mole or other skin lesion might degenerate to a malignant tumor, especially melanoma, is a significant concern for all involved. However, the risk of malignancy is balanced against a desire to minimize scar formation, to minimize the child's exposure to anesthesia, and to decrease the number of benign lesions that are removed unnecessarily. Despite the fact that these lesions do not present a particularly challenging surgical problem, they can require significant planning on the part of the surgeon to optimize management.

Although the focus of much of the pediatric surgeon's clinical practice involves identifying and treating potentially malignant lesions, the overwhelming majority of skin lesions that are evaluated by a physician are benign. Melanocytic nevi are an incredibly common childhood occurrence, with >98 % of Caucasian children developing at least one nevus sometime during their early childhood. Furthermore, there are a number of other benign skin lesions, including congenital melanocytic nevi, Spitz nevi, and many others that can be associated with an increased risk of melanoma, but might also be misdiagnosed as a malignant lesion. It is critically important for the pediatric surgeon to have a thorough understanding of these various benign skin lesions, in order to avoid unnecessary removal of reassuring lesions while also being able to identify lesions that may need to be monitored more closely for malignant transformation.

Conversely, it is also important for practicing pediatric surgeons to have a thorough knowledge of the presentation and management of malignant melanoma. Melanoma is thankfully exceedingly rare before puberty, accounting for approximately 2 % of childhood malignancies. However, unlike adult melanomas, which usually adhere to the ABCDE algorithm of diagnosis, pediatric melanomas are often confused with other common non-melanocytic lesions of childhood, such as pyogenic granulomas, molluscum contagiosum, or Spitz nevi. Given these challenges inherent in identifying malignant lesions, the accuracy with which this diagnosis is made is usually quite poor. Therefore, not only should physicians working with pediatric populations have a working knowledge of common benign lesions, but they should also be able to recognize and manage lesions with concerning features as well.

Acquired Melanocytic Nevi

Acquired melanocytic nevi, or common moles, are a collection of benign melanocytes, or nevus cells, located within the outer layers of skin. Melanocytes are cells derived from the neural crest that normally reside as individual cells within the basal layer of the epidermis and produce melanin, the natural pigmentation of the skin. Nevus cells are anomalous melanocytes in that they tend to cluster as nests within the lower epidermis or dermis. These nests of nevus cells form melanocytic nevi, which typically begin to appear after the first 6 months of life. These benign moles tend to increase in number over time, particularly in patients with fair skin, light hair color, and a history of sun exposure. Peak numbers of nevi are usually present by the third decade of life, with a slow rate of regression thereafter. In several population studies, it has been noted that the mean number of nevi in Caucasian adolescents ranges from 15 to 25, although numbers >50 are not uncommon. Children of African, Asian, or Native American descent tend to have fewer acquired nevi,

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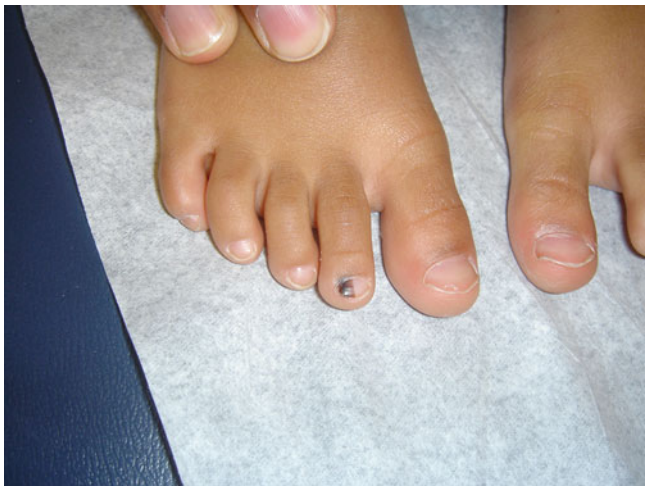

Fig. 107.1 A benign subungual acquired melanocytic nevus (courtesy of Delora Mount, MD)

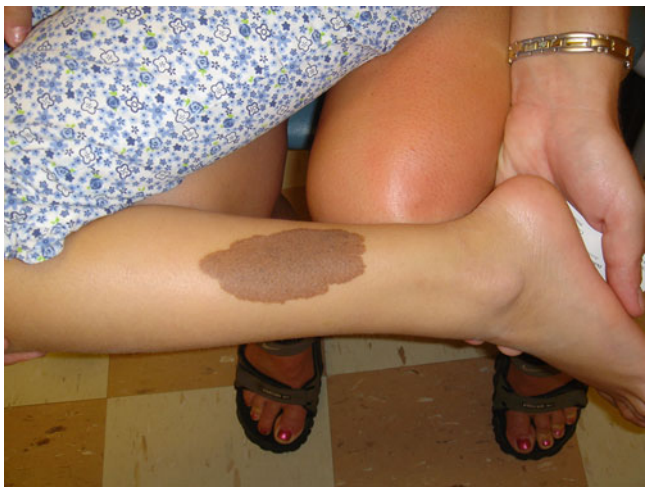

Fig. 107.2 A medium-sized congenital melanocytic nevus of the leg (courtesy of Delora Mount, MD)

most of which tend to be distributed on nonpigmented areas such as the palms and soles (Fig. 107.1).

Although common melanocytic nevi can assume any appearance, they are characteristically symmetric, with homogenous tan to dark brown pigmentation, well-demarcated borders, and a regular round or oval shape. There are several classifications of benign moles depending on the location of the nevus cells within the layers of the skin—junctional nevi are those that occur at the dermo-epidermal junction, intradermal nevi are found exclusively within the dermis, and compound nevi are found in both locations. All of these benign nevi typically undergo subtle changes over time, including involution; changes in color, depth, or size; development of a "halo" of nonpigmented skin around the lesion; or eczematous change. Most of these variations are considered to be normal changes in the course of a mole's life span and thus should not be confused with more concerning features associated with malignant degeneration. However, nevi that do undergo significant change should always be followed closely, with serial photographs often being helpful to detect concerning features that arise over time.

Despite the fact that acquired moles can assume any size or shape, individuals who develop more than one acquired nevus tend to develop a predominant type or "signature nevus." Multiple patterns of signature nevi have been described, many of which would be considered to be unusual if they presented individually. However, the presence of a signature type of nevus can be useful diagnostically, as lesions that do not fit the typical pattern can easily be identified and evaluated for potential malignant transformation. Patients and parents should expect that the development of new acquired nevi over time is normal, but they should also continue to perform periodic skin examinations to identify concerning outliers that do not fit into the typical nevus pattern.

Congenital Melanocytic Nevi

Unlike acquired melanocytic nevi, congenital melanocytic nevi (CMN) are cutaneous pigmented nevi that are either present at birth or develop within the first few months of life (Fig. 107.2). A subset of CMN known as tardive CMN may not be clinically apparent at birth due to the overall lack of pigmentation but slowly become apparent over time, usually by 2 years of age. The overall incidence of newborns and infants with pigmented nevi consistent with the diagnosis of CMN is approximately 1–2 %. Compared to acquired melanocytic nevi, CMN tend to reside deeper in the dermis, often involving structures such as sweat glands, hair follicles, and blood vessels. CMN can range in color from tan to black and typically do not exhibit the regular borders and texture usually associated with a benign acquired melanocytic nevus. In fact, CMN usually have irregular borders, as well as a tendency to undergo significant changes following puberty. While most lesions start out as flat patches or raised plaques with uniform color distribution, they can develop significant nodularity, irregularity in color, and an increased density of terminal hairs over time.

CMN are typically classified according their predicted final size in adulthood, which also has bearing upon their potential for malignant degeneration to melanoma. *Small* CMN are defined as having a diameter <1.5 cm and are present in approximately 1:100 live births, while *medium* CMN range from 1.5 to 19.9 cm in diameter with an incidence rate of approximately 1:1000 live births. Although the exact rate of malignant transformation of small and medium CMN is not known, the reported lifetime risk of developing melanoma is thought to be between 1 and 4.9 %. Like acquired melanocytic nevi that undergo dysplastic change, small and medium CMN that develop malignant features tend to do so after puberty. Additionally, these melanomas

typically develop at the dermo-epidermal junction near the periphery of the CMN, thereby making early diagnosis feasible and most often leading to a melanoma of the superficial spreading type.

Large CMN are ≥20 cm in diameter, with a small subset >50 cm in diameter that are commonly known as *giant* nevi. Many of these large or giant nevi are associated with "satellite nevi," which are multiple small or medium CMN that develop around the main lesion. These larger nevi are much rarer than small or medium CMN, with an incidence somewhere in the range of 1:20,000–500,000 live births. Unlike small and medium CMN, which tend to have a small lifetime risk of malignant conversion, the risk for large CMN is estimated to be in the range of 5–10 %. Patients with giant nevi located in an axial location and accompanied by multiple satellite lesions have the greatest risk of developing melanoma. Most importantly, malignant transformation is much more difficult to detect in these lesions, given the inherent complexity of the parent nevi and the tendency of melanomas to develop below the dermo-epidermal junction. Because of this distinction, most of the melanomas that develop in giant nevi tend to be of the nodular subtype and are often detected later than melanomas in smaller CMN. Furthermore, it is estimated that 60 % of melanomas that develop within large CMN do so before the age of 3, unlike those in small and medium CMN, which tend to develop after puberty. Large nevi found primarily in axial locations or those with multiple (>20) satellite lesions are also associated with a risk of neurocutaneous melanosis, a condition in which the leptomeninges of the central nervous system contain an overabundance of melanin and melanocytes. Therefore, these patients are at risk of developing primary central nervous system melanomas, in addition to the traditional cutaneous melanomas.

Blue Nevi

Blue nevi are a proliferation of benign dendritic dermal melanocytes that produce melanin. While these lesions can sometimes be congenital, they are more often acquired and present as smooth, dark blue, or black nodules on the head and neck, distal extremities, and the sacral area. These areas are preferentially affected by blue nevi because they represent the sites on the body where dermal melanocytes are still present and active at birth (Fig. 107.3). The coloration of these lesions can be explained by the Tyndall effect, which states that shorter wavelengths of light are preferentially scattered by dermal melanin.

There are two major clinical types of blue nevi, which include the common blue nevus and the cellular blue nevus. Common blue nevi tend to occur in adolescence and are usually solitary nodules measuring <1 cm in diameter, with uniform blue-black coloration. Cellular blue nevi, on the other hand, tend to be larger (>1 cm) with an irregular border and can often be present at birth. In addition, while common blue nevi have a predilection for the distal extremities, cellular blue nevi tend to be more common on the scalp, sacrum, and face. These benign lesions are often mistaken for melanoma given their dark coloration, but they tend to lack the rapid growth phase that is common with malignant melanoma. Rarely, cellular blue nevi, particularly those on the scalp, have shown malignant features, and some have also shown invasive behavior even in the absence of malignancy.

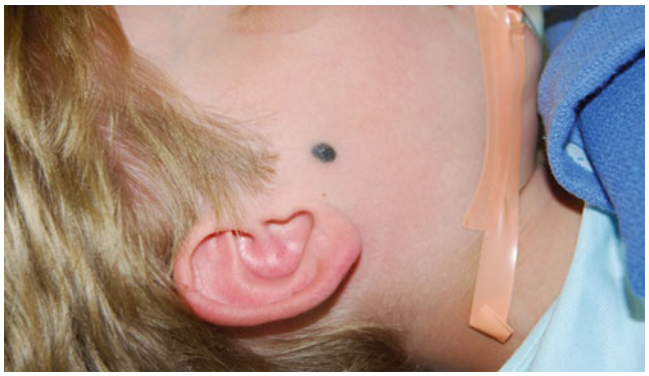

Fig. 107.3 Classical appearance of a blue nevus (courtesy of Delora Mount, MD)

Generally speaking, blue nevi are almost always benign and can usually be managed expectantly with regular examinations and a photographic record of growth or change of the lesion. However, lesions that are undergoing rapid change or those that are in a difficult area to monitor regularly can be excised prophylactically.

Spitz Nevi

Spitz nevi, or spindle and epithelioid cell nevi, are benign nevi that represent a particular diagnostic and therapeutic challenge in the pediatric population. These lesions were first reported by Sophie Spitz in 1948, when she first observed a subset of benign nevi that share multiple histopathologic features with malignant melanoma. Clinical presentation for a classic Spitz nevus involves the development of a rapidly growing, amelanotic, pink, or flesh-colored papule or nodule, usually located on the face or extremities. They are usually solitary, well-circumscribed, smooth lesions, although they can also be verrucous and occasionally darkly pigmented. In fact, there is a variant of a Spitz nevus known as a Reed nevus, which is a benign dark brown or black papule that usually presents on the lower extremities in early adolescence.

The feature that makes Spitz nevi difficult to assess and treat is their tendency to demonstrate histologically atypical

features similar to those expressed by malignant melanoma. While congenital melanocytic nevi are often considered to be true "melanoma precursors," Spitz nevi are often referred to as "melanoma simulator" that lie on a spectrum with true malignant melanomas. Some melanomas are so similar in histologic architecture to Spitz nevi that they are actually referred to as "spitzoid" melanomas, and even experienced dermatopathologists can have difficulty distinguishing the two entities from one another.

There are also a number of other lesions in between these two extremes, often referred to as atypical Spitz tumors (AST), which have an unknown malignant potential, but tend to have an association with locoregional recurrence and distant metastasis. These AST tend to be larger (>1 cm) than a typical benign Spitz nevus and also display concerning features such as nodularity, ulceration, and rapid growth. There have been a number of case studies that have demonstrated that up to 50–66 % of children with a diagnosis of a Spitz nevus also had a positive sentinel lymph node biopsy, although no adverse events or distant metastases were ever detected in these patients. Therefore, these types of Spitz nevi are often surgically excised early in their development, as they are regarded as premalignant, less aggressive variants of conventional melanomas.

Atypical/Dysplastic Nevi

An atypical nevus is a benign acquired melanocytic nevus that demonstrates certain clinical features consistent with melanoma. Similar to presentation in adults, atypical nevi with dysplastic cellular features tend to possess asymmetry, border irregularities, color variegation, and a diameter >6 mm (the standard ABCDE criteria for diagnosis of adult melanoma). However, the true diagnosis of a dysplastic nevus is based upon two major and four minor histopathologic criteria that were determined by the World Health Organization in 1992, with a 92 % concordance rate in diagnosis (Table 107.1). Therefore, while an atypical nevus can be identified based upon its clinical features alone, a full surgical excision and pathologic examination must be performed to confirm the diagnosis.

Atypical features in acquired melanocytic nevi usually begin to appear around puberty and continue to develop throughout a patient's lifetime. Many of the same risk factors that confer an increased risk of developing melanoma are the same for developing multiple atypical nevi. First, as would be expected from a purely statistical argument alone, the number of dysplastic nevi directly correlates with the total number of melanocytic nevi on a certain individual. Furthermore, most atypical nevi develop in sun-exposed areas of the body, particularly in light-skinned individuals that do not tan easily. Clinical atypia is present in approximately 2–10 % of Caucasian populations, with significantly lower rates in other populations. In addition to environmental factors, however, there is also a large genetic component to the development of dysplastic nevi. In one study of families with a strong history of melanoma, 37 % of children developed dysplastic nevi, and all cases of pediatric melanoma were diagnosed only in those patients who possessed this type of nevus. In addition, there are a number of genetic disorders that confer an increased risk of developing dysplastic nevi, including familial atypical multiple moles and melanoma (FAMMM) syndrome (otherwise known as dysplastic nevus syndrome) and other genetic mutations. These syndromes can lead to the development of incredibly high numbers (>100) of acquired moles, many of which possess dysplastic features.

Although atypical nevi are considered to be a risk factor for the development of malignant melanoma, there is a debate in the medical community as to whether they represent truly premalignant lesions. In one large study of patients with melanoma, having one dysplastic nevus doubled the risk of developing melanoma, while having ten or more dysplastic nevi conferred a 12-fold increased risk. However individual acquired atypical nevi only have an estimated lifetime risk of 1:10,000 for transforming into a malignant melanoma, although documented cases of malignant transformation have occurred.

Most childhood melanomas arise de novo, in that they are not associated with a preexisting acquired nevus, whether it be completely benign or atypical. In fact, nearly all atypical nevi, despite possessing multiple abnormal features, tend to remain stable in appearance and never degenerate into melanoma. For these reasons, while some scientists theorize that atypical nevi are truly premalignant lesions representing a middle ground between a benign nevus and a melanoma, there is not significant evidence to support this claim. Children and adolescents who have been diagnosed with atypical nevi should undergo regular skin examinations as they are at increased risk for the development of melanoma, but individual atypical moles are rarely biopsied unless they undergo significant change from their baseline appearance.

Table 107.1 WHO histopathologic criteria for the diagnosis of atypical nevi

Major criteria	Minor criteria
1. Basilar proliferation of atypical nevomelanocytes 2. Organization of proliferation in a lentiginous or epithelioid cell pattern	1. Presence of lamellar fibrosis or concentric eosinophilic fibrosis 2. Neovascularization 3. Inflammatory response 4. Fusion of rete ridges

Malignant Melanoma

Despite the overall rise in the incidence of malignant melanoma in the United States, the diagnosis of melanoma in childhood remains fortunately quite rare. Malignant melanoma represents only 2 % of childhood cancers, with only 0.3 % of cases occurring before puberty. Recent data from the Surveillance, Epidemiology, and End Result (SEER) program demonstrates that only about 1300 cases of childhood melanoma were diagnosed between 1973 and 2009. However, data also suggest that there is an overall increase in the rate of pediatric melanoma of approximately 2 % per year, particularly in young women aged 15–19 and those who live in geographic areas with higher UV exposure. Therefore, the identification and treatment of childhood melanoma remains a small, but real, concern for pediatricians and pediatric surgeons.

The diagnosis of malignant melanoma in children is difficult not only because of its rarity but also because pediatric tumors tend not to follow the traditional ABCDE algorithm that is usually described to identify adult melanomas. Retrospective studies performed on a subset of children younger than 20 years old who were diagnosed with melanoma demonstrated that the most common clinical findings were amelanosis, bleeding, bumps, uniform color, a range of diameters, and de novo development (not associated with a prior nevus). In fact, most melanomas identified in early childhood assume the appearance of amelanotic nodules similar in appearance to pyogenic granulomas or Spitz nevi. Therefore, a high level of suspicion is warranted, especially if the patient has multiple risk factors for melanoma in addition to a lesion that shares these characteristic features.

In addition to having characteristics different from those of adult melanoma, childhood melanoma can also exhibit radically different clinical behavior. Malignant tumors diagnosed in children usually have a thicker Breslow depth at presentation and a higher incidence of lymph node involvement than those diagnosed in adults. Despite these advanced histopathologic features, however, childhood melanoma carries an overall prognosis similar to or better than that of adult melanoma. This favorable survival rate diminishes with the age of the child, as mortality rates have been found to be 8–18 times higher after puberty. Furthermore, there are various histopathologic subtypes of melanoma that also contribute to variable survival rates in this age group.

Spitz nevi and malignant melanoma share many histological features, leading to the diagnostic distinction of "spitzoid" and "non-spitzoid" melanomas. When comparing the behavior of these two entities, researchers have found that children diagnosed with spitzoid melanomas tend to be younger, with more advanced disease (nodular melanoma subtype with high Breslow thickness, increased mitotic rate, positive sentinel lymph nodes), while non-spitzoid melanomas tended to arise from a preexisting nevus at a later age. Unexpectedly, children with spitzoid tumors had a lower mortality rate of 6 % when compared to those with non-spitzoid tumors, despite the advanced pathologic features of the spitzoid tumors at presentation. Whether this difference in mortality was related to the age at presentation, the inherent biological nature of the tumors themselves or the possibility that Spitz nevi and other benign lesions are potentially overdiagnosed as melanomas remains unclear.

Although the clinical presentation and behavior of malignant melanomas in children are often quite different from that of adults, the risk factors between the two populations remain the same. Factors such as the child's age, skin type, family history, and sun exposure all play a role in the risk of developing childhood melanoma. Children with a Fitzpatrick I type pigmentation, or those with fair skin and blonde or red hair, are at a significantly higher risk of melanoma formation, as are those with blue eyes and a higher density of freckles. Patients who have large numbers of acquired melanocytic nevi, whether they are benign or atypical, are also at increased risk of melanoma formation, with the risk of melanoma increasing by as much as a factor of 12 for those with ten or more dysplastic nevi.

Family history also plays a role, as children who have a parent with malignant melanoma have a relative risk of approximately 1.75. Having a parent with multiple malignancies increases that relative risk to 62. There are also several familial and genetic conditions that confer an increased risk of development of melanoma. FAMMM syndrome is often caused by mutations in cyclin-dependent kinase 2A (CDKN2A), which is an important regulator of cell cycle control. The reported prevalence of this genetic mutation in families with a strong predilection for melanoma is anywhere from 3 to 57 %. Patients with xeroderma pigmentosum, an autosomal recessive defect in DNA repair mechanisms for UV damage, have an increased risk of developing melanoma that is 2000 times that of a normal control. Approximately 5 % of these patients develop melanomas by 19 years of age. Finally, patients who are immunosuppressed, whether because of medication use, transplantation, or congenital immunodeficiency syndromes, have a three- to sixfold increased risk of developing melanoma in childhood. However, all of these risks are also applicable to the adult population and should be considered as an integral part of the patient's clinical history.

General Management

Despite our extensive knowledge of the clinical presentation and risk factors for both benign and malignant skin lesions in children, the question still remains as to the appropriate management approach for these patients. As with any other therapeutic challenge in medicine, the ultimate choice of treatment

modality is usually the result of a multifactorial decision on the part of the physician and the patient. Many different factors need to be considered, including the location of the lesion, the ease of regular surveillance, the likelihood of scar formation, and the difficulty of surgical removal. However, the predominant concern that drives most treatment decisions is the risk of a particular cutaneous lesion undergoing malignant degeneration. Most cutaneous lesions are thus stratified into high-risk and low-risk categories, with high-risk lesions usually treated more aggressively.

Certain skin lesions that have a high propensity for malignant degeneration should always be considered for surgical excision. Obviously, any skin lesion in which definitive diagnosis of malignant melanoma has been made on surgical biopsy should be promptly removed to prevent further dissemination of the disease. However, it is also important to keep in mind that the definitive histopathologic diagnosis of melanoma can be exceedingly difficult, and it is often necessary to involve multiple dermatopathologists in the decision-making process prior to removal. Treatment approaches for malignant melanoma in children mirror those recommended for adults and are based upon the Breslow depth of the lesion on presentation. Surgical excision margins are dictated by the National Comprehensive Cancer Network (NCCN) guidelines, which state that there should be 0.5-cm margins for in situ lesions, 1-cm margins for melanomas <1 mm thick, 1–2-cm margins for melanomas 1–2 mm thick, and 2-cm margins for melanomas >2 mm thick. Furthermore, sentinel lymph node biopsy (SLNB) is also recommended for children in accordance with adult guidelines and should be recommended for patients with lesions >1 mm thick or those <1 mm thick that present with ulceration, high mitotic rate, or other concerning features.

Patients who are found to have disseminated disease on sentinel lymph node biopsy should undergo completion lymphadenectomy according to standard protocols. However, despite the fact that surgical excision guidelines for pediatric melanoma are well defined, the use of adjuvant therapies for more advanced disease is not as clear. The only adjuvant therapy that has been approved for high-risk melanomas in children is α-interferon, which confers a significant prolongation in disease-free survival and overall survival in multiple trials performed by the Eastern Cooperative Oncology Group (ECOG). However, studies on this treatment are still limited. Other commonly utilized adult therapies, like IL-2, bacillus Calmette-Guerin (BCG), or traditional chemotherapeutic agents like DTIC, have only been studied in small case studies in children and thus are not currently the standard of care.

Although the decision to surgically remove a biopsy-proven melanoma is clear and undisputed, the decision for prophylactic removal or treatment of other congenital and acquired nevi is not always as straightforward. Given the benign, low-risk nature of most pediatric skin lesions, the most prudent decision is usually to involve a well-qualified dermatologist to follow pediatric patients with regularly scheduled total body skin examinations and dermatoscopic evaluation of any concerning lesions. Photographic records can also be helpful if one chooses to monitor a lesion over time, as these provide an absolute visual record of the various changes that may occur over the lifetime of a given skin lesion. This type of approach is usually advocated for patients with large numbers of benign melanocytic nevi, as well as atypical nevi. These lesions are usually followed conservatively unless they develop concerning features to warrant biopsy or if they are in a location that would be difficult to monitor regularly.

It is expected that a child prone to developing melanocytic nevi will continue to have increasing numbers of nevi over time, so the removal of any one of these lesions is both impractical and unnecessary. However, if a lesion develops features that are worrisome, then biopsy should always be considered to definitively rule out malignancy. Lesions <1.5 cm can usually be examined by excisional biopsy, leaving approximately 5-mm margins on all sides of the lesion. Larger lesions (>1.5 cm) can often be examined by an incisional or punch biopsy, although multiple areas may need to be sampled for an accurate diagnosis. As with all skin lesions, shave biopsies should be avoided, as they preclude any analysis of depth, and therefore stage, of the lesion.

While the management of benign and malignant lesions is relatively straightforward, there are a number of skin lesions that fit more into a "gray zone" of management strategy. For instance, congenital melanocytic nevi can represent a difficult therapeutic challenge, since the recommendation for surgical resection usually depends upon the size of the lesion. Small- and medium-sized CMN usually have a low rate of malignant transformation before puberty and thus are usually managed conservatively with regular examinations by a qualified dermatologist. Prophylactic surgical excision could be planned for these lesions, depending upon the level of the patient's anxiety about malignant transformation, or for cosmetic purposes. Lesions that would otherwise be difficult to monitor due to their location, such as those on the scalp or in the genitourinary areas, might also be considered for prophylactic excision so they no longer need to be monitored.

Large and giant CMN, on the other hand, particularly those with inherent nodularity that would make detection of melanoma difficult, are often recommended for early surgical excision. The process of surgical excision should begin preferably before the age of 1 year, usually between 6 and 9 months when the risk of general anesthesia is low. However, there are several important considerations that must be taken into account regarding the surgical removal of these lesions. First, the size of these lesions often necessitates a staged reconstruction with possible tissue expansion, so parents should be counseled on the need for multiple surgeries over the course of several years.

Patients should also be made aware that there can be a significant amount of scarring with this type of staged reconstruction, and their expectations about the cosmetic and functional result should be realistic. Finally, large CMN usually cannot be completely excised, because of the depth and complexity of the lesions. Patients should be counseled that residual nevus cells might be left behind, and they should continue to undergo yearly skin examinations to evaluate for potential melanoma.

Spitz nevi also represent a particularly difficult management challenge, as the line between benign and malignant is often blurred in these lesions. As discussed in the section on pediatric malignant melanoma, these lesions often share many of the histopathologic characteristics of melanoma, and sometimes the two entities cannot even be distinguished on formal pathology. However, the majority of these nevi are completely benign and, as such, can be followed conservatively with regular dermatoscopic examinations every 3–6 months. This is particularly true for small lesions (<1 cm) that do not display any clinical abnormalities and those that present before puberty. Lesions that display atypical characteristics, such as nodularity, ulceration, rapid growth, and increased size >1 cm, should always be excised due to the concern for malignant transformation. In addition, lesions that present in late adolescence or early adulthood should also be prophylactically excised, as the potential for malignant degeneration is much higher as the patient ages. Given the potential malignant behavior that has been demonstrated by these atypical Spitz tumors, particularly with regard to lymph node metastasis, several researchers have advocated for SLNB in patients with this diagnosis as well. However, there have been no studies to suggest that this intervention confers any survival benefit, so it has not been adopted as the standard of care.

Regardless of the decision to pursue a surgical excision or a more conservative approach for a particular skin lesion, a qualified dermatologist should always be involved in the care of children to perform regular skin examinations. The role for prevention in these patients cannot be overstated, and it is important to stress that patients and their families regularly perform total body skin examinations to detect any changes in their nevi. Furthermore, children should regularly be protected from sun exposure, as *daily sunscreen use has been shown to reduce the rate of invasive melanomas in 10-year follow-up studies*. Also, avoiding indoor tanning significantly reduces the risk of melanoma formation in young adults, particularly if they already have a strong family history.

Future Considerations

Despite our extensive knowledge of the behavior of benign and malignant skin lesions in adults, there are still a number of unanswered questions regarding the natural progression of these tumors in childhood. There is a noticeable, clear difference in the clinical presentation and prognosis of childhood melanoma, indicating potential differences between the molecular behaviors of these tumors. As our understanding of the molecular biology and immunologic regulation of melanoma continues to expand, it is possible that we may discover novel, targeted therapies for the treatment of childhood melanoma that might exploit these molecular differences.

Similarly, our understanding of the behavior of Spitzoid lesions and their relationship to pediatric melanoma is still severely lacking. Even with the most sophisticated examination tools, it is still difficult to determine whether these lesions will have a tendency toward malignant or benign behavior. As such, our management strategy for these lesions will only become more advanced through careful study of these tumors to better understand their biological behavior. Finally, there are a number of unanswered questions that remain regarding the best adjuvant treatment approaches for children who are diagnosed with malignant melanoma. Although surgical excision will continue to be the mainstay of therapy, other treatment modalities like immunologic therapies, chemotherapy, and SLNB still have not been extensively studied in the pediatric population. More extensive, randomized controlled trials for these therapies are warranted, in order to better serve the pediatric population and tailor therapies to their specific clinical needs.

Summary

Pediatric nevi are a common childhood occurrence, with over 98 % of Caucasian children developing a benign nevus sometime in childhood. Acquired melanocytic nevi begin to appear shortly after birth in conjunction with sun exposure and often are characterized by homogenous tan to dark brown pigmentation, well-demarcated borders, and a regular round or oval shape. Congenital melanocytic nevi are characterized by size, with large CMN tending to have a greater malignant potential earlier in life. Blue nevi are benign blue-black nodules on the face, scalp, and extremities that can often be mistaken for melanoma but typically lack rapid growth associated with malignancy. Spitz nevi are rapidly growing, pink, or flesh-colored papules and/or nodules, usually located on the face or extremities, which must be evaluated by a dermatopathologist as they are often histopathologically indistinguishable from malignant melanoma. Atypical melanocytic nevi tend to have features classically associated with malignant transformation, including asymmetry, border irregularities, color variegation, and a diameter >6 mm, but they are often benign.

Most childhood melanomas arise de novo, in that they are not associated with a preexisting acquired nevus, whether it be completely benign or atypical. Malignant melanoma in children should be treated with the same guidelines as adult melanoma, with wide local excision based upon depth being the

mainstay of therapy. All suspicious lesions should be followed by a well-qualified dermatologist, and biopsies should often be reviewed by multiple dermatopathologists to aid in definitive diagnosis of potential malignancy. Prevention is key, with reduction of sun exposure and regular total body skin examinations being instrumental in prevention of melanoma.

Editor's Comment

Parents are often very anxious about moles, a relatively common indication for surgical intervention. However, except for giant melanocytic nevi and familial syndromes associated with multiple atypical nevi, melanoma only rarely arises from a long-standing nevus, regardless of its features. It is much more of a concern in pale nevi that arise de novo or in moles that have changed dramatically or become symptomatic. Nevertheless, when there is no other way to reassure them, it is extremely difficult to deny a request for biopsy when parents are anxious about the possibility of cancer.

The diagnosis of malignant melanoma is surprisingly difficult to confirm with certainty, and dermatopathologists reviewing the same case in different parts of the country frequently disagree. Until a genetic signature or biochemical marker becomes available, there will continue to be the need to solicit multiple expert opinions and make the best recommendation with the information available. It is probably best in most cases to err on the side of being more aggressive given the consequences of undertreating a true malignant melanoma, but this is difficult when wide excision becomes necessary on a functionally or cosmetically important part of the body. At least the recommended margin of the wide excision has been decreased to no more than 2 cm (compared to the 5-cm margin that had been mandated not too long ago).

When excising a known melanoma, it is important to take margins consistent with published guidelines. But it is not uncommon for a 1-cm margin, carefully measured and marked in the OR, to be described as a 0.7-cm margin in pathology. Because an excised skin specimen can shrink by as much as a third, take a little more than recommended if the body location allows it, and, most importantly, take intraoperative photographs of the lesion before and after excision with pen markings and a ruler clearly visible in the field and enter it formally in the patient's medical record. The elliptical incision should be oriented such that the closure will be under minimal tension and cosmetically acceptable, not simply to respect Langer's lines.

Giant melanocytic nevi pose a problem in that the risk of developing melanoma is high, but reconstruction is challenging. Depending on location, options include skin grafting, tissue expanders, rotation flaps, and, rarely, myocutaneous flaps. Staged excision is sometimes possible, in which case each elliptical excision should be within the borders of the nevus so that the scar can be excised at the next operation and the surrounding normal skin remains untouched until the final stage.

Sentinel lymph node biopsy is an important adjunct that should be available at any children's medical center that provides care for children with melanoma. It is not technically challenging, but it does require nuclear medicine expertise and a Geiger counter. On the morning of the procedure, lymphoscintigraphy is performed to identify the sentinel node. The radioactivity remains trapped in the node for several hours. Injection of blue dye is probably not helpful or necessary. At surgery, the node is identified using the Geiger counter, and an appropriate incision is made to allow excision of the node. Measuring high radioactivity in the excised node and minimal residual counts in the operative field confirm that the correct node was excised. Complications are rare but include seroma, lymphedema, and false-negative results.

Suggested Reading

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Necrotizing Soft Tissue Infections

108

Angela Gibson

Case presentation: A 7-day-old full-term otherwise healthy baby girl is admitted to the hospital after concerns for omphalitis. She was febrile and had erythema surrounding her umbilical stump, but was otherwise hemodynamically well. After admission to the pediatric floor, she received intravenous antibiotics. Laboratory values were significant only for hyponatremia. Over the day of admission, her erythema progressed to cover her entire abdomen and flank bilaterally. Antibiotics were broadened to piperacillin/tazobactam and vancomycin. She became hypotensive requiring massive fluid resuscitation. A surgical consult was obtained after a purplish black discoloration was noted around the umbilicus (Fig. 108.1). Vasopressors were initiated and she was taken to the operating room for extensive debridement (Fig. 108.2). Despite aggressive operative control of the infection, she developed multisystem organ failure. She died less than 2 days after admission, ultimately from a necrotizing soft tissue infection.

NSTI is a comprehensive term encompassing infection that proceeds in a necrotizing fashion throughout various layers of tissue and includes systemic toxicity. Although technically the term necrotizing fasciitis (NF) describes infection traveling along the fascial planes, it is often used as the general term for all necrotizing infections. NSTI is on the spectrum of skin and soft tissue infections, classified as purulent or non-purulent and non-necrotizing or necrotizing infections (Fig. 108.3). NSTIs are extremely rare in the pediatric population, approximately 1–3 cases per million children each year. Most pediatric surgeons, with the exception of burn or plastic surgeons, only encounter one case in their whole career. Yet, few consults have the ability to grab the attention of a surgeon the way that NSTI does. Given the rarity of NSTIs, the first instinct is to assume the patient has simple cellulitis or an abscess. In fact, often initially the infection is misdiagnosed as cellulitis. However, complacency in entertaining NSTI as a diagnosis will almost certainly result in significant morbidity, if not mortality given the rapid advancement of the infection with very little early clinical warning signs.

A hallmark finding in the patient with NSTI is pain out of proportion to initial physical findings. This occurs due to the extreme tissue destruction that develops and progresses along the deeper tissue plans. Additional findings include the presence of erythema and extensive edema in otherwise normal appearing tissue. The skin overlying the deeper infection may also be anesthetic, despite a normal appearance. When cutaneous manifestations are present, they often progress rapidly and can include vesicles, bullae, violaceous necrosis, and crepitus. Systemic symptoms such as high fever, hypotension, neutrophilia or neutropenia, and acidosis, if present, are often out of proportion to the skin manifestations of the infection. Additionally, extreme fatigue, disorientation, weakness, uncooperative behavior, or combativeness may also accompany the other physical findings. Alternatively, there may be very minimal systemic symptoms early on in the course of the disease.

In adult patients, comorbidities that predispose a patient to developing NSTI include diabetes, cancer, and kidney and vascular diseases. Risk factors in pediatric patients who develop NSTI include surgery, trauma, chronic illnesses, or recent varicella infection; however, a majority of the patients may have no previous identifiable risk factor.

Often confused with less severe soft tissue infections, the hallmark distinguishing factor in NSTI is necrotizing destruction of the soft tissues. Among the terms that have been ascribed to the NSTIs are hospital gangrene, myonecrosis, clostridial infection, Meleny's cellulitis, gas gangrene, and "flesh-eating" bacterial infection. Often the anatomic location or the layer of tissue necrosis is used to determine the nomenclature. Fournier's gangrene (FG) is NSTI specific to the perineum.

Two types of NSTI are commonly recognized depending on the microorganisms present. Type 1 comprises polymicrobial infections including anaerobes and gram-negative bacteria. Type 2 is monomicrobial in nature, most often resulting

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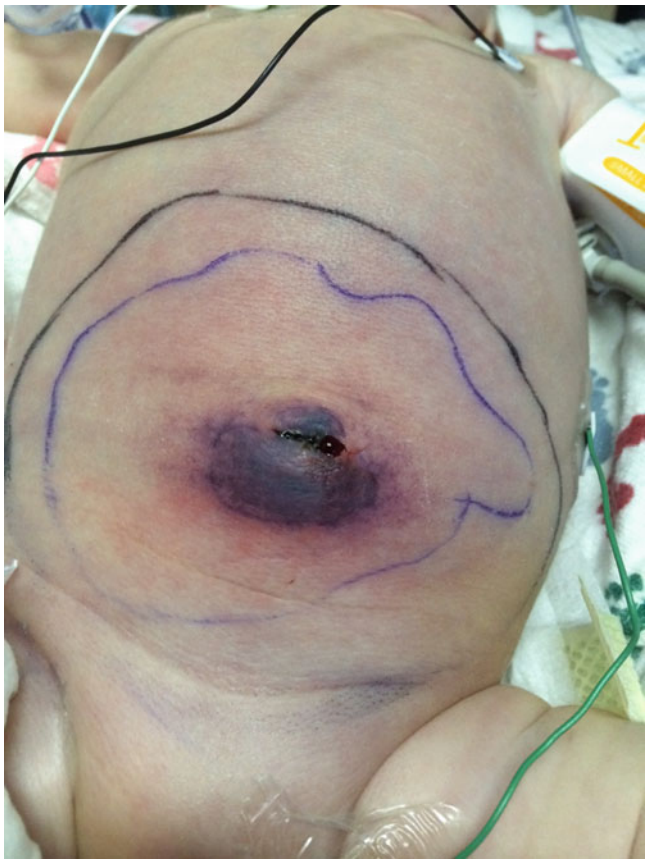

Fig. 108.1 A 7-day-old infant with necrotizing fasciitis prior to operative intervention (image courtesy of Lisa Abramson, MD, Children's Surgical Specialists, Sutter Medical Group)

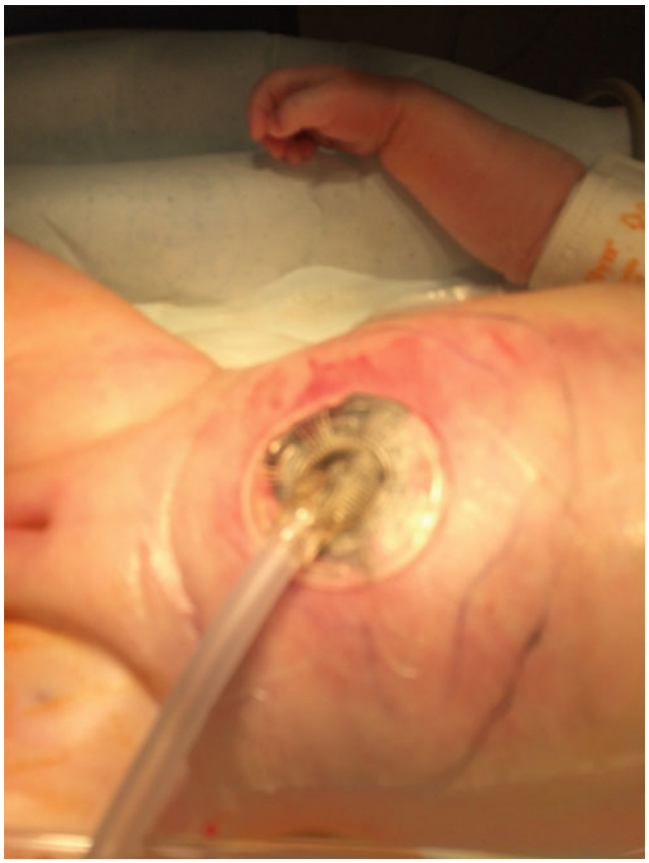

Fig. 108.2 A 7-day-old infant with necrotizing fasciitis after initial debridement (image courtesy of Lisa Abramson, MD, Children's Surgical Specialists, Sutter Medical Group)

from *Staphylococcus aureus* or *Streptococcus pyogenes* infections. A portal of entry is necessary to allow microorganisms to pass the epithelial barrier. At times, it may be an insignificant appearing lesion that is overlooked on initial exam.

In children, group A beta-hemolytic streptococcus (GABHS) is frequently the offending microorganism in the setting of a varicella infection and skin lesions. Polymicrobial infections have been seen after elective surgical procedures such as inguinal hernia repair or with community-acquired omphalitis in the infant population. The location of the NSTI often correlates with the type of organism that is responsible and will help guide the empiric antimicrobial choice until culture speciation and sensitivities are available. Mixed anaerobic and aerobic infections are common in the perineal region, whereas infections consisting of normal skin flora are found in areas distant to mucous membranes. Classically, gas formation and bullous lesions are associated with *Clostridium* and *Enterobacter* species. Foul odor is associated with anaerobic gram-negative bacilli, while GABHS and *S. aureus* infections often present with significant swelling and tenderness. The initial decision to be made is whether or not the infection represents a necrotizing infection that needs immediate operative debridement. The extensive debridement can be disfiguring and disabling; however, a delay in debridement may result in death, and thus the decision to proceed to the OR weighs heavily on the pediatric surgeon.

Evaluation and Initial Management

The patient with a potential diagnosis of NSTI is best served in the intensive care unit. Telemetry monitoring, invasive blood pressure monitoring, pulse oximetry, and urinary catheterization with temperature-sensing capabilities are vital to detect deterioration, which may be rapid. Placement of central IV access is necessary to allow for administration of vasopressors, IV antibiotics, blood product administration, and rapid IV fluid resuscitation. Oxygen support via noninvasive or invasive methods should be available as needed. Initial evaluation should include a history of the possible inciting trauma or event, continuous hemodynamic monitoring, and serial physical examination of the area of concern. Fine needle aspiration may reveal "dishwater" fluid and should be sent for gram stain and culture if obtained. Although uncommon, crepitus is a sign of gas-forming bacteria that can reveal the necrotizing nature of the infection.

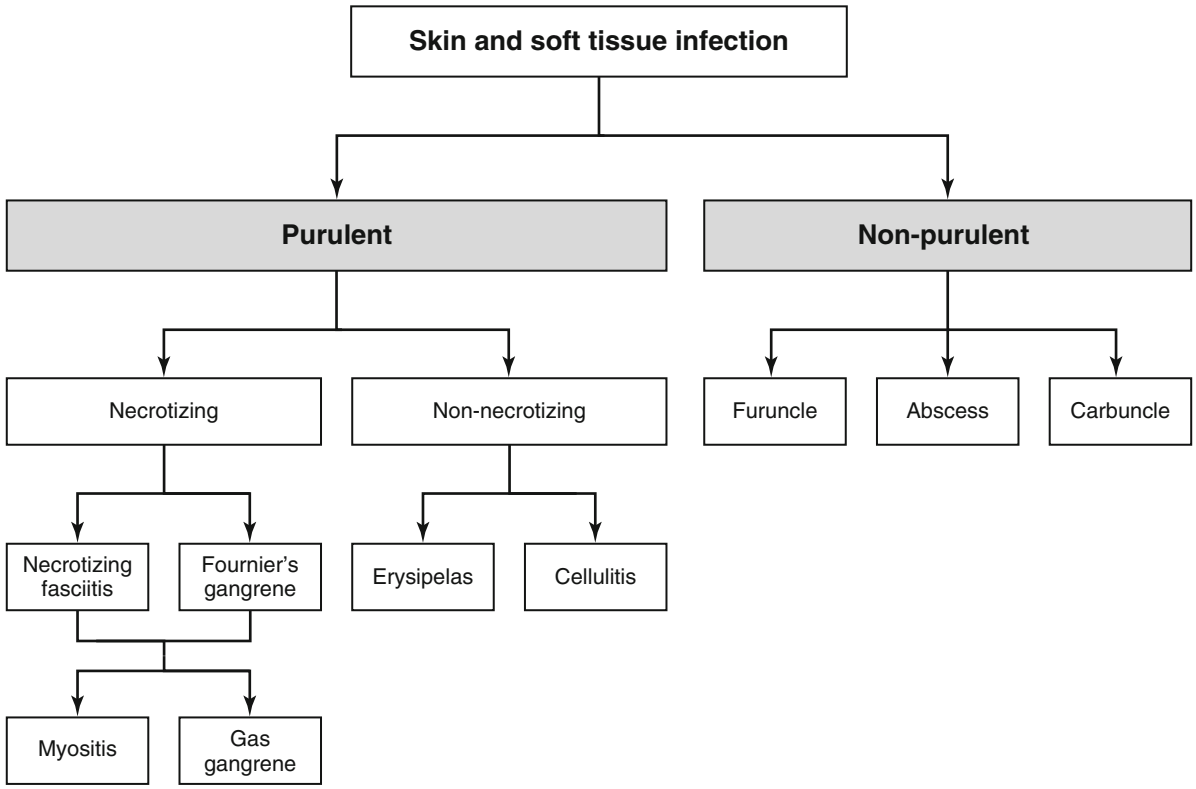

Fig. 108.3 Taxonomy of skin and soft tissue infections

Laboratory findings are only marginally helpful and should not be used in isolation for the diagnosis of NSTI. Leukocytosis greater than 15,400 cells/mm^3 and hyponatremia less than 135 mmol/L are associated with NSTI. The absence of both values has a high negative predictive value, yet the positive predictive value is only around 25 % and thus cannot be used to confirm NSTI. Laboratory risk indicator for necrotizing fasciitis (LRINEC) score is a diagnostic tool used in adults for NSTI. It includes WBC, hemoglobin, sodium, creatinine, glucose, and CRP to confirm or rule out NSTI. Scoring systems such as LRINEC have not been validated in the pediatric population and are not reliable to diagnose pediatric NSTI.

Various imaging modalities have been considered to aid in the diagnosis of NSTI. Gas along tissue planes is characteristic of a necrotizing clostridial infection when seen on plain film imaging. However, this is a late finding accompanied by other clinically obvious signs that lead to the diagnosis. CT is more sensitive in detecting infections in deeper tissues. Subcutaneous emphysema and extensive edema can be visualized tracking along tissue planes on CT; however, these findings are nonspecific for NSTI. In general, a negative imaging exam should not be reassuring if there are other findings suggesting necrotizing infection. MRI is an unnecessary, costly, and time-consuming test that should not be in the algorithm if necrotizing fasciitis is high on the differential diagnostic list and could potentially be life threatening if hemodynamic instability occurs during the imaging.

Operative Intervention

Diagnosis of an NSTI mandates immediate operative exploration and aggressive debridement. Time until surgical debridement is the main predictor of survival. In cases where NSTI is not a clear diagnosis, operative exploration can be utilized as an additional diagnostic method. Findings consistent with a diagnosis of NSTIs include gray necrotic tissue, lack of bleeding tissue, murky appearing "dishwater" fluid, lack of muscle contraction upon stimulation with electrocautery, and the ability to finger dissect tissues with minimal resistance consistent with frank necrosis. If none of these operative findings are present after inconclusive laboratory results and physical exam findings, the incision used for exploration is minimal and can be packed with gauze. The patient then avoids an extensive procedure. However, if a necrotizing infection is found, extensive operative debridement can proceed until all necrotic tissue is removed. Surrounding tissue that has some erythematous or edematous changes, without clear necrotic tissue, can be preserved with planned daily serial exploration and debridement if necessary. Often these areas resolve after the necrotic burden of tissue is removed.

Consent should include a frank conversation with the family members and patient (if appropriate) about the significance of NSTIs. A discussion about the possible extent of the debridement and the need for skin graft, flap coverage, amputation, disarticulation, disfigurement, and repeated trips to the

operating room should be conveyed. Repeated debridement should occur until the patient is stabilized, there is no further evidence or extension of tissue necrosis, and healthy tissue is present. On average, NSTI patients undergo three to four operative debridements during their initial hospitalization. In extremity NSTI, the adage "life over limb" must be remembered. The decision to amputate an extremity affected by NSTI is difficult, especially in a child. However, it is inappropriate to attempt limb salvage by performing minimal and insufficient debridement in the setting of a rapidly advancing infection in a septic patient. In a patient with a perineal NSTI, the use of diverting colostomy or alternatively a rectal tube and stool softening medications may control the contamination until wound closure can be accomplished. Reconstruction or wound coverage is not considered until all evidence of infection is resolved and the patient is stable. Consultation with a plastic surgeon for complex reconstruction may be necessary.

Antimicrobial Therapy

Infectious disease consultants recommend obtaining cultures prior to initiation of antibiotics in most circumstances to provide data used to narrow the spectrum of antimicrobial activity. However, in NSTI source control via operative intervention is the first priority. Broad-spectrum antimicrobial therapy including coverage for gram-negative, gram-positive, and anaerobic bacteria should begin as soon as possible. Given the lack of tissue perfusion in deeper necrotic tissues, antimicrobial agents are unlikely to affect culture results prior to debridement, and thus intraoperative specimens should be sent for gram stain and culture even if systemic antibiotics have been administered prior to obtaining the sample. These results can be used to tailor the antibiotics once sensitivities are available.

There is no consensus on the length of treatment; however, it is reasonable to discontinue antibiotics once operative debridement is completed, the patient has been afebrile for 48–72 h, the WBC has normalized, and the patient is showing signs of clinical improvement. Infectious Disease Society of America recommends vancomycin (or linezolid) plus either piperacillin/tazobactam (or a carbapenem) or ceftriaxone and metronidazole as the initial empiric antimicrobial treatment (Table 108.1). If there is known GABHS or clostridium NSTI, and the patient is not penicillin allergic, the recommend regimen is penicillin with clindamycin.

Postoperative Management

Immediate postoperative management involves continued close monitoring in the intensive care unit and may entail supportive care of any organ failure that developed, with ventilator support, hemodialysis, or vasopressors. Additionally, wound care, pain control, nutrition, occupational and physical therapies, health psychology, child life, and social work are all important aspects to consider for the long-term wound care and healing needs similar to a patient with extensive burn injury. An evaluation and treatment algorithm for suspected NSTU is useful and helps avoid delays and confusion in the care of these complex patients (Fig. 108.4).

Complications

The severity of NSTI lends itself to the development of complications, especially during the critical illness phase of the disease. Among these complications are acute kidney injury and hospital-acquired infections such as central line-associated infections, ventilator-associated pneumonia, and urinary tract infections. Pediatric patients, healthier at baseline, are less likely to develop cardiac complications than the adult population.

Compartment syndrome is a complication of necrotizing myositis that occurs if the wound is not monitored and debrided appropriately and in a timely fashion. The delay in diagnosis due to the depth of the infection can lead to significant rhabdomyolysis, myoglobinuria, and subsequent acute renal failure. Pigmented casts are associated with renal failure due to rhabdomyolysis and contribute to renal tubular obstruction. Treatment for rhabdomyolysis begins with removal of necrotic tissue followed by hydration and alkalinization of the urine. Bicarbonate infusions have been suggested, but there are no studies showing benefit over aggressive fluid resuscitation to flush out the kidneys and prevent acute renal failure.

Wound Management

After the acute infection is under control, there is often a significant amount of tissue loss that requires coverage. Repeated dressing changes require significant pain medication and sedation in the pediatric population. Pain regimens should address procedural pain, background pain, and breakthrough pain. Daily moderate sedation using ketamine and midazolam can be performed at the bedside. Wound care in the operating room under anesthesia is an alternative; however, this is resource intensive for daily dressing changes. The use of negative pressure wound therapy (NPWT) provides temporary wound closure and pain control with less frequent need for dressing changes. NPWT can be considered if there is no evidence of infection remaining in a critically ill patient too sick for definitive wound closure.

Considerations for wound closure should include discussion in a multidisciplinary fashion. Prior to any wound closure, the patient must be clinically improving and the

Table 108.1 Antibiotic recommendations for pediatric NSTIs

Microorganism	Antibiotic options	Pediatric dosage—infants and children[a]
Streptococcus	Penicillin Clindamycin	100,000–400,000 U/kg/day IV, div q 4–6 h 15–25 mg/kg/day IV, div q 6–8 h
Staphylococcus aureus	Nafcillin Oxacillin Cefazolin Vancomycin (for resistant strains) Clindamycin	100–200 mg/kg/day IV, div q 4–6 h 100–200 mg/kg/day IV, div q 6 h 25–100 mg/kg/day IV, div q 6–8 h 10–15 mg/kg IV q 6–8 h See above
Clostridium species	Penicillin plus clindamycin	See above
Mixed infections	Piperacillin-tazobactam Vancomycin Meropenem Ertapenem Cefotaxime Metronidazole Clindamycin	300 mg/kg/day IV, div q 8 h—dosing based on piperacillin See above 30–60 mg/kg/day IV, div q 8 h 30 mg/kg/day IV, div q 12 h 75–200 mg/kg/day IV, div q 6–8 h 30 mg/kg/day IV, div q 6 h See above

(kg = kilogram, mg = milligram, U = units, div = divided, q = every, h = hour, d = day)

[a]Consult with pharmacist for age appropriate dosing

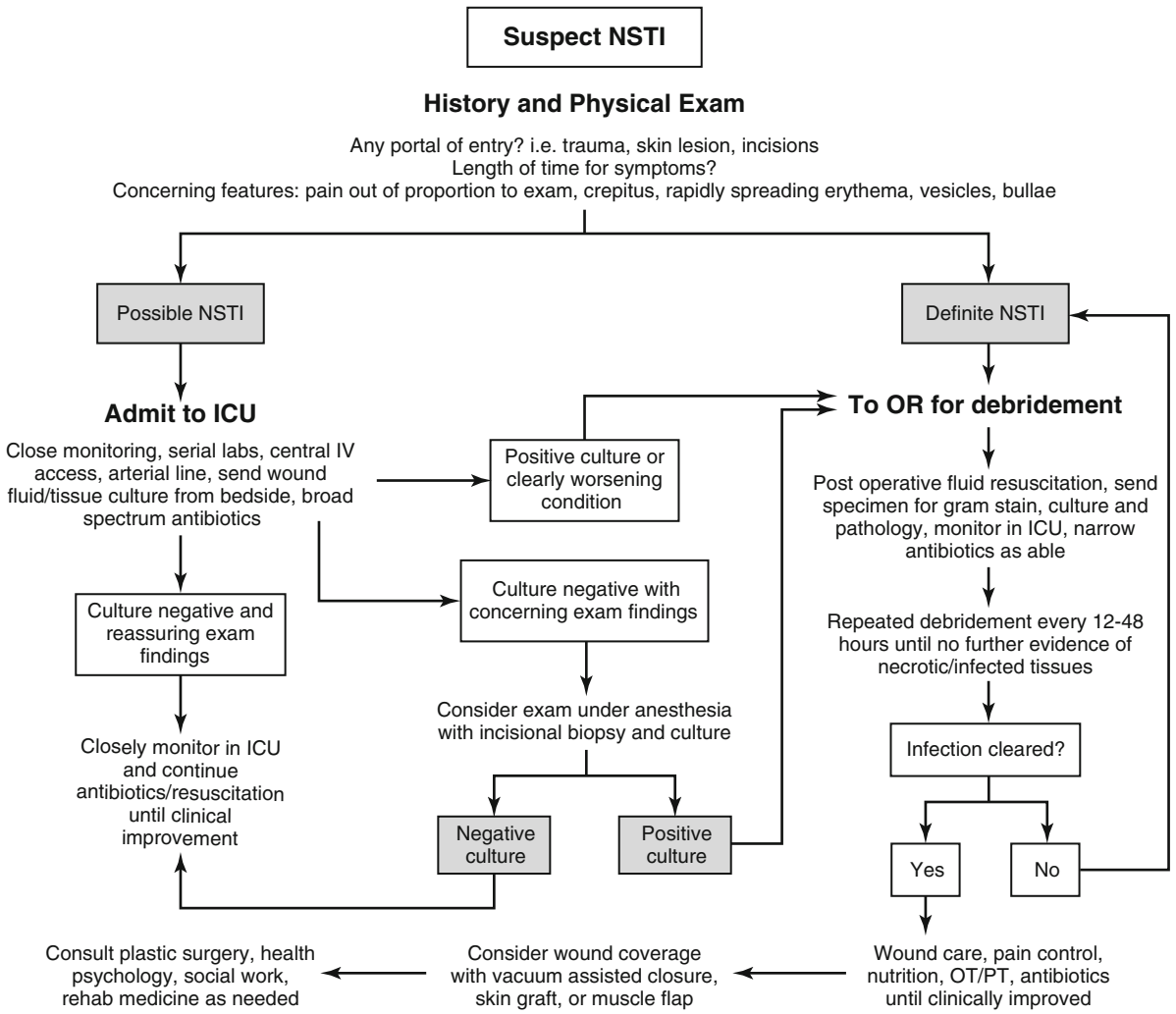

Fig. 108.4 NSTI evaluation and treatment algorithm

infection completely eradicated; otherwise, the wound coverage is doomed to fail. Consultation with a plastic surgeon after an assessment of the function and cosmesis goals is appropriate if flaps are needed for tissue coverage. Other wounds may only require an autologous skin graft. Delayed primary closure of large defects is possible, as long as the infection is eliminated, with the expectation that approximately 30 % will require reopening due to contamination or infection. This is a reasonable risk with approximately 70 % success and significant reduction in wound healing time as long as the wounds are assessed daily for signs of infection.

Alternative/Adjunctive Treatments

Adjunctive treatments such as hyperbaric oxygen (HBO) and intravenous immunoglobulin (IVIG) deserve mention. Theoretically, HBO increases oxygen concentration at the tissue level facilitating healing, bacterial clearance, and enhancing antibacterial efficacy. IVIG is used with staphylococcal and streptococcal bacterial infections to theoretically bind the exotoxins produced by these bacteria. Neither of these adjunctive therapies have strong clinical data to support their use. Furthermore, HBO therapy requires a high-pressure chamber that is not readily available in most health-care facilities and significantly limits the care of critically ill patients.

Recently, there have been reports suggesting success with a nonoperative approach to the treatment of NSTIs. It is difficult to interpret the validity of these studies without a clear understanding of the definition used for NSTI. It is highly improbable that nonoperative management of an NSTI was successful; rather these were likely severe non-necrotizing infections that responded to IV antibiotics. Unless one finds themselves in the most austere of environments without access to surgical intervention, it is recommended to perform rapid evaluation of the infection in the operating room where wide debridement can be performed with adequate anesthesia. In the worst cases of NSTI, the necrotizing tissue destruction can be seen advancing within minutes, leading to extensive debridement and massive tissue loss. These severe cases of NSTI will prove to be uniformly fatal if a nonoperative approach to care is taken.

Summary

NSTIs are extremely rare in children. It is a disease entity that most pediatric surgeons only see once in their entire career. It is a problem that requires an astute surgeon who correctly identifies and moves forward with operative management for the greatest chance of success and survival. Features that are suggestive of NSTI include rapid progression despite broad-spectrum antibiotics, pain out of proportion to skin examination, tenderness extending onto normal appearing tissue, and indistinct margins.

Mortality increases with delays in operative debridement greater than 12 h from initial onset. On average 3–4 serial debridements are necessary. Initial debridement should be attempted prior to interhospital transfer if possible. Broad-spectrum antibiotics should be started immediately, narrowed as possible, and continued until no further operative debridement is necessary and patient is showing signs of clinical improvement for at least 48 h.

Editor's Comment

A necrotizing infection in a child can test the judgment and skills of a pediatric surgeon like few other clinical problems can. The decision to rush a child off to the OR for disfiguring and potentially debilitating surgery must often be made quickly and on the basis of very little clinical information. And, of course, time is of the essence—a delay of even an hour can literally mean the difference between life and death. One does not have the luxury of waiting for imaging studies or delaying surgery until the next morning. To make matters worse, there are no pathognomonic early signs, only those that appear when it is too late to make a difference.

The decision to operate is made on the basis of the unforgettable appearance of a child who demonstrates (1) panic, irritability, or lethargy; (2) extreme discomfort (analogous to the exquisite pain of peritonitis or bowel ischemia); (3) weird but often subtle skin changes (violaceous hue, bullae, crepitus, severe and well-demarcated edema, numbness, exquisite tenderness); and (4) hemodynamic changes consistent with systemic sepsis, all out of proportion to that expected for a simple soft tissue cellulitis or abscess. Clinical suspicion must be high, and, when in doubt, it is better to perform an operation that later proves to have been unnecessary than to miss an opportunity to limit the extent of spread of a necrotizing infection.

Although fasciitis is the archetypical form of the disease, necrotizing infections can involve tissue planes other than fascia—muscle, tendons, or subcutaneous tissues (necrotizing cellulitis). The surgical approach is always the same—aggressive debridement of all necrotic tissue down to structures that bleed and are therefore probably still viable. As there are no reliable bedside indicators of disease progression, a planned second-look operation in 12–24 h should be strongly considered in all cases. Omphalitis can develop into a particularly devastating type of necrotizing infection because the full thickness of the abdominal wall is involved and might need to be debrided, exposing the abdominal contents and requiring extraordinary measures to achieve adequate coverage. A type of Fournier's gangrene can also occur

after inguinal hernia repair or circumcision, requiring extensive debridement of the perineum.

Reconstruction after the successful treatment of these devastating infections and their surgical aftermath can be quite challenging. Vacuum dressings and elaborate tissue transfer techniques have proven valuable, while hyperbaric oxygen therapy and the application of topical growth factors have not. Skin grafts applied directly to fascia or muscle in young children yield surprisingly good functional and cosmetic results. Early collaboration with a pediatric plastic surgery team is critical.

Invasive molds (rhizopus, mucorales, phycomycetes) can cause an aggressive necrotizing cellulitis in oncology patients with neutropenia. The treatment also includes emergency wide debridement, but the resection margin must not only be viable; it needs to be negative for hyphae on frozen section. The first sign is usually a dark purple or black spot on the skin ("mold spot"). We have a protocol that includes STAT bedside punch biopsy followed by an emergency trip to the OR if frozen section is positive for mold. Most patients need multiple debridements over the course of days. The open wound must be inspected 2–3 times daily for additional black spots of mold and another prompt debridement. The use of electrocautery should be avoided as cautery burns can simulate or camouflage new mold growth.

Suggested Reading

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Hemangiomas and Vascular Malformations

109

David W. Low and Oksana A. Jackson

Pediatric vascular anomalies can be classified into two broad categories: hemangiomas and everything else. More specifically, clinicians should understand the difference between hemangiomas (and a handful of other biologically active, proliferative vascular tumors) and biologically inactive, non-proliferative vascular malformations.

It is important to distinguish between the two, as the treatment and timing of intervention differ drastically. Parents today have ready access to the Internet and support groups, and it is not unusual for parents to be well informed, sometimes misinformed, by non-peer-reviewed online information. There are also medicolegal implications if parents sense they have been given a misdiagnosis or an inappropriate recommendation that has resulted in a permanent deformity.

Hemangiomas are the most common benign neoplasm of infancy, occurring in 10 % of full-term babies and as many as 25 % of premature babies weighing less than a kilogram. Many clinicians still erroneously call all vascular birthmarks hemangiomas, and since all hemangiomas regress spontaneously and most require no surgical intervention, parents are often advised to wait patiently for five years for the hemangioma to "disappear." Unfortunately, 30 % of hemangiomas leave significant deformities that cannot be entirely corrected by surgery, and vascular malformations have no ability to regress, leaving a population of children and parents with inappropriate therapy and overly optimistic expectations. Vascular malformations include abnormally formed capillaries, arteries, veins, lymphatics, or combinations of different vessels that occur in utero, are present at birth (although not always clinically evident), and persist throughout life.

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Spectrum of Lesions

The typical hemangioma presents in the first few weeks of life as a small strawberry-colored skin lesion that begins to grow out of proportion to the growth of the infant (Fig. 109.1). The proliferative phase may continue for 6–12 months until the angiogenic factors that stimulate endothelial growth begin to turn off. The first signs of regression include a pale grayish-white color change and a decrease in tissue turgor as the vessels begin to involute. The typical hemangioma takes about five years to fully regress.

A small subset of rapidly involuting congenital hemangioma (RICH) are present at birth and undergo rapid involution during the first year of life (Fig. 109.2). Conversely, non-involuting congenital hemangiomas (NICH) never seem to involute, are bluish with a fine telangiectatic pattern, and are warm to the touch, resembling arteriovenous malformations (Fig. 109.3). Subcutaneous hemangiomas appear blue but are nevertheless composed of proliferating capillary endothelial cells rather than larger vessels; they are still often erroneously referred to as "cavernous" hemangiomas. Some hemangiomas have both dermal and subcutaneous components and therefore present with a combination of protruding strawberry and subcutaneous blue bulky soft tissue (Fig. 109.4).

Although they can occur in any location, 60 % of true hemangiomas are located on the head or neck. Visceral hemangiomas (hepatic, splenic) can also occur. Babies with six or more cutaneous hemangiomas warrant an abdominal ultrasound to rule out this potentially life-threatening condition, which can also be associated with failure to thrive and high-output cardiac failure. In addition, hemangiomas are sometimes part of a syndrome or association. The PHACES association includes **p**osterior cranial fossa abnormalities such as Dandy-Walker cysts, a large facial **h**emangioma, **a**rterial anomalies, **c**ardiac defects or **c**oarctation of the aorta, **e**ye abnormalities, and **s**ternal cleft. Children with PELVIS syndrome have a large **p**erineal or sacral hemangioma associated

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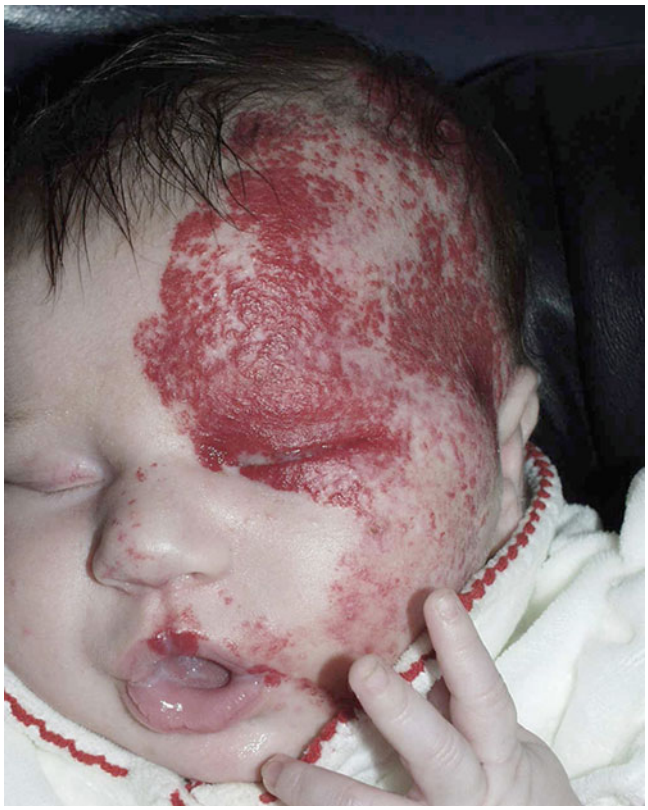

Fig. 109.1 Periorbital hemangioma in the proliferative phase

with **e**xternal genitalia abnormalities, **l**ipomyelomeningocele with a tethered spinal cord, **v**esicorenal abnormalities, **i**mperforate anus, and perineal **s**kin tag.

Other proliferative vascular anomalies that occur in infancy include *Kaposiform hemangioendothelioma* (Fig. 109.5) and *angioblastoma* (tufted angioma). Both can cause platelet-trapping and life-threatening thrombocytopenia (Kasabach-Merritt syndrome) and often require a tissue biopsy to make the diagnosis. *Angiosarcomas* are extremely rare malignant tumors that occur mostly in the elderly, but have been reported in children.

Pyogenic granuloma, more accurately termed *lobular capillary hemangioma*, occurs at any age, might be caused by minor skin trauma with inappropriate angiogenesis, and are characterized by small vascular lobules. They have a fragile epidermal cover and can bleed profusely (Fig. 109.6).

Vascular malformations, unlike hemangiomas, are present at birth (although not always clinically evident) and grow proportionately with the child. They are not vascular tumors, do not expand rapidly unless there is intralesional bleeding or lymph accumulation, and they do not regress spontaneously.

Capillary vascular malformations (port wine stains) are usually present at birth as patches of pink or purple skin, often in a dermatomal distribution (Fig. 109.7). If the ophthalmic dermatome (V1) of the trigeminal nerve is involved, there can be simultaneous ocular or CNS involvement (*Sturge-Weber syndrome*), which can cause glaucoma and seizures.

Macular stains ("stork bites") resemble port wine stains in the central forehead and posterior occipital/neck region

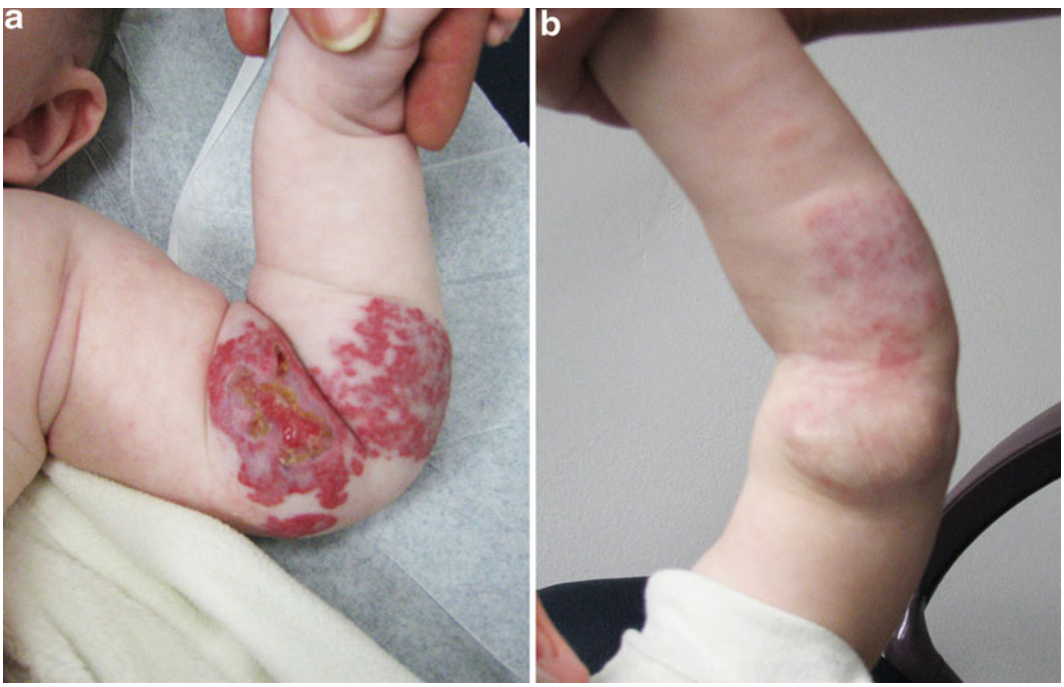

Fig. 109.2 Rapidly involuting congenital hemangioma of the arm (**a**) with marked improvement one year later (**b**)

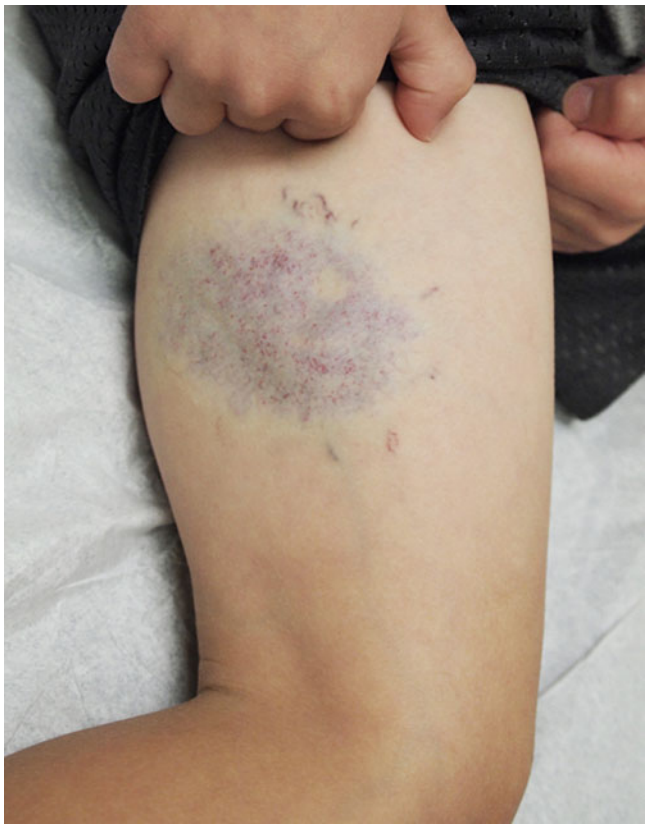

Fig. 109.3 Non-involuting congenital hemangioma of the thigh

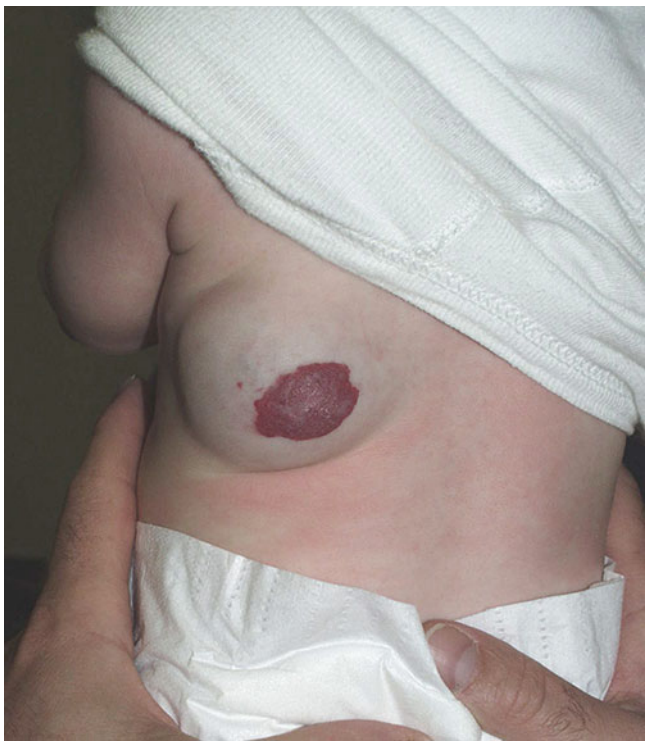

Fig. 109.4 Hemangioma of the back with both subcutaneous and dermal components

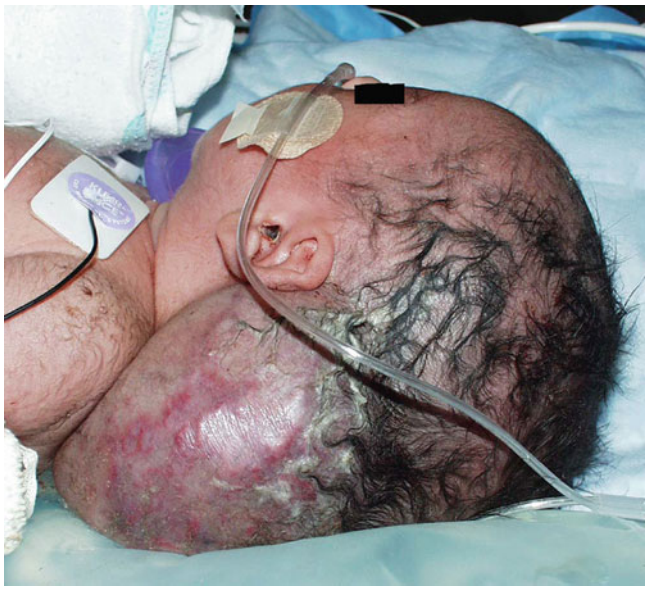

Fig. 109.5 Kaposiform hemangioendothelioma

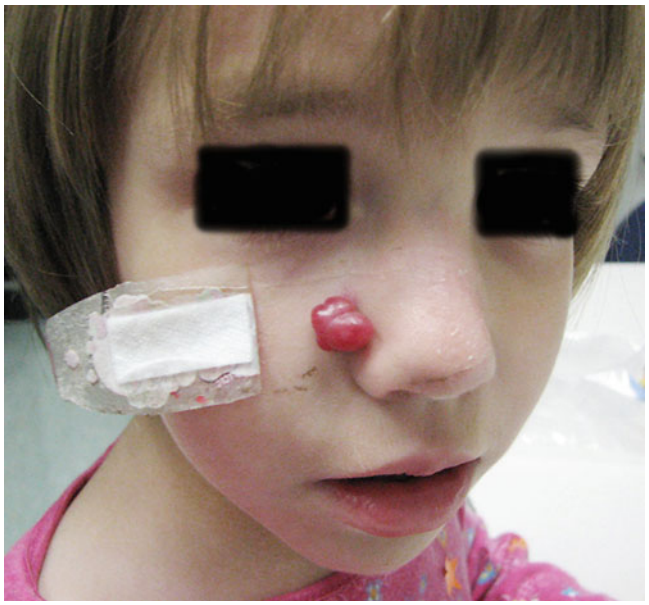

Fig. 109.6 Pyogenic granuloma

and have the inexplicable ability to lighten significantly during the first year of life.

Venous malformations appear as clusters of subcutaneous veins that engorge when the affected area is dependent and then empty and soften when the area is elevated (Fig. 109.8). Rapid enlargement can occur but is more likely due to vascular rupture and hematoma formation rather than actual growth of the abnormal vessels. Pain and swelling can also be associated with thrombosis of the dilated veins due to sluggish or stagnant flow. They can occur anywhere on the body and sometimes involve underlying subcutaneous tissue, muscle, or viscera.

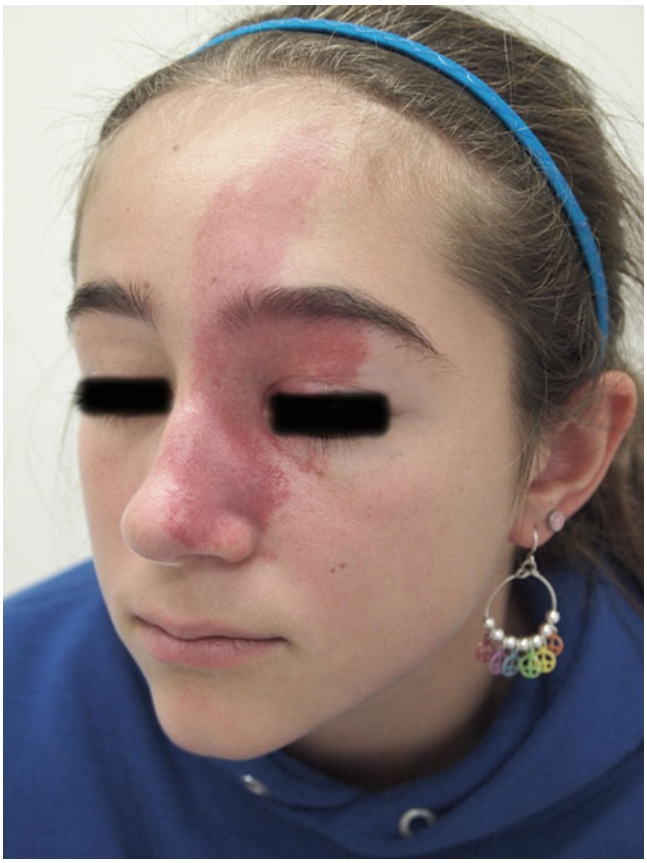

Fig. 109.7 Capillary vascular malformation (port wine stain)

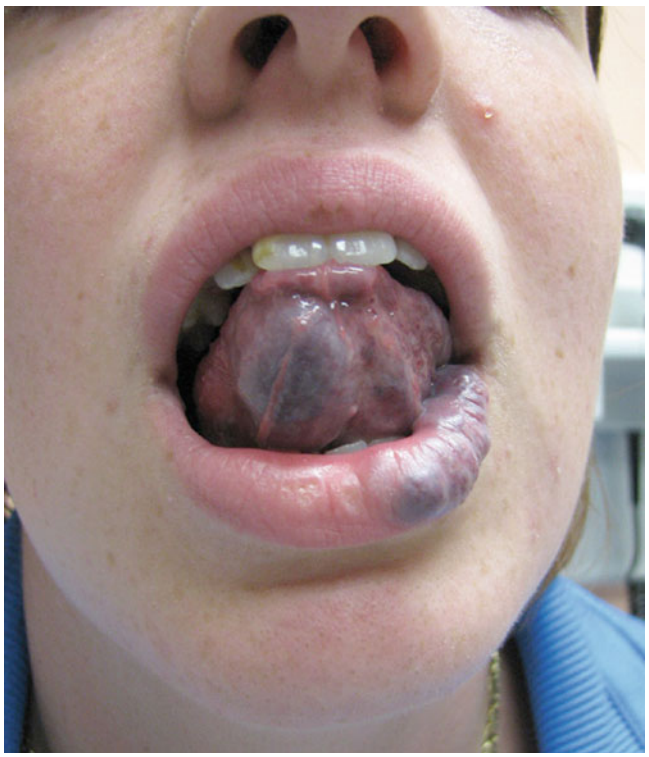

Fig. 109.8 Venous vascular malformation of the tongue and lower lip

Some can even be transmural: a venous malformation of the cheek might extend from the dermis, through the muscles, and into the submucosa. Venous malformations of the scalp occasionally communicate intracranially with the sagittal sinus.

The *blue rubber bleb nevus syndrome* (Fig. 109.9) is a genetically transmitted form of venous malformation that occurs in multiple sites all over the body, including the gastrointestinal tract, leading to bleeding and anemia or bowel obstruction due to intussusception. Venous malformations first appear in infancy, but the appearance of new malformations continues into adulthood.

Glomus tumors or glomangiomas look like small clusters of bluish-purple dermal or subcutaneous vessels and are composed of glomus cells, which normally regulate cutaneous circulation (Fig. 109.10). They are often tender to touch and can be exquisitely tender when located beneath a fingernail in the nail bed. Some have a genetic mode of transmission.

Lymphatic malformations sometimes manifest at birth as obvious soft tissue masses with severe soft tissue hypertrophy (Fig. 109.11). They are composed of thousands of tiny lymphatic cysts or several large macrocysts (in the cervicofacial region used to be called *cystic hygromas*). Dermal or mucosal involvement results in visible lymphatic vesicles. Blood can leak into the dermal lymphatics, resulting in crusty cutaneous lesions (*angiokeratomas*) that might appear to bleed profusely, but the discharge is predominantly lymph stained with blood pigmentation. Some large cystic lymphatic malformations appear to have the capacity to regress, which is probably due to repeated episodes of infection or inflammation that gradually cause fibrosis of some of the abnormal lymphatic spaces.

An *arteriovenous malformation* (AVM) presents as warm, pulsatile masses that occur anywhere on the body (Fig. 109.12). The AVM may include a patchy cutaneous capillary vascular malformation and hypertrophy of the involved area (Parkes-Weber syndrome). High turbulent flow within the lesion often causes a bruit or thrill to be appreciated on examination. There is sometimes a noticeable increase in size during puberty, presumably due to hormonal stimulation and additional vascular shunting.

Spider angiomas are common dermal vascular malformations with a central feeding vessel and a radiating pattern of tiny telangiectasias (Fig. 109.13). When compressed, the lesions blanch and then readily refill from the center to the periphery when pressure is released.

Klippel-Trenaunay syndrome describes a patchy capillary vascular malformation overlying a low-pressure, low-flow venolymphatic malformation, usually with local tissue hypertrophy (Fig. 109.14). In the lower extremity, a markedly dilated lateral vein is sometimes noted and represents a remnant from fetal development. The skin sometimes exhibits

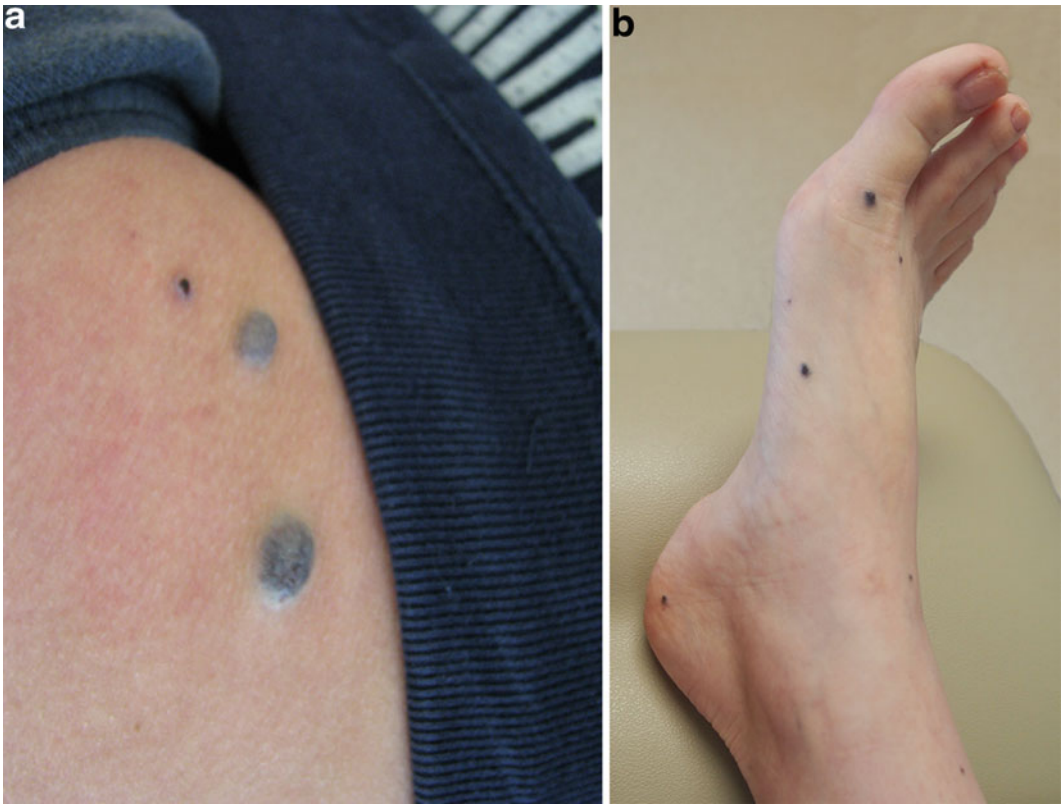

Fig. 109.9 Blue rubber bleb nevus syndrome (acquired venous malformations) of the shoulder (**a**) and the foot (**b**)

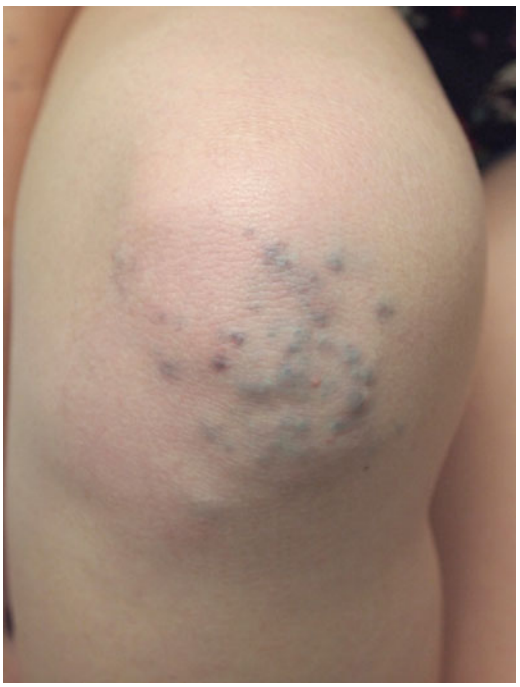

Fig. 109.10 Glomus tumor of the knee

multiple angiokeratomas scattered diffusely over the areas of port wine stain.

Proteus syndrome is an overgrowth condition that affects the entire body to varying degrees, creating vascular malformations, lipomas, epidermal nevi, and thickened, wrinkled plantar surfaces. John Merrick, the "Elephant Man," is thought to have had Proteus syndrome, not neurofibromatosis.

Maffucci's syndrome, which includes enchondromas of the hands, vascular malformations in unrelated areas, and rare angiosarcomas, is associated with a 15–20 % lifetime risk of developing chondrosarcoma.

Diagnosis

In most cases, history and physical examination allow an accurate diagnosis, making further testing unnecessary. In some patients, serial clinical examinations will help make the diagnosis, based upon the growth or lack of growth of the vascular anomaly, such as when a flat patch of vascular pigmentation initially thought to be a capillary vascular malformation (port wine stain) might become strawberry red and raised and increase its area of involvement, which is indicative of a hemangioma.

An MRI with contrast will usually distinguish the true etiology of a vascular anomaly and is indicated for atypical hemangiomas, when the diagnosis is in doubt, for lesions involving the head and neck (to assess the extent of periorbital, parotid, airway, or posterior cranial fossa involvement), and for those overlying the spine (to rule out lipomyelomeningocele with spinal cord tethering). An ultrasound to exclude hepatic or splenic involvement is indicated in children with more than six

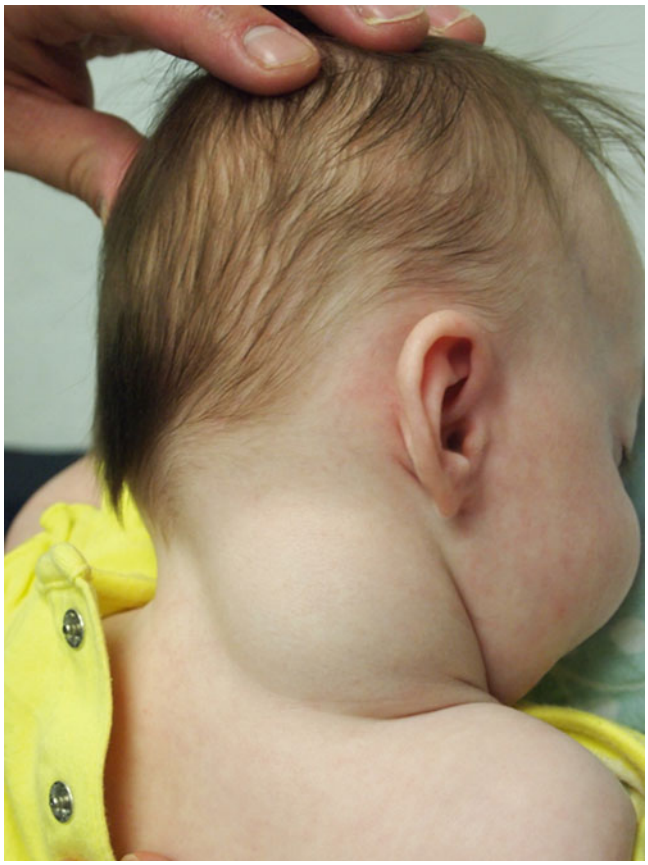

Fig. 109.11 Lymphatic malformation of the posterior neck in a newborn

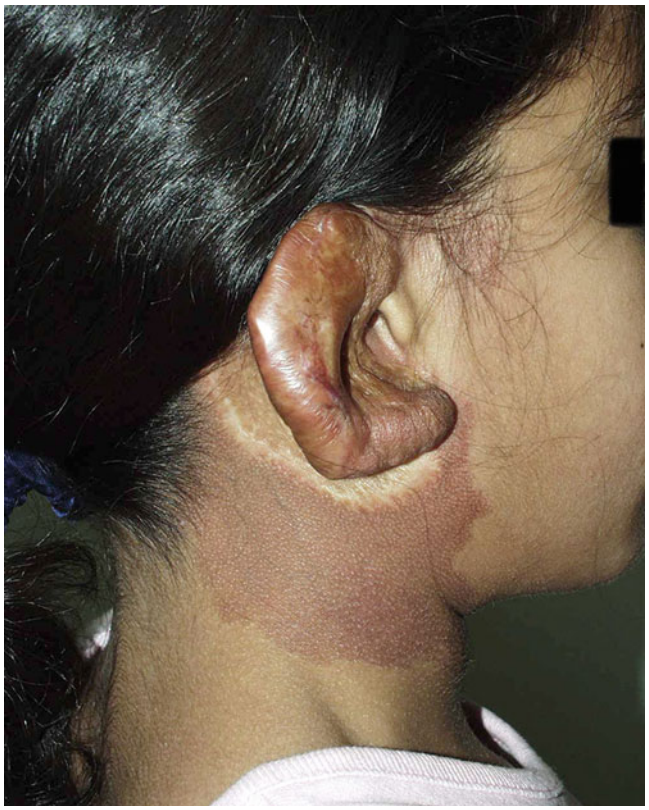

Fig. 109.12 Arteriovenous malformation of the ear and neck with an associated port wine stain

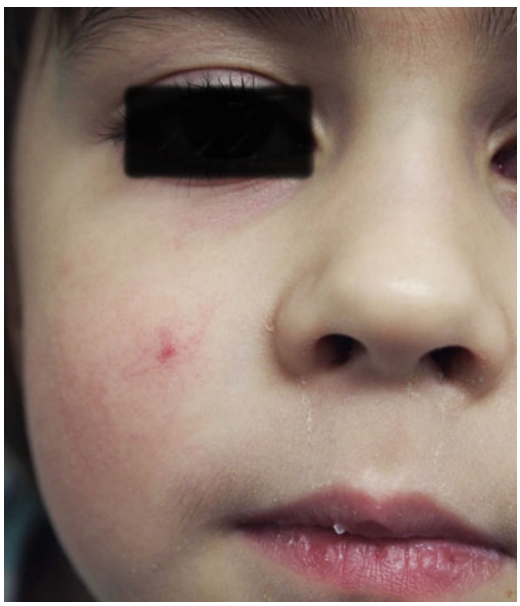

Fig. 109.13 Spider angioma, commonly seen on the face

cutaneous hemangiomas, while an echocardiogram is sometimes needed to rule out cardiac abnormalities if the lesion is thought to be part of a syndrome.

Although an MRI can usually demonstrate the extent of a vascular malformation particularly if they have muscular or visceral involvement, it is only recommended if it will change therapy. The best treatment for Klippel-Trenaunay syndrome with obvious involvement of the leg is conservative compression therapy, and so an MRI is not needed to make the diagnosis or to recommend therapy. On the other hand, if one is considering sclerotherapy or venous ligation with removal of abnormal veins, an MRV might be useful to not only document the course of the anomalous veins but also to ensure the presence of normal draining veins.

For a suspected AVM, an MR-angiogram is an excellent initial screening test, reserving an angiogram for those cases that require additional diagnostic and potentially therapeutic arteriography. Ultrasound guidance facilitates injection of lymphatic and venous malformations for sclerotherapy. Although urinary levels of basic fibroblast growth factor (bFGF) are elevated during the proliferative phase of a hemangioma, the test is rarely necessary as the diagnosis is usually obvious. Thyroid function tests are indicated in patients with hepatic hemangioma, as the active form of thyroid hormone can be inactivated by increased levels of type 3 iodothyronine deiodinase, resulting in hypothyroidism.

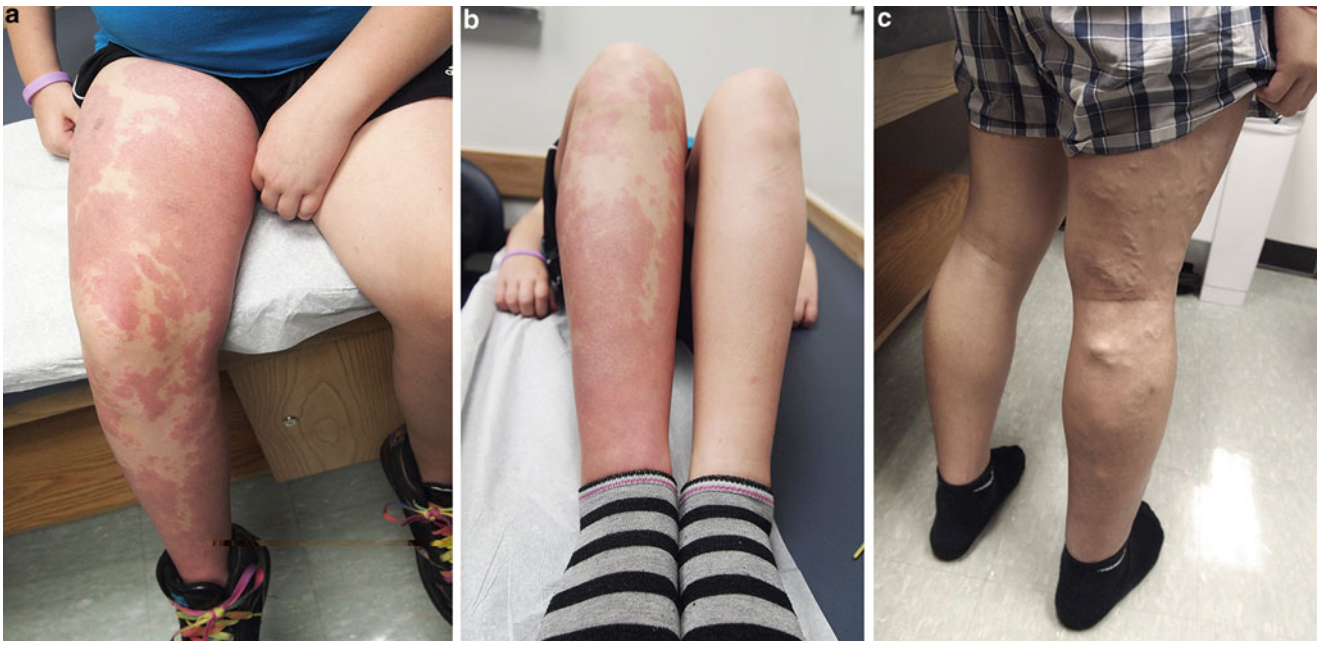

Fig. 109.14 (**a**) Klippel-Trenaunay syndrome. (**b**) Leg hypertrophy is evident with the patient supine and the lower extremities side by side. (**c**) Varicosities can lead to problems with localized intravascular coagulation

Treatment of Hemangioma

Pediatricians advise the vast majority of parents whose infants have hemangiomas to be patient and wait for eventual cessation of growth and gradual involution. Half of all hemangiomas will have to be involuted by age five years, 70 % by age seven. Although approximately 70 % of all hemangiomas will involute satisfactorily without requiring any further intervention, at least 30 % will leave a residual deformity in the form of redundant skin, dermal scarring, bulky fibrofatty tissue, or facial disfigurement. Hemangiomas of the lips, nose, and cheeks commonly leave behind redundant and distorted tissue that will require surgical attention and result in some kind of surgical scar.

With the advent of the Internet, parents are increasingly eager to take an active role in the management of their child's hemangioma. Rather than watch them become progressively more deformed, they desperately hope to abort the natural history of the hemangioma. They seek early laser therapy or surgical excision, and some will shop around until they find a surgeon who will take an aggressive approach. A balanced approach is necessary and the surgeon must always weigh the risks and benefits of a surgical scar and operative complications against the possibility that natural involution could have a better final result. Our personal philosophy is that because surgery leaves a scar 100 % of the time, one should be reasonably confident that natural involution will leave a worse deformity. Also, the decision to operate before complete involution increases the risk of bleeding and decreased visibility, which increases the risk of damage to nerves and other key anatomic structures.

Life-threatening subglottic hemangiomas and vision-threatening periorbital hemangiomas cannot be managed conservatively. Corticosteroids were long the treatment of choice for problematic hemangiomas, despite their many side effects including irritability, change in appetite, temporary and reversible growth suppression, hypertension, and Cushingoid appearance. At many institutions, propranolol has replaced corticosteroids as first-line therapy. First reported in 2008 to be able to suppress the growth and speed the involution of hemangiomas, beta-blocker therapy certainly appears to have far fewer side effects. Initiation of therapy usually warrants several days of inpatient observation and cardiology consultation for side effects such as hypoglycemia, hypotension, and bradycardia. Small hemangiomas have also been treated with topical beta-blocker (Timolol eye drops) twice daily, but similar to topical steroids or intralesional steroid injections, the rate, distribution, and amount of medication delivered are much less predictable.

Laser photocoagulation with a pulsed yellow-dye laser is sometimes useful for small, flat hemangiomas, but because the light can only penetrate about 1 mm into the dermis, it is generally not useful for bulky or subcutaneous lesions. Since most parents describe a few weeks of regression after laser therapy followed by some rebound growth, repeated treatments are often necessary to suppress the hemangioma until permanent involution occurs. The laser is also useful for painful or ulcerated hemangiomas. Although somewhat unpredictable, in many cases, laser therapy appears to be able to

suppress pain within 24–48 h, possibly by photocoagulation of the sensitive nerve endings in the lesion, and accelerate healing, perhaps by suppressing vascular proliferation.

In most situations, surgical excision or debulking is similar to excision of a nevus or cyst. Hemangiomas that leave redundant skin or excess fibro-fatty scar tissue will often benefit from elliptical excision, trading the hemangioma for a linear scar. The timing of excision is a judgment call that is influenced by the degree of deformity, the size of the hemangioma, the amount of residual vascularity, the location (less cosmetically important hemangiomas tend to carry less urgency), the anxiety level of the parents, and the experience of the surgeon. Large hemangiomas sometimes require staged excision, particularly if debulking surgery is elected prior to complete involution, increasing the potential for significant operative bleeding. Large hemangiomas in the lip or nasal regions benefit from early debulking to facilitate feeding and social acceptance, with the understanding that a secondary surgical revision will be necessary in the future.

Nasal tip hemangiomas commonly splay apart paired tip cartilages and leave behind excess skin and bulky fatty tissue after the vessels have involuted. Correction commonly requires judicious trimming of nasal skin and hemangioma and suturing the tip cartilages together. Lip hemangiomas are usually asymmetric, and surgical debulking or removal of a hemangioma essentially creates a cleft lip deformity. Techniques for cleft lip repair, often with minor adjustments to individualize the procedure for a given patient, provide a strategy for addressing these very challenging deformities (Fig. 109.15).

Subcutaneous hemangiomas that leave excess fibro-fatty tissue will occasionally be amenable to debulking by liposuction if enough time is allowed for complete vascular involution.

Scalp hemangiomas will often cause dermal scarring and damage the hair follicles, leaving a patch of alopecia. Excision (alopecia reduction) is the treatment of choice, rather than punch or micro-hair grafting.

Cheek hemangiomas can leave problematic deformities in an area that is normally very smooth. Surgical scars in the middle of the cheek are often very noticeable, and therefore one must be fairly certain that natural regression will leave a worse result than a surgical scar before proceeding with excision. Options for surgical intervention include standard elliptical excision, excision with a purse-string closure, carbon dioxide laser skin resurfacing, or pulsed-dye laser with sclerotherapy for residual vessels. Excision of redundant skin and subcutaneous tissue caused by a parotid hemangioma must be undertaken very carefully to avoid injury to branches of the facial nerve.

Ear hemangiomas can cause significant skin and subcutaneous excess, but the subcutaneous component often involutes dramatically. To avoid a soft tissue deficiency, it is often safer to postpone debulking until the ear hemangioma has almost completely involuted.

Treatment of Vascular Malformations

The treatment of *capillary vascular malformations* (port wine stains) most commonly involves the use of a pulsed yellow-dye laser. The wavelength can vary with the type of laser, but currently the third- and fourth-generation-pulsed yellow-dye lasers use a 595-nm wavelength, which is absorbed by oxyhemoglobin. The hand pieces most often deliver circular pulses of variable width and power density. A cryogen cooling spray to accompany each laser pulse decreases the pain of the laser pulse and protects the skin from thermal injury. Protective goggles for all personnel and protective goggles or corneal shields for the patient are essential. Depending upon the age of the patient and the location of the lesion, topical anesthetic cream or general anesthesia might be necessary. Clinicians must inform parents that despite multiple laser treatments (at least 6–8 and often more), it is highly unlikely that the birthmark will ever completely fade. Furthermore, the laser typically leaves extremely dark bruises for 2–3 weeks, and if the power density is too high or the pulses are delivered too close together, scarring can occur. Because it can take 2–3 months to see the full benefit of each treatment, laser treatments are separated by at least two months. The laser is not equally effective on all areas of the face, and it is less effective as one moves distally on the extremities towards the hands and feet. Parents and patients should be made aware that results are sometimes disappointing. Additionally, despite successful laser treatment, some will darken with age as residual vessels further dilate. In this situation, laser treatment can be resumed and might offer additional benefit.

Facial capillary vascular malformations, particularly those on the lips, can also cause significant hypertrophy, which often necessitates surgical debulking. Again, plastic surgical techniques for cleft lip repair or reconstruction can be applied to obtain cosmetically acceptable results after major debulking (Fig. 109.16).

The treatment of *venous malformations* might include laser therapy, sclerotherapy, surgical excision, or a combination of all three. Venous malformations of the head and neck are often best approached by sclerotherapy, as the malformation is usually transmural, visible just beneath the epidermis and through the oral mucosa. In such situations, surgical debulking may be accompanied by excessive bleeding that is difficult to control, inability to adequately resect the involved area, or excessive scarring and postsurgical deformity. A series of sclerotherapy sessions using alcohol or sodium tetradecyl sulfate under fluoroscopic or ultrasound guidance is often the best treatment option. The laser or milder sclerosing agents such as polidocanol can be used for superficial dermal components. The potassium titanyl phosphate or KTP laser, a 532-nm green light laser, delivers a continuous beam of laser energy rather than

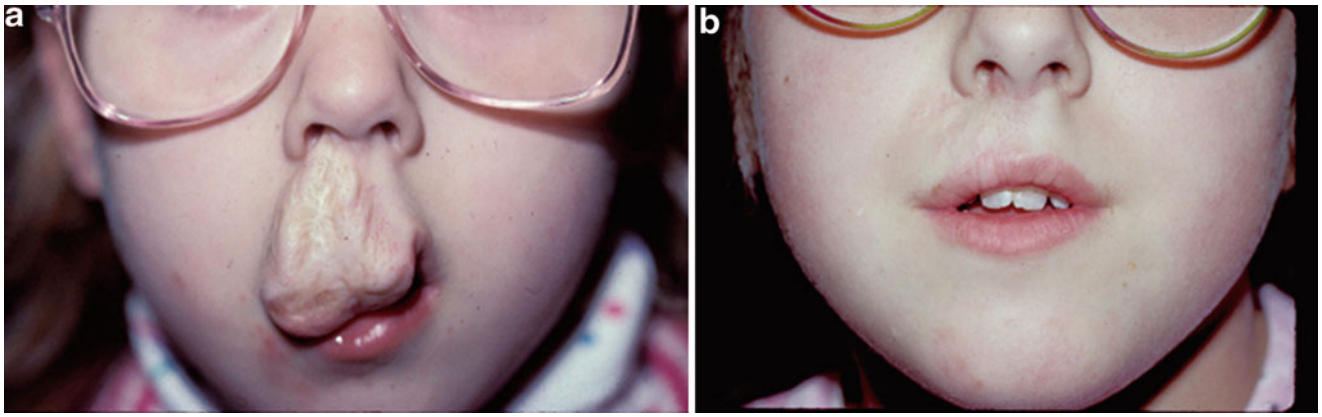

Fig. 109.15 Upper lip hemangioma (**a**) before and (**b**) after debulking

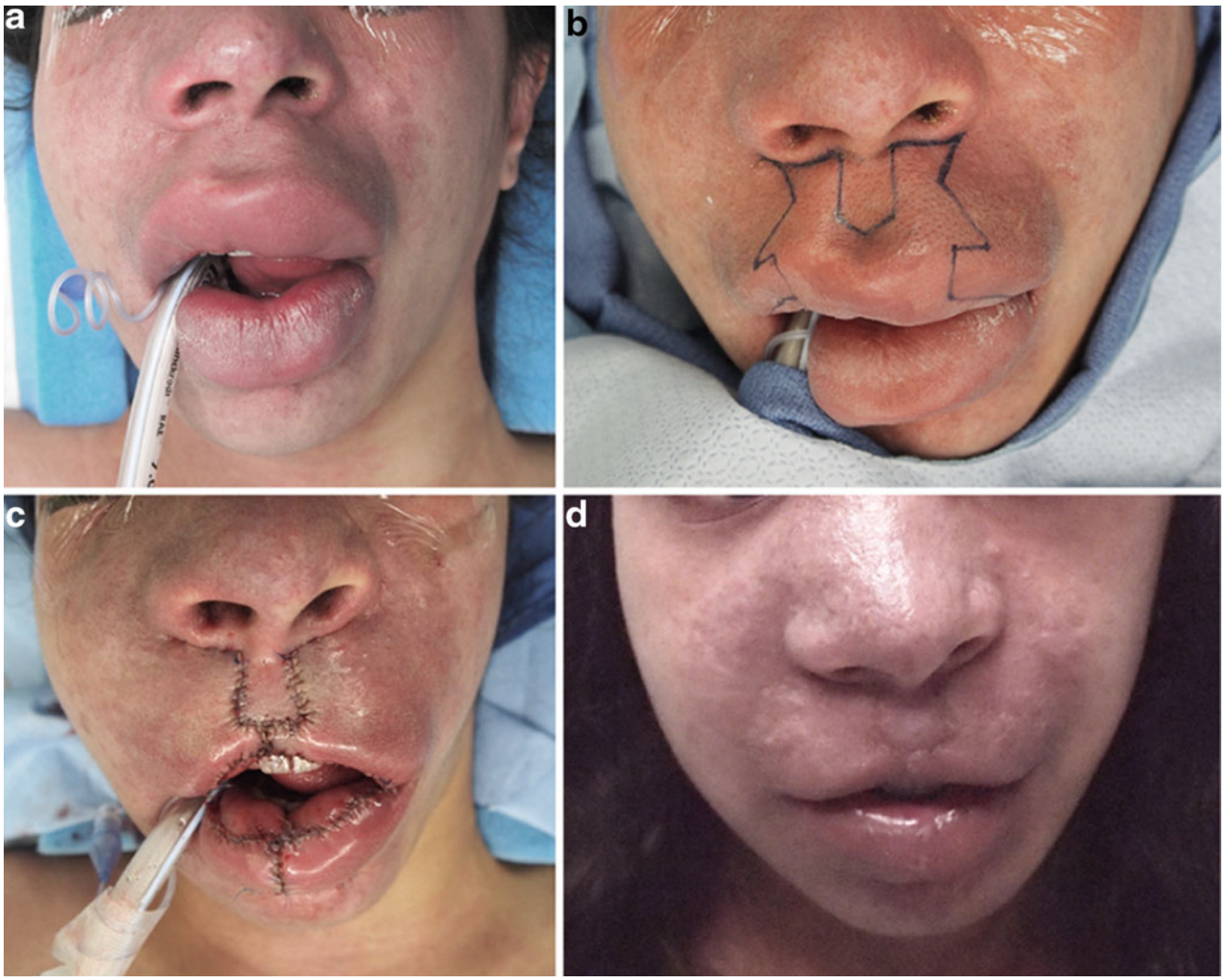

Fig. 109.16 Debulking strategy for a markedly hypertrophied upper and lower lip associated with a capillary vascular malformation: (**a**) preoperative appearance, (**b**) upper lip markings demonstrating lip tissue to be excised, (**c**) immediate appearance after debulking of the upper and lower lip, and (**d**) appearance 6 weeks later

pulses of light and is useful for intraoral coagulation. The laser light travels down a fiber-optic cable which can be inserted directly into the malformation for intralesional photocoagulation. However, the technique is highly operator dependent, the amount of laser energy delivered is difficult to judge, and the thermal effects can be difficult to limit, making it less precise than sclerotherapy.

Venous malformations of the tongue can be directly excised or significantly debulked with very limited blood loss by clamping the base of the tongue with cushioned vascular clamps. The incised edge can be over-sewn prior to release of the clamps. Because of the anticipated postoperative tongue edema, patients will require in-hospital observation for airway monitoring or overnight intubation.

Lower extremity venous malformations can be treated only if the malformation does not serve as the main vascular runoff for the involved leg. Sclerosis of a major venous malformation or varicosity using ultrasound guidance is commonly performed by interventional radiologists. To prevent the passage of sclerosant or clot into the circulation, the radiologist may occlude the draining vein with coils or glue, and it is occasionally necessary to ligate vessels that communicate with a major normal draining vein prior to an attempt at sclerotherapy. Large caliber varicosities such as those seen commonly along the lateral leg in patients with Klippel-Trenaunay syndrome (lateral vein of Servelle) may also be amenable to endovenous laser therapy, usually done by interventional radiologists with ultrasound guidance.

Lymphatic malformations are among the most frustrating of the vascular malformations to treat surgically. Hours of painstaking dissection often result in minimal benefit, facial nerve injuries, or postoperative edema that takes a very long time to subside. The best results are with macrocystic lymphatic malformations that are amenable to repeated sclerotherapy, often obviating direct surgical debulking. Sclerosing agents have included alcohol, doxycycline, and Picibanil (OK432, still awaiting FDA approval). Microcystic lymphatic malformations do not always respond to sclerotherapy and therefore require direct surgical debulking, especially for cervicofacial malformations and those in other areas that cannot be managed conservatively with compression garments. Sometimes a combination of surgical debulking and postoperative compression will help to maintain a reasonable decrease in size. The carbon dioxide laser can be used to vaporize cutaneous lymphatic vesicles, offering limited palliative improvement for draining dermal lymphatics. Recently, the immunosuppressive drug rapamycin (Sirolimus) has shown significant efficacy in suppressing the progression of lymphatic and venolmphatic malformations, thought to be through a biochemical pathway that inhibits angiogensis

Arteriovenous malformations can either be followed conservatively with periodic palliative selective embolization or excised in their entirety. Simple ligation of the major feeding vessels without removal of the malformation is contraindicated, as the AVM will readily recruit flow from other regional arteries, making future management even more difficult. Preoperative embolization a day prior to surgery might significantly decrease intraoperative blood loss and also provide the surgeon with a vascular roadmap. Ideally, the malformation should be completely excised to remove all vascular shunting. The subsequent defect sometimes requires sophisticated flap reconstruction to optimize the postoperative outcome.

Complications

Surgical excision of a vascular lesion always carries a risk of bleeding; therefore, the surgeon must decide which cases require a type and cross match or preoperative embolization. If the risk of bleeding is significant, most parents will prefer a directed donor unit in spite of evidence that banked blood statistically is safer. Particularly with hemangiomas, the surgeon should be confident that the surgical scar will be better than the deformity left by natural involution. Hemangiomas that are debulked prior to complete involution can have greater intraoperative bleeding, increased risk of nerve damage due to poor visualization and distorted anatomy, and poor healing with dehiscence of the incision since sutures are often placed into skin edges compromised by vascular tissue. When the breast is involved in girls, early debulking is contraindicated as injury to the breast bud will affect normal breast development.

Intraoperative blood loss can be decreased by application of a tourniquet when an extremity is involved, injection of lidocaine with epinephrine around the area to be excised when a tourniquet cannot be utilized, digital pressure surrounding the lesion to be excised or debulked, temporary application of cushioned vascular clamps on tongue and lip lesions, and preoperative embolization in the case of arteriovenous malformations. For small lesions that can be excised in their entirety, operating in the surrounding normal tissue, thus avoiding incisions within the vascular lesion itself, minimizes blood loss. The bayonet bipolar cautery can be extremely useful as a hemostatic dissector. In some cases, residual parts of a hemangioma or vascular malformation can be simply cauterized between the tips of the bipolar forceps without having to excise them. This can be especially useful with larger malformations and hemangiomas where the surgeon is performing a debulking rather than a complete excision. Surgical drains should be placed for large excisions, especially with venous and venolymphatic excisions, to prevent problematic hematomas and seromas.

The use of any laser can cause scars, ocular injury, or operating room fires. The pulsed-dye laser for port wine stains can cause a flash burn if it causes upper lip and nasal hairs to singe in an oxygenated environment.

Editor's Comment

"Birthmarks" cause a great deal of anxiety and sometimes genuine anguish, for parents and grandparents. Vascular lesions should always be taken seriously. Parents need to be made aware of all available options and actively involved in the decision-making process. All too often, especially with hemangiomas, their concerns are casually dismissed because the lesion is considered merely cosmetic or likely to resolve spontaneously. The care of children with vascular malformations has also greatly improved with the increased use of interventional radiographic techniques such as embolization and sclerotherapy, as well as the emergence of the multidisciplinary "vascular malformation clinic" that makes available the expertise of devoted specialists and state-of-the-art treatments. Large dermal lesions pose a challenge because the aesthetic results of surgical therapy might be no better than if the lesion were left untreated. These patients are best treated by an experienced pediatric plastic surgeon or vascular malformation team.

Subcutaneous lesions cause a significant amount of angst for parents because of concerns about a potential malignancy. Unless imaging studies confirm with a high degree of certainty that the mass represents a hemangioma and is therefore likely to resolve spontaneously, most of these patients should be offered excision. If there is any possibility of involvement of deeper structures, an ultrasound or MRI should be done to avoid surprises in the operating room. It is probably unnecessary to leave a drain except when very large tissue flaps are created. It is usually possible to ignore a postoperative seroma, unless it is symptomatic or infected, in which case it can be drained painlessly with a needle placed directly into the incision, which is insensate. Recurrence of a vascular malformation that is completely excised is generally uncommon; notable exceptions include lymphatic malformations and intramuscular venous malformations, for which embolization or sclerotherapy should be considered. Large facial hemangiomas, especially those that threaten the airway or compromise vision, pose a significant dilemma. Even if they resolve spontaneously, the fibro-fatty residual can be cosmetically significant.

Propranolol has replaced corticosteroids as the primary medical therapy for hemangiomas and in many ways has been revolutionary. Patients should be carefully monitored for potentially serious adverse effects as well as unforeseeable consequences. The drug should be administered by experienced clinicians as part of a carefully thought out and monitored protocol rather than simply prescribed in a cavalier manner or outpatient setting. Intralesional corticosteroid injection, especially for hemangiomas of the airway, seems to be a useful adjunct in some cases but also requires expertise and experience to avoid a devastating complication.

The best advice in these scenarios is to involve the parents completely in the decision-making process. This is partly because managing expectations is one of the most important aspects of what we do as surgeons and because it is the right thing to do in all dealings with parents when involved in the care of their child, but also because parents today are very savvy and informed—even if they have not read all about medical therapy and sclerotherapy before they come to see us, they will invariably have learned about it during the course of their therapy or a long period of observation, in which case they might begin to doubt our honesty and humility. In the event of a less-than-perfect cosmetic outcome, which is likely regardless of the therapeutic path taken, they will begin to question whether another course of action might have had a better result. Therefore, one should plan to spend a great deal of time explaining all potential therapeutic options, discussing and defending the specific reasons why you feel one option is better than another, and answering many questions regarding the options. Of course, frequent follow-up is important in this regard as well.

Suggested Reading

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Disorders of the Breast

110

Tiffany Zens and Lee G. Wilke

Breast disease can occur at any age, but the majority of breast abnormalities in children are benign. Common presenting symptoms include breast enlargement or asymmetry, abnormal nipple development, or discharge, pain, skin changes, or discrete masses. As with any new medical concern, the provider must first conduct a complete history and physical examination. It is important to assess the onset of symptoms, including changes in shape or size over time and correlation with menstrual cycles, associated pain, skin changes, and presence of nipple discharge. In addition, the provider must ask questions regarding developmental abnormalities, prior surgery in the region, recent trauma, age of menarche, personal and family history of malignancy, history of chest wall radiation, and current medications. On physical examination, the provider should assess for current Tanner stage, developmental anomalies, breast symmetry, nipple discharge, axillary and supraclavicular adenopathy, skin changes, and discrete breast masses. When evaluating a breast mass in a child, the provider should take note of the size, mobility (fixed or mobile), location, and texture (firm, rubbery, well circumscribed).

Although the primary evaluation of a pediatric breast abnormality is based on physical examination, breast ultrasound is a useful next step in helping better define the mass. It can help distinguish solid from cystic masses, as well as physical characteristics and vascularity. In general, benign breast masses seen on US are round or oval, uniformly hyperechoic, well-circumscribed masses with macrolobulations and a thin echogenic capsule. In contrast, concerning masses are often irregularly shaped with spiculated margins and have microlobulations, microcalcifications, and ductal extension. Mammography is rarely used in the evaluation of pediatric breast disease because it exposes the child to ionizing radiation and is not sensitive in this population due to the high density of fibroglandular breast tissue.

Given the extremely low incidence of breast malignancies in children and the potential of diagnostic procedures and surgery to cause damage to the developing breast, the vast majority of pediatric breast disease is treated conservatively. Often the patient is observed with serial examinations and imaging over several months or menstrual cycles to evaluate for changes. 10 to 40 % of breast masses will completely resolve, and those that do not can often be safely observed until the child has completed puberty. Core biopsy should be considered for all suspicious masses that cannot be definitely determined to be benign on examination and imaging. Surgery is reserved in patients with large lesions that are rapidly growing, symptomatic, or without regression on follow-up, in cases of considerable psychological stress to patients or family, and in patients with malignancy or strong suspicion of a malignancy based on a biopsy.

Breast Development

Breast development begins at approximately 4–6 weeks gestation when thickened streaks of ectoderm form along a line between the anterior axilla and the labia majora. These curvilinear streaks are called the milk lines, milk ridges, or Hughes lines. Between week 8–10, the proximal and distal aspects of the milk lines atrophy. The area over the pectoralis starts to develop into breast tissue when the ectoderm grows into the mesenchyme and forms the primary mammary bud. First there is branching, budding, canalization, and growth of lactiferous ducts and lobules of the breast. Next, the fibrous breast tissue, connective tissue, and adipose breast tissue form. Finally, the areola and nipple form at 20–23 weeks gestation as a depressed, inverted structure that will eventually elevate and evert. A palpable breast bud is present by 34

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weeks gestation. Breast buds will persist and even enlarge over the first 6–12 months of life due to maternal hormones, but eventually involute.

The second stage of breast development, thelarche, occurs with the onset of puberty. The average age of thelarche is nearly 9 years for African American girls and about 10 years for Caucasian girls but can occur between 8 and 13 years old. Hormones mediate the growth of breast tissue. Estrogen promotes the development of fibroadipose tissue and lactiferous ducts. Progesterone mediates lobular growth and alveolar budding. Full breast development occurs over the course of 2–4 years as ducts elongate and branch into terminal duct lobular units. During this time period, the child will progress through the five Tanner stages of breast development (Table 110.1). Menarche usually occurs 2 years after thelarche. Premature thelarche is defined as a child who develops breast tissue before age 6–7 years old in African American girls or 7–8 years old in Caucasian girls. If this is an isolated finding, often the child can be observed for a short period of time and the breast tissue will regress. In cases of coinciding axillary or genital hair growth or vaginal bleeding, the child should be referred for a formal work-up for causes of precious puberty including estrogen-producing lesions of the ovary or adrenal gland.

Anomalies in Pediatric Breast Development

Although the developing breast is often nodular and asymmetric, there are several anomalies of pediatric breast development that should be recognized and may result in referral to a surgeon.

Polythelia and Polymastia

Polythelia (supernumerary nipple or accessory nipple) is an anomaly of breast development affecting 1–2 % of the population. It is most often unilateral but can be bilateral in in 30-35% of children with polythelia. These supernumerary nipples are located along the milk line in 95 % of cases. Polythelia has been linked to renal anomalies, so a renal ultrasound is often indicated. Supernumerary nipples are benign but may be removed for cosmetic reasons.

Polymastia (accessory breast tissue) commonly occurs in the axilla or just below the native breast tissue but can be found anywhere along the milk line. Accessory breast tissue is often not appreciated until pregnancy or puberty. Although polymastia is benign, it may require resection for cosmetic reasons or due to cyclic pain or irritation. Accessory breast tissue is at risk of developing any breast pathology, including fibrocystic changes, mastitis, fibroadenomas, and malignancies.

Athelia and Amastia

Athelia and amastia are a congenital lack of the nipple-areolar complex or both the nipple and breast tissue, respectively. The etiologies of these conditions are unknown but thought to be a result of either lack of formation or obliteration of the milk line. Bilateral amastia is associated with Poland's syndrome. A congenital anomaly is found in approximately 40 % of patients with amastia. Medical causes of androgen excess or ovarian failure should be investigated if the child presents with other abnormalities in secondary sexual characteristics or delayed puberty. Reconstructive surgery for athelia is often deferred until after puberty and consists of tissue reconstruction and tattooing. If amastia is present, nipple reconstruction can be performed after breast augmentation is completed.

Juvenile Hypertrophy (Virginal Hypertrophy)

Juvenile hypertrophy (also known as virginal hypertrophy) is a condition of very rapid large breast development over a short period of time. This growth is thought to be secondary to excessive end-organ sensitivity to hormones and is seen after the onset of menarche or during pregnancy. Breast tissue in these patients has a normal number of hormonal receptors, and serum hormonal levels in these adolescents are unremarkable. Histology shows irregular distribution of ducts and intraductal hyperplasia within a dense hypocellular stroma but no lobular units.

Juvenile hypertrophy can be very symptomatic with breasts weighing up to 50 lb (Fig. 110.1). As a result, patients often complain of neck and back pain, breast pain, skin changes, and

Table 110.1 Tanner stages of breast development

Stage 1	Elevation of the breast papilla only
Stage 2	Elevation of the breast and papilla as a small mound and enlargement of the areola diameter. The areola becomes pink
Stage 3	Further enlargement of the breast and areola with no separation of their contours. Montgomery's tubules appear
Stage 4	Further enlargement and projection of the areola and papilla to form a secondary mound above the level of the breast
Stage 5	Projection of the papilla only and recession of the areola to the contour of the breast

dilated superficial veins. Spontaneous resolution is rare. Treatment for juvenile hypertrophy includes hormonal therapy with medroxyprogesterone or tamoxifen for several months prior to consideration of surgery. The goal of treatment is to provide stabilization of the breast growth prior to a reduction surgery. If a reduction mammoplasty is done, hormonal therapy may need to be continued postoperatively as there have been documented cases of recurrence. When the hormonal therapy is discontinued, the patient should be seen at short intervals to ensure the hypertrophy does not recur. Juvenile hypertrophy carries no increased risk of breast cancer.

Tuberous Breast Anomalies

Tuberous breasts are characterized by breasts that have limited dimensions at the base, with an overdeveloped nipple-areolar complex. They can be noted as a unilateral or bilateral phenomenon. The etiology is unknown but thought to be secondary to superficial fascia that is abnormally adherent to the dermis and restricts medial and lateral breast expansion, causing the breast to expand preferentially forward. Another possible etiology is abnormal involution of the milk line during development. This anomaly of breast development can be very severe and disfiguring in some young girls. Although tuberous breast anomalies are benign, they often require surgical reconstruction. An experienced plastic surgeon should be consulted as the reconstruction of this anomaly is often complicated, requiring breast augmentation, release or scoring of the base, and lowering of the inframammary fold over the course of one or multiple surgeries.

Fibrocystic Changes

Fibrocystic changes are common in adults but can also occur in adolescent girls. Patients typically present with complaints of cordlike breast thickening and lumps that enlarge and become tender during menses. Although the etiology of this disorder is not completely understood, it is benign and thought to be secondary to an imbalance of estrogen and progesterone. Diagnosis can be made based on history and serial examinations. US can be helpful to rule out a discrete mass. Conservative treatment includes encouraging young women to wear supportive bras. Additionally, oral contraceptives can improve symptoms in 70–90 % of patients, and NSAIDs are often an effective analgesia.

Gynecomastia

Gynecomastia is a condition that affects two thirds to three fourths of adolescent boys and is characterized by abnormal breast enlargement. Gynecomastia can be described as either physiologic or pathologic. Physiologic gynecomastia occurs in three age groups: infants, pubertal boys, and elderly men. In boys, the peak age of onset during puberty is 13–14 years. Gynecomastia can be unilateral or bilateral and typically resolves over the course of 2 years. The etiology is unknown but is thought to be due to either abnormalities in leptin production or a decrease in the testosterone-to-estrogen ratio, often secondary to increased peripheral testosterone to estrogen conversion in excess body fat. Pathologic causes of gynecomastia may be secondary to endocrinopathies, including estrogen-producing Sertoli or Leydig cell tumors, adrenal cortical tumors, gonadotropin-secreting tumors, and prolactinomas. Medical

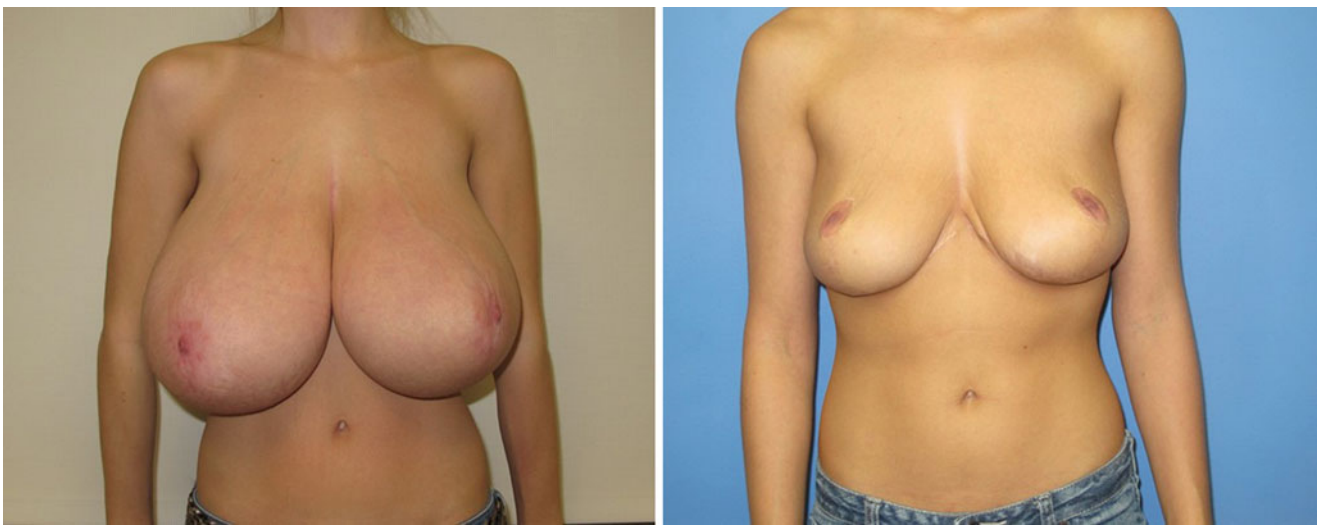

Fig. 110.1 Juvenile hypertrophy in a 19-year-old F (**a**) pre- and (**b**) postreduction

conditions, including liver disease, Klinefelter syndrome, hyperthyroidism, and neurofibromatosis type 1, can all cause gynecomastia. Finally, drugs, including marijuana, spironolactone, ketoconazole, anabolic and corticosteroids, cimetidine, antipsychotics, digitalis, and tricyclic antidepressants, have all been reported to induce gynecomastia.

Diagnosis of gynecomastia often is based on clinical presentation and physical examination and does not require imaging. Depending on the severity of breast development, a medical work-up for possible pathologic causes might be warranted or a termination of a causative medication. In severe cases, medical treatment with anti-aromatase or antiestrogen medications may be needed. Surgical options for the treatment of gynecomastia include ultrasound-assisted liposuction, skin excision, nipple replacement, and mastectomy, but should be done by an experienced plastic surgeon or breast surgeon.

Benign Pediatric Breast Masses

Pediatric breast masses can be benign or malignant, though the vast majority are benign. Nevertheless, they create a great deal of anxiety for the patient and her parents and therefore require a thoughtful and systematic approach.

Fibroadenoma

The most common breast mass in children is the benign fibroadenoma, accounting greater than 70 % of the cases. Fibroadenomas arise from breast lobules and surrounding stroma and are estrogen sensitive. The mean age of presentation is 15–17 years old. Fibroadenomas present as a discrete, rubbery, mobile, painless breast mass most often in the upper outer quadrant. They are bilateral in 10 % of cases and multiple in 10–15 %. Fibroadenomas are rarely seen in males because they lack terminal duct lobular units. Fibroadenomas are more common in African American adolescents, who are also more likely to have multiple or bilateral lesions. The average size of a fibroadenoma is 2–5 cm. Giant fibroadenomas refer to those that are 5–10 cm, but this classification does not change the pathologic diagnosis. Because these masses are estrogen sensitive, they will grow during pregnancy (but not necessarily with the menstrual cycle). Their natural progression is slow growth until eventual regression. Nearly 40 % of fibroadenomas can be expected to resolve completely over the course of 7–9 years.

Fibroadenomas can be classified as simple or complex. Complex fibroadenomas contain cysts, sclerosing adenosis, epithelial calcifications, and apocrine metaplasia on histologic evaluation. Although fibroadenomas are benign and should not be considered a precancerous lesion, complex fibroadenomatous disease is associated with a slightly higher breast cancer risk over the next 20 years.

After physical examination confirms suspicion of a fibroadenoma, the next step is an ultrasound. On ultrasound, fibroadenomas appear as well-circumscribed, round or oval, microlobular, uniformly hypoechoic masses with posterior acoustic transmission and avascular by color Doppler. A mammogram should only be used in patients under the age of 25 if the ultrasound characteristics are not definitive for fibroadenoma.

If imaging and physical examination are consistent with a fibroadenoma, no further intervention is required. Fibroadenomas can safely be observed with serial examinations and ultrasounds, usually repeated every 6 months for 2 years and then as needed if the mass has remained stable during this time. For patients with masses greater than 5 cm or those with rapid growth over a short period of time, biopsy is recommended to confirm the diagnosis and exclude a phyllodes tumor or juvenile fibroadenoma. Excision can then be performed if there is any discrepancy with a core needle biopsy or patient preference for removal based on symptoms. Typically excision is recommended for those lesions that are rapidly growing to ensure the mass can be removed with a more cosmetic incision. Excision is typically done with a circumareolar incision, and the breast tissue is minimally divided or separated down to the mass where it is excised with a combination of finger dissection and electrocautery. Negative margins around a fibroadenoma are not necessary, and thus the majority of these lesions can be "enucleated" from the surrounding tissue. On pathology, fibroadenomas will appear as a smooth or lobulated gray-white gelatinous mass with a pseudocapsule. Histology will demonstrate a proliferation of epithelial stroma and myoepithelial elements in the terminal lobular unit.

Juvenile Fibroadenomas

Juvenile fibroadenoma is an uncommon variant of the fibroadenoma, representing 7–8 % of all fibroadenomas. Juvenile fibroadenomas demonstrate rapid growth with an average size of 5–10 cm. They are often associated with overlying skin changes including ulcerations and distended superficial veins (Fig. 110.2). These fibroadenomas can occasionally not be differentiated from a phyllodes tumor on imaging or biopsy. For both cosmetic reasons and for pathologic confirmation, they should be excised. Pathology reveals multilobulated, cleft-like depressions and cysts similar to a phyllodes tumor. Histology demonstrates hypercellular stromal proliferation composed of spindle cells and myxoid stroma with a few mitoses within the stroma. Despite hypercellular changes, which may include some atypia, no future risk of malignancy is seen with the juvenile fibroadenoma.

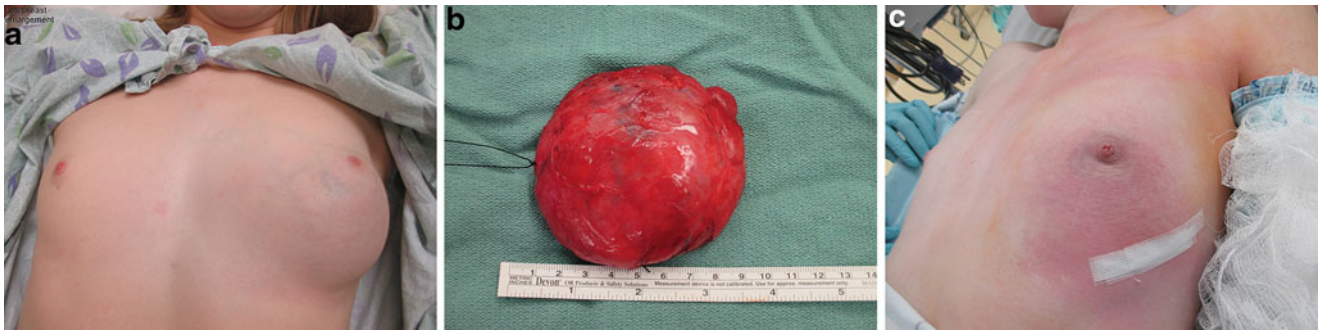

Fig. 110.2 A 15-year-old girl with a rapidly growing inferior left breast mass which on core biopsy was consistent with a juvenile fibroadenoma. Due to the location and size of the mass, a periareolar incision would have caused significant disruption of the breast bud, and therefore an inframammary incision was chosen. (**a**) Presurgical appearance, (**b**) operative specimen, (**c**) postoperative incision

Juvenile Papillomatosis

Juvenile papillomatosis is a localized proliferative disorder seen in adolescents. The mean age of onset is 19 years old. It is characterized by papillary epithelial hyperplasia of ductal epithelium. This leads to formation of a mobile mass consisting of multiple cysts in a dense stroma. In contrast to intraductal papillomas, there is frequently no nipple discharge. On pathology and imaging, these masses have a "Swiss cheese" appearance. Treatment of juvenile papillomatosis consists of surgical excision with negative margins. Although this is not considered a precancerous lesion, it is considered a marker for increased risk of breast cancer. Patients should be monitored closely for breast cancer once they reach adulthood.

Montgomery Gland Cysts

When the Montgomery glands at the edge of the areola become obstructed in adolescent girls, Montgomery gland cysts can form. Patients typically present with either local inflammation (60–65 %) or a painless mass (35–40 %). This diagnosis is typically made based on clinical examination. Breast ultrasound can confirm the diagnosis by demonstrating multiple thin-walled cysts behind the areola with echogenic debris. Montgomery gland cysts are benign and resolve without surgical intervention. Conservative management of Montgomery gland cysts includes antibiotics with coverage of *Staphylococcus* and NSAIDs. Compression of the cysts should be avoided as it can slow resolution.

Cysts

Breast cysts are fluid-filled sacs within the breast tissue that occur when ducts become obstructed and enlarge. They can occur at any age. A galactocele is a type of breast cyst that is filled with milk. Breast cysts can be easily diagnosed on physical examination and US imaging. Simple cysts do not require treatment unless they are large or symptomatic and can be monitored clinically. Cyst aspiration is often the initial treatment of choice for enlarging or symptomatic cysts and can lead to complete resolution. Aspirated fluid should not be sent for cytology unless the cyst was a complex cyst with unusual imaging features. In these cases, a core biopsy of the cyst wall is recommended over cytology of the cyst fluid.

Vascular Malformations

Hemangiomas and lymphangiomas in children are benign breast findings that rarely require surgical intervention unless they are rapidly growing or do not involute spontaneously. Steroids are often ineffective in this patient population. Most are diagnosed by physical examination, but ultrasound or MRI can help confirm the diagnosis. Hemangiomas present primarily in infants as slow-growing multilobular masses associated with a strawberry nevus. The natural history of these lesions is progressive growth until 11–12 months of life, followed by slow spontaneous involution. Lymphangiomas are caused by dilations in lymphatic or venous channels. Unlike hemangiomas, which are high-flow neoplasms, these vascular malformations have slow or absent flow without an associated mass and enhance in the venous phase of T2 MRI imaging.

Malignant Pediatric Breast Masses

Malignant breast masses in children are uncommon and can present atypically.

Phyllodes Tumor

Phyllodes tumors (cystosarcoma phyllodes) are rare fibroepithelial stromal tumors, which can be characterized by histology as benign, intermediate, or malignant. These tumors

represent <1 % of breast lesions. Although 5 % of phyllodes tumors occur in patients <20 years old, the peak age of incidence is in the fourth decade of life. They present similarly to juvenile fibroadenomas: painless, rapidly growing, rubbery masses that are typically >6 cm in size. On pathology, they appear as fleshy masses with clefts and a bosselated surface. Necrosis or hemorrhage in these masses is concerning for malignancy. On histology, they typically have significant stromal cellularity, mitotic activity, and branching epithelial line spaces. Mitotic activity is the strongest predictor of metastatic behavior. Favorable lesions are typically ones that are <4 cm in size, have pushing rather than infiltrative borders, no necrosis, and fewer than 3 mitoses per high-powered field. Those with >10 mitoses per high-power field and infiltrative features are considered malignant.

Once again, US is the imaging modality of choice. Phyllodes tumors typically appear as well-circumscribed, round, macrolobulated, hypoechoic masses with posterior enhancement. They are distinguished from benign fibroadenomas because they demonstrate internal heterogeneous echotexture and anechoic cysts or clefts. FNA of phyllodes tumors are not reliable due to the heterogeneous internal architecture, and therefore core biopsy is recommended to confirm the diagnosis. Core biopsy should be performed of all rapidly growing masses suspected to be fibroadenomas to determine if they are of the juvenile subtype or a phyllodes tumor. Treatment of phyllodes tumors consists of excision with 1-cm margins for borderline or malignant lesions and negative margins for those that are benign. Nodal evaluation is not necessary with phyllodes tumors as they demonstrate hematogenous spread. Radiation is likely indicated for malignant lesions. The local recurrence rate for borderline and malignant phyllodes is estimated at 15–20 %, and the distant recurrence rate is approximately 5–10 %. Overall the prognosis for children with phyllodes tumor is more favorable than their adult counterparts.

Carcinoma

Primary breast cancer in children is extremely rare, accounting less than 0.1 cases per 100,000 patients under the age of 20 years, <1 % of all childhood cancers, and <0.1 % of all breast cancers. Unlike in adult populations, the most common type of breast cancer in children is secretory breast cancer, which has a favorable prognosis and 9–10 % nodal metastasis at presentation. These lesions typically present as painless, firm, immobile, well-circumscribed masses. On pathology, they appear as grayish-white masses with lobules separated by dense fibrous bands surrounded by a thick-walled pseudocapsule.

The overall 5-year survival for secretory breast cancer is estimated at 85–90 %, and no deaths have been documented in pediatric patients with secretory breast cancer to date. Less common and more aggressive forms of breast cancers are documented in children including infiltrating ductal, infiltrating lobular, inflammatory, and medullary cancer. Definitive operative and adjuvant treatment for confirmed breast cancer in children remains controversial given the few reported cases, so consultation with a breast oncology team is recommended.

Metastatic Cancer

Metastatic cancers to the breast are more common in children than primary carcinomas but are still a very rare pathologic finding in pediatric populations. The most common form of pediatric cancer that metastasizes to the breast is rhabdomyosarcoma, specifically the alveolar type with a primary lesion in the extremity. Other malignancies that metastasize to the breast include neuroblastoma, Burkitt's lymphoma, hepatocellular carcinoma, leukemia, Ewing's sarcoma, melanoma, and renal cell carcinoma. The presentation and treatment of these lesions vary depending on their primary source. They often are discovered on surveillance CT as masses with associated adenopathy.

Nipple Discharge

Abnormal nipple discharge (including bloody discharge) in children is often caused by chronic nipple irritation or trauma. Other etiologies of abnormal nipple discharge in children include mammary duct ectasia and galactorrhea.

Mammary Duct Ectasia

Children and infants with mammary duct ectasia present with bloody nipple discharge, noncyclic breast pain, and subareolar inflammation with or without a bluish retroareolar mass. The etiology of mammary duct ectasia is secondary to benign dilations of the subareolar ducts caused by epithelium obstructing the lumen and subsequent bacterial overgrowth of *Staphylococcus aureus* or *Bacteriodes.* Ultrasound of the breast demonstrates tubular anechoic structures and ducts filled with debris. Mammary ductal ectasia is diagnosed by physical examination and treated with antibiotics. The majority of cases resolve with conservative management, but surgery may be indicated in rare cases of resistant or recurrent symptoms or persistent subareolar abscess.

Galactorrhea

Milky nipple discharge can present in infants and children from multiple causes. Milky nipple discharge in infants is common for the first months of life and is a result of elevated

fetal prolactin levels. This phenomenon is exacerbated by palpation of the breast buds. In children, neurogenic lactation is often stimulated by chest trauma, thoracotomy, herpes zoster infections, or chronic nipple stimulation. The most common cause of galactorrhea in young adults is hypothyroidism. Pituitary causes of galactorrhea include prolactinoma. Finally, drugs such as dopamine receptor blockers and catecholamine-depleting agents can stimulate milky nipple discharge. Initial work-up for galactorrhea often involves fat staining of the discharge to confirm diagnosis and serum levels of prolactin, FSH, LH, and thyroid hormones.

Breast Infections

Inflammatory disorders of the breast can be secondary to local trauma, epidermal cysts, foreign bodies, piercing, bacterial overgrowth after mammary duct obstruction, or folliculitis. They can manifest as mastitis or breast abscesses. Presenting symptoms of breast tissue infections include erythema, edema, pain, and fluctuant mass. These infections can occur at any age and typically resolve with conservative treatment of antibiotics and analgesics. The most common bacterial cause of breast infections is *Staphylococcus aureus*, but beta-hemolytic *Strep*, *E. coli*, *Enterococcus*, *Pseudomonas*, *and Klebsiella* have all been documented. Broad antibiotic coverage including *MRSA* should be considered for severe infections and while awaiting culture results. Ultrasound can be used to differentiate simple mastitis from breast abscess. If antibiotic treatment is unsuccessful, percutaneous needle aspiration or incision and drainage can be considered but may result in damage to the developing breast bud.

Breast Trauma

Accidents and trauma are the leading causes of morbidity and mortality in children, and traumatic insults or burns to the chest may cause significant negative functional or cosmetic consequences to the developing breast. Both accidental and iatrogenic trauma from thoracotomies, port-a-cath placement, and breast surgery can lead to damage of the underlying breast. Potential consequences include failure of normal development, undergrowth, and contracture of breast tissue, fat necrosis, infection, and scarring of the lactiferous ducts resulting in loss of lactation potential. The asymmetry or deformity that can result from such insults is often quite severe and difficult to repair even among experienced plastic surgeons. Furthermore, surgeons must often wait until adulthood when the child has completed development for definitive reconstruction, which can lead to problems with poor self-esteem and body image. As a result, the best treatment is prevention and avoidance of unnecessary surgical or diagnostic procedures on the developing breast tissue.

Editor's Comment

A breast mass in a toddler is a relatively common indication for referral to a pediatric surgeon. These cause tremendous anxiety for parents but almost always represent breast buds and should never be biopsied. There are women with severe breast deformities or amastia because they were subjected to biopsy of a breast bud as a child. Reassurance and serial examinations should be the rule, with US performed for enlargement of the mass or extreme parental anxiety.

Most breast masses in teenagers will be fibroadenomas, which can be multiple and bilateral. Unless they are symptomatic, larger than about 4 cm in diameter or growing rapidly, they should be observed. Many will resolve spontaneously after a few months or years of observation. Sometimes there is increased pressure to perform a biopsy because of an ultrasound report, usually from an adult radiologist, that states the lesion is "suspicious" or "biopsied is recommended." Repeat US performed by an experienced pediatric radiologist can sometimes provide the reassurance needed to avoid unnecessary surgery. Unless it is far from the nipple, fibroadenomas should always be removed through a precise periareolar incision, and because they can usually be separated cleanly from the surrounding breast tissue with blunt dissection, the specimen should include little if any normal breast tissue. Furthermore, except in girls with a history of radiation exposure (Hodgkin's disease), resection of a breast mass with a margin is rarely necessary.

Fine-needle aspiration is useful when dealing with a cyst but is rarely indicated in children. Most pediatric centers lack the expertise in performing the procedure and interpreting the results of cytologic analysis. Likewise, needle-localization biopsy is almost never indicated as this is usually performed in a woman with a nonpalpable lesion detected by screening mammography, which is never indicated in a child. Many adolescents complain of breast pain, for which there is often no effective treatment. When there is pain, many patients think they feel a mass when in fact there is only normal developing breast tissue, which can be very firm and tender to palpation, or fibrocystic change, which is not treated surgically.

Mastitis is treated with antibiotics, while an abscess should be aspirated or surgically drained. A judgment needs to be made whether injury to the breast is more likely with incision and drainage or the undrained infection itself. Needle aspiration or an incision performed carefully through a tiny incision at the areolar border is usually the better choice, especially for an abscess that is symptomatic or enlarging. Abscess cavities should never be packed with gauze, as this is unnecessary and cruel. Ectopic breast tissue most commonly occurs in the axilla and can be cyclically painful. The tissue is usually intimately adherent to the overlying dermis, and an acceptable cosmetic result can be difficult to obtain.

Gynecomastia can be psychologically distressing but often resolves after the height of puberty. Many surgeons

will refuse to operate (and insurance companies will refuse to pay) until the patient has reached 18 years of age and can demonstrate that the breast tissue has failed to begin to diminish in size. The goal of mastectomy in these cases should be to remove only the breast tissue, although removing some fat is often necessary, especially in patients who are also obese. It is often difficult to know how much tissue should be removed from behind the nipple—removing too much can cause necrosis or nipple inversion, while leaving too much can result in recurrence, especially if the child is still young. It is usually best to leave a small amount and to warn the patient that recurrence could occur, albeit rarely.

The inframammary incision can be useful and is cosmetically superior to other thoracotomy incisions; however, when the incision is made while the patient is supine and under general anesthesia, it will almost invariably end up being too high (on the breast). If there is any chance that an inframammary incision will need to be made, this site should be marked with the patient in an upright position prior to the operation.

Suggested Reading

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