Contemporary Pediatric and Adolescent Sports Medicine

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Lyle J. Micheli
Laura Purcell *Editors*

The Adolescent Athlete

A Practical Approach

Second Edition

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Additional material to this book can be downloaded from http://extras.springer.com.

ISSN 2198-266X ISSN 2198-2678 (electronic)
Contemporary Pediatric and Adolescent Sports Medicine
ISBN 978-3-319-56187-5 ISBN 978-3-319-56188-2 (eBook)
https://doi.org/10.1007/978-3-319-56188-2

Library of Congress Control Number: 2018939545

Printed on acid-free paper

This Springer imprint is published by the registered company Springer International Publishing AG part of Springer Nature
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

The Micheli Center for Sports Injury Prevention

The mission of the Micheli Center for Sports Injury Prevention is at the heart of the *Contemporary Pediatric and Adolescent Sports Medicine* series.

The Micheli Center uses the most up-to-date medical and scientific information to develop practical strategies that help young athletes reduce their risk of injury as they prepare for a healthier future. The clinicians, scientists, activists, and technologists at the Micheli Center advance the field of sports medicine by revealing current injury patterns and risk factors while developing new methods, techniques, and technologies for preventing injuries.

The Micheli Center, named after Lyle J. Micheli, one of the world's pioneers in pediatric and adolescent sports medicine, had its official opening in April 2013. Thus far, the Micheli Center has served more than 2800 athletes and has published more than 100 studies. Dr. Micheli is the series editor of *Contemporary Pediatric and Adolescent Sports Medicine*.

Consistent with Dr. Micheli's professional focus over the past 40 years, the Micheli Center conducts world-class medical and scientific research focused on the prevention of sports injuries and the effects of exercise on health and wellness. In addition, the Micheli Center develops innovative methods of promoting exercise in children.

The Micheli Center opens its doors to anyone seeking a healthier lifestyle, including those with medical conditions or illnesses that may have previously limited their abilities. Fellow clinicians, researchers, and educators are invited to collaborate and discover new ways to prevent, assess, and treat sports injuries.

Series Editor Biography

Dr. Lyle J. Micheli is the series editor of *Contemporary Pediatric and Adolescent Sports Medicine.* Dr. Micheli is regarded as one of the pioneers of pediatric and adolescent sports medicine, a field he has been working in since the early 1970s when he co-founded the USA's first sports medicine clinic for young athletes at Boston Children's Hospital.

Dr. Micheli is now director of the Division of Sports Medicine at Boston Children's Hospital, and Clinical Professor of Orthopedic Surgery at Harvard Medical School. He is a past president of the American College of Sports Medicine and is currently the Secretary General for the International Federation of Sports Medicine. Dr. Micheli co-chaired the International Olympic Committee consensus on the health and fitness of young people through physical activity and sport.

In addition to many other honors, Dr. Micheli has served as Chairperson of the Massachusetts Governor's Committee on Physical Fitness and Sports, on the Board of Directors of the United States Rugby Football Foundation, as Chairman of the USA Rugby Medical and Risk Management Committee, and on the advisory board of the Bay State Games. He served as Attending Physician for the Boston Ballet from 1977 to 2016 and is Medical Consultant to the Boston Ballet School.

Dr. Micheli received his undergraduate degree from Harvard College in 1962 and his medical degree from Harvard Medical School in 1966. As an undergraduate student, Dr. Micheli was an avid athlete, competing in rugby, gridiron football, and boxing. Since graduating, Dr. Micheli has played prop for various Rugby clubs including the Boston Rugby Football Club, the Cleveland Blues Rugby Football Club, Washington Rugby Club, and Mystic Valley Rugby Club, where he also served as team coach.

Dr. Micheli has authored over 300 scientific articles and reviews related to sports injuries, particularly those sustained by children. His present research activities focus on the prevention of sports injuries in children. Dr. Micheli has edited and authored several major books and textbooks.

Preface

It is with great pleasure that we introduce the second edition of *The Adolescent Athlete: A Practical Approach*.

This updated edition is inspired by the popularity of the first volume—and the amount of new information in the field that warrants a place in these pages.

All the chapters have been updated. Some of the more important additions are updated references, color figures, and inclusion of cutting-edge discussion of management of such high publicity sport injuries as concussions, ACL tears, and femoroacetabular impingement.

This new information makes this second edition an important contribution to the literature. Yet the fundamental reasons for this book remain the same. We still believe strongly that good health should be a goal of all children and adolescents, as well as the parents and guardians who care for them. Regular physical activity is part of achieving this goal. Sports can provide manifold benefits, including fitness, motor skill development, teamwork, and of course, fun. As with any pursuit that provides such benefits, however, there are risks involved, particularly for growing athletes. Physicians and other health professionals caring for active children should be able to provide appropriate care and advice for sport and fitness-related medical issues.

We received very positive feedback on the first edition's emphasis on being a practical guide for those who provide sports care for young athletes. The focus in this updated edition remains musculoskeletal injuries that occur in this unique population, as well as conditions that may present as a musculoskeletal injury, but may have more serious consequences. The first section of the book focuses on rehabilitation and diagnostic imaging of musculoskeletal conditions in adolescents. The second section—organized according to anatomical region—addresses specific injuries that adolescents may sustain as a result of sport/activity participation. Each of these body part–specific chapters begins with a review of the relevant anatomy, followed by details of clinical evaluation. Specific injuries, such as acute and chronic injuries, are described in detail, including the management/treatment of each condition. Prevention of injuries and return to play guidelines are given full attention, as befits a book published under the Micheli Center for Injury Prevention. Each chapter concludes with "clinical pearls" that provide an insight into the way each of our expert authors practice their craft.

We thank all those who donated their time and expertise to making this second edition possible. Revising and updating chapters is a time-consuming and painstaking process, and we are very grateful to the chapter authors for their commitment. We also appreciate the effort and attention to detail of our editors at Springer. Without these contributions, this new and updated version of a very valuable resource would not have come to fruition.

Boston, MA, USA Lyle J. Micheli
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1 Current Pediatric and Adolescent Sports Medicine: An Overview

Laura Purcell and Lyle J. Micheli

Sports participation by children and adolescents has exploded in recent years. In the USA, more than 35 million children participate in organized sport, with millions of others participating at a recreational level [1]. A Canadian study found that 94% of adolescents participated in sports in the previous year [2]. In 2014 and 2015, an estimated 7.8 million adolescents in the USA participated in high school sports [3]. Children are becoming involved at younger ages, and are often participating in sports year-round. They are also participating at increasingly competitive levels, which requires training with greater intensity.

Injuries related to sports participation occur frequently, the majority of them in young athletes. Participation in high school sports resulted in about 1.4 million injuries in the USA in the 2015–2016 academic year [3]. Participation in organized and non-organized sport in the USA results in an estimated 775,000 emergency visits per year for those aged 5–14 years [4]. Among 12- to 17-year-olds, sport-related injuries are the number one reason for emergency visits [4]. Childhood injuries are a frequent reason for visits to primary care offices as well, accounting for 1 of every 10 visits, with >25% of adolescent visits attributable to sports [5]. Musculoskeletal injuries are the third most common reason for adolescents to seek medical attention, with knee pain being the most frequent complaint [6].

With the bourgeoning participation of today's youth in sports, it is imperative that health care providers who take care of these children and adolescents are prepared to address their unique needs. Young athletes have specific needs that set them apart from adult athletes. An understanding of the developmental changes that occur during childhood and adolescence, which result in different injury patterns and psychological issues, is essential to provide exceptional care for young athletes. Knowledge of the physical and emotional development, as well as the level of skill and motivation of adolescents, will help prevent injuries and promote healthy participation and enjoyment of sport.

Benefits of Sports

Sports provide a myriad of psychosocial, physical, and health-related benefits. Athletic participation is an enjoyable opportunity for children and adolescents to be active. Being active helps youths to achieve and maintain a healthy weight and increase physical fitness. Sports may provide youth the opportunity to develop independence,

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L. J. Micheli, L. Purcell (eds.), *The Adolescent Athlete*, Contemporary Pediatric and Adolescent Sports Medicine, https://doi.org/10.1007/978-3-319-56188-2_1

identify with a peer group, and increase social interaction. Youths can achieve success by improving and mastering new skills and participating in a common goal, which can in turn improve their sense of self-esteem and can help build confidence [7].

Older children who participate in sports are less likely to adopt risky behaviors, such as smoking, drinking, doing drugs, and engaging in unlawful activity. Sports participation is associated with elevated social status among peer groups, and it may provide opportunities for traveling with a team, as well as the possibility of athletic scholarships [7].

A healthy active lifestyle during adolescence may reduce the risk of chronic health problems in adulthood, such as cardiovascular disease, obesity, and type II diabetes. Positive sport experiences in childhood and youth may increase the likelihood of continued participation in exercise and sport during adulthood. [7].

Adults have an important role in providing positive sports experiences for children. They teach children motor skills, the rules of the sport, and sportsmanship. Adults can be positive role models for youth, and are instrumental in organizing sporting opportunities for children. However, organized sports should be developmentally appropriate for children so that being physically active is enjoyable [8–12]. Children should be encouraged to participate in a variety of activities and avoid early specialization [13, 14].

Sport Readiness

"Sport readiness" implies a certain level of physical, cognitive, and emotional development that allows the acquisition of the necessary skills to meet the demands of sports [8–11]. Although there are many benefits to sport, sporting activities must be developmentally appropriate to ensure that children enjoy the activity. Placing children in sports that are beyond their developmental ability can cause frustration and loss of enjoyment, and ultimately lead to the decision not to participate [8–12].

An important component of sport readiness is motor development. Learning and mastering fundamental motor skills such as throwing, running, and jumping is an innate process, independent of gender or physical maturity. Each fundamental skill is composed of a sequence of developmental stages that all children progress through, but at variable rates. Most children have acquired some fundamental skills by preschool age. However, it is not until children reach 6 years of age that sufficient combinations of fundamental skills are attained to allow them to begin organized sports [8–12].

Choosing appropriate sport activities can be guided by knowledge of the developmental capabilities of children of various ages (Table 1.1). Sports activities can be modified to match children's developmental levels by simple modifications, such as shorter games, smaller equipment, and frequent changing of positions [8–12].

By middle childhood, most children achieve mature patterns of fundamental motor skills and are beginning to learn transitional skills (Table 1.1). Transitional skills are fundamental abilities performed in combination or with variation, such as throwing for distance or accuracy. Improvement of transitional skills progresses through late childhood, and by the time they reach adolescence, most youths are able to master complex motor skills, such as a layup in basketball. Motor skills continue to improve throughout adolescence [8–12].

Cognitive development is another component of determining sport readiness. Young children have short attention spans, limited memory, and an inability to make rapid decisions. Sports activities for young children should therefore concentrate on mastering fundamental skills and the development of transitional skills. Instruction should be short, rules should be flexible, and the emphasis should be on fun, not competition. As children grow older, their memory improves and their attention spans increase, but may remain selective. Older children are capable of learning strategy and tactics, and can begin to master more complex play combinations [8–12].

Children differ from adults in that they are growing. Growth predisposes children to unique injuries. Growth during adolescence is particularly

Table 1.1 Developmental skills and sport recommendations during childhood and adolescence

	Middle childhood 6–9 year	Late childhood 10–12 year	Early adolescence 13–15 year	Late adolescence 16–18 year
Motor skills	• Mature fundamental sport skills • Posture, balance improving • Beginning transitional skills (e.g., throwing for accuracy)	• Improving transitional skills • Mastering complex motor skills (e.g., layup in basketball)	• Tremendous growth • Loss of flexibility • Differences with timing of puberty	• Continued growth into adulthood • Mature sport skills
Learning	• Short attention span • Limited memory and rapid decision-making	• Attention span improving but remains selective • Improving memory	• Improved attention span • Good memory skills, able to memorize plays and strategize	• Good attention span, memory skills
Skill emphasis	• Emphasize fundamental skills • Encourage beginning transitional skills	• Emphasize skill development • Increasing emphasis on tactics and strategy	• Promote individual strengths	• Promote individual strengths
Suggested activities	Entry-level soccer and baseball; swimming; running; gymnastics; skating; dance; racquet sports	Entry-level football, basketball, ice hockey	Early-maturing boys: track and field, basketball, ice hockey Late-maturing girls: gymnastics, skating	All sports depending on interest

Source: Purcell L. Sport readiness in children and youth. Paediatr Child Health 2005; 10:343–344. (Oxford University Press)

marked. There are dramatic increases in muscle mass, muscle strength, and cardiopulmonary endurance during this period. Adolescents continue to increase both fat mass and fat-free mass, although during puberty, girls tend to accumulate fat mass at a greater rate. Muscle strength increases in both sexes, but is greater in boys. Loss of flexibility and a temporary decrease in coordination and balance is common during adolescence [15].

Growth, Maturation, and Development

As children progress through adolescence to adulthood, they are subject to three interacting processes: growth, maturation, and development [12, 15]. As they grow, children increase in height and weight, in lean and fat tissues, and in the size of their organs. Maturation is the state of maturity, in which growth has been completed. Development is the process of learning appropriate behaviors in society. Children develop behaviorally in the acquisition of motor skills, as well as cognitively, emotionally, socially, and morally. It is important to be aware of these interactions in children and adolescents, and how they may potentially affect a youth's ability to participate in sports [12, 15].

Sexual Maturity

Adolescence is marked by sexual growth and maturity, i.e., the process of puberty. Secondary sexual characteristics, including pubic hair in both sexes, breast development and menarche in girls, and penis and testes development in boys, form the basis of assessment of sexual maturity [15]. Tanner developed a sexual maturation scale based on the development of secondary sexual characteristics (Table 1.2) [16].

Puberty can affect sports performance [15]. The onset of puberty can be quite variable and can result in differences in physical attributes important to sport. Boys who mature early are taller, stronger, and have greater muscle mass than those who enter puberty later, and are therefore usually better suited to sports requiring physical strength, such as gridiron football. Girls who mature late have narrower shoulders and hips, and are well-suited to aesthetic sports, such as figure skating and dance [8–11, 15].

Table 1.2 Tanner staging

A. Girls			
Tanner stage	Stage of development	Pubic hair	Breasts
Stage 1	Preadolescence	No pubic hair	Juvenile breasts with elevated papilla and small flat areola
Stage 2	Early adolescence (10–13 years)	Sparse, long, and straight, slightly pigmented	Buds form papilla, and areola form small mound
Stage 3	Middle adolescence (12–14 years)	Dark and curly	Continued enlargement of breast bud and areola, with no separation of breast contour
Stage 4	Middle adolescence	Coarse in texture; number of hairs continue to curl and increase	Papilla and areola separate to form a secondary mound
Stage 5	Late adolescence 14–16 years	Adult triangle pattern with spread to surface of medial thigh	Mature areola mound recedes into contour of the breast, nipples project
B. Boys			
Tanner stage	Stage of development	Pubic hair	Penis/testes
Stage 1	Preadolescence	No pubic hair	Identical to early childhood
Stage 2	Early adolescence (10.5–14 years)	Sparse, long, and straight, slightly pigmented at base of penis	Enlargement of testes and scrotum; reddish color and enlargement of penis
Stage 3	Middle adolescence (12.5–15 years)	Increase curl and pigmentation, spreading laterally	Continued growth, penis increases in length
Stage 4	Middle adolescence	Coarse in texture, more adult in distribution	Continued growth of testes and scrotum skin darkens, penis grows in width, glans penis develops
Stage 5	Late adolescence (14–16 years)	Mature distribution with spreading to medial thigh	Mature adult size and shape of testes, scrotum, and penis

Source: Adapted by permission from Tanner JM. Growth at Adolescence. 2nd ed. Osney Mead, Oxford: Blackwell Scientific Ltd.; 1962. © Formerly Blackwell Scientific Publications; now Wiley-Blackwell

Skeletal Maturity

Children's bones are different from adults' bones in that they are still growing. The response of growing bones to trauma is therefore different. Growing bones are not as dense, are more porous, and possess a striated cortex with loosely attached periosteum. Bones in children have a growth plate complex, which includes the epiphysis, physis, and diaphysis. The developing physis or growth plate is especially vulnerable to injury, and if growth plate injuries are not managed properly, such injuries can result in permanent disability [17].

The physis is located between the epiphysis and metaphysis (Fig. 1.1). It is a cartilaginous plate where endochondral growth occurs and the bones lengthen. It is the weakest link in the bone–ligament complex, which results in different injury patterns in children. Injuries in adults are more likely to be ligament ruptures, whereas in children, because the ligament is stronger than the physis, a growth plate injury is more likely to occur, particularly in the knee and ankle [17].

Growth plate injuries are classified according to the Salter–Harris classification (Fig. 1.1). Type 1 injuries involve stress to the physis with or without radiographic evidence of widening. Type II injuries involve stress to the physis and a fracture exiting the metaphyseal region of the bone. In type III injuries, the fracture involves the growth center and the epiphyseal region of the bone. Type IV fractures involve both the metaphyseal region and the epiphysis. Type V injuries are crush injuries and are often only appreciated after growth arrest or deformity.

As skeletal maturity approaches, the physis narrows and is replaced by bone until it closes. This results in unique injuries at this age, particularly injuries about the ankle. Fractures in young

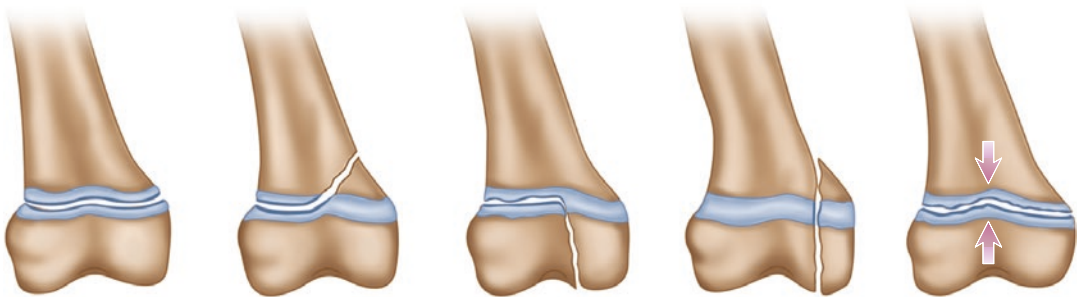

Fig. 1.1 Salter–Harris classification of growth plate injuries. From Albers HW, Micheli LJ, Musculoskeletal trauma and overuse injuries. In: Green M, Haggerty RJ, Weitzman M eds. Ambulatory Peds. Philadelphia: WB Saunders 1999; 3(1):220–237. Reprinted with permission from Elsevier (formerly Saunders)

children usually occur parallel to the physis, whereas in adolescents, fractures occur through the physis and into the articular surface (Fig. 1.1) [17, 18].

Another unique feature of children's bones is the presence of apophyses. An apophysis is a prominence of bone that is also a center of bone growth. It acts as an attachment for muscle groups. Apophyses are found around the pelvis, the patella, the tibial tubercle, the calcaneus, and the base of the fifth metatarsal, and as such are sites of avulsion injuries in growing athletes. During growth spurts when bones grow faster than the soft tissues around them can lengthen, muscles and tendons get stretched out which can result in increased tension at the sites of attachment, causing inflammation and pain (apophysitis). Some examples of apophysitis include Osgood–Schlatter and Sever's diseases. With sufficient force, the muscles attached to apophyses can pull off a piece of bone, resulting in an avulsion fracture. These injuries are commonly seen in adolescents who are going through growth spurts [18].

Risk of Injury

Injuries are an inevitable part of participating in sports. Risk factors include type of sport, gender, amount of exposure/training, and previous injuries. Certain injuries are associated with particular sports, such as concussions and ankle sprains in football [3]. Contact and collision sports, such as hockey, football, basketball, and soccer, typically have higher injury rates [2, 3, 19]. In the 2015–2016 academic year, the highest rates of injuries in US high school students, based on injury rate/1000 athletic exposures, were associated with boys' football and wrestling, and girls' soccer and basketball [3]. Concussions, ankle, and knee injuries are among the most common injuries seen in sports [2, 3, 6, 20]. Sprains and strains are the most common type of injuries [2, 21]. Previous injuries have been associated with up to half of new sport-related injuries [2]. Overuse injuries are more common in females [19, 22] and in sports such as figure skating, dance, gymnastics, track and field, running, swimming, and tennis [19]. Overuse injuries are most common in the lower extremity [19] and are associated with greater hours/week of sports participation [13, 20].

Injury Prevention

Various methods of preventing injuries can be employed. Preparticipation physicals can help identify medical problems, previous injuries, or risk factors for further injury in young athletes. By assessing an athlete's general health, level of fitness, flexibility, strength and joint stability, treatment, or preconditioning, recommendations can be made to reduce injury risk before sports participation. Appropriate sport-specific conditioning programs can prepare athletes for the demands of their particular sport [23]. Specific sport-training programs have been shown to be effective in reducing injury rates in sport. Neuromuscular training programs such as the FIFA 11 have reduced the risk of lower extremity injury in sports such as soccer, particularly ACL tears in females [24–28].

Ensuring a proper diet and conditioning in all adolescent athletes is key to maintaining general health. Rest is also important for growing athletes to recuperate from sport, particularly during times of growth when injury risk is higher. Avoidance of overtraining will help prevent overuse injuries and "burnout" [29]. Participating in a variety of activities will help ensure children develop a variety of skills and will help prevent overuse injuries [13, 14]. Making sure that injuries are properly rehabilitated can help prevent re-injury [23].

Parents, coaches, and trainers can reduce the incidence of injuries by ensuring the proper use of protective equipment, ensuring safe play conditions, enforcing rules, and providing appropriate supervision. Ensuring the proper selection of sporting events can also minimize injuries. Sports should be matched to the child's interest and abilities [8–11, 20].

Injury surveillance can result in rule changes that can also help prevent sport injuries in youth athletes. For instance, a recent study found that concussions in hockey in 11- and 12-year-olds were reduced by 64% following the 2013 Hockey Canada's national policy change delaying checking in boy's hockey until ages 13–14 years [30].

Conclusion

Sports are an excellent way for youth to be physically active. There are many benefits to sports participation, including physical health, skill development, and social interaction. Children and adolescents can get the most out of sports when the activities are geared towards their interests and developmental level.

The risk of injury is inherent to sports participation. Children and adolescents are subject to unique injuries because they are still growing. Injuries can be prevented by ensuring children are in good physical condition, by the use of proper equipment and by ensuring that playing conditions are safe. Participating in a variety of activities instead of specializing in one or two sports will also help minimize injuries.

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Part I

Rehabilitation and Diagnosis

Principles of Rehabilitation

2

Michelina C. Cassella and Kathleen Richards

The number of adolescent athletes competing in organized sports has significantly increased over the past several years, thus causing a rise in sports-related injuries. Adolescents are specializing in sports at an earlier age and, in some cases, performing excessive and repetitive training that often leads to overuse injuries. More than 2.6 million children and young adults require medical attention each year for sports and recreational injuries [1]. Many sports-related injuries do not receive proper rehabilitation. Adolescents may return to sports training and/or competition too quickly after an injury. This often causes a recurrence of the injury and/or the development of a new injury. Therefore, a comprehensive rehabilitation program to successfully manage an injury is extremely important to ensure the safe return to sports and/or competition. Appropriate rehabilitation and education of athletes, parents, and coaches are essential components in assisting the young athlete's recovery. In addition, the rehabilitation program should include the athlete's personal goals.

The evidence for rehabilitation practice in the field of adolescent sports medicine is often lacking proper research studies, particularly clinical trials. Many of the recommended rehabilitation programs are based on clinical experience, mainly with an adult population. However, recently, there are programs focusing on the prevention of sports-related injury, such as the PEP (Prevent Injury and Enhance Performance) Program [2] and the Micheli Center for Sports Injury Prevention [www.themichelicenter.com].

Before establishing a rehabilitation program, consideration must be given to the adolescent athlete's stage of maturation, which is more important than chronological age. Adolescence is a difficult period to define because of the wide variation in time of onset and termination. Age ranges of 8–19 years in girls and 10–22 years in boys are often listed as limits for the adolescent period. During this period, bodily systems become adult both structurally and functionally. Structurally, the rate of growth in stature marks the onset of the adolescent growth spurt. The rate of the statural growth reaches a peak, decelerates, and finally terminates with the attainment of adult stature [3].

Functionally, adolescence is defined by sexual maturation. Tanner and associates developed a sexual maturation scale that correlates with peak height velocity (*see* Table 1.2 in the Introduction) [3]. Tanner stage 1 is determined by growth hormone production, whereas stages 2–5 are related

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L. J. Micheli, L. Purcell (eds.), *The Adolescent Athlete*, Contemporary Pediatric and Adolescent Sports Medicine, https://doi.org/10.1007/978-3-319-56188-2_2

Table 2.1 Patient history

Patient history
• Demographics and developmental history
• Current medical diagnoses
• Previous diagnoses
• Past injuries with dates
• Surgical history with dates and complications (if any)
• Medications
• Chronological age; bone age
• Review of clinical tests (MRI, bone scan, radiograph)
• Past and present activity level
• Recreational versus competitive activity
• Pain assessment at rest, night, with activity (age-appropriate pain scale) patient's current concerns and goals

Source: Cassella M, Richards K. Physical therapy/rehabilitation. In: The Pediatric and Adolescent Knee. Micheli L, Kocher, eds. 2006. By permission of Elsevier

to sex hormones [4]. Therefore, children are described as prepubertal (Tanner stage 1), pubertal (Tanner stage 3), and postpubertal (Tanner stage 5). Postpubertal individuals are physically adults. Tanner staging is useful in determining the appropriate treatment and rehabilitative interventions. This chapter discusses the principles of rehabilitation, with emphasis on the evidence supporting these principles.

Principles of Rehabilitation

The major principle of rehabilitation is to safely maximize the athlete's abilities, despite an existing and/or a developing impairment. The goals of a rehabilitation program are to control inflammation and pain, promote healing, restore function, safely return to sports training and/or competition, and prevent future injury. In addition, maintaining the athlete's level of physical fitness while recovering from an injury is an essential component of the rehabilitation program.

The rehabilitation program includes assessments of posture, joint range of motion, muscle strength, endurance, balance, coordination, and function [5–9]. Posture deviations and muscle weakness and/or tightness often lead to serious imbalances that can cause malalignment, an increase in pain, a decrease in function, and a predisposition to future injury.

Rehabilitation Program

A comprehensive rehabilitation program includes a detailed patient history, a review, an examination of all systems, and the establishment of a plan of care.

Patient History

Information is gathered from both the patient and parent (Table 2.1).

Systems Review

Gathering baseline information before treatment intervention is necessary to establish goals, monitor the effects of both therapeutic and conditioning exercises, and identify risks factors that may contribute to future injury. Systems to review include:

1. Cardiovascular/pulmonary: Knowledge of normal respiratory rates, heart rates, and blood pressure for adolescents is necessary to monitor their response to treatment (Tables 2.2 and 2.3) [10, 11].

Table 2.2 Resting adolescent heart rate by sex and age

Age	12	13	14	15	16	17
White males	76	76	74	73	70	73
White females	86	83	84	83	84	81
Afro-American males	75	71	73	71	69	66
Afro-American females	81	80	80	80	78	77

Source: Rabbia et al. [10]

Table 2.3 Blood pressure for girls and boys by age and height percentile of 50%

Age	Girls systolic/diastolic	Boys systolic/diastolic
11	103/61	104/61
12	105/62	106/62
13	107/63	108/62
14	109/64	111/63
15	110/65	113/64
16	111/66	116/65
17	111/66	118/67

Source: Staley and Richard [12]

2. Integumentary: Assessment of the integumentary system includes skin integrity, color, trophic changes, and scar formation. Blistering, skin temperature, scar tissue pliability, texture, and sensation should be observed. Activities or movements that aggravate the incisional site should be documented in adolescents who have had surgery. Scar types include contracture, hypertrophic, and keloid. A contracture scar is a tightening of surrounding tissues. These scars tend to cause impaired movement. Hypertrophic scar tissue can be caused by the overproduction of connective tissue. They are raised above the skin, thick, red, and itchy. Keloid formations are highly thickened areas of scar tissue. They are larger and more raised than the hypertrophic scars. This type of scarring is often genetic [12].
3. Musculoskeletal: Tightness in the muscle–tendon units seems to occur in the absence of injury as the athlete enters puberty. Adolescent athletes, particularly males, demonstrate a generalized loss of flexibility, especially in larger muscle groups, such as the hip flexors, hamstring, quadriceps, and triceps surae. Linear growth in the long bones and spine exceeds the rate of growth of the muscle–tendon unit. Therefore, during the adolescent growth spurt, a loss of both strength and flexibility can often occur (Fig. 2.1) [13]. The loss of strength and flexibility not only impacts the athlete's athletic ability but also often leads to serious injuries. Therefore, detailed posture, joint range, muscle strength, and functional assessments should be performed at regular intervals to determine the athlete's fitness for sports activities. Specific tests and measurements will enable the professional to establish a baseline for appropriate treatment interventions for an existing injury and to prevent future injuries.
4. Posture: A detailed posture assessment helps the examiner identify deviations and/or malalignment (Table 2.4). Both can have a serious, negative impact on body mechanics and sports-specific techniques. In addition, identifying postural deviations leads the examiner to further investigate specific joint and/or muscle impairments.
5. Joint range of motion: Standardized testing includes measuring each joint, especially those that impact the athlete's performance. A few examples of tests that measure tightness in muscle groups that are generally affected during the adolescent growth spurt are as follows:
   (a) Thomas test: The Thomas test measures tightness in the iliopsoas muscle (Fig. 2.2). Restricted flexibility in this muscle can cause increased lumbar hyperlordosis, decreased hip extension, and an increase in knee hyperextension. The test is performed passively. The patient is positioned supine with both hips and knees flexed to the chest, with the lower back flat on the table. The patient holds

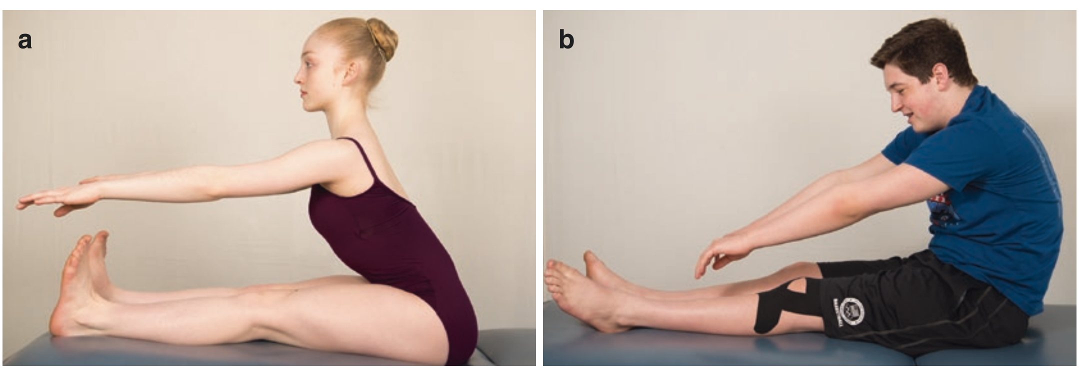

Fig. 2.1 Hamstring length. (**a**) Normal and better than normal hamstring length. The dancer is able to exceed a 90° hip angle keeping her knee straight. (**b**) Tightness in the hamstring. The athlete has had an increase in linear growth; therefore, he is unable to attain a 90° hip angle with his knees straight

Table 2.4 Posture assessment

Posture Evaluation Form				
Name: ____________________ Medical Record NO. _________ D.O.B. ______ Sex _____ Diagnosis __________________ Surgical Procedure/Date _________________________ Precautions ______________________________________				
Posterior view			Left	Right
Head	Centered	Tilt		
Shoulders	Level	Elevated		
Scapulae	Level	Elevated		
Spine	Aligned	Shifted		
Waist folds	Symmetrical	Increased		
Pelvis	Level	Elevated		
Knees	Aligned	Varus		
		Valgus		
Heels	Aligned	Varus		
		Valgus		
Anterior view			Left	Right
Head	Centered	Tilt		
Neck folds	Symmetrical	Increased		
Breasts	Symmetrical	Prominent		
Arm length	Equal	Longer		
Pelvis	Level	Elevated		
Knees	Aligned	Varus		
		Valgus		
Forefoot	Aligned			
	Pronated			
	Supinated			
Lateral view			Left	Right
Head	Aligned		Forward	Backward
Cervical (anterior) curve	Normal		Increased	Decreased
Shoulders	Level		Forward	Backward
Scapulae	Aligned		Protracted	Retracted
Thoracic (posterior) curve	Normal		Increased	Decreased
Lumbar (anterior) curve	Normal		Increased	Decreased
Pelvis	Aligned		Anterior Tilt	Posterior Tilt
Adams forward bend test			Left	Right
Thoracic	Negative		Rib hump	Rib hump
Lumbar	Negative		Increased m. bulk	Increased m. bulk
Knees	Aligned		Hyperextension	Hyperextension
Ankles	Aligned		Increased DF	Increased DF
			Increased PF	Increased PF

Source: Cassella M, Richards K. Physical therapy/rehabilitation. In: The Pediatric and Adolescent Knee. Micheli L, Kocher, eds. 2006. By permission of Elsevier

one leg flexed to the chest. The examiner cradles the other leg and has one hand around the pelvis. The examiner's thumb is positioned on the anterior superior iliac spine (ASIS) to determine when the pelvis begins to move anteriorly. The examiner passively lowers the leg. When the ASIS begins to move anteriorly, the test is stopped and the angle of hip flexion is measured [14].

(b) Straight leg raise: The straight leg raise measures hamstring tightness (Fig. 2.3). Restricted flexibility in the hamstrings will negatively affect low back, pelvis, hip, and knee alignment. The straight leg raise test focuses on proximal hamstring tightness.

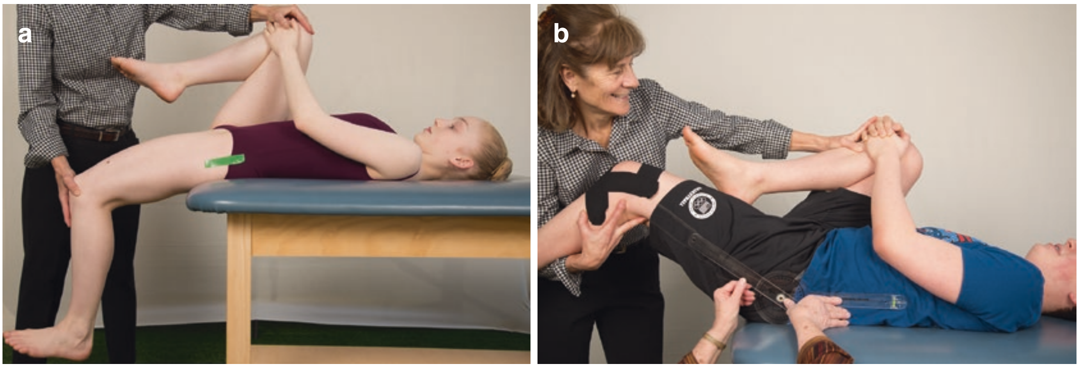

Fig. 2.2 Thomas test. (**a**) *Negative* Thomas test. The lumbar spine remains flat on the table, the pelvis is in a neutral position, and the thigh is in contact with the table, indicating appropriate length of the iliopsoas muscle. (**b**) *Positive* Thomas test. The lumbar spine loses contact with the table, and the pelvis moves anteriorly at 30° of hip flexion, indicating tightness in the iliopsoas muscle

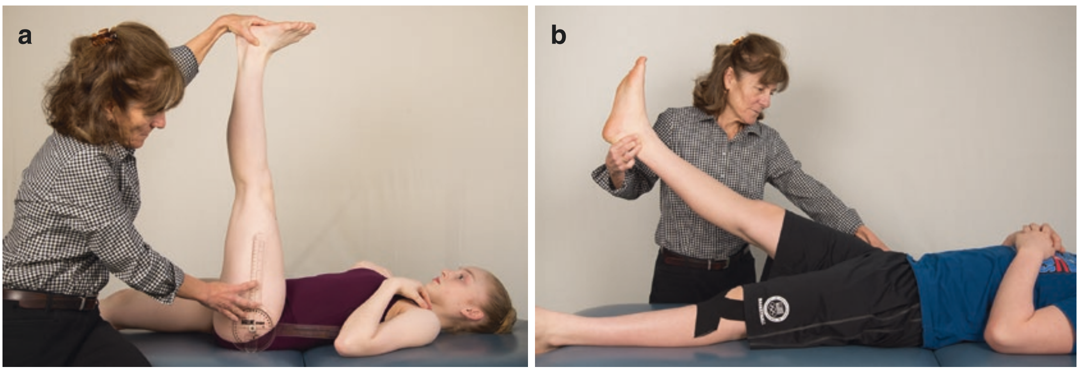

Fig. 2.3 Straight leg raise test. (**a**) *Negative* straight leg raise test. The pelvis remains in a neutral position as the straight leg is passively flexed to 90°, indicating appropriate length of the hamstring muscles. (**b**) *Positive* straight leg raise test. The pelvis begins to move anteriorly at 40° of hip flexion, indicating tightness in the hamstring muscles

The test is performed passively. The patient is positioned supine with hips and knees extended and the pelvis in a neutral position. The examiner cradles the leg with one arm and has the other hand around the pelvis. The examiner's thumb is positioned on the ASIS. The examiner passively raises the leg, keeping the knee straight. As soon as the ASIS begins to move posteriorly, the test is stopped and the angle of hip flexion is measured [15, 16].

(c) Ober test: The Ober test measures tightness in the iliotibial band (ITB) (Fig. 2.4). Restricted flexibility of the ITB often promotes lateral tracking of the patella. This malalignment of the patella can disrupt knee joint mechanics. Tightness of the ITB not only contributes to knee pain but can also interfere with function. The test is performed passively. The patient is positioned side lying, with the lumbar spine in flexion. The hips and knees are flexed to the chest. The patient's neck and trunk are also flexed. The patient holds the bottom leg to the chest, while the examiner cradles the top leg, keeping the knee flexed. The examiner flexes the hip and then widely abducts and extends the hip to allow the tensor fasciae latae muscle to move over the greater trochanter.

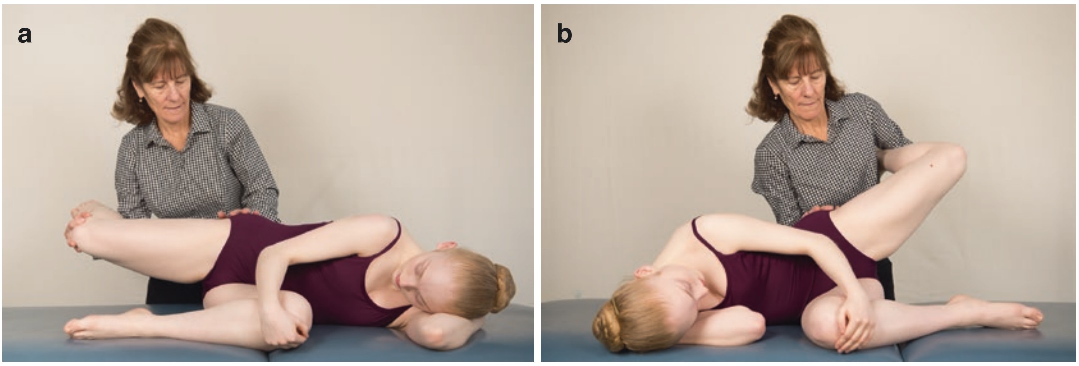

Fig. 2.4 Ober test. (**a**) *Negative* Ober test. The thigh and knee are horizontal in relation to the hip joint, indicating normal length of the ITB. (**b**) *Positive* Ober test. The thigh and knee are above the horizontal in relation to the hip joint indicating a tight ITB

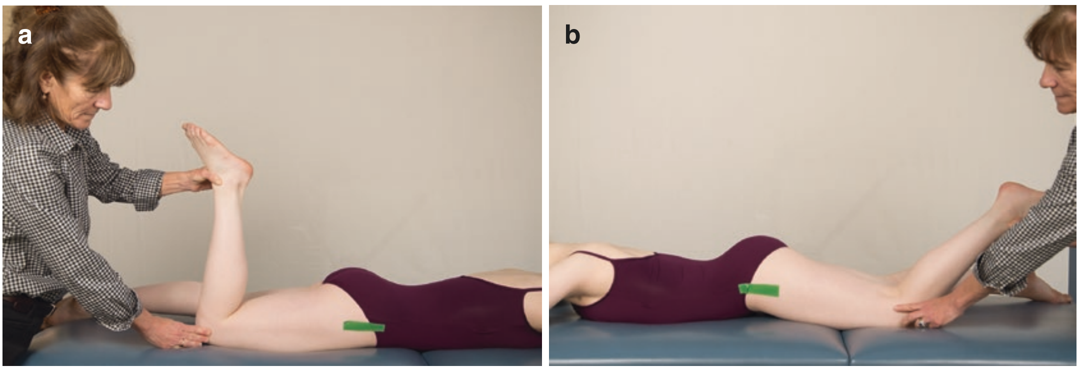

Fig. 2.5 Ely test. (**a**) *Negative* Ely test. The anterior hip remains in contact with the table when the knee is flexed to 90°, indicating appropriate length of the rectus femoris muscle. (**b**) *Positive* Ely test. The anterior hip loses contact with the table and the buttock begins to rise when the knee is flexed to 60°, indicating tightness in the rectus femoris muscle

The examiner attempts to passively lower the leg to the horizontal position [15].

(d) Ely test: The Ely test measures tightness in the rectus femoris muscle (Fig. 2.5). Restricted flexibility in this muscle can also have a negative effect on patellar alignment. The test is performed passively. The patient is positioned prone, with the hips and knees extended. The examiner grasps the lower leg and slowly flexes the knee. The test is stopped when the hip begins to flex and the buttock begins to rise. The angle of knee flexion is measured [15].

6. Muscle strength: Manual muscle test is used to determine the extent and degrees of muscle weakness resulting from an injury and/or disuse [9]. Test outcomes will help the healthcare professional design an appropriate treatment plan. Standardized muscle tests were first designed in 1912 by Dr. Robert W. Lovett, Orthopedic Surgeon at The Harvard Medical School and by Janet Merrill, Director of Physical Therapeutics at Children's Hospital, Boston. The manual muscle tests and grading system they designed are still being used today. For details on how to perform and grade the tests, please refer to the references [8, 9].
7. Neuromuscular system: The neuromuscular system includes assessment of postural control, balance, strength, coordination, proprioception,

agility, and gait. Postural control is necessary for all activities of daily living, athletic and recreational activities. Balance is defined as being able to maintain an upright posture. Coordination and agility are the ability to perform movements with appropriate speed, distance, direction, rhythm, and muscle tension. When assessing adolescents, normal development of skill acquisition must be taken into consideration so that testing is age appropriate. By age 5, the child can hop ten hops, but a skillful hop that requires flight and distance continues to develop into early adolescence [16]. Neuromuscular training describes a progressive exercise regimen that restores synergy and synchrony of the muscle firing patterns that are necessary for dynamic stability and fine motor control. This is accomplished by enhancing the dynamic muscular stabilization of the joint and by increasing the athlete's cognitive awareness of both joint position and motion.

Establishment of a Plan of Care

A successful rehabilitation program depends not only on physiological factors but also on the emotional and psychosocial attitudes of the adolescent athlete. Psychological factors need to be considered when establishing a treatment plan for the injured athlete. A positive, post-injury attitude has been associated with a successful return to preinjury level [17]. These factors have a considerable influence on compliance, performance, and the expectations of both the athlete and the health professional.

Positive communication is the key to a successful rehabilitation program. Communication between health professionals, team members managing the athlete's condition, and the parents is necessary to achieve a positive outcome. The adolescent understands the consequences of compliance, but often focuses on the here and now [18]. Education and detailed explanations with the rationale for each activity will help to promote the athlete's compliance.

The rehabilitation program is based on the diagnosis, the goals of treatment, the athlete's expectations, and the anticipated course of healing (Table 2.5). Acute injuries require early medical attention, especially if the injury affects mechanics and performance. An accurate diagnosis is necessary so that the appropriate management can be planned. The goals of rehabilitation are to control inflammation and pain, promote healing, and restore function. Once the athlete has

Table 2.5 Guidelines for a rehabilitation program based on the stages of healing

Time	Stages of healing	Rehabilitation program	Therapeutic goals
Phase 1 Days 1–3	Acute inflammation	Modified activities, motion, ice, compression, elevation (MICE), crutches, braces, supportive devices, PRN	1. *Control inflammation and pain*
			Acute care management
			Protect affected area (protective weight bearing in lower extremity injuries)
			Reduce swelling and inflammation
			Minimize hypoxic damage to tissue
Days 4–7	Repair/substrate/ inflammation	Isometric exercises	Limit further tissue damage
		Gentle "pain-free" active range of motion	Gradually increase "pain-free" range of motion
Phase 2 Days 7–21	Proliferation	Restore active full range of motion	2. *Promote healing*
		Gentle progressive resistive exercises	Decrease protected status if indicated (i.e., partial weight-bearing status)
			Reduce muscle atrophy
			Improve: range of motion, flexibility, strength

(continued)

Table 2.5 (continued)

Time	Stages of healing	Rehabilitation program	Therapeutic goals
Phase 3 Week 3–6	Healing and maturation	Functional activities as tolerated	3. *Restore function*
		More complex movements	Continue to restore range of motion and strength
		Progress loading (i.e., cycling, light weights)	Restore proper muscle activation and biomechanics
			Improve: proprioception, endurance
Phase 4 Week 6–6 month	Tissue remodeling	Sports-specific training	4. *Return to activities and sports*
		Simulate the demands of the sports/activity	Restore anatomic form, physiologic function
		Coordination and balance exercises	Improve conditioning
			Return to play/sports
		Eccentric loading exercises	Consider training modifications and return to play/sports
Plans			5. *Prevent future injury*
			Protective equipment
			Injury prevention exercises/programs

Source: Jarvinen TAH, Jarvinen TLN, Kaariainen M, et al. Muscle injuries: biology and treatment. Am J Sports Med, 2005;33(5);745–764. Reprinted by permission of Sage Publications, Inc.

recovered sufficiently, return to sports and/or competition can be considered. Maintaining the athlete's physical fitness during recovery, education on preventing future injuries, and specialized training to increase performance are essential components of the rehabilitation program.

Rehabilitation Plan of Care

The aims of a rehabilitation plan of care are to:

- Provide immediate injury care (RICE)
- Restore function
- Return to sports and/or competition
- Prevent future injury

Immediate Care

In the past, the acronym **RICE** (**r**est/modified activity depending on the severity of the injury, **i**ce, **c**ompression, and **e**levation) has been the standard of care following an acute injury. Recent studies have indicated that prolonged or excessive use of ice may delay the healing process. However, most health-care professionals agree that following an acute injury and/or surgery using ice for short intervals of time is beneficial to decrease pain and swelling. The current recommendations are to apply ice 10–15 min, remove for 20 min, and continue this process until the pain and swelling has subsided [19]. Controlling pain and reducing inflammation facilitates the healing process.

Restore Function

The goal of restoring function is to achieve independence in all activities with maximum efficiency and effectiveness. Exercises to increase and maintain flexibility, muscle strength, proprioception, speed, power, neuromuscular training, and cardiovascular endurance are the major components for full restoration of function. The rate of exercise progression is based on the athlete's abilities and the nature of the injury. An experienced therapist is helpful in determining the appropriate program.

Early mobilization may be limited because of pain, swelling, internal joint derangement, scar tissue formation, and prolonged immobilization. Controlling pain and reducing inflammation helps to facilitate the rehabilitation process. Prolonged immobilization can often lead to muscle shortening, loss of sarcomeres, atrophy, and weakening of the muscle. After some injuries, tightening of surrounding tissues from scarring may cause impaired movement. The period of muscle–tendon immobilization should be short, usually less than 1 week, to limit the extent of connective tissue proliferation at the site of injury [20].

Currently, there are reliable and valid tools to assess pain in neonates, infants, toddlers, school age children, adolescents, and adults. Adolescents are often able to accurately report their pain level because they have developed a more complex pain vocabulary. The visual analog scales can be used with the adolescent athlete. It consists of a horizontal or a vertical line exactly 10 cm long, with anchors (0 no pain, 10 extreme pain) at either end. The athlete marks a point through the line that best describes the pain level, which can be read as a percentage or a number [21].

The athlete needs to be able to differentiate between the pain associated with an injury and the discomfort that can be expected from therapeutic exercise. The athlete also needs to understand that pain is the body's sign that there is a problem. However, the athlete should also be informed that delayed muscle soreness might be expected after stretching or strengthening exercises. If recurrent swelling, increased stiffness, loss of motion, or severe discomfort occurs at any time during the rehabilitation program, the exercise should be discontinued and the athlete's physician notified. Treatment is only resumed with physician approval.

The application of the following treatment modalities may not only reduce pain and inflammation but may also enhance the rehabilitation process.

Medications are sometimes prescribed. However, medications should be used judiciously because the athlete's natural healing potential is good. The most commonly prescribed medications for sports-related injuries are nonsteroidal anti-inflammatory drugs, or NSAIDs (Table 2.6). These medications are sometimes used to control inflammation and pain. However, studies in animal models have suggested that some of these medications may interfere with the normal tissue healing process. Long-term use of NSAIDs is not indicated for children or adolescents. Pain should not be masked with the use of NSAIDs, or any other type of medication, to allow the athlete to compete. Most NSAIDs, other than ibuprofen and naprosyn, are not approved for use in children.

Table 2.6 The use of NSAIDs for sports injuries

Table – Highlights of studies on the use of NSAIDs for sports injuries
• Short-term use of NSAIDs may provide relief from pain and swelling after fracture, but long-term use of these medications may result in poor bone healing or nonunion
• There is little role for NSAIDs in the treatment of patients with tendon injury other than pain relief during the first several days after injury
• Short courses of NSAIDs of 3–7 days may be of benefit in managing ligament injury
• Pain resulting from muscle injury and the time to return to full activity may be reduced with short-term NSAID use
• There are a number of alternatives to systemic NSAID administration. These medications should be considered as valid options in the management of musculoskeletal injuries

Source: (J Musculoskel Med. 2011;28:207–212)

Superficial heat and cold increases or decreases tissue temperature at a depth up to 5 cm, depending on the method of delivery. The physiological response to heat causes vasodilatation and erythema, whereas the application of cold causes vasoconstriction followed by vasodilatation. Ice can help reduce metabolism and secondary hypoxic injury. Heat and cold can reduce fast and slow nerve fiber sensation. The initial goal is to decrease pain and promote relaxation of the tissues. In addition, applying pressure with cold reduces posttraumatic swelling. It is essential to have a proper barrier between the skin and the hot or cold pack to prevent skin irritation and/or damage [22].

Hydrotherapy is the immersion of body segments in water, for example, in a whirlpool. Water immersion promotes an increase or decrease in superficial tissue temperature in a large body part. The main goal of hydrotherapy is to decrease swelling, relieve pain and stiffness, and promote relaxation [22].

Acupuncture describes a family of procedures involving stimulation of anatomical points on the body by a variety of techniques. Acupuncture originated in China over 2000 years ago, and it has been used in the treatment of many health problems, including musculoskeletal injuries, headaches, gastrointestinal problems, and pain [23]. An example is the insertion of fine needles into selected acupuncture points to bring the body's systems into "balance."

Transcutaneous electrical nerve stimulation (*TENS*) is the procedure of applying controlled, low-voltage electrical impulses to the nervous system by passing electricity through the skin. It is effective for the symptomatic treatment of acute and chronic pain. TENS is based on the theory that the peripheral stimulation of large-diameter cutaneous afferent nerve fibers blocks sensation at the spinal cord through the gate control mechanisms [24].

Massage is the manipulation of soft tissues by the hands. Pressure and stretching compresses soft tissue, causing an increase in arterial blood and lymphatic circulation, thus promoting better muscle nutrition and relaxation [25]. Massage before performing a series of exercises can promote better mobility, pain reduction, and cardiovascular and neuromuscular relaxation, and it also has psychological benefits [26].

Myofascial release (*MFR*) is a manipulative technique that relieves tension in the fascia. Applying pressure and tractional forces to the restrictive areas can increase blood flow and enhance the lymphatic system allowing for normal functional range of motion. Techniques include the following manual manipulations: cross-hand, longitudinal plane, transverse plane, and compression [27]. Foam rollers, cylinders of high-density foam, are a form of self MFR. Rollers are inexpensive, lightweight, and portable. Rollers do not offer the precision and interpersonal, hands-on connection attained with massage, but allows the athlete a less-expensive and time-consuming alternative [28].

Therapeutic ultrasound is produced by a transducer, which converts electrical energy into sound energy. Ultrasound produces a thermal effect by increasing tissue temperature 1–2 °C at a depth of 5 cm. Nonthermal effects include cavitation and mechanical and chemical alterations. The main goal is to increase tissue extensibility and decrease inflammation, swelling, pain, and muscle spasm. In addition, ultrasound can help to reduce joint contractures and scar tissue [29]. Ultrasound should never be applied over open epiphyses [30]. Although ultrasound is widely used, there is minimal evidence that ultrasound has long-term effects on the outcome of musculoskeletal injuries [31].

Neuromuscular electrical nerve stimulation (*NMES*) is electrical current applied to the skin that activates motor units, causing an involuntary skeletal muscle contraction [36]. The main goal is to provide biofeedback and muscle reeducation to the involved muscles. Neuromuscular electrical nerve stimulation has been shown to enhance muscle function postoperatively [32].

Orthotic, *assistive devices*, *and taping* are prescribed to support or immobilize a body part, correct or prevent deformity, and/or to assist function. Devices include braces, foot orthotics, shoulder slings, splints, prosthetics, crutches, and many others. Devices such as braces restrict, control, or eliminate joint movement, whereas others, such as prosthetics, assist movement [33]. Some orthotic devices can help to reduce pain, decrease swelling, control and enhance movement, and improve proprioception. Proper selection, evaluation, and fit of the orthoses are critical to ensure both safety and patient compliance. Instruction in proper orthotic application and care is a key component to a successful outcome. External supports have been shown to reduce ankle sprains in high-risk recreational activities in adolescents with previous ankle sprains [34].

Muscle length (*flexibility*) can have a detrimental effect on the overall rehabilitation program. Stretching exercises may have to be discontinued while the athlete is recovering from a specific injury. The injured area must be fully healed before resuming a stretching program. However, maintaining the athlete's overall flexibility is essential to ensure fitness when the athlete is ready to return to sports and/or competition. PNF (proprioceptive neuromuscular facilitation) and static and dynamic stretching have been shown to have a positive effect on increasing muscle flexibility. Dynamic stretching prior to an activity has been shown to increase performance, specifically power and strength, because a dynamic "warm-up" mimics the activity [35].

A dynamic warm-up prepares the body for physical performance by moving the body through the required motion and speed. For example, hip swings, walking lunges, and scissor jumps would prepare soccer players for their game [36].

Static stretching has been proven to be most effective following an activity. It involves lengthening a muscle and holding the position for 30 s increasing the plasticity of muscles. This allows muscles to gradually elongate [36].

Joint range of motion is often compromised following an injury or surgery. Restoring joint range of motion may need to begin very slowly with active, assistive exercises done with gravity eliminated. For example, the athlete with an acute knee injury is positioned side lying on his involved side, with the uninvolved leg over a pillow. The side-lying position not only eliminates gravity but also helps to facilitate active, assistive knee flexion and extension (Fig. 2.6). Non-weight-bearing active or passive exercises in the side-lying position can be very comfortable and are less painful. Gentle "contract/relax" exercise techniques can help to quickly regain full, pain-free range of motion [37].

Joint range of motion can also be increased with manual therapies, including both manipulation and mobilizations. Manipulation is defined as a small-amplitude, high-velocity thrust technique involving a rapid movement beyond a joint's available range of motion. Mobilizations are low-velocity techniques that can be performed in various parts of the available joint range based on the desired effect [38]. Mobilization techniques have been shown to produce concurrent effects on pain, sympathetic nervous system activity, and motor activity. Joint mobilizations are considered far safer than manipulations because the patient participates in the technique.

Fig. 2.6 Active-assisted knee flexion and extension. Side lying on the involved side to facilitate pain-free knee flexion and extension with gravity eliminated

Restore and improve strength requires a safe, well-designed, age-appropriate, resistive exercise program. Optimal loading of the muscles during strength training exercises includes varying the amount of resistance, repetitions, frequency, speed, and rest intervals (Table 2.7) [39]. Appropriate exercise programs are designed to apply controlled, sufficient, but not excessive, stress to healing structures. After an injury, there can often be persistent weakness, muscle atrophy, and painful inhibition. A well-designed exercise program helps to alleviate the sequelae of an injury.

Eccentric loading involves the development of tension while the muscle is contracting and being lengthened, e.g., the downward movement (eccentric) of a biceps curl using a dumbbell. The high forces produced in muscles eccentrically can cause damage and/or injury, particularly in muscle and tendon tears, as well as in overuse

Table 2.7 Guide to strength training in the young athlete

Number of exercises	8–12 address all major muscle groups
Frequency	2 nonconsecutive strength training sessions per week
Resistance	60–75% maximal weight load
Repetitions	10–15 repetitions of each exercise
Sets	1 challenging set
Speed	Controlled 3–5 s each rep
Range	Full range of pain-free motion
Technique	Proper posture, biomechanics, and smooth movement
Progression	Increase resistance 5–10% when 15 reps can be completed

Source: Adapted by permission from Faigenbaum and Westcott [39] injuries [40]. However, if the eccentric contractions are applied progressively and repeatedly, the muscle–tendon unit can adapt to these high forces. Eccentric loading exercises have been demonstrated to help in rehabilitation of chronic tendinopathies, such as Achilles and patellar tendinosis, using incline drop squats [41].

The term "kinetic chain" refers to the coordinated activities of body segments and the forces generated from proximal to distal. Open kinetic chain (OKC) exercises are performed with the distal lower extremity segment-free (Fig. 2.7a). A short-arc knee extension, quadriceps-strengthening exercise, is an example of an OKC. Closed kinetic chain (CKC) exercises are performed with the distal segment fixed (Fig. 2.7b) [42]. An example of a CKC exercise is a leg press. CKC exercises tend to be more functional and safer.

Core stability is the recruitment of the trunk musculature while controlling the position of the lumbar spine during dynamic movements. The stabilization of the central core (trunk) in sports has benefits for preventing injuries, as well as improving performance. The core muscles include the abdominals, extensors, and rotators of the spine. The core muscles act as a bridge between the upper and lower extremities providing stability to the limbs. The strength of the abdominal muscles is critical in maintaining optimal alignment of the trunk and pelvis [5]. Figure 2.8 illustrates normal abdominal muscle strength.

Proprioception allows the body to maintain stability and orientation during static and dynamic activities at both the conscious and unconscious level. Mechanoreceptors are the

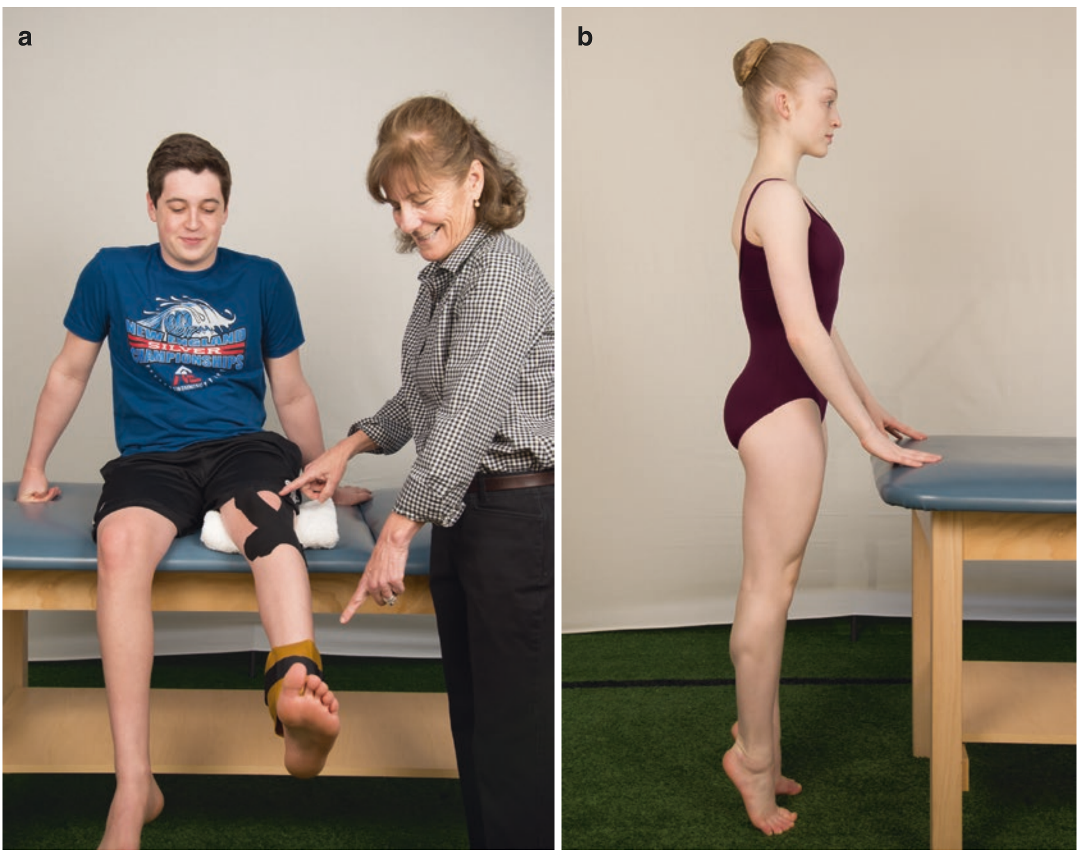

Fig. 2.7 OKC and CKC. (**a**) *OKC* exercise using BIODEX equipment. The distal segment is free as the athlete performs a long-arc quadriceps-strengthening exercise. (**b**) *CKC* exercise. The distal segment is fixed as the dancer performs a gastrocnemius-strengthening exercise

Fig. 2.8 Core stability. The dancer is able to keep lumbar spine in contact with the table, while strengthening both the upper and lower abdominal muscles

Fig. 2.9 Dynamic stability (proprioception training). The dancer is catching a medicine ball (weighted), while maintaining her balance on a wobble disc

neurosensory cells that are responsible for monitoring joint position and movement. After an injury, proprioception can be diminished due to damage of the mechanoreceptors. In addition, loss of tensile properties of static structures such as ligaments or the joint capsule, and the latent response of muscles to provide reflex stabilization of a joint, can also have a negative effect on proprioception [43]. A rehabilitation program designed to improve proprioception stimulates the mechanoreceptors that encourage joint stabilization, balance, and postural activities at both the conscious and unconscious levels.

Neuromuscular training describes a progressive exercise program that restores synergy and synchrony of the muscle firing patterns required for dynamic stability and fine motor control. This is accomplished by enhancing the dynamic muscular stabilization of the joint and by increasing the cognitive awareness of both joint position and motion. Activities are designed to both restore functional stability around the joint and enhance motor control skills. The use of balance equipment, such as a wobble board and therapeutic exercise balls, can challenge the proprioceptive and balance systems (Fig. 2.9). This helps to restore dynamic stability and allow the control of abnormal joint translation during functional activities [44].

Plyometrics is a natural event that occurs in jumping, hopping, skipping, and even walking. Sports-specific plyometric exercises can be incorporated into the athlete's functional programs (Fig. 2.11). The principle of plyometric training is the stretch-shortening cycle, which is when the muscle is stretched eccentrically and immediately contracted, leading to an increase in the force of the contraction. Plyometric training increases the athlete's power and speed. An example of a plyometric program consists of one set of 5–10 repetitions of low-intensity drills, such as squat jumps and medicine ball chest passes, performed two times per week.

Table 2.8 Example of functional test for lower extremity

Test	Goal	Directions	Measure	Normative data (NV)
SLS for distance	To hop as far forward as possible on one leg	Stand on test leg heel on zero mark. Hop as far forward as possible, landing on test leg	Horizontal distance hopped from heel at start position to heel on landing position	Age 14.5 NV = 119.9–155.1 cm
SLS triple jump for distance	To hop as far forward three consecutive times	Start position as above. Hops three consecutive times on the test leg. On the final hop, hop for maximal distance. Hold landing foot stationary for 1 s	Horizontal distance hopped from heel at starting position to heel on landing position	Unknown
SLS vertical jump	To jump as high as possible and land on one leg	Record standing reach. Jump on test leg touching wall with chalked hand. Landing on the same leg Record reach	Maximal height jumped minus patient's standing reach height	Age 14.3–15.8 NV = 46.9–49.0 cm
SLS 6 m hop for distance	To hop 6 m as quickly as possible	Stand on test leg. Hop forward for 6 m as quickly as possible	Time to nearest 0.01 s	Unknown

Source: Manske R, Smith B, Wyatt F. Test-retest reliability of lower extremity functional tests after a closed kinetic chain isokinetic testing bout. J Sport Rehab 2003;12(2):119–132
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Depending on the athlete's ability, the program may progress to multiple hops, jumps, and throws [45]. One study demonstrated that jumping power and running velocities were improved in prepubescent boys that performed plyometric exercises; the improvements were maintained after a brief period of reduced training compared with matched controls [46]. Another study of female athletes ages 15.3 ± 0.9 years who underwent 6 weeks of training, which included plyometric training, core strengthening, and balance and speed training, showed improved measures of performance and movement biomechanics [47].

Safe Return to Sports/Competition

Athletes can safely return to their sports/competition when their injuries are healed and their physical attributes are sufficient to withstand the demands of their activity. A comprehensive rehabilitation program must include progressive exercises to ensure the athlete's readiness for these demands. A program designed for sports-specific activities is implemented when the athlete has achieved full, pain-free, passive, and active joint range of motion. In addition, adequate muscle strength and cardiovascular and muscle endurance are essential components in restoring normal movement patterns.

The athlete must have medical clearance before returning to full activity. Functional testing helps to determine the athlete's readiness to return to a specific sport (Table 2.8). Functional tests emphasize skill-related activities and often include assessments of agility, balance, coordination, speed, power, and reaction time (Fig. 2.10).

Prevention of Future Injuries

Prevention is the ideal management for all sports injuries. However, because the nature of sports activities involves risk taking and, in some cases, pushing individuals to the limits of performance, injuries are bound to occur. The risk factor that is associated most with future injury is a previous history of a similar injury [48]. Preseason conditioning and "warm-up" exercises can often help to reduce injuries [35].

The Federation International de Football Association (FIFA) developed an injury prevention program for soccer players. The FIFA 11

Fig. 2.10 Agility and balance. The athlete is instructed to jump within the rungs of a ladder to promote agility, balance, and coordination

Injury Prevention Program is a dynamic warm-up program for male and female soccer players age 14 and older. It takes 20 min to complete and should be performed two times per week. The program consists of running, muscle strengthening, plyometrics (Fig. 2.11), and balance exercises. Special attention is placed on the quality of exercise performance.

In 2017, FIFA reviewed six studies of clustered-randomized and randomized control trials to determine the effectiveness of the FIFA 11. A total of 3806 soccer players participated in the FIFA 11, and 3645 soccer players were in the control group and did not participate in the injury prevention program. The players that participated in the injury prevention program showed a 39% decrease in injuries, when compared to the control group. Based on these results, the authors concluded that a worldwide adoption and implementation of the FIFA 11 Injury Prevention Program should be encouraged for all soccer players [49]. All adolescent athletes should be encouraged to participate in preseason sports-specific injury programs such as the FIFA 11.

To reduce the risk of reinjury when returning to an intensive training schedule, the athlete must maintain a high level of fitness during the rehabilitation phase. Selection of an appropriate aerobic conditioning program must consider the athlete's injury, physical ability, and condition. The athlete should begin slowly and not be overexerted with the aerobic activity. Activities such as swimming, cycling, low-impact exercises, and strengthening of the uninjured area will help to maintain this high level of fitness. Suggested increases for frequency, intensity, and duration are approximately 5–10% per week, depending on the athlete's level of fitness [50]. Adequate periods of recovery should be planned between training sessions.

Summary

An athlete can often lose confidence after a serious injury, even if the injury is healed. A well-designed rehabilitation program that not only focuses on the injured area but also maintains the athlete's fitness level and incorporates sports-specific functional exercises will help to alleviate the athlete's fear. The skill and movement of the sports are broken down into individual parts and are progressed slowly to build the athlete's confidence. Placing appropriate demands on the recovered injured area will not only help the athlete safely return to sports but also decrease fear and apprehension.

A successful rehabilitation program includes a comprehensive team approach. Communication between the physician, parent, athlete, other health-care providers, and coaches is essential to determine the athlete's readiness to return to sports. A successful program returns the athlete to his or her preinjury level without putting the athlete or others at risk for injury.

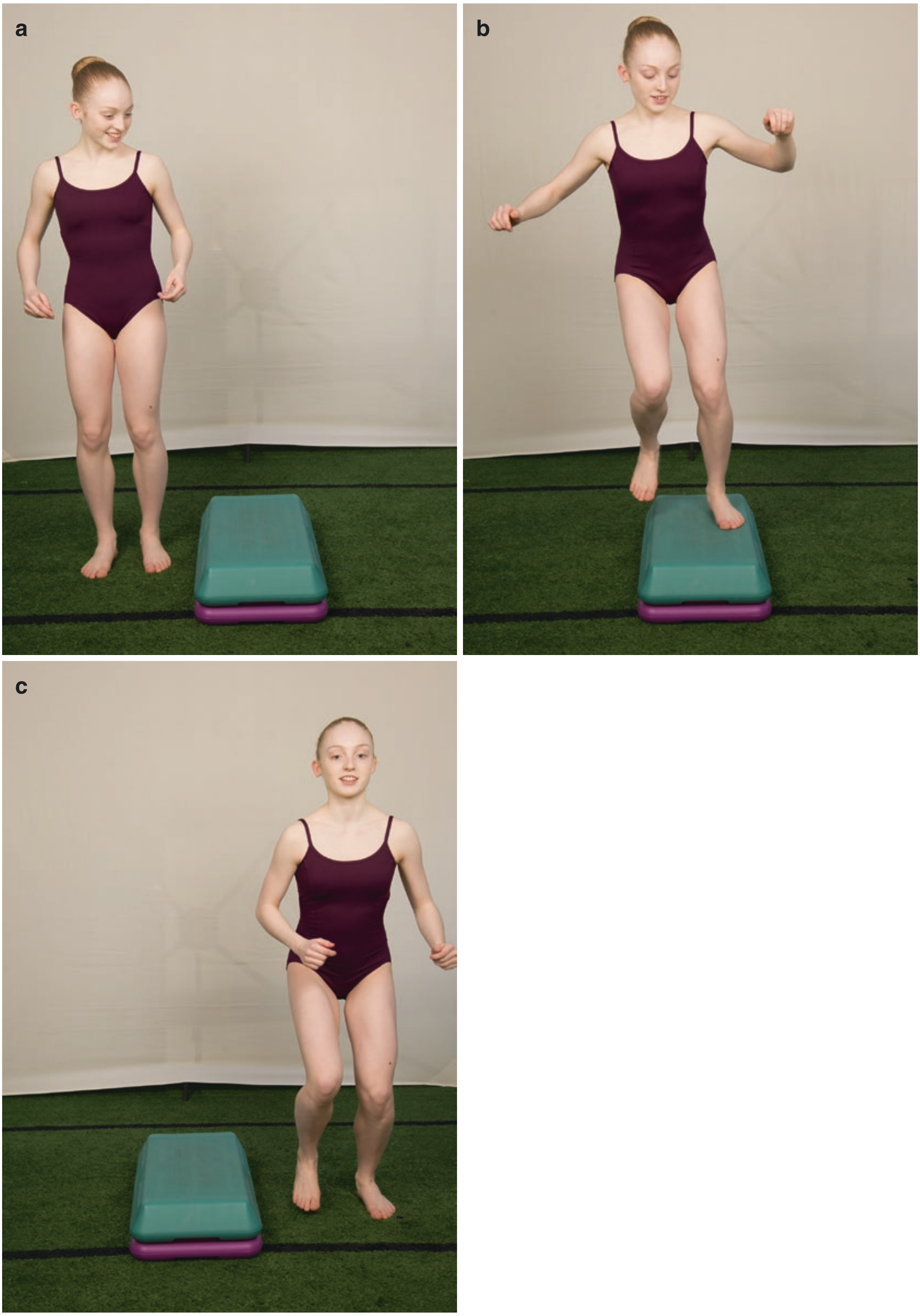

Fig. 2.11 Plyometrics. The jump sequence is an example of a plyometric exercise. The dancer (**a**) jumps up to (**b**) a high step and (**c**) back down to the floor

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3 Diagnostic Imaging

Diego Jaramillo and Vernon M. Chapman

Diagnostic imaging is frequently performed in the evaluation of adolescent sports-related injuries. Imaging often helps determine the nature and severity of injuries and is important for deciding appropriate management. There are several diagnostic imaging techniques available for examining the musculoskeletal system. An understanding of the principles, advantages, and disadvantages of these techniques and their clinical application in adolescent patients is important for optimal imaging evaluation.

Imaging Techniques

Radiography

Radiography is the oldest diagnostic imaging technology, dating back to the discovery of x-rays by physicist Wilhelm Roentgen in 1895. Over the last two decades, digital radiography has created a revolution in this technology. Radiographs are created by placing the body part of interest between an x-ray source and a film. The body part absorbs the x-rays depending on the density of its various tissues, and the x-rays that pass through are used to generate the image [1]. A typical radiograph examination is performed in less than 10 min. Radiographic images, as well as images from all other modalities, are usually recorded on a digital format on a picture archiving and communication system (PACS). Digital radiography allows changing the window and level of the display and increases the contrast or the size of the object. There have also been great advances in the technology to capture the image. The result has been an improvement in image quality, reduction of dose, and added capability such that the soft tissues and the bones can be reviewed separately [2].

Digital imaging is divided into computerized radiography (CR) and direct radiography (DR) [2]. Computed radiography uses a cassette with a plate containing photostimulable crystals that detects the x-ray beam and is used to create an image. The system is mobile and has a wide dynamic range, which means that images are less susceptible to variations in radiation exposure. They are ideal for portable radiography and can be used with existing x-ray machines.

With direct radiography, a photoconductor, usually selenium based, converts the x-ray beam into electrical charges that become an image. These systems are fast and result in excellent image quality but are not portable. Most radiology departments use a mix of both, and the images are almost indistinguishable to the observer.

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L. J. Micheli, L. Purcell (eds.), *The Adolescent Athlete*, Contemporary Pediatric and Adolescent Sports Medicine, https://doi.org/10.1007/978-3-319-56188-2_3

More recently a technology called EOS has become useful for imaging of large fields of view where resolution is less important and dose reduction (by a factor of approximately five to ten) can be achieved [3]. In the knee, this is useful when evaluating abnormalities of alignment or length. The images are obtained by two orthogonal pencil-like beams that scan the entire area. The biplanar exposure takes approximately 20 s so motion artifacts are common; it requires collaborative patients that can stand. Aside from the significant reduction in radiation exposure, EOS has the capability of generating coarse 3-D images.

Five basic tissue densities are evaluated in radiographs: bone, soft tissue, fat, air, and metal. The first three are most important in the evaluation of radiographs obtained for orthopedic injuries before any surgical intervention. Though bone is the most basic structure evaluated on radiographs, close inspection of the surrounding soft tissues and fat is often useful for assessing the presence or severity of an injury. This is particularly important in disorders such as Osgood–Schlatter disease, where detection of edema of the prepatellar soft tissues and of Hoffa's fat pad is more diagnostic than detection of osseous irregularity of the tibial tubercle.

The advantages of radiography are high spatial resolution, which is several times greater than that of any other modality, widespread availability, low cost, and brief exam time. High spatial resolution allows the identification of very subtle injuries, such as nondisplaced fractures. The availability, low cost, and rapid acquisition of radiographs mean that radiography may be performed almost anywhere, in nearly any patient.

The disadvantages of radiography are its limited soft tissue contrast, two-dimensional imaging, and radiation exposure. Though excellent for assessing bone pathology, radiography is extremely limited in evaluating soft tissue pathology, including injury to ligaments, tendons, and muscles. Furthermore, radiographs are two-dimensional depictions of three-dimensional structures; although it is common to obtain multiple views, true three-dimensional images cannot be reconstructed from radiographic data. Though radiography has associated radiation exposure, it is substantially less than that associated with computed tomography or nuclear medicine bone scan.

Computed Tomography

In computed tomography (CT), an x-ray source and detector rotate around a patient as the patient moves through the center of rotation. The data acquired are then computer reconstructed into a series of two-dimensional slices of the area of interest. Whereas older CT scanners consisted of a single x-ray source and a single detector, modern scanners use one or two x-ray sources and 64 or more detectors, acquiring data continuously in a helical fashion as the patient moves through the scanner. The result is faster examinations with thinner slices and improved postprocessing capability.

In CT, tissues are depicted based on their x-ray attenuation relative to the reference value of water, which is assigned a value of zero (expressed in Hounsfield units [HU]). The resulting images can be viewed in the axial plane or reformatted to sagittal, coronal, or oblique planes [4]. The soft tissue contrast on CT can be accentuated with the use of iodinated intravenous contrast, which is commonly performed for evaluation of the chest, abdomen, and pelvis. Evaluation of the musculoskeletal system, on the other hand, rarely requires intravenous contrast, unless vascular injury is suspected.

The advantages of CT are rapid scan time and three-dimensional imaging. On a modern multidetector CT scanner, imaging of the head, spine, chest, abdomen, pelvis, and/or extremities can be performed in less than 1 min. The scan data can then be used to construct three-dimensional images, which are frequently useful in the preoperative assessment of orthopedic injuries.

The disadvantages of CT are radiation exposure [5], cost, and availability. The radiation exposure varies, depending on the type of examination, but is several orders of magnitude greater than radiographs. In general, a CT examination delivers a radiation dose that is equivalent to that of 100–250 conventional radiographs, particularly when imaging areas that include the trunk such as the hips or shoulders. This is an important consideration in regard to risk of radiation-induced malignancies, particularly in young patients whose tissues are more susceptible to radiation carcinogenesis and who have to carry the burden of the radiation damage for many years. In general, it is stated that there are no proven effects when using less than 50 mSV. One CT of the hip is in the range of 2–3 mSV. In extremities, it is possible to image with a much lower dose, as the structures can be imaged remotely from most of the body. A CT of the wrist, for example, results in an exposure of 0.03 mSV [6]. The cost is substantially greater than that of radiography, which, coupled with its limited availability (depending on location), may limit patient access to CT.

In the last two decades, advances in CT have improved orthopedic imaging. Dual-energy CT is the capability of scanning at different energies. It allows imaging of specific densities such as that of gout crystals and the subtraction of metallic prostheses. Cone beam CT has brought CT scanning into the operating room, allowing three-dimensional guidance of bone surgeries. An O-arm functions in a fashion similar to a C-arm but with the capability of generating cross-sectional images.

Magnetic Resonance Imaging

Magnetic resonance imaging (MRI) utilizes differences in the frequency of spinning protons in various tissues to create images. Images are obtained using a complex array of gradients and delivered radio-frequency pulses, with the patient lying in a strong magnetic field (approximately 10,000 times as strong as the earth's magnetic field) [7]. Over the past several decades, MRI has become a powerful technique for evaluating many organ systems, particularly the musculoskeletal and nervous systems. It is the imaging method of choice for the spine, joints, and soft tissues.

The advantages of MRI are excellent soft tissue contrast, three-dimensional imaging, and lack of radiation exposure. The tissue contrast achieved with MRI far surpasses that of radiography, CT, or any other modality, making it the best modality for evaluating both osseous and nonosseous musculoskeletal trauma. Although the mineralized portions of bone are poorly visualized, the marrow and surrounding tissues are seen well and serve as indicators of injury. Like CT, MRI allows multiplanar imaging, and image data may be used to create three-dimensional images. Furthermore, MRI is associated with no radiation exposure, which is a particularly appealing attribute in the pediatric population.

The disadvantages of MRI are long examination time, cost, limited availability, and contraindications. Most musculoskeletal MRI exams require between 30 min and 1 h, depending on the site being imaged. 3 T MR units and the use of newer sequences like parallel imaging have allowed faster studies, and many joints can be studied in 15–30 min. Sedation is rarely required for older children and younger adolescents suffering sports-related injuries, but patients with injuries may become "fidgety," leading to motion-degraded images. The cost of an MRI examination is greater than any other musculoskeletal imaging modality, with the possible exception of a nuclear medicine bone scan and positron emission tomography (PET). Furthermore, some patients are unable to have an MRI examination because of certain indwelling metallic objects (aneurysm clips, cardiac pacer/defibrillator devices, etc.). In recent years, MRI of the musculoskeletal system has improved, thanks to 3-D imaging techniques, quantitative imaging of cartilage, and faster imaging techniques that reduce examination time. Contrast material, which uses one of several gadolinium chelates, usually is not necessary for studies performed for musculoskeletal trauma, but is very useful whenever the differential diagnosis includes infection or tumor.

Nuclear Medicine

The most commonly performed nuclear medicine study for musculoskeletal pathology is a bone scan. For a bone scan, imaging is performed after intravenous injection of a radiopharmaceutical.

Depending on the indication, imaging may be performed at multiple time points (three-phase; most commonly used for infection) or at a single, delayed time point (most commonly for fracture or metastatic disease).

Bone scans may be viewed as planar (two-dimensional) images or as a series of three-dimensional multiplanar images, using single-photon emission computed tomography (SPECT). Using SPECT improves the sensitivity of the bone scan for detecting lesions, particularly in the spine [8]. Recently, PET imaging using phosphate compounds has been used to provide high-resolution images of the bone. Different radiotracers can be used for PET imaging, including FDG-PET, which is sensitive to areas with a high glucose consumption, and NaF-PET, which provides images similar to those of bone scintigraphy but with a much higher spatial resolution. PET images are fused with CT or MR images to localize more precisely the areas of abnormalities.

The advantages of the nuclear medicine bone scan are whole-body imaging and the ability to detect subtle bone injuries. Whereas other modalities require focused exams, a bone scan includes whole-body planar images with additional focused images, as needed. This, coupled with its sensitivity for bone pathology, makes the bone scan an excellent tool for evaluating injuries with little or no radiographic abnormality, such as stress fractures.

The disadvantages of the bone scan are radiation exposure, low resolution and specificity, very limited depiction of soft tissue pathology, and the need for an IV injection. The radiation exposure is between that of radiography and CT, with the highest dose to the bladder. The resolution of the images obtained is less than CT or MRI, resulting in the grainy appearance of the images. Though abnormal radiotracer uptake on a bone scan indicates pathology, the exact cause can frequently not be determined without additional imaging.

Ultrasound

Ultrasound uses sound waves of frequencies greater than those of audible sound to penetrate tissues and create images that may be viewed in real time. An ultrasound examination involves a technologist and/or physician placing a probe over the area of interest with gel, and possibly a spacer, between the probe and the skin to maximize image quality [9]. Ultrasound examinations take approximately 15–30 min to perform, depending on the size and complexity of the area being imaged. As discussed later in this chapter, there is increasing enthusiasm for using ultrasonography for the evaluation of musculotendinous injuries. Most tendons and ligaments and their insertions are well depicted sonographically. In addition, sonography is useful for dynamic imaging, which makes it invaluable for studies involving muscle contraction such as the detection of a muscle hernia or for dynamic studies of a joint.

The advantages of ultrasound are lack of radiation exposure, relative low cost, dynamic imaging, and portability. Because ultrasound utilizes percussion waves rather than electromagnetic radiation, there is no risk of induced malignancy. In addition, the examination is relatively inexpensive, between that of radiography and CT. Unlike any other modality, ultrasound allows the user to view the area of interest in real time.

The major disadvantages of ultrasound are user variability and nonvisualization of the bone. The quality and success of an ultrasound examination is dependent on the experience and skill of the person scanning, whether it is a technologist or physician. This is particularly true with musculoskeletal ultrasound, as these exams are rarely performed in most radiology departments, limiting user familiarity with the examinations. Although ultrasound nicely depicts muscle and other soft tissues, the interface of soft tissue with the bone reflects all sound, preventing evaluation of osseous structures. Musculoskeletal ultrasound is perhaps the fastest growing modality in bone and soft tissue imaging.

Arthrography

Arthrography involves the intra-articular injection of contrast and subsequent imaging with fluoroscopy, CT, or MRI. Nearly all injections are performed with fluoroscopic or sonographic guidance and include iodinated and/or gadolinium-based contrast material. The injection takes approximately 10 min, with variable time involved thereafter, depending on the wait and time to perform subsequent imaging.

The major advantage of arthrography is improved visualization of the joint space, articular surfaces, and cartilage (particularly with MR arthrography) because of joint distention and increased image contrast. In addition, radiation exposure is low (except with CT arthrography) and limited to the joint.

The disadvantages of arthrography are its cost and invasiveness. Though much of the former results from the cost of the subsequent imaging (frequently MRI), the examination does require a procedure. Accordingly, the procedure portion of the examination carries a small risk of bleeding and infection. Indirect arthrography, in which contrast material injected intravenously diffuses into the synovial space, is possible with MRI. Indirect MR arthrography is useful in joints in which joint distention is not crucial, such as the wrist and hip, but is of limited value in the shoulder.

Sites of Injury

Head and Face

Injuries associated with participation in sports and recreational activities account for approximately 21% of all traumatic brain injuries in children. Though death in children participating in sports activities is rare, the most common cause of death is brain injury. As with all sport injuries in children and adolescents, the majority of head and face injuries are the result of falls, collisions, or being struck by an object [10].

The imaging evaluation of a patient with suspected intracranial trauma begins with an unenhanced head CT. CT is a rapid means of assessing for intracranial hemorrhage, parenchymal contusion, and fracture (Fig. 3.1) and may be performed in conjunction with CT of the chest, abdomen, pelvis, or extremities in a patient with multisystem trauma. Prompt diagnosis of intracranial injury is important for timely neurosurgical evaluation and possible intervention. Furthermore, the head CT may be repeated serially to evaluate for change in intracranial hemorrhage.

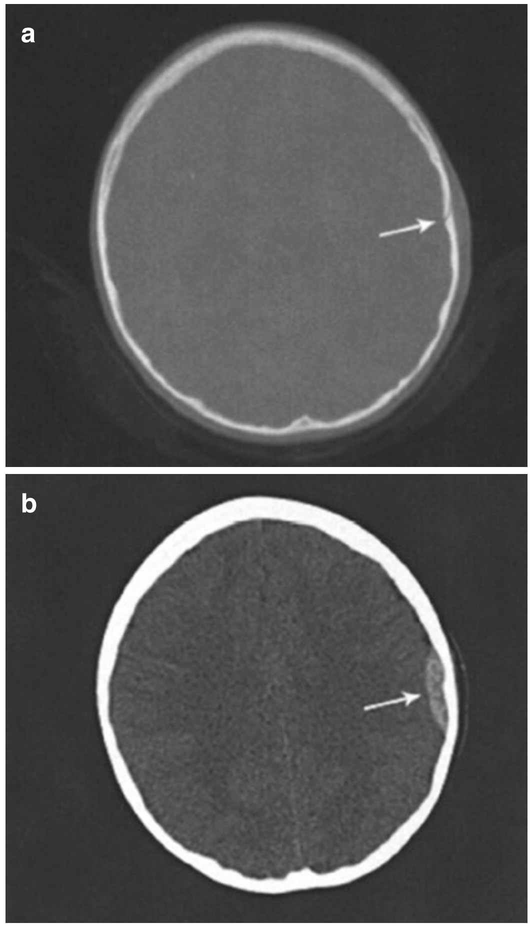

Fig. 3.1 Head trauma: 9-year-old boy struck in the head by a knee during soccer practice. An unenhanced head CT was obtained and demonstrated a nondisplaced linear fracture of the left parietal bone (**a**, arrow) with a small subjacent epidural hematoma (**b**, arrow)

If the initial head CT is negative and the patient's clinical exam remains concerning for intracranial injury, MRI of the brain may be performed. MRI is excellent for demonstrating subtle parenchymal injuries, such as acute and chronic blood products, diffuse axonal injury, and changes of ischemia or infarction [11].

Similar to the assessment of intracranial injury, CT is the primary modality for evaluating patients with suspected facial fractures [12]. The pattern and extent of these fractures is clearly depicted, and the data may be reformatted in any plane or used to create three-dimensional images for surgical planning (Fig. 3.2). In addition, associated hematomas, sinus hemorrhage, optic canal involvement, and intracranial injury are well demonstrated.

In recent years there has been increasing concern about the long-term effects of concussions with subtle brain injury, as it is associated with higher risk of negative neurological outcomes [13] and there is ongoing research about the best way to detect these subtle insults to the brain.

Spine

Sports-related injuries of the spine in adolescents include acute fracture/subluxation, disc herniation, and spondylolysis. Fracture or subluxation of the spine during participation in sports is extremely rare and most commonly affects the cervical spine. In younger children injuries tend to occur in the upper cervical spine, whereas older children and adolescents tend to injure the lower cervical spine. Given that the incidence of injury is extremely low and the risk of radiation exposure in young patients is significant, it is prudent to begin the imaging evaluation with conventional radiographs. However, with a history of severe trauma or focal neurologic deficit, it is best to go directly to CT or MRI [14]. The former is most useful for assessing for fracture or subluxation (Fig. 3.3), and the latter is best for determining ligamentous or cord injury.

Disc herniations are best imaged by MRI, as radiographs and CT provide little useful information. MRI clearly depicts the herniations, as well as the mass effect on surrounding structures, such as the spinal cord and descending and exiting nerve roots. In addition, findings on MRI can distinguish between a disc herniation and slipped ring apophysis, a rare condition that is most common in the lower lumbar spine and may mimic a disc herniation clinically.

Patients with suspected spondylolysis may be imaged with radiographs, nuclear medicine bone scan, or CT. Oblique radiographs demonstrate

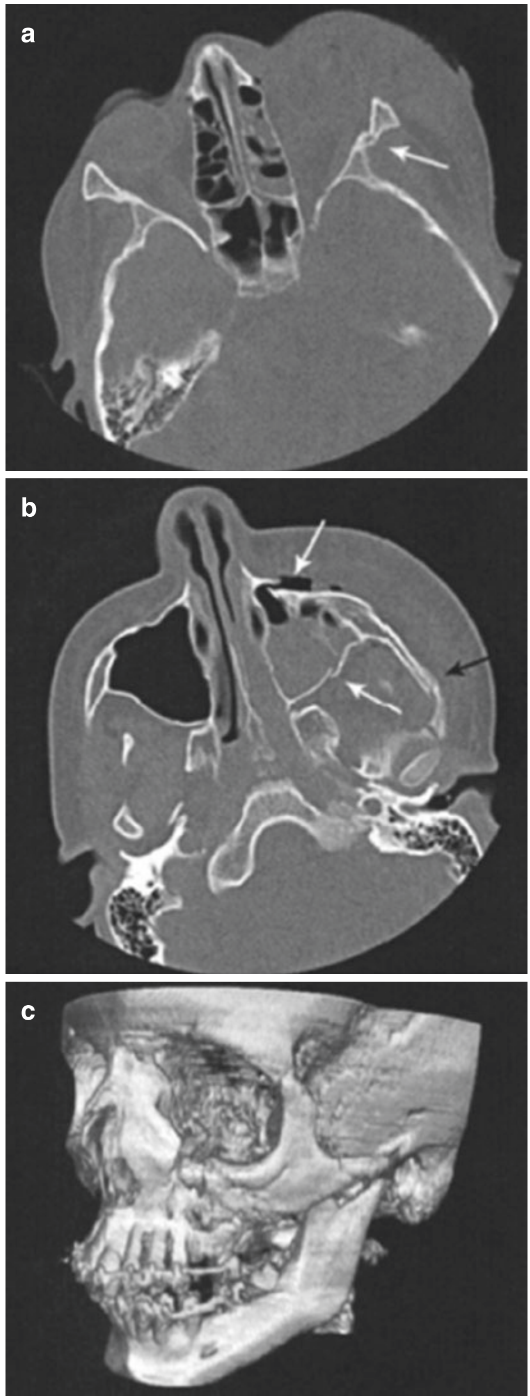

Fig. 3.2 Facial trauma: 11-year-old boy involved in a snow skiing accident. Axial images from a maxillofacial CT demonstrate fractures of the lateral wall of the left orbit (**a**, arrow), the anterior and posterior walls of the left maxillary sinus (**b**, white arrows), and the zygomatic arch (**b**, black arrow), which is consistent with a zygoma complex ("tripod") fracture. A three-dimensional image (**c**) clearly shows the fracture and assists in surgical planning

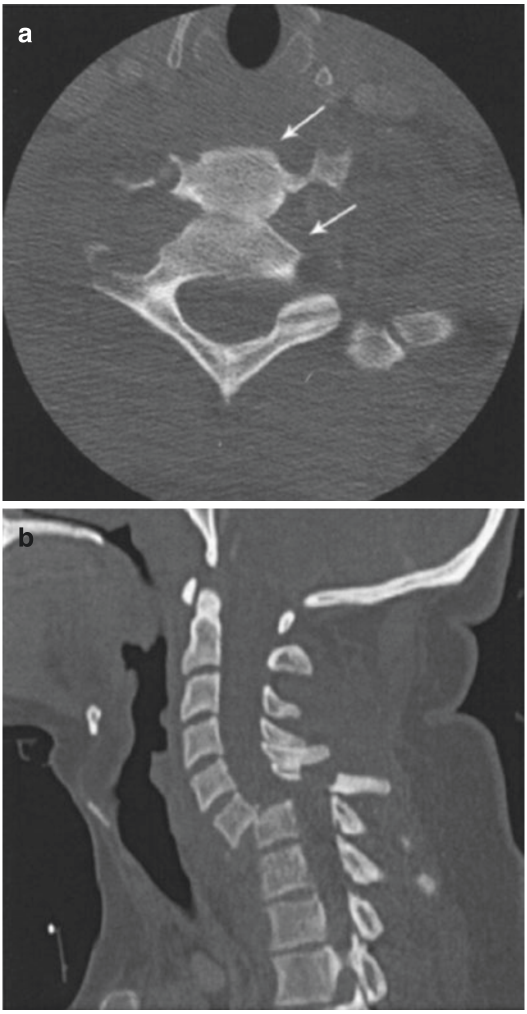

Fig. 3.3 Cervical spine trauma: 18-year-old male who struck a pole while snow skiing. An axial image through the lower cervical spine (**a**) shows the C6 and C7 vertebrae on the same image (arrows), which is consistent with a subluxation. A midline sagittal reformatted image (**b**) confirms this finding, which was secondary to bilateral interfacet dislocation

the bony disruption through the pars interarticularis and are performed in conjunction with frontal and lateral views, the latter of which demonstrates any associated spondylolisthesis. Alternatively, a bone scan with SPECT can be performed, demonstrating abnormal uptake of the radiopharmaceutical in the pars interarticularis [15]. CT is usually reserved to assess the size of the defect, to assess the need for possible surgical intervention, and to evaluate the healing of the pars fracture after treatment.

Chest and Abdomen

Injury to the chest or abdomen in children and adolescents is most commonly the result of bicycle accidents or sports-related trauma. The most concerning injuries are parenchymal contusions or lacerations (including the lung, liver, spleen, kidneys, or pancreas) and pneumothorax. Injuries to the chest are best evaluated initially with radiographs to assess for a pneumothorax, which would require immediate chest tube placement, after which CT may be performed in cases of suspected mediastinal or vascular injury. Trauma to the abdomen or pelvis, on the other hand, is best evaluated initially with ultrasound or CT. Though ultrasound can depict parenchymal injury or abnormal fluid collections, it is user dependent and may miss clinically important injuries. As a result, CT is most commonly performed for the evaluation of trauma in these patients which is faster, does not require direct access to the patient, and is generally easier to interpret [16].

Extremity Injuries

Fractures

By 16 years of age, 42% of boys and 27% of girls have sustained a fracture, with 6–30% of fractures involving the growth plate [17]. Growth plate fractures are characterized using the Salter–Harris classification, where the higher the numerical type, the greater the risk of subsequent growth arrest [18]. Radiographs are most commonly utilized for the initial and follow-up imaging evaluation of fractures. CT clearly demonstrates the path of the fracture, including involvement of the growth plate, and scan data may be used to create three-dimensional images for surgical planning (Fig. 3.4).

Occasionally occult physeal injuries can be detected during the evaluation of an internal derangement of the knee. Such injuries can be recognized by thickening and increased T2 signal intensity of the physeal cartilage, disruption of the perichondrium, and a cleft through the cartilage. In physeal fractures, MR imaging can detect the interposition of periosteum, which worsens

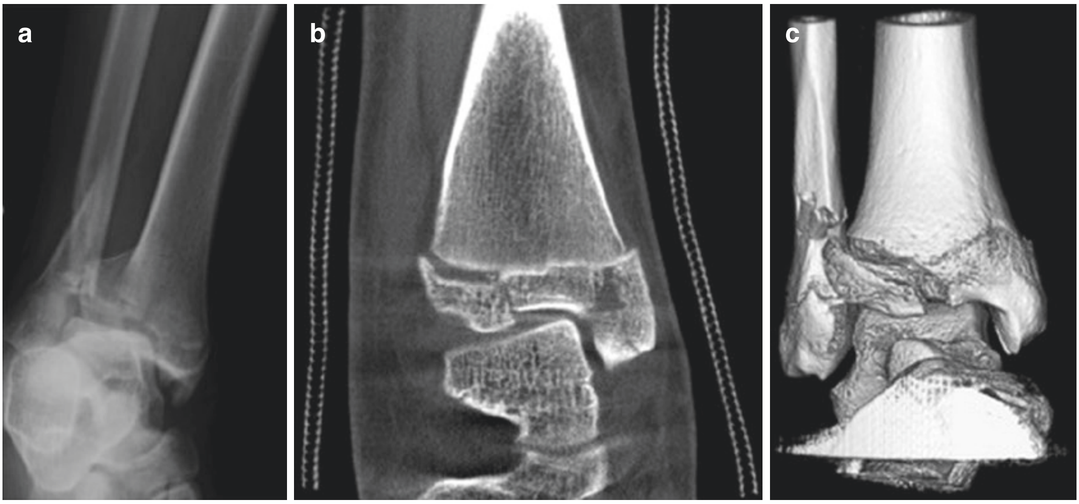

Fig. 3.4 Triplane fracture demonstrated by CT: 14-year-old boy who twisted his ankle while playing soccer. A frontal radiograph of the ankle (**a**) demonstrates complex fractures of the distal right tibia and fibula. A coronal CT reconstruction (**b**) demonstrates that there is an epiphyseal fracture which produces a step-off in the articular surface. The separation of the fragments is much better depicted on the surface 3-D reconstruction (**c**)

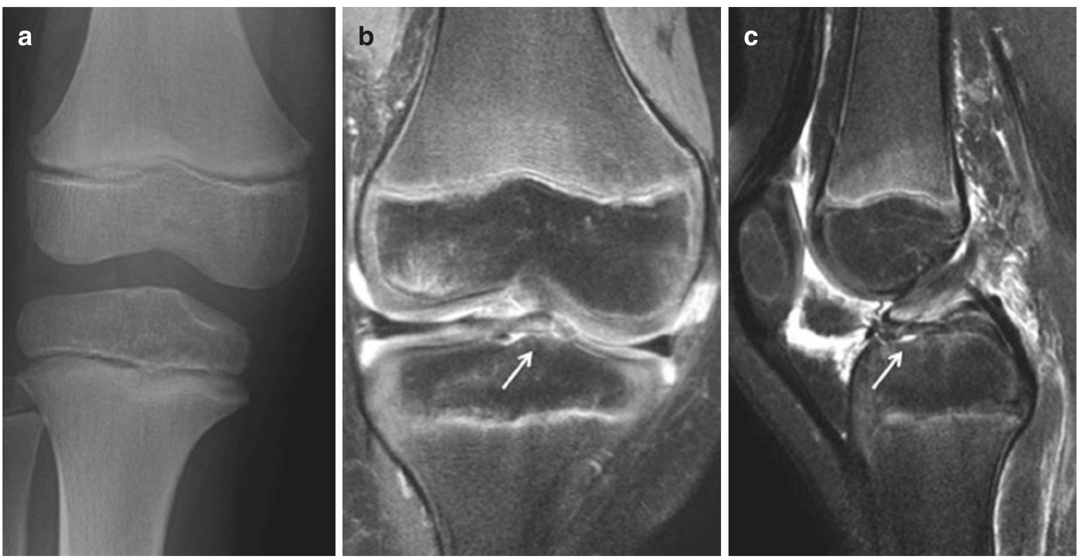

Fig. 3.5 Tibial eminence fracture and partial tear of the anterior cruciate ligament in a 12-year-old girl who fell during a lacrosse game. The frontal radiograph (**a**) is normal. Coronal proton density-weighted image (**b**) shows discontinuity of the articular/epiphyseal cartilage at the tibial spine (arrow). (**c**) The tibial spine avulsion (arrow) is better depicted on the sagittal T2-weighted image. There is also increased signal intensity in the anterior cruciate ligament, indicating an associated partial tear

the prognosis [19]. MRI may be of diagnostic and prognostic value in growth plate fractures, particularly those involving the knee, where there are frequently associated meniscal and ligamentous injuries and a high incidence of posttraumatic growth disturbance. In epiphyseal injuries, MR imaging is useful in evaluating associated ligamentous injuries such as anterior cruciate ligament tears in a Segond fracture or a tibial eminence fracture [20] (Fig. 3.5). MR imaging is also useful when the most important component of the injury is cartilaginous such as in certain tibial tubercle injuries during puberty.

Avulsion Injuries

In adolescents, the ligaments, tendons, and capsular tissues are stronger than the growth plates at or near their attachments, thereby predisposing them to avulsion injuries, which are quite common in this age group [20]. Avulsions around the hip and pelvis are most common and are best diagnosed on radiographs (Fig. 3.6). Initial radiographic changes may be subtle, but follow-up radiographs frequently demonstrate prominent new bone formation at the site of avulsion. Imaging with other modalities, including CT, MRI, and bone scan, is rarely necessary, except when the radiographic findings are atypical and suggest other pathology, such as neoplasia.

Internal Derangement

In general, the nonosseous tissues of a joint (including ligaments, tendons, muscles, cartilage, and capsular tissue) are best evaluated with MRI or MR arthrography (Fig. 3.7) [20, 21]. Many joints, such as the knee, ankle, and elbow, are adequately imaged with MRI alone; however, other joints, such as the shoulder and hip, are better evaluated with intra-articular contrast. The decision to perform an MR arthrogram frequently depends on the suspected injury. For example, evaluation of the shoulder for a rotator cuff tear is usually adequate using MRI alone, but evaluation for a labral tear is best done with MR arthrography [21].

Fig. 3.6 Tendon avulsion: 16-year-old male with right groin pain after weightlifting. A frontal radiograph of the pelvis demonstrates a crescent-shaped fragment of avulsed bone adjacent to the right ischial tuberosity (arrow), which is consistent with a hamstring avulsion

Chronic Physeal Injury

Repetitive stress on growing bone, which commonly affects adolescent athletes, can lead to chronic growth plate injury. Such injury can be a source of pain and weakens the growing bone, predisposing to acute injury and fracture. Examples include "gymnast's wrist," which is secondary to repetitive axial loading of the distal radius; "little leaguer's shoulder," resulting from repetitive torsion and distraction of the proximal humerus from throwing [22, 23]; or "little leaguer's elbow," when similar changes are seen in the medial epicondyle. The thickness of the growth plate is normally constant until skeletal maturation. With chronic injury, however, the growth plate becomes widened and irregular, with cartilage extending vertically into the metaphysis and the development of thin bone bridges, without evidence of growth arrest [24]. The findings of chronic growth plate injury may be seen on radiographs, but are often more conspicuous on MRI, where cartilage-sensitive sequences clearly demonstrate the characteristic growth plate change. MRI is also useful in the follow-up of these lesions after resting, as these findings can be reversible [25].

Chronic physeal injury may lead to a superimposed acute injury, as in the case of slipped capital femoral epiphysis (SCFE). SCFE is the result of chronic repetitive shear stress at the hip, leading to progressive physeal damage and, ultimately, an epiphyseal separation and subluxation (or "slip") of the epiphysis [26]. Radiographs are usually sufficient to demonstrate the injury with

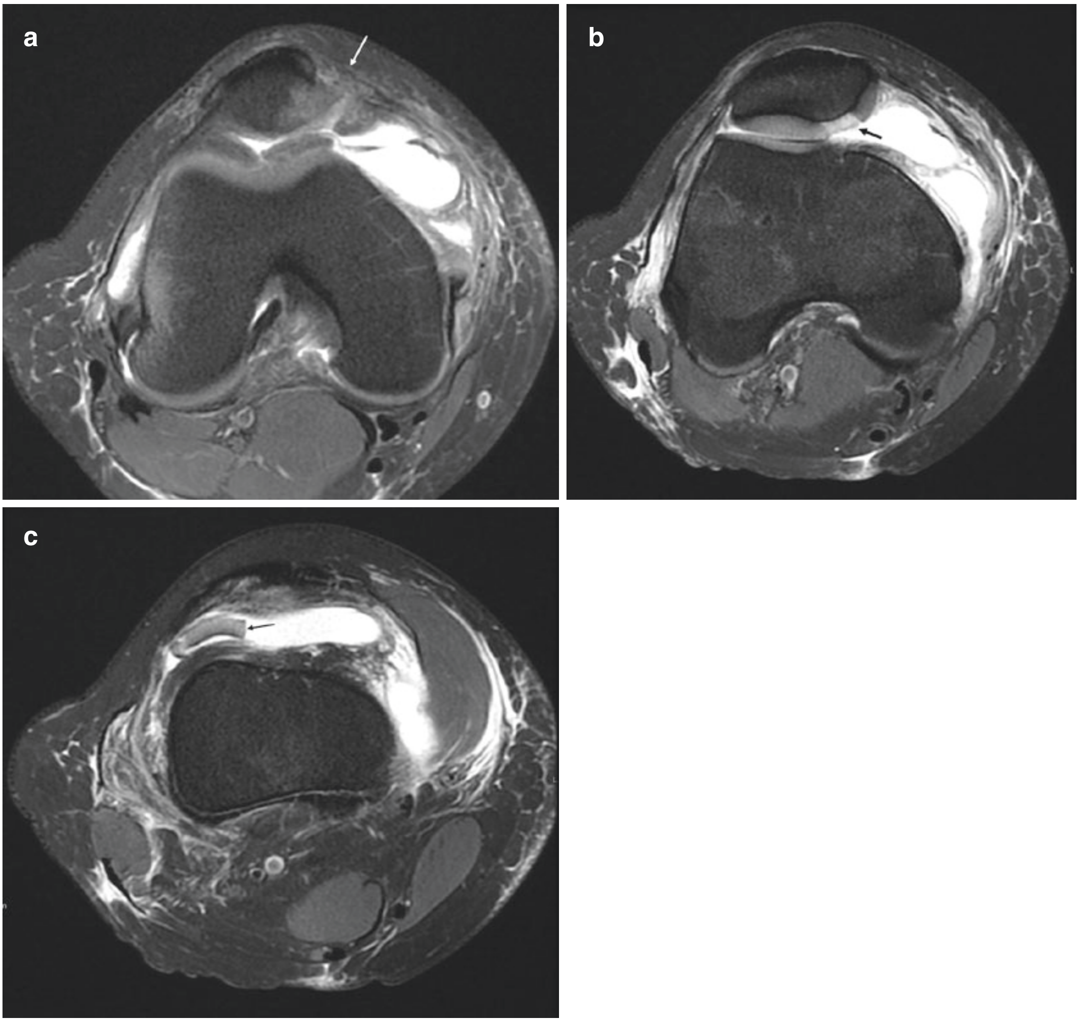

Fig. 3.7 13 year-old girl: who twisted the knee while skating one week ago. (**a**) Axial proton density image shows tear of the medial patellofemoral ligament (arrow). (**b**) Axial proton density image shows that there is an osteochondral injury in the apex of the patella (arrow). (**c**) Axial proton density image more cephalad reveals an osteochondral fragment (arrow) that originated in the patellar defect

subluxation of the epiphysis. Before epiphyseal subluxation, however, radiographs will be normal despite growth plate injury. In such cases, MRI shows findings of chronic growth plate injury (or "pre-slip"), allowing early intervention and prevention of subluxation.

Stress Injuries

Stress injuries include insufficiency-type (normal stress on abnormal bone) and fatigue-type (abnormal stress on normal bone) injuries. In adolescents, these injuries are nearly all fatigue-type

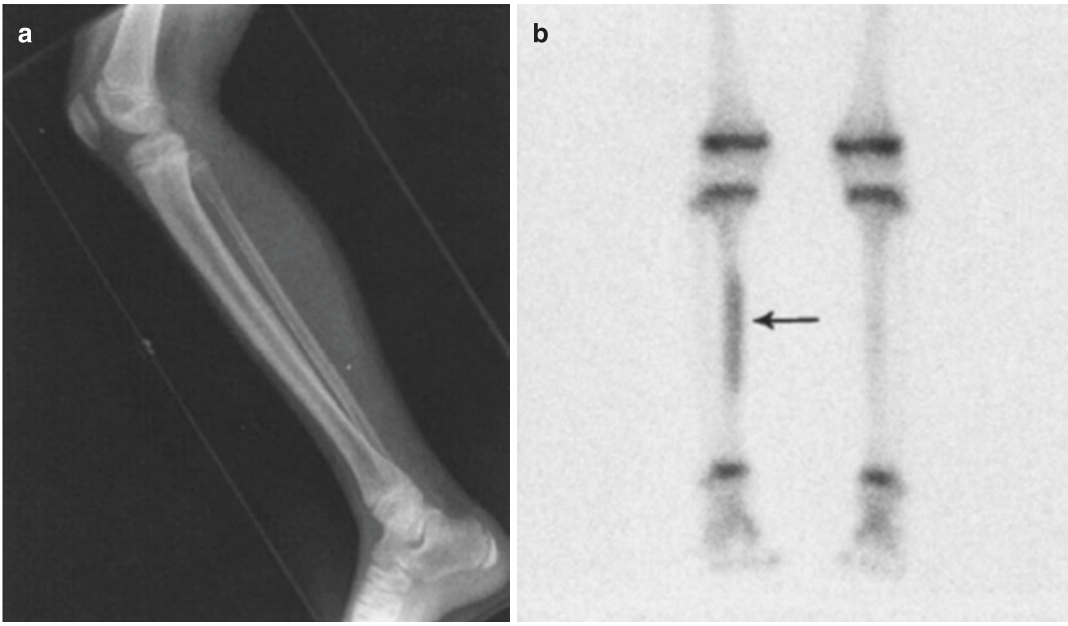

Fig. 3.8 Stress injury: A 10-year-old male soccer player with left leg pain. A lateral radiograph of the left lower leg (**a**) demonstrates subtle thickening of the anterior and posterior cortices of the mid tibia. Images from a nuclear medicine bone scan (**b**) demonstrate segmental increase in radiopharmaceutical uptake in the mid tibia (arrow), which is consistent with stress injury. No discrete fracture was identified on either study

injuries, frequently affecting the lower extremities [20]. Any bone may be involved, but the tibia and femoral neck are most commonly involved and associated with running. Radiographs may be normal early on, but later show periosteal new bone formation or linear sclerosis at the site of fracture. If radiographs are normal, nuclear medicine bone scan and MRI are useful for further evaluation. Bone scan demonstrates normal uptake on flow and blood pool images, with increased uptake on delayed images (Fig. 3.8). Images from MRI show prominent marrow edema with a low signal intensity fracture line. Stress reactions result in marrow edema in the absence of cortical disruption; the edema differs from that of osteomyelitis or tumor in that it is almost entirely confined to the bone.

Growth Arrest

Growth arrest most commonly develops because of growth plate injury, affecting approximately 15% of physeal fractures [27]. The risk of growth disturbance after physeal injury is dependent on several factors, including the severity of the injury, the patient's growth potential (i.e., age or skeletal maturity), and the anatomic site involved [28]. The mechanism of posttraumatic growth arrest is transphyseal vascular communication between the epiphysis and the metaphysis after the injury, leading to deposition of osteoblast precursors and formation of a bone bridge that tethers together the epiphysis and metaphysis [29]. In general, posttraumatic physeal bridge formation is more common in the distal physes of the lower extremities, where there are normal undulating or multiplanar physes [30]. For example, the distal femur and the proximal tibia, though uncommon sites of physeal fracture (1.4% and 0.8%, respectively), are frequent sites of posttraumatic bone bridge formation and growth arrest (35 and 16%, respectively). The most common site of posttraumatic growth arrest is the distal tibia [31].

Growth recovery lines (or Parks–Harris lines) develop when growth slows down after the fracture and resumes during the process of healing. The line is visible on radiographs and indicates the position of the growth plate at the time of injury; the distance between the growth plate and the line indicates the amount of growth since the injury. If there is growth arrest, the growth recovery line will either be absent (indicating no growth), or it will not be parallel to the physis (indicating angular deformity). CT with coronal and sagittal reformatted images may be performed to demonstrate the transphyseal bone bridge, but MRI more clearly demonstrates the size and location of transphyseal bridges [32]. Sequences that differentiate the growth plate from surrounding bone may be performed and postprocessed to yield a transverse map of the growth plate. This map can then be used to determine the percent of the growth plate that the bridge occupies, as bridges smaller than 50% of the total physeal area may be resected with good clinical result (Fig. 3.9).

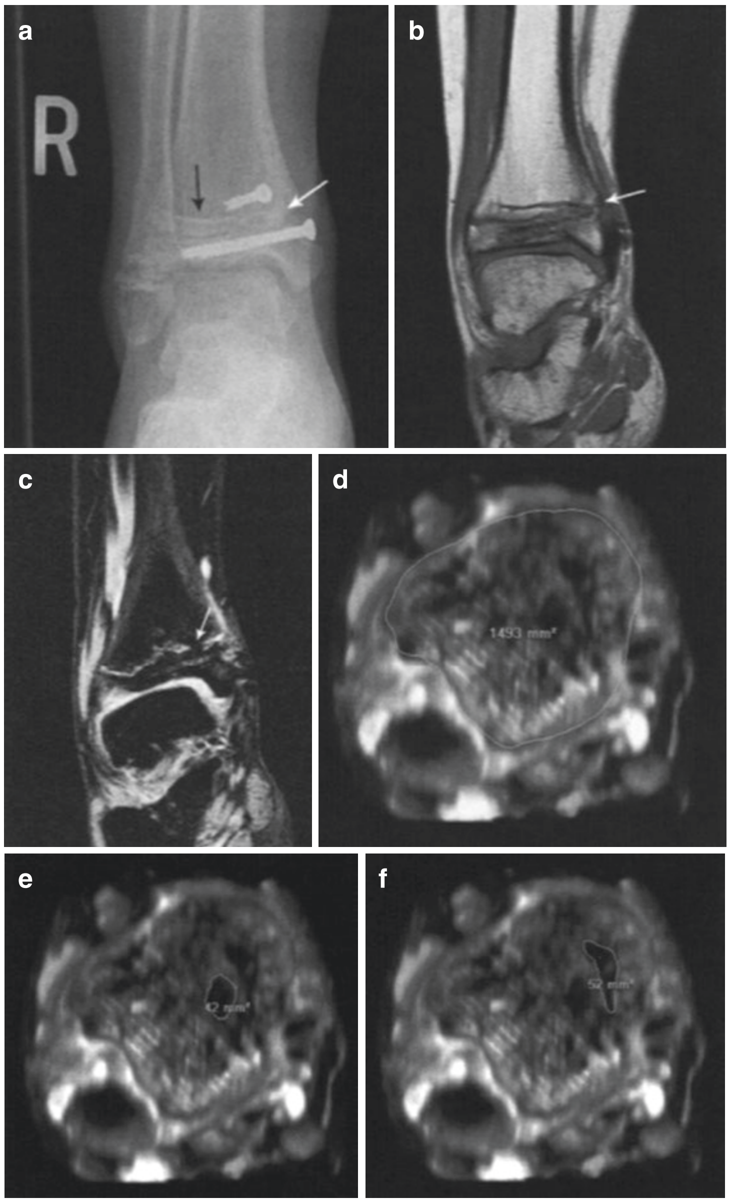

Fig. 3.9 Growth arrest: 14-year-old male who twisted his ankle and sustained a Salter IV fracture of the distal tibia during a basketball game. A frontal radiograph of the ankle 1 year later (**a**) demonstrates screws related to open reduction and internal fixation of the fracture. There is focal sclerosis of the growth plate medially (white arrow), with a growth recovery line extending laterally at an angle from the site of sclerosis (black arrow), which is consistent with a bony bar and growth arrest. Coronal fat-sensitive (T1-weighted; **b**) and fluid-sensitive (gradient echo; **c**) images of the ankle performed 6 months later, after hardware removal, demonstrate the bony bridge (arrows). Maps of the growth plate show the area of the growth plate (**d**) and the area of two bony bridges (**e**, **f**), assisting with surgical planning for resection of the bridges

Conclusion

Imaging is frequently required in the evaluation of adolescent sports-related injuries. The modalities available for imaging the musculoskeletal system include radiography, CT, MRI, nuclear medicine, ultrasound, and arthrography. Though each modality has associated advantages and disadvantages, it is the nature and site of the injury that frequently determines the most appropriate imaging technique.

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Part II

Anatomic Regions

4 Traumatic Head Injuries

Laura Purcell

Head injuries are common among children, and they result in a significant number of visits to emergency departments (ED) and physicians' offices each year. About 15% of pediatric head injuries result from participation in sports and recreational activities [1], resulting in approximately 200,000 ED visits annually in the United States for patients 0–19 years of age [2]. Approximately 70% of all sport-related traumatic brain injuries (TBI) occur in children and adolescents 0–19 years of age [2]. The incidence rate of sport-related TBI is highest in 12–18-year-olds (120.6/100,000 persons) [3]. Sport-related TBIs are twice to three times as common in males compared with females [2, 3].

Head injuries as a result of sport participation include minor injuries such as skin contusions, lacerations, and superficial hematomas, as well as more serious injuries, including concussions, skull fractures, and intracranial hemorrhages. The vast majority (80–90%) of sport-related TBIs seen in ED are considered mild and result in patients being discharged home [2–4]. Head injuries can occur in both organized sports, such as football, hockey, basketball, and soccer, as well as recreational activities, including bicycling, skiing, skateboarding, and rollerblading [1, 2, 5–7]. Severe TBIs are more likely to occur in equestrian, wheeled, and snow sports [1, 3, 4].

Anatomy

The brain is enclosed in the bony skull or cranium (Fig. 4.1a). Below the skull, there are three layers of meninges between the skull and the brain. The meninges, or mater, include the outer dura mater, enclosing the venous sinuses; the arachnoid mater, which bridges the sulci on the cortical surface of the brain; and the pia mater, which is a delicate vascular membrane lining the cerebral cortex. There are three potential meningeal spaces: the epidural space between the cranium and the dura; the subdural space between the dura and arachnoid; and the subarachnoid space between the arachnoid and pia, which contains cerebrospinal fluid.

The brain consists of right and left cerebral hemispheres, which are divided into lobes corresponding to the overlying cranial bones: frontal, parietal, occipital, and temporal (Fig. 4.1b). The cerebral cortex consists of gyri (folds) and sulci (grooves). Posterior and inferior to the cerebral cortex are the cerebellum and the brainstem, consisting of the medulla oblongata, pons, and midbrain.

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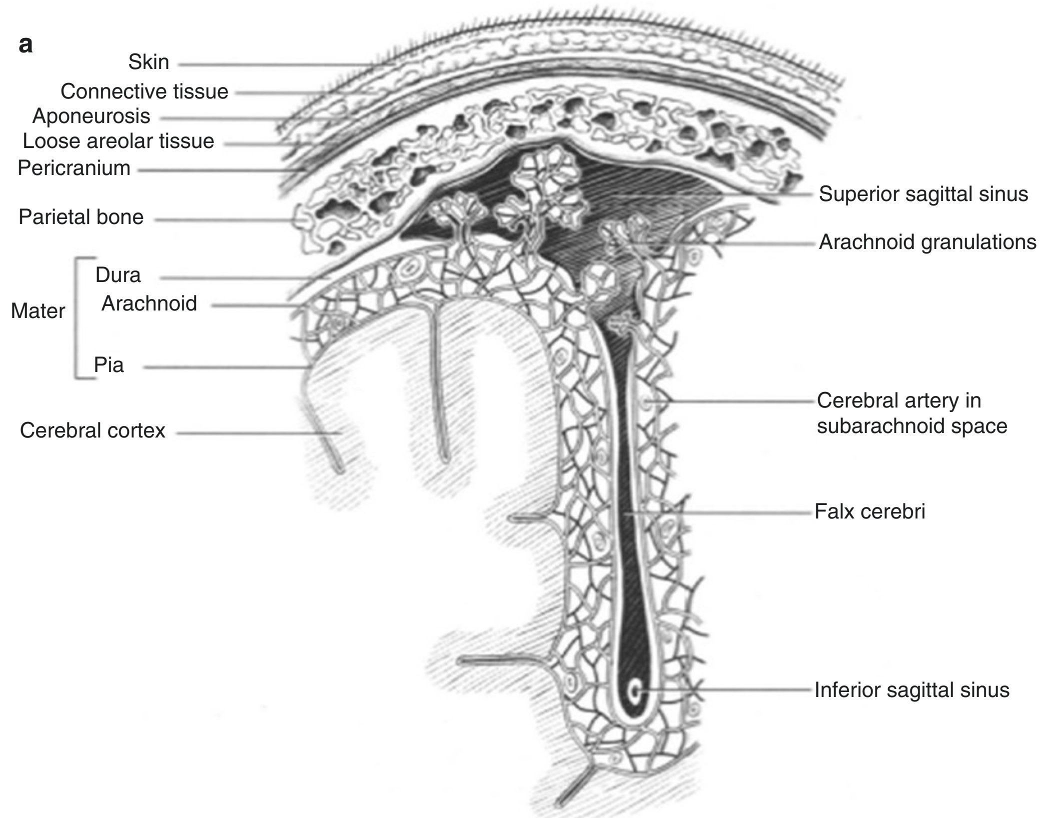
L. J. Micheli, L. Purcell (eds.), *The Adolescent Athlete*, Contemporary Pediatric and Adolescent Sports Medicine, https://doi.org/10.1007/978-3-319-56188-2_4



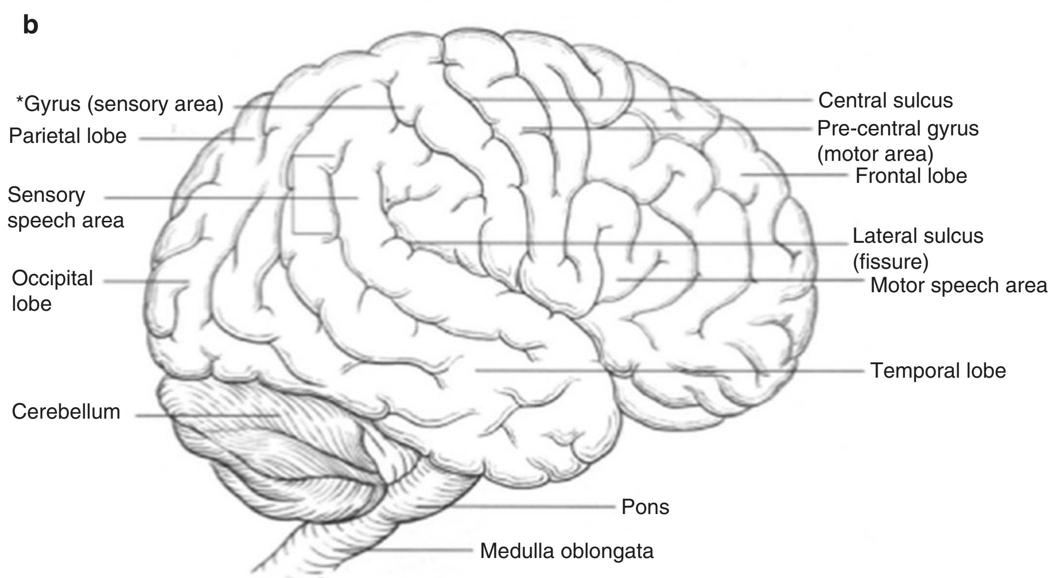


Fig. 4.1 (**a**) Coronal section of the skull and meninges, including the dura, arachnoid, and pia mater. (**b**) Lateral view of the brain

Clinical Evaluation

The athlete's level of consciousness should guide management priorities [8–11]. In an unconscious athlete, a cervical spine injury should be assumed, and appropriate immobilization of the cervical spine should be immediately instituted to protect against potential catastrophic spinal injury [9–13]. Management then proceeds through the ABCs (airway, breathing, and circulation) [8–13]. A patent airway must be established and protected. If the patient is unable to protect the airway or if there are signs of neurological deterioration, such as posturing or pupillary abnormalities, the athlete should be intubated and hyperventilated [10, 12–14]. If the airway is patent, adequate ventilation must be ensured. Circulation should be monitored and supported as necessary. The athlete should be transported with spinal precautions by ambulance to the nearest trauma center as quickly as possible [8–10, 12–14].

An athlete with a suspected head injury who is conscious should be immediately removed from the field of play and taken to an area where medical examination can take place [9–11]. The athlete should not return to play, should not be left alone, and should be frequently reassessed for signs and symptoms of deterioration, such as decreasing level of consciousness, repeated vomiting, or worsening headache [9–11]. The athlete should be assessed by a physician with experience evaluating sport head injuries as soon as possible [15].

History

Information regarding the mechanism of injury should be obtained from the athlete and any witnesses [8, 10]. It should be determined if there was any loss of consciousness and, if so, for how long, as well as occurrence of amnesia, seizures, or vomiting. Presenting symptoms should be elicited, such as impaired level of consciousness, headache, confusion, nausea, or difficulty concentrating. Medical history of previous head injury, neurological disorders, and medications should be obtained. Athletes may seem dazed or have difficulty answering questions. They may also be irritable, moody, or combative and may not want to answer questions.

Cognitive Assessment

In a conscious athlete, a cognitive assessment should be done as part of a head injury evaluation. Orientation should be evaluated by asking the athlete questions about person, time, and place [9, 10, 16, 17]. For example, ask the athlete to identify the opposing team, what position he/she plays, and the score of the game. Assess memory by asking questions regarding events before the injury, such as how the team got to the field of play, the score at halftime, etc. Immediate and delayed memory should be evaluated by giving the patient a list of five words to recall immediately and at the end of the examination [9, 10, 16, 17]. Concentration is often affected, and it can be assessed by asking the patient to recite the months of the year backwards or doing serial sevens. In younger children, ask the patient to recite the days of the week backwards [17]. Note the athlete's ability to do the test—do they get frustrated or confused, take a long time to answer, or make mistakes?

Physical Examination

Airway, breathing, and circulation (ABCs) should be assessed initially in all injured athletes. If stable, neurological assessment should begin with a determination of level of consciousness using the Glasgow Coma Scale (Table 4.1) [8, 9, 12–14, 18]. Any athlete with a Glasgow Coma Score of 13 or less (moderate to severe head trauma) should be transported to hospital emergently for further evaluation (Table 4.2) [9, 14].

Once the athlete has been removed from the field of play, inspection of the head and scalp

Table 4.1 Glasgow Coma Scale

Eye opening	*E*
Spontaneous	4
To speech	3
To pain	2
No response	1
Verbal response	*V*
Alert and oriented	5
Disoriented conversation	4
Speaking but nonsensical	3
Moans or unintelligible sounds	2
No response	1
Motor response	*M*
Follows commands	6
Localizes pain	5
Movement/withdrawal to pain	4
Decorticate flexion	3
Decerebrate extension	2
No response	1
Total score = E + V + M	

Source: Teasdale G, Jennett B. Assessment of coma and impaired consciousness. A practical scale. Lancet 1974;2:81–84. © Elsevier. Used by permission

Table 4.2 Indications for neuroimaging

Repeated vomiting (>3 times)
GCS <14
Focal neurological signs
Pupillary abnormalities
Cardiovascular or respiratory compromise (abnormal vital signs)
Suspicion of skull fracture
Seizure
Loss of consciousness >5 min
High-risk mechanism of injury (fall from height, impact with projectile)
Clinical deterioration (worsening headache, decreased LOC)

should be conducted, looking for scalp tenderness, lacerations, hematomas, bleeding from the ear, and leakage of cerebrospinal fluid from the nose [8]. If the athlete is stable, a neurological exam should be performed, including cranial nerve assessment, gross visual field examination, pupillary and fundoscopic examination, strength and sensation, deep tendon reflexes, and cerebellar testing, as well as gait and Romberg testing [8–10]. In the vast majority of cases, the neurological exam is normal. Occasionally, in concussion, balance may be affected, and patients may have a positive Romberg [19, 20].

If there are abnormalities on the neurological exam, patients should be transported to hospital for further evaluation [9, 14]. However, it is important to note that absence of abnormal signs, particularly early in the course of injury, does not rule out a potentially serious brain injury. Frequent reassessments are necessary to monitor potential deterioration, which may indicate a serious brain injury [9, 10, 12].

Diagnostic Tests

Sideline/Office Assessment

The Sport Concussion Assessment Tool (SCAT) was developed by the Concussion in Sport Group at the Second International Conference on Concussion in Sport in 2004 [19]. This multimodal assessment tool was designed for patient education, as well as physician assessment of sports concussion on the sideline of a playing venue and in an office setting. It was developed by combining several existing tools, including the Maddocks questions [21] and Standardized Assessment of Concussion (SAC) [22, 23]. The SCAT assesses orientation, immediate memory, concentration, and delayed memory, in addition to cervical spine, neurological status, and balance. This assessment tool has been revised several times, and the most recent version, the SCAT 5, has been published in 2017 [16, 20]. The SCAT5 is recommended for use in athletes 13 years and older. For children aged 5–12 years, the ChildSCAT3 was developed at the 4th International Consensus Conference on Concussion in Sport in 2012. It was revised to the Child SCAT 5 at the 5th International Concussion in Sport Conference in 2016 [17, 20, 24].

Neuroimaging

Any patient with a moderate (GCS 9–13) or severe head injury (GCS < 9), or any focal or localizing neurological signs, should have a CT scan [8, 10, 12, 15, 19, 20, 25]. Table 4.2 contains additional indications for neuroimaging.

For mild head injuries (GCS 14–15), it can be more difficult to determine which patients require a CT scan. Concern about radiation exposure from CT scans, particularly in children, and low positive yield has led to the development of clinical prediction rules to guide physicians in determining when to order a CT scan for minor head injuries [26–29]. One such clinical prediction rule is the Pediatric Emergency Care Applied Research Network (PECARN) rule which was developed by analyzing more than 42,000 patients at 25 sites and identified characteristics whose absence indicated no need for CT [29]. A secondary analysis of this data demonstrated that 53% of sport-related TBIs underwent CT scanning but only 4% had a TBI on CT, of which only 1% were clinically important [1].

Another clinical prediction rule is the Canadian Assessment of Tomography for Childhood Head Injury (CATCH) rule derived from a prospective cohort study of 3886 pediatric patients presenting to 10 Canadian ED with minor head trauma [28]. The CATCH rule identifies high-risk (GCS < 15 2 h after injury, suspected open or depressed skull fracture, worsening headache, irritability) and medium-risk factors (sign of basal skull fracture; large, boggy scalp hematoma; dangerous mechanism of injury) for significant findings on head CT and was found to be 98% sensitive in predicting acute structural brain injury [28].

In cases of concussion, imaging studies are usually normal and, therefore, should not be routinely ordered [15, 19, 20]. Magnetic resonance imaging (MRI) is a more sensitive modality to detect subtle structural injuries, such as contusions and diffuse axonal injury (DAI) [30]. There are more specialized imaging techniques, such as single-photon emission computed tomography (SPECT), positron emission tomography (PET), and functional MRI (fMRI), which may be able to demonstrate pathophysiologic and functional abnormalities after concussion [30].

Neuropsychological Testing

After head injury, children may have cognitive functional deficits, such as impaired attention and concentration, mild disorientation, and memory difficulties [22, 31, 32]. There have been numerous studies looking at neuropsychological testing in the athletic population following concussion, including traditional pen and paper tests [21, 22, 31, 32] and computer-based programs [33–36].

Computerized neuropsychological tests (CNT) have been adopted in many settings as an integral component of concussion management, particularly for return-to-play (RTP) decisions. However, there is little to no data to support the use of these tests in pediatric athletes [20, 37]. The reliability of CNT in children is limited due to age-related cognitive development resulting in constantly changing baselines [37]. In addition, CNT can be affected by many factors, including previous head injury, test anxiety, fatigue, testing venue, attention deficit disorder, psychiatric conditions, very high or low cognitive functioning, or learning disabilities [32, 37].

For these reasons, widespread routine use of baseline CNT for concussion is not recommended. CNT is one tool that may be used in concussion management under qualified supervision as an adjunct to clinical assessment [20, 37].

Types of Head Injuries

Moderate to Severe

Moderate to severe head injuries are uncommon in sporting activities, accounting for about only 1–3% of TBIs [1–3]. These types of TBIs are more likely to occur in snow sports, such as skiing and snowboarding; wheeled sports, such as roller-skating and skateboarding; and equestrian activities, such as horse and bull riding [1, 3]. There is a high incidence of permanent neurological deficits or death following moderate to severe TBIs. CT or MRI should be performed for all moderate to severe TBIs as well as neurosurgical evaluation [8, 9].

Skull Fractures

Skull fractures (Fig. 4.2) are not common in the sport setting but are serious injuries that may

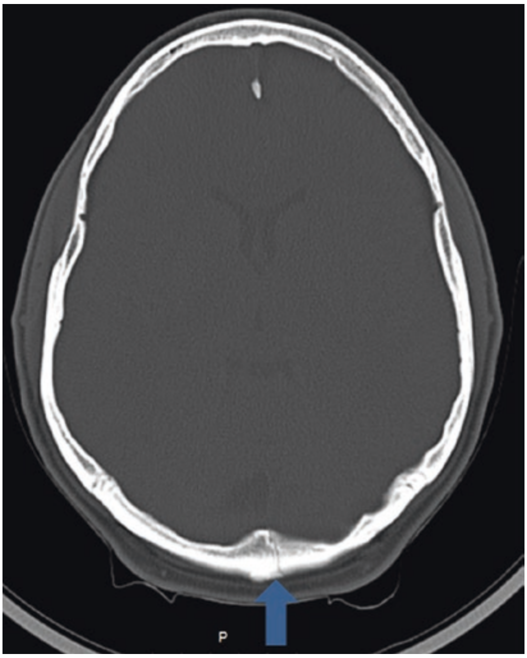


Fig. 4.2 Undisplaced left occipital bone fracture (Courtesy of Diagnostic Imaging Department, Cambridge Memorial Hospital, Cambridge ON, Canada)

require neurosurgical consultation. Skull fractures may be associated with underlying brain injury and may result in focal neurologic deficits or seizures [9]. A CT scan is the best initial study in this setting because it will demonstrate both the fracture and any associated intracranial bleeding [9]. Skull fractures are often associated with epidural hematomas or other intracranial hemorrhages and should be assessed by neurosurgery [9, 12, 13, 38].

Contusion

A contusion is bleeding into the brain tissue or bruising resulting from trauma (Fig. 4.3). It usually results in a headache and possibly neurologic deficits, depending on the brain area affected [13, 38]. Seizures may occur secondary to the irritative presence of blood [38]. Symptoms may not clear or improve, necessitating imaging with CT or MRI. Contusions require close observation for development of mass effect or hydrocephalus and may require neurosurgical intervention [13].

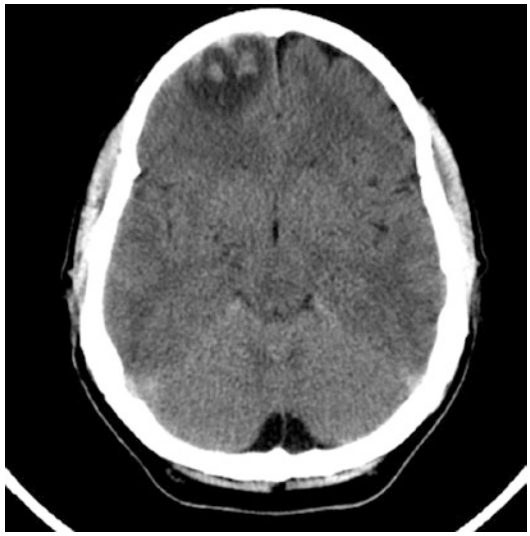


Fig. 4.3 Cerebral contusion in the frontal lobe (Courtesy of Department of Diagnostic Imaging, Cambridge Memorial Hospital, Cambridge ON, Canada)

Contusions may show complete radiological resolution over time or may result in a residual defect, such as encephalomalacia [39]. Cerebral contusion results in an increased risk of seizures [39].

Intracranial Hemorrhage

The leading cause of death from sport-related head injury is intracranial hemorrhage with a mortality rate of about 1% [4, 12, 38]. Intracranial hemorrhage includes epidural hematoma, subdural hematoma, intracerebral hematoma, and subarachnoid hematoma. Hematomas of the brain usually cause headache and may result in neurological deficit, depending on what area of the brain is affected. Seizures may be precipitated by the accumulation of blood. Traumatic seizures usually last only 1–2 min. Hemorrhage in the brain can be rapidly fatal, and therefore, prompt, accurate assessment and follow-up after a sport-related head injury are mandatory [9, 38].

Epidural Hematoma

Epidural hematomas result from damage to the middle meningeal artery (Fig. 4.4), causing blood to accumulate between the skull and the dura of

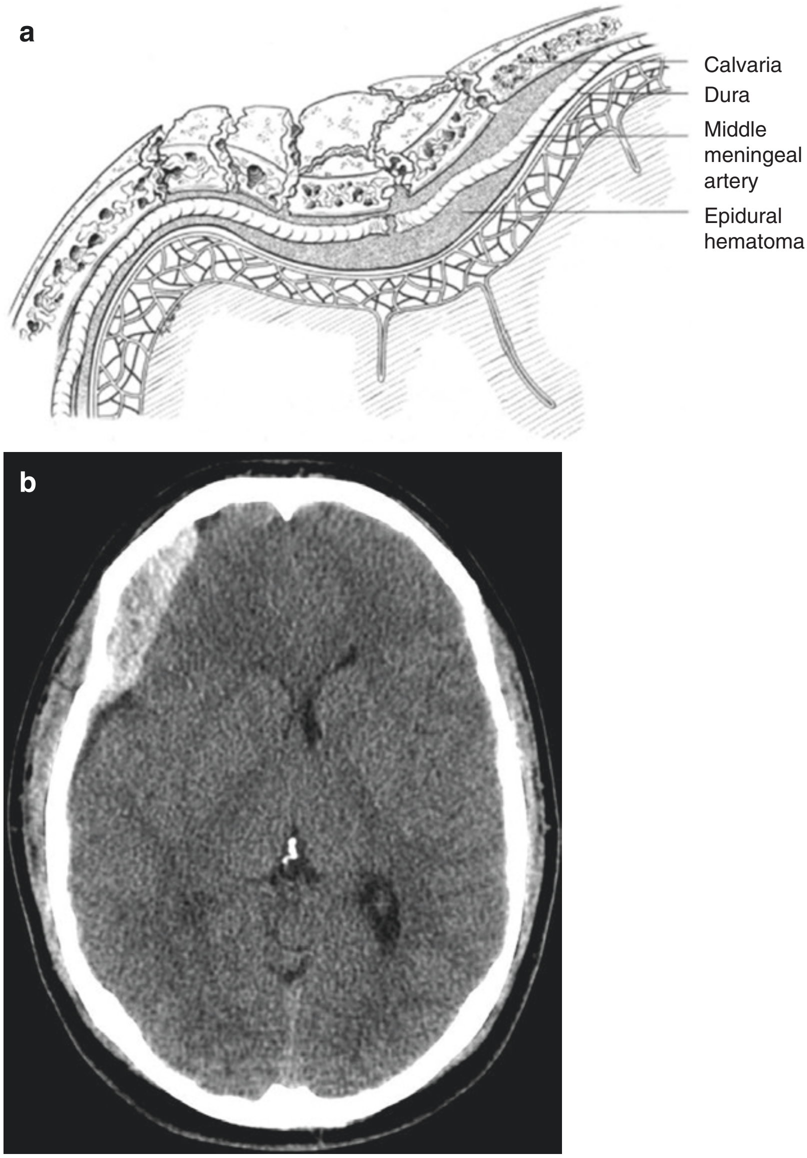


Fig. 4.4 Epidural hematoma. (**a**) An epidural bleed is caused by tearing of the middle meningeal artery, resulting in blood accumulating between the skull and the dura and ultimately causing compression of the brain. (**b**) CT scan of a 15-year-old hit with a bat showing a large frontal epidural bleed with midline shift (Panel **b** courtesy of Dr. Diego Jaramillo, Radiologist-in-Chief and Professor, Department of Radiology, Children's Hospital of Philadelphia, University of Pennsylvania, Philadelphia, PA, USA)

the brain [9, 10, 12, 13, 38]. It is often associated with a fracture of the temporal bone [9, 12, 38]. The brain itself is usually uninjured. The mechanism of injury is typically a high-impact event, such as getting hit by a baseball [10]. The injured athlete may have a brief period of unconsciousness or being stunned and then have a lucid period before developing a severe headache and progressive decline in level of consciousness [9, 10, 12, 13, 38]. This deterioration can happen quite quickly, in a matter of minutes to hours after the injury, and can be rapidly fatal if it is missed. It occurs as a result of the accumulation of the clot and resulting increase in intracranial pressure [12, 38]. It is imperative that these athletes be immediately transferred to a hospital with neurosurgical expertise to prevent death [10, 12, 38]. If the clot can be evacuated promptly, the athlete usually has a complete neurological recovery, as the brain is not injured [12, 38].

Subdural Hematoma

Subdural hematomas are three times more common in sport-related head injuries than epidural hematomas [9, 13]. High-impact injuries to the head can result in damage to the venous structures beneath the dura mater, causing bleeding below the dura (Fig. 4.5) [10, 38]. There is often associated injury to the brain tissue [12, 38]. The mechanism of injury is usually a fall or high-speed collision [10]. If a skull fracture is also present, signs and symptoms can evolve rapidly. However, if there is no fracture, signs and symptoms may be delayed for several days [10]. This injury typically results in a prolonged loss of consciousness (greater than a few minutes) [9, 12, 13, 38]. There is a 30–60% mortality rate from subdural hematomas; there is often significant residual morbidity secondary to brain damage [9–13, 38]. Neurosurgical intervention is required for subdural hematomas [12].

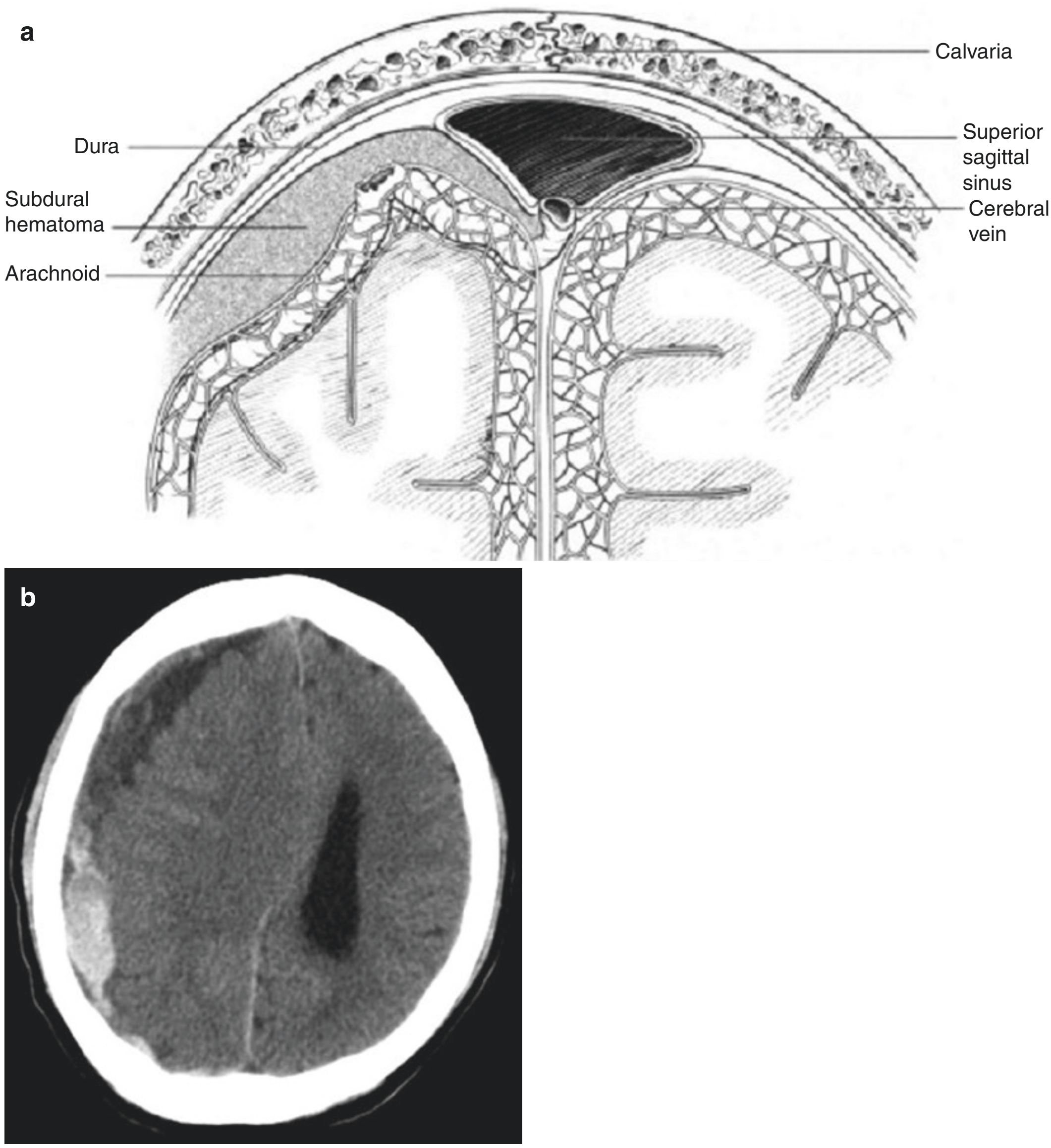


Fig. 4.5 Subdural hematoma. (**a**) In a subdural hematoma, blood accumulates between the dura and the arachnoid mater, causing midline shift. There is associated underlying brain injury. (**b**) Right-sided acute on chronic subdural hematoma with midline shift to the left (Panel **b** courtesy of Diagnostic Imaging Department, Cambridge Memorial Hospital, Cambridge ON, Canada)

Fig. 4.6 CT image of a massive left-sided intraparenchymal hemorrhage with subarachnoid extension causing midline shift to the right (Courtesy of Department of Diagnostic Imaging, Cambridge Memorial Hospital, Cambridge ON, Canada)

Intracerebral Hematoma

This usually results from a torn artery, which causes bleeding into the brain itself, usually associated with an extremely severe acceleration injury to the head (Fig. 4.6) [12, 38]. This may also result from congenital vascular lesions, such as aneurysms or arteriovenous malformations [38]. Consciousness is usually impaired. Often, these injuries can be rapidly fatal and result in death before transport to hospital is possible [38].

Subarachnoid Hematoma

Bleeding in this instance results from tearing of tiny surface brain vessels, resulting from trauma (Fig. 4.7), causing bleeding that is confined to the cerebrospinal fluid space [38]. It may also result from a congenital malformation [12]. Neurologic deterioration, including death, may be quite rapid due to brain swelling [12, 38]. Surgery is rarely necessary, unless there is a congenital vascular lesion, because the bleeding is superficial [12, 38].

Malignant Brain Edema Syndrome

Malignant brain edema syndrome is a rare condition that occurs in children as a result of head trauma [9, 10, 12, 38]. Brain edema develops rapidly, secondary to loss of vascular autoregulation of the brain's blood supply, with resultant vascular engorgement and increasing intracranial pressure (ICP) [9, 12, 38]. As the ICP increases, brain herniation and brainstem compromise occurs, rapidly leading to death in almost 50% of cases [9, 38]. Death occurs in minutes to hours. This is believed to be the underlying abnormality in second impact syndrome, which occurs rarely when a young athlete returns to competition while still symptomatic from a head injury and sustains another injury [10, 13, 38].

Diffuse Axonal Injury

This is an uncommon injury in sports because it requires severe trauma [13]. It results from severe shearing forces on the brain, causing the disruption of axonal connections [12, 13]. There is no hematoma associated. The athlete is deeply comatose. This condition generally results in long-term neurologic deficits. It is the most common cause of persistent vegetative state resulting from a head injury [13].

Mild

Mild traumatic head injuries or mTBIs account for the majority of head injuries in sports [2–4]. Mild injuries typically resolve fully in a short period of time with no residual deficits.

Concussion

Concussions are the most common head injury in children participating in sports. Incidence rates are highest in contact sports, such as rugby, football, ice hockey, and lacrosse [7, 40]. Concussion is a "traumatic brain injury induced by biomechanical forces" resulting "in the rapid onset of

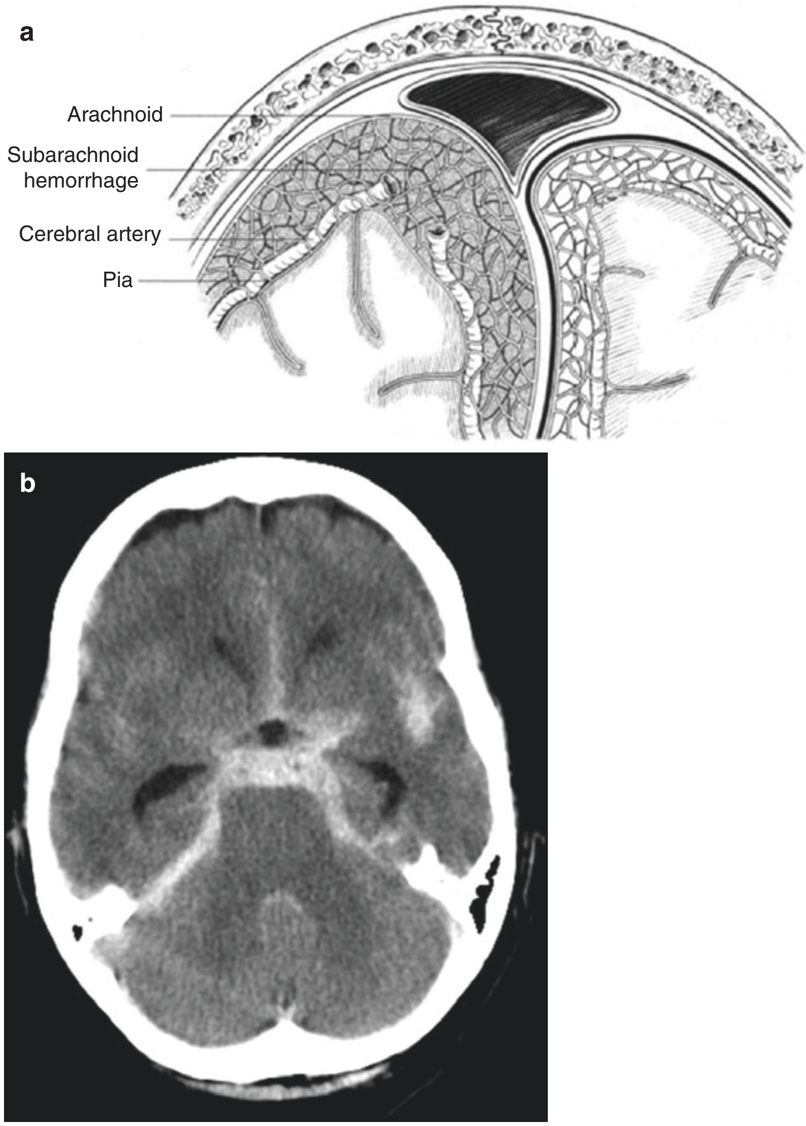


Fig. 4.7 Subarachnoid hemorrhage. (**a**) Blood accumulates between the pia mater and arachnoid layers, accumulating in the fissures and sulci. (**b**) CT scan showing a very large subarachnoid hemorrhage resulting in early hydrocephalus as evidenced by dilatation of the temporal horns of the lateral ventricles (Panel **b** is courtesy of Department of Diagnostic Imaging, Cambridge Memorial Hospital, Cambridge ON, Canada)

short-lived impairment of neurological function that resolves spontaneously" [20]. Signs and symptoms may evolve over minutes to hours following injury and typically resolve in a sequential course. Concussion does not result in a structural injury to the brain; rather, it is a functional disturbance. Concussion may be sustained by a direct blow to the head, face, or neck or by a blow to somewhere else on the body that transmits an impulsive force to the head [19, 20]. The symptoms and signs of concussion cannot be explained by alcohol, drug, or medication use, other injuries (cervical or vestibular dysfunction), or other comorbidities (coexisting medical conditions or psychological issues) [20].

Concussion typically does not cause loss of consciousness. Concussion can be difficult to diagnose and can present a management challenge to many physicians who care for these children [41–43]. Diagnosis can be challenging because signs and symptoms of concussion are not specific and may result from several entities including migraine, cervical, vestibular, or mental health issues [15, 20, 44, 45]. There are many signs and symptoms that may result from concussion, including somatic, cognitive,

Table 4.3 Features of sport-related concussion [15]

Symptoms/physical signs	Behavioral changes	Cognitive impairment	Sleep disturbances
Headache Nausea/vomiting Dizziness Visual disturbances Photophobia Phonophobia Loss of consciousness Amnesia Loss of balance or poor coordination Decreased playing ability	Irritability Emotional lability Sadness Anxiety Inappropriate emotions	Slowed reaction times Difficulty concentrating Difficulty remembering Confusion Feeling in a fog Feeling dazed	Drowsiness Trouble falling asleep Sleeping more than usual Sleeping less than usual

Source: Purcell L, Canadian Paediatric Society, Healthy Active Living and Sport Medicine Committee. Sport-related Concussion: Evaluation and management. Paediatr Child Health 2014; 11(7):420–428. (Oxford University Press)

behavioral, and sleep symptoms (Table 4.3) [15, 20, 25, 37].

Concussions in children and adolescents typically resolve within 1–4 weeks, with no sequelae [37, 46–49]. However, 10–55% of patients may have prolonged signs and symptoms lasting for weeks to months [37, 46–49]. Athletes with persistent symptoms should be managed by physicians with specific concussion expertise and may require a multidisciplinary management team, possibly including neurologists, neurosurgeons, sport medicine physicians, physiotherapists, physiatrists, and neuropsychologists [15, 20].

Management

The first priority in any injured athlete is to rule out serious head or spinal injury. If the athlete is unconscious, a spinal injury should be assumed and appropriate cervical spine precautions must be taken before transport to hospital [10, 12, 13]. Structural head injuries such as skull fractures and intracranial hemorrhages require neurosurgical evaluation [9, 12].

The majority of head injuries do not result in a loss of consciousness. A conscious athlete who is suspected of having sustained a head injury should be immediately removed from the game and not allowed to return to play the same day [10, 12, 13, 15, 20]. *If in doubt, sit them out!* A player should not return to sport if symptomatic to prevent worsening of symptoms and potential recurrent injury [10, 12–15, 19, 20]. A physician or other qualified healthcare professional should evaluate the athlete as soon as possible. After medical assessment, most athletes can be observed at home by a responsible caregiver who has been instructed on signs of neurological deterioration [8]. Signs of neurological deterioration warrant urgent transport to hospital for reexamination by a doctor and imaging studies (Table 4.2). Consultation with neurosurgery may be necessary [8, 10, 12].

Athletes who have sustained a concussion should rest, cognitively and physically, for a brief period of 24–48 h, and then gradually increase activity as symptoms allow [20, 37, 50]. Cognitive rest may necessitate avoiding or limiting daily activities that require mental concentration, such as reading, computer work, and video games. Athletes may require a brief absence from school initially because high levels of cognitive activity such as school may make symptoms worse and prolong recovery [15, 25, 37, 45, 51–53]. Physical rest includes avoidance of sports, exercise, and recreational activities such as bike riding or wrestling with friends or siblings [15, 20, 25]. The exact amount and duration of rest are not yet known [20, 50], but prolonged rest may actually delay recovery and result in more symptoms [54].

Return to School

Until recently, the focus of concussion management has been on RTP. However, return to school (RTS) should be a management priority following concussion in children and adolescents, as school is a student's main occupation [55]. A recent systematic review identified several factors that should be considered in the RTS process post-concussion [37, 53]. The factors included:

1. *Symptom load/severity*: more symptoms, more severe symptoms associated with missing more days of school and having difficulties upon RTS; longer recovery [46, 56–58].
2. *Types of symptoms*: headache, visual disturbances, memory deficits, and vestibular abnormalities may negatively affect a student's ability to attend school after a concussion [46, 56, 57, 59].
3. *Age*: adolescents tend to have more symptoms and greater severity of symptoms and take longer to recover, to RTS and to RTP than younger children [46, 57, 58]; adolescents are more concerned about the negative academic effects of concussion than younger children [58].
4. *School subjects*: math, reading/language, arts, science, and social studies pose greater problems for students returning to school after a concussion [58].
5. *Risk factors for prolonged recovery*: age (13–17 years), more symptoms, greater severity of symptoms, certain symptoms such as blurred vision and vestibular abnormalities, higher cognitive activity following concussion while still symptomatic, and history of previous concussions are associated with prolonged concussion recovery and more difficulty with RTS [46, 52, 56, 58].

Other factors to be considered upon RTS include school concussion policies/resources, medical guidance to schools for students with concussion, and medical follow-up after concussion [60–62].

For students who have mild symptoms and who recover quickly from concussion, RTS may require minimal support. Following a brief period of relative rest to allow symptoms to improve, student athletes should gradually increase activities, limited by symptoms [15, 20, 37, 50, 63]. Once the athlete can tolerate about 30 min of cognitive activity without significant exacerbation of symptoms, children should try going back to school half-days. If they do not have worsening/recurring symptoms, they may return full time (Table 4.4) [15, 37, 51, 53, 63, 64]. The period of school absence should be minimized to avoid development of possible secondary problems such as social isolation, depression, and anxiety about falling behind in school [15, 20, 25, 37, 45, 51, 64].

Table 4.4 Graduated return to school strategy [16, 17, 20]

Mental activity	Activity at each step	Goal of each step
1. Daily activities that do not give the child symptoms	Typical activities that the child does during the day as long as they do not increase symptoms (e.g., reading, texting, screen time). Start with 5–15 min at a time and gradually build up	Gradual return to typical activities
2. School activities at home	Homework, reading, or other cognitive activities outside of the classroom	Increase tolerance to cognitive work
3. Return to school part time	Gradual introduction of school work. May need to start with a partial school day or with increased breaks during the day	Increase academic activities
4. Return to school full time	Gradually progress school activities until a full day can be tolerated	Return to full academic activities and catch up on missed work

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Upon RTS after a concussion, 11–73% of children and adolescents may have difficulty and require accommodations or modifications to help with the transition back to school [46, 61, 62, 65, 66]. Accommodations should be individualized and symptom targeted to allow students to RTS without significant exacerbation of symptoms (Table 4.5) [15, 45, 51, 53, 63]. A randomized control trial found that academic accommodations post-concussion were more likely to be provided in schools with concussion policies [60]. As well, outpatient medical follow-up, parental education, and a medical RTS letter

Table 4.5 Academic accommodations [15]

Post-concussion symptom	Effect of school attendance	Accommodation
Headache	Difficulty concentrating	Frequent breaks, quiet area, hydration
Fatigue	Decreased attention, concentration	Frequent breaks, shortened day, only certain classes
Photophobia/ phonophobia	Worsening symptoms (headache)	Sunglasses, ear plugs or headphones, avoid noisy areas (cafeterias, assemblies, sport events, music class), limit computer work
Anxiety	Decreased attention or concentration, overexertion to avoid falling behind	Reassurance and support from teachers about accommodations, reduced workload
Difficulty concentrating	Limited focus on schoolwork	Shorter assignments, decreased workload, frequent breaks, having someone read aloud, more time to complete assignments and tests, quiet area to complete work
Difficulty remembering	Difficulty retaining new information, remembering instructions, accessing learned information	Written instructions, smaller amounts to learn, repetition

Source: Purcell L, Canadian Paediatric Society, Healthy Active Living and Sport Medicine Committee. Sport-related Concussion: Evaluation and management. Paediatr Child Health 2014; 11(7):420–428. (Oxford University Press)

following assessment in an ED were associated with provision of academic accommodations upon RTS after concussion [61, 62]. Good communication between medical personnel, student and family, and school personnel is essential to ensure successful RTS for students post-concussion [51, 53, 55, 67–69].

Active Rehabilitation

Specific treatments, such as physiotherapy, cognitive behavioral therapy, vestibular rehabilitation, massage therapy, and chiropractic, can help with concussion symptom resolution [15, 20, 45, 50, 70]. Symptoms such as neck pain, headaches, balance issues, and visual deficits can be targeted with active interventions (Table 4.6). Subthreshold exercise at a level which does not exacerbate symptoms has also been shown to be beneficial in concussion symptom resolution in patients with persistent symptoms [71–73].

Table 4.6 Targeted treatments for post-concussion symptoms [15]

Symptoms	Targeted treatments
Persistent headache	Lifestyle adjustments (proper hydration, adequate sleep, regular exercise)
	Avoidance of acetaminophen/ ibuprofen overuse
	Prophylactic medications (e.g., for migraines)
Neck pain	Physiotherapy
Balance problems/ dizziness	Vestibular rehabilitation
Sleep disturbances	Sleep hygiene reinforcement
	Medications (e.g., melatonin)
Depression/ anxiety	Referral to a mental health professional; addressing social isolation or withdrawal
	Medications

Source: Purcell L, Canadian Paediatric Society, Healthy Active Living and Sport Medicine Committee. Sport-related Concussion: Evaluation and management. Paediatr Child Health 2014; 11(7):420–428. (Oxford University Press)

Persistent Symptoms

Up to 50% or more of patients may have symptoms lasting for more than 4 weeks, sometimes for several months [37, 46–49, 53, 57, 58, 65, 74]. Predictors of persistent symptoms include high initial symptom loads, more severe symptoms, age (adolescents), migraine, previous concussions, and particular symptoms such as visual and vestibular symptoms [37, 46, 53, 56–58, 74]. Patients with persistent symptoms should be evaluated for other possible etiologies, such as cervical, vestibular, visual, sleep issues or mental health issues [15, 20, 45, 64] and targeted treatments initiated (Table 4.6). Investigations such as neuroimaging and/or neuropsychological tests may be required [15, 20, 44]. These patients should ideally be referred to specialists and managed in a multidisciplinary concussion clinic [15, 20, 44, 45, 64].

Prevention

Protective Equipment

Head injuries may be prevented by wearing the appropriate protective equipment for a specific sport [6, 9, 75–78]. Approved helmets should be worn for all contact sports and for recreational activities with a risk of head injury (i.e., cycling, skateboarding, or in-line skating) [9, 19, 20] The equipment should be worn properly and be well maintained [79, 80]. Any damaged equipment should be replaced promptly. It is important to note that there is no such thing as a "concussion-proof" helmet. Risk compensation, whereby players feel they are not at risk for head injury if wearing a helmet and therefore play more aggressively, may actually put athletes at greater risk of injury [81].

Education

Education of athletes, coaches, and parents regarding head injury risk and management is vital to help decrease incidence of head injuries in sport [6, 19, 20]. To minimize risk of head injury, athletes should respect the rules of their sport and practice fair play. Parents and coaches should teach athletes good sportsmanship and ensure that athletes demonstrate good sportsmanship in all athletic endeavors [19, 20].

Sporting Technique/Skills

Coaches and trainers must ensure that athletes learn the proper sport techniques, such as correct body checking technique in hockey, correct tackling technique in football, and correct heading technique in soccer [19, 20].

Injury Surveillance

Injury surveillance is critical in sport injury prevention by identifying injury mechanisms that can be modified [6]. Identification of injury mechanisms can lead to sport rule changes and rule enforcement resulting in decreased head injuries in sport [19, 20, 81]. For instance, padded goal posts in soccer and football and the banning of spearing in football have reduced the number of head injuries in these sports [81, 82]. Concussions in hockey in 11- and 12-year-olds were reduced by 64% following the 2013 Hockey Canada's national policy change delaying checking in boy's hockey until age 13–14 years [83].

Types of Sports

Discouraging enrollment in sports where intentional head injury is encouraged may also decrease sport-related head injury in children and adolescents [15].

Return to Play

After Moderate to Severe TBI

Certain conditions have historically precluded return to sport after a head injury (Table 4.7) [12, 84, 85]. However, there have been some case reports of athletes returning to sport following a severe TBI, despite persistent deficits [84]. Return to contact sports following a craniotomy for a TBI is controversial and has historically not been encouraged [85, 86]. There have been no

Table 4.7 Conditions that preclude participation in contact sports [11, 12]

Permanent neurological deficits
Persistent post-concussion symptoms
Hydrocephalus
Spontaneous subarachnoid hemorrhage
Damage to underlying brain parenchyma

Source: Cantu RC. Return to play guidelines after a head injury. Clinics in Sport Med 1998;17(1):45–60. ©Elsevier. Used by permission controlled studies looking at this issue, but primary concerns include strength of the bone flap, potential fragility of the tissue at the operative site, and alterations in the normal CSF pathways due to scarring which may decrease brain buoyancy [86]. Newer techniques and individual considerations may lead to fewer restrictions on return to contact play following craniotomy, but further research is needed [86].

Return to noncontact sports following a moderate to severe TBI is not contraindicated if recovery has been completed. Athletes with an intracranial hemorrhage or contusion that did not require surgery, or with an epidural hematoma without brain injury, who have a complete recovery may return to contact sport, in selected cases, a year or longer after the injury; however, extreme deliberation with the athlete and family should occur before return [12, 39].

After Concussion

Return to sport after a concussion continues to be a controversial area, particularly in the pediatric age group. Current recommendations are largely anecdotal, based on recommendations for adults but urging more caution in children and adolescents. One point of consensus is that an athlete with a concussion should not be allowed to return to activity/sport until symptom-free at rest and with exertion [9, 10, 12, 13, 15, 19, 20, 25, 37, 38]. It is important that athletes do not RTP the day of an injury because even if initial symptoms resolve quickly, they may recur later that day or evening. A recent study demonstrated that athletes who continued to play after sustaining a concussion took twice as long to recover and were almost nine times more likely to have prolonged recovery (>21 days) [87]. Despite numerous concussion management guidelines and extensive media coverage about concussion, a significant number of children are still not managed appropriately post-concussion. A recent Australian study found that 19% of children were not immediately removed from play and 29% were allowed to RTP the same day following head injury [88].

Current guidelines for activity following a concussion recommend an initial few days of rest followed by gradual return to daily activities, limited by symptoms [20, 37, 50]. Prolonged rest is not recommended as it may delay concussion recovery [54]. In fact, participation in physical activity in the first 7 days post-concussion has been associated with decreased risk of persistent post-concussion symptoms compared with no physical activity [89]. Once all post-concussion symptoms have resolved and the athlete has fully returned to school, the athlete should follow a medically supervised graduated approach to return to their sport (Table 4.8) [20]. Each step should take at least 24 h, and athletes may progress through the steps as long as they remain asymptomatic. If symptoms recur, athletes should rest for 24–48 h and attempt to progress again, starting at the step where their symptoms recurred. The time required to progress through

Table 4.8 Graduated return to sport strategy [20]

Exercise step	Functional exercise at each step	Goal of each step
1. Symptom-limited activity	Daily activities that do not provoke symptoms	Gradual reintroduction of work/school activities
2. Light aerobic exercise	Walking or stationary bike at low to medium pace. No resistance training	Increase heart rate
3. Sport-specific exercise	Running or skating drills. No head impact activities	Add movement
4. Noncontact training drills	Harder training drills, e.g., passing drills. May start progressive resistance training	Exercise, coordination, and increased thinking
5. Full-contact practice	Following medical clearance, participation in normal training activities	Restore confidence and assess functional skills by coaching staff
6. Return to play/sport	Normal game play	

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Clinical Pearls

- Mild head injuries (concussions) occur frequently in sport.
- Athletes, trainers, coaches, officials, and parents should recognize symptoms of a head injury and the need to seek prompt medical attention in the event of a head injury. **IF IN DOUBT, SIT THEM OUT!**
- Any head injury should be considered serious. If the GCS is 13 or less, the injured athlete should be urgently transported to the hospital for neuroimaging and neurosurgical evaluation.
- In an injured unconscious athlete, a cervical spine injury should be assumed, and appropriate immobilization of the cervical spine should occur before transport to hospital.
- There is potential for players to get worse over time; therefore, they should not be left alone and should be monitored for signs of deterioration for 24–48 h by a responsible adult.
- Any athlete who sustains a head injury should be assessed by a physician/qualified healthcare professional as soon as possible.
- No player with a head injury should return to sport while symptomatic. There should be no same day return to play.
- After a brief period of rest at home, return to school following a concussion should be gradual and symptom-limited. Appropriate academic accommodations should be offered to prevent significant exacerbation of symptoms.
- Return to play after a concussion should follow a graduated progression of exertion, guided by a healthcare professional knowledgeable in the management of sport-related concussion. Full return to school should precede return to sport.

these steps may be variable, depending on the severity of concussion and the individual athlete's age, concussion history, and sport schedule [15, 19, 20].

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5 Cervical and Thoracic Spine Injuries

Pierre d'Hemecourt and Jessica Flynn Deede

Cervical spine injuries are relatively common in sports and can range from minor muscle strains to life-threatening spinal cord injuries. While catastrophic cervical and thoracic spine injuries are relatively rare events, they have been reported in young athletes competing in sports such as wrestling, gridiron football, ice hockey, rugby, diving, gymnastics, trampolining, and equestrian sports [1, 2]. It has been estimated that up to 15% of gridiron football athletes suffer from cervical spine injury at some point in their playing career. For the academic year 2014–2015, the National Center for Catastrophic Sports Injury reported 78 sports-related catastrophic injuries, and 14% of these injuries were related to the cervical spine [3]. From 2005 until 2016, contact sporting events were the fourth most common cause of spinal cord injury (SCI) in the United States, behind motor vehicle accidents, violence, and falls. In athletes under 30 years of age, contact sports are the second leading cause of SCI. Approximately 12,500 new cases of SCI are reported in the United States each year, and 9% of these spinal cord injuries are related to sports participation [4]. Although thoracic spine injuries are less frequently involved in catastrophic injury, they do occur in adolescent athletes participating in hockey, gridiron football, gymnastics, and wrestling, as well as other contact sports.

Participation in noncontact sports can also lead to overuse injuries to the cervical and thoracic spine. In the adolescent athlete, these injuries can cause spinal deformity such as kyphosis, as well as adult pattern injury. The sports medicine physician must understand the different injury patterns of specific sports, as well as the evaluation of the athlete for these injuries. As the cervical and thoracic spine contains the spinal cord, a thorough knowledge of anatomy and assessment of mechanical and neurologic stability at the initiation and completion of treatment is important. A safe return-to-sports participation also requires an understanding of injury prevention with proper conditioning, sports technique, and equipment.

Anatomy

The cervical and thoracic spine is structurally critical for motion and support. The thoracic spine serves to transfer forces between the upper and lower extremities, and the cervical spine provides support and motion for the skull. Together, these two upper spinal segments act as a conduit for the central nervous system and are prone to

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L. J. Micheli, L. Purcell (eds.), *The Adolescent Athlete*, Contemporary Pediatric and Adolescent Sports Medicine, https://doi.org/10.1007/978-3-319-56188-2_5

injury in the athlete. This includes both acute and chronic overuse injuries.

The cervical spine is a flexible structure between the head and more rigid thoracic spine. This mobility imparts a greater risk for injury to the discs and osseous structures. In contrast, the thoracic spine is more rigid and protected with the rib attachments. However, the lower two ribs are free floating and allow some increased motion in the lower thoracic spine. Consequently, traumatic and overuse injury patterns are more frequent in these transition zones of flexibility at the lower cervical and lower thoracic spine.

The lordotic curvature of the cervical spine is important to spine function. While this lordosis remains similar from childhood through the adult years, the internal construct of lordosis varies between genders and age. Males have smaller upper cervical lordosis and higher lower cervical lordosis than females. Children tend to have more kyphotic anterior vertebral body wedging and lordotic intervertebral disc wedging than their adult counterparts [5].

The cervical vertebrae can be divided into two distinct areas of the upper and lower cervical spine. The lower portion, C3 through C6, has a typical appearance, with vertebral bodies separated by the intervertebral disc. Furthermore, the superior-lateral aspects of the body have a projection of the uncus that articulates with the convex inferior endplate of the cephalad vertebrae. In late childhood, this developmentally becomes an articulation, the joint of Luschka. This articulation forms an anterior border of the neuroforamina and, with degeneration, may contribute to foraminal stenosis. The facet joints form the posterior border of the foramina. These facets are in a more horizontal plane and progress to a more vertical coronal plane in the thoracic spine. The horizontal orientation allows rotation. The transverse process contains the foramen for the vertebral artery [6]. The lower cervical spine is primarily responsible for flexion and extension. Lateral flexion is coupled with rotation [7].

The upper cervical spine is comprised of the occiput to C1, as well as the C1–C2 articulation. The atlas, C1, has a smaller anterior arch and a larger posterior arch connected by the lateral masses. The axis, C2, contains the odontoid process that articulates with the anterior arch of the atlas and is constrained by the transverse ligament. Between the occiput-C1 and C1–C2 articulations, 40% of cervical flexion and extension occurs, whereas 60% of rotation occurs at these levels [8].

The thoracic vertebrae gradually increase in size from T1 through T12. This region is unique because of the facets on the vertebral bodies for the heads of the ribs and the facets on the transverse processes, which articulate with the tubercle of the rib (Fig. 5.1). The thoracic facet joints are in a more coronal orientation to allow for lateral flexion. However, there is a transition of the upper and lower thoracic vertebrae, with the upper vertebrae configured in a more cervical morphology, whereas the lower vertebrae resemble the lumbar vertebrae [9]. All of these articulations have been associated as pain generators. A further confounding structure to the thoracic spine is the scapula. This triangular-shaped bone lies between the second and seventh ribs. It projects 30–40° to the frontal plane. Bony ridges or osteophytes may rub against the ribs. Furthermore, several bursae assist with scapulothoracic articulation. There are several at the superior medial angle and one at the inferior corner (Fig. 5.2). Each of these is subject to inflammation and pain.

From C3 through T12, as well as the lumbar spine, each functional unit of motion acts as a tripod, with the disc anterior and the facet joints posterior. Anteriorly, the intervertebral disc is composed of the anulus, with ligamentous layers encompassing the gelatinous nucleus pulposus. The anulus, comprised of 10–20 layers of concentric, obliquely oriented ligamentous lamellae, provides for torsional stability [10]. The outer layers of the anulus are innervated by the sinuvertebral nerves posteriorly and by the gray ramus communicans anteriorly. Mechanical and chemical irritation from the nucleus pulposus may produce pain.

The growing spine has some unique considerations. The anulus is attached to the growth cartilage of the epiphysis and apophyseal ring. The vertebral body is bound on the superior and inferior borders by the epiphyseal growth plate with its overlying cartilaginous endplate and its contiguous ring apophysis (Fig. 5.3). This growth

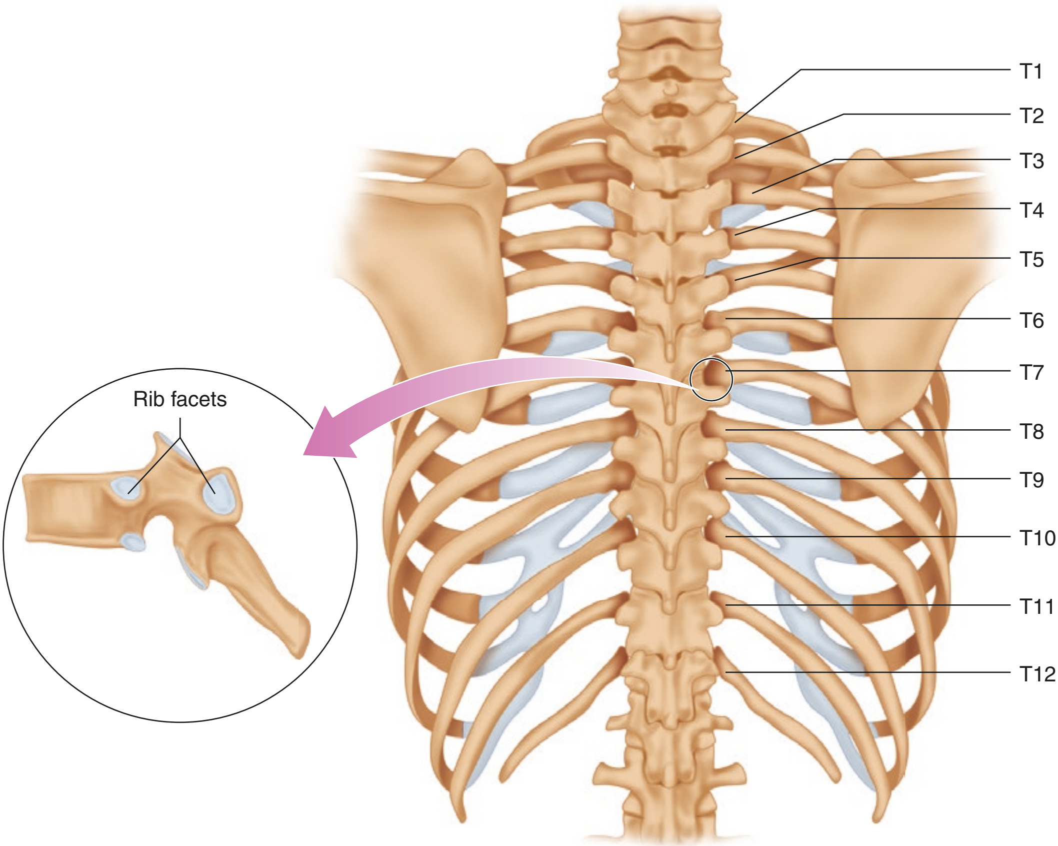

Fig. 5.1 Thoracic vertebrae with rib articulations

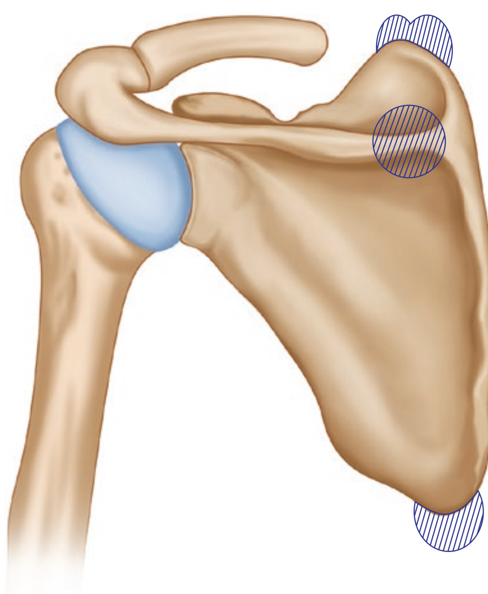

Fig. 5.2 The scapula is a triangular-shaped bone that lies between the second and seventh ribs

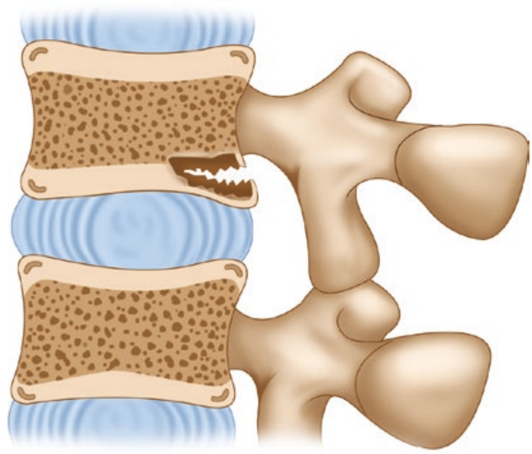

Fig. 5.3 Adolescent endplate

cartilage is the weak link. Injury to the growth zone has been demonstrated with both flexion and extension and an applied compression load, which may be a factor with pain and increased kyphosis in the adolescent spine [11]. During adolescent growth, there is a normal increase of approximately 10° of thoracic kyphosis [12]. Repetitive flexion and extension during this growth period have been shown to accentuate this kyphosis [13].

There are numerous paraspinal muscles of the thoracic and cervical spine inherently associated with the lumbopelvic musculature. Each of these may be involved in myotendinopathies and acute contusions and strains. Functionally, the anterior and middle scalene muscles are important, as they arise from the anterolateral cervical spine and attach to the first rib. The brachial plexus traverses between these in its passage through the thoracic outlet and is subject to impingement here, as well as between the clavicle and first rib.

Clinical Evaluation

History

When assessing an athlete with a neck or back complaint, whether on the athletic field or in the office, it is crucial to obtain a detailed history of the inciting event and pattern of symptoms. When there is suspicion of a traumatic spinal injury, appropriate measures must immediately be taken to immobilize and protect the spinal column until further evaluation with radiographic assistance can be undertaken in the hospital setting. Airway management should be closely coordinated with immobilization and transport. This should always be well rehearsed before the event.

The demographics of gender, age, and type of sport or occupation are relevant. Gender may be important, with males having more spondyloarthopathies, whereas females have more osteoporosis issues. Younger athletes are predisposed to growth cartilage injury, whereas the young adult may be more predisposed to discogenic issues. The type of sport can predispose to certain patterns of injury. For instance, participants in gymnastics have a high prevalence of thoracolumbar disc and endplate injury [14].

The history should include mechanism of injury, onset of pain (sudden or insidious), location of pain, and associated neurologic symptoms (including transient paresthesias, paralysis, or weakness). Cervical pain may radiate to the interscapular region, as well as into the upper extremity. Thoracic pain may radiate to the anterior trunk or to the lower extremities. With the cervical and thoracic spine, myelopathic symptoms must be elicited. These include an unstable gait, weak or fumbling hands, and bowel or bladder incontinence. One should also inquire about previous evaluation and treatment, as well as previous medical problems, such as Down syndrome or Klippel-Feil syndrome with cervical instability.

In the setting of trauma, the mechanism of injury and position of the head during impact can aid in determining the distribution of forces in the injured spine. Hyperflexion injuries are the most common and can cause compression fractures of the anterior vertebral body and disruption of the posterior spinal ligaments. Hyperextension injuries can cause the opposite, with compression of the posterior elements and disruption of the anterior longitudinal ligament. Axial loading can cause compression or burst fractures of the vertebral bodies. Rotational injuries may cause injury to the facet joints.

Neurologic symptoms are very important to elicit when taking a sideline history. Whether these symptoms persist or have resolved, they will give clues to the location of possible spinal cord involvement. A classic injury observed in gridiron football players is the "burning hands" syndrome, in which transient burning dysesthesias in the hands are associated with hyperextension of the cervical spine and central cord contusion [15]. Loss of consciousness may imply more serious closed head injury, with possible shearing injury to the cervical spinal cord and brainstem.

Common red flags include ages >55- or <18-year-old, night pain, trauma, and history of cancer and immunosuppression, which may be seen with use of systemic steroids, HIV, or drug abuse. Further considerations include trauma, weight loss, systemic symptoms, crescendo pain, structural deformity, gait disturbance, and inflammatory symptoms, such as prolonged morning joint stiffness for greater than 1 h. Finally, cauda equina syndrome, manifested by difficulty with micturition, incontinence of bowel or bladder, loss of anal sphincter tone, and saddle anesthesia, is a surgical emergency [16].

Physical Examination

Examination of the spine begins with inspection for obvious deformities, sites of impact, or postures that may predispose to injury. Next, palpation of the posterior elements is conducted from the base of the skull to the sacrum. Posterior element fracture or ligamentous disruption may be suggested by tenderness to palpation over the corresponding spinous processes. Palpation of the surrounding musculature in the neck and upper back may reproduce pain that is consistent with muscle spasm.

Range of motion of the spine should be examined. Active range of motion should be tested before passive range of motion. Flexion and extension of the neck are tested by asking the patient to put their chin to their chest and then look up at the ceiling. This is followed by side-to-side flexion, which is established by having the patient put their right ear to their right shoulder, and then repeat this task on the left. Normal range of motion on lateral bending is approximately 40°. Finally, lateral rotation of the neck is tested by asking the patient to turn their chin to the left and then right. Normal range of rotation is 60–80° [17]. Range of motion of the thoracic spine is tested in the standing position. The patient is asked to bend forward with their chin to their chest and touch their toes. If this causes or is limited by pain, injury to the anterior elements of the spine should be suspected, such as a disc injury or vertebral body fracture. Extension of the thoracic spine is tested by asking the patient to bend back while the examiner stabilizes the patient's hips. Pain with this maneuver may be suggestive of posterior element injury, such as facet injury.

The examination should then turn to provocative maneuvers of the neck, which may help to identify the etiology of neck or upper extremity symptoms. The Spurling test is used to look for cervical root compression caused by pathology of the root or narrowing of the exiting foramen. The patient's neck is extended and rotated toward the symptomatic side as a simultaneous gentle axial load is applied. This position narrows the foramen of the exiting nerve and may reproduce symptoms. This test is highly specific for cervical nerve root compression but has very poor sensitivity [18]. The axial compression test is similar. The examiner applies a compressive force on the head of the patient in the axial plane, therefore narrowing the intervertebral space and foramina. This may reproduce pain caused by disc disease or foraminal narrowing. The final provocative test of the cervical spine is the distraction test, in which vertical traction is carefully applied to the patient's head. If this relieves symptoms, the pain may have been caused by increased pressure or compression at the intervertebral disc or facet joints.

Neurologic examination of the upper and lower extremities is imperative in evaluating the athlete with neck or back pain. If the cervical spine is affected, neurologic examination should also include cranial nerve testing. Neurologic exam should begin with muscle strength testing. Weakness in a specific muscle group may direct you to the level of spinal cord injury. Muscle tone is also important to assess. Flaccid muscle tone would indicate lower motor neuron injury or spinal shock, whereas increased muscle tone would be indicative of either muscle spasm or upper motor neuron injury. Deep tendon reflexes should then be tested in the upper and lower extremities, followed by sensation testing. The dermatomal distribution of the sensory defect should be established to localize the level of injury. The ipsilateral posterior spinal tract is tested with light touch, vibration, and proprioception. The lateral spinal tract is tested with contralateral thermal and pain perception.

Imaging

There are many options available for imaging the cervical and thoracic spine. Each study has its own strengths in evaluating different elements of the spine. However, the clinician must remember that radiologic studies of the spine may often have findings that are not associated with the patient's symptoms [19–21]. Therefore, it is imperative that the imaging method of choice is specific and localized to the area of suspected injury. The four major methods of radiographic imaging are X-ray, computed tomography (CT) scan, magnetic resonance imaging (MRI), and bone scan.

Radiographs are best used to evaluate the bony structures of the spine and their spatial relationships to each other. They can be used as a screening tool in the cervical and thoracic spine for congenital malformations and injuries such as dislocations, compression fractures, and posterior element fractures.

In the cervical spine, the lateral view is often the first view, especially in the trauma setting. All seven cervical vertebrae from C1 through the top of T1 should be visualized. Arm traction or a swimmer's view with one arm elevated may enhance the visualization of the C7-T1 junction. At times, a CT may be needed to see this area. On the lateral view, several bony relationships are carefully reviewed with the understanding that the child has some variations from the adult (Fig. 5.4). First, four lines are considered: the anterior vertebral line, the posterior vertebral line, the spinolaminar line, and the tips of the spinous processes. All of these should have an even contour with parallel facets. A widened interspinous space greater than 10 mm may indicate instability [22]. In the child, there is increased ligamentous laxity, along with a more horizontal facet joint. This imparts a common pseudosubluxation at C2 through C3 and, less commonly, at C3 through C4. In the child, this pseudosubluxation is acceptable up to 4–5 mm. In the adult, a translation of only 3 mm is acceptable at every level. However, acceptable sagittal plane angulation at any level should be less than 11° in both the child and adult [23]. The atlantodens interval (ADI) is also assessed on the lateral view. This should be less than 3 mm in the adult and less than 4 mm in the child under 8 years of age. Atlantoaxial instability is a feature in approximately 15% of adolescents with Down syndrome, with an ADI of up to 5 mm. Retropharyngeal soft tissue swelling may also indicate spinal injury on the lateral view. Acceptable levels of swelling in the adult are 6 mm of soft tissue swelling at C2 and 22 mm at C6. In the child, this can equate to 7 mm in the retropharyngeal space and 14 mm in the retrotracheal space [24]. A patient's active flexion and extension dynamic view are controversial in the acute setting but may help distinguish instability. If deemed necessary to do, a physician should be present for the exam.

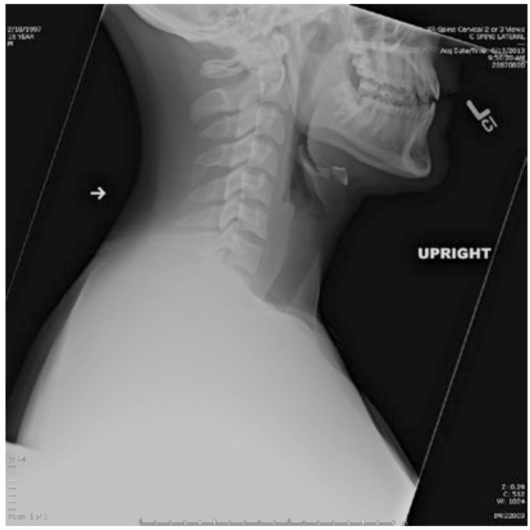

Fig. 5.4 Lateral radiographic view of the cervical spine

The AP view aids in assessing for scoliosis, congenital malformations, and lytic lesions (Fig. 5.5). In the traumatic setting, an offset spinous process may indicate a facet dislocation [25].

A third view that should always be obtained when evaluating for a cervical spine injury is the open-mouth odontoid view (Fig. 5.6). On this view, one looks for an odontoid fracture and signs of C1–C2 instability manifested by greater than 7 mm (total of both sides) of lateral mass overhang or asymmetric position of the dens between the lateral masses.

In the thoracic spine, the standing anterior-posterior (AP) view will assess scoliosis and congenital vertebral malformation. It may also detect paravertebral soft tissue swelling. The lateral view will assess for kyphosis and Scheuermann's changes. The normal thoracic kyphosis has an upper range of 45–50°. Scheuermann's disease involves multiple endplate changes of the thoracic spine, which are discussed later in this chapter.

Fig. 5.5 AP view of cervical spine

CT scan is the best study for assessing osseous injury in detail. CT scan is often used in a trauma situation to assess the spine for stability, particularly in the patient with mental status changes or with persistent symptoms and subtle findings, such as soft tissue swelling. A CT is useful in assessing facet arthroses, as well as unclear degenerative disc-osteophyte complexes seen on MRI. Lytic or sclerotic lesions seen on X-ray may also be better defined.

MRI is excellent for evaluating soft tissues and offers good bone resolution without ionizing radiation. With the trauma assessment of the child, the upper cervical spine is often involved and is well assessed with an MRI. Any patient with neurologic complaints or findings on exam that may be consistent with spinal cord or nerve

Fig. 5.6 The open-mouth odontoid view is necessary to obtain information for cervical spine injury

root injury should be evaluated with MRI. This is superior for assessing detail of the spinal cord and its exiting nerve roots, as well as the intervertebral disc. Disc herniations are well defined on MRI and may be further classified as protruded (contained by the outer anulus), extruded (uncontained by the outer anulus), and sequestrated (separated from the disc). Signal changes may also be noted in the corresponding vertebral bodies, which indicates increased load to those osseous structures secondary to loss of disc shock absorption. Increased T2 signal in the endplates of the vertebral bodies in an immature skeleton may indicate endplate apophysitis, which is a common cause of back pain in the young athlete. And finally, when investigating for infection, active tumor, and syringomyelia, gadolinium intravenous injection may enhance visualization.

MRI often picks up subtle spinal column and cord changes that are missed on X-ray and CT scan. MRI is readily available in most medical centers and has resulted in a decrease in the prevalence of a particular type of spinal injury specific to the pediatric population. In 1982, spinal cord injury without radiographic abnormality (SCIWORA) was defined as myelopathy on exam after a traumatic injury without positive findings on plain films, flexion-extension films, or CT scan [26]. It occurs with greater severity in children less than 8 years of age. The existence of SCIWORA is an important reminder that children can have significant spinal cord injuries in the absence of detectable osseous injury.

Bone scan is a study of the metabolic activity of the skeletal system. Lesions associated with increased activity on bone scan are fractures, tumors, infection, stress reactions, and, oftentimes, arthritis. However, it is important to remember that any area with increased bone formation or destruction may "light up" on bone scan, and in the skeletally immature patient, that includes the growth plates. With improvements in MRI technique, SPECT bone scan is being used less often to diagnose pars interarticularis stress and spondylolysis injuries due to the significant radiation dose and higher rates of false-positive and false-negative results. [27].

Acute Injuries

Burners/Stingers

Burners (also called stingers) are nerve injuries to the brachial plexus or cervical nerve roots caused by a direct blow or traction injury. These are the most common cervical injuries seen in gridiron football and other contact sports, such as rugby and ice hockey, but also have been described in wrestling and gymnastics. Injury results from either compression or traction of the upper trunk of the brachial plexus or, less commonly, cervical nerve roots C5 and C6. Brachial plexus traction injury occurs when the shoulder is held in a depressed position and the neck is distracted toward the opposite side, therefore stretching the ipsilateral brachial plexus [28, 29]. Compression of the brachial plexus occurs with either neck hyperextension combined with ipsilateral flexion or from a direct blow to the supraclavicular fossa [30–32]. From 2009 to 2015, the NCAA Injury Surveillance Program (NCAA-ISP) reported a stinger injury rate of 2.04/10,000 athlete exposures (AE) in NCAA American football athletes. Stingers were most commonly due to player contact (93.0%), particularly while tackling (36.7%) and blocking (25.8%). Positions most affected were defensive ends/linebackers (25.8%) and offensive linemen (23.6%). Stingers in the NCAA were transient events, resulting in less than 24 hours away from sports (63.8%). However, one in five (18.8%) cases of stingers was recurrent [33].

Athlete anatomy is an important consideration in evaluating stingers. Cervical nerve root injuries may be predisposed by cervical neuroforaminal stenosis or spinal canal stenosis, conditions seen more commonly in older college and professional athletes. It is thought that the neuroforaminal space is narrowed with neck extension and rotation; this crowding is even more pronounced in athletes with anatomically narrowed foramina or canals.

The most common mechanism of injury for burners is tackling. The player will report that immediately after contact, he or she developed a burning pain in the upper extremity. This pain will often start in the supraclavicular fossa and progress down the ipsilateral arm in a diffuse, non-dermatomal pattern. Sometimes the player will also report sensations of numbness or weakness in the extremity as well. These symptoms usually resolve within 1–2 min but may progress for days or weeks [34, 35]. Physical exam should begin with making sure that the athlete has not incurred a head or neck injury during the play. Attention should then be turned to the affected arm. It is common for the athlete to shake the affected arm immediately after injury to relieve the burning or numbness. Inspection should be followed by palpation of the arm and shoulder to assess for other possible injuries, such as muscle rupture, contusion, or fracture. Range of motion of the shoulder should be assessed to rule out dislocation, followed by a careful neurologic exam of the upper extremity.

Burners usually affect the upper trunk of the brachial plexus, which consists of nerve fibers from the C5 and C6 nerve roots. These nerves primarily supply innervation to the biceps brachii, deltoid, supraspinatus, infraspinatus, and pronator teres muscles. Therefore, strength in these muscles should be assessed during the exam. It is very important to reexamine the patient within 24 h of injury because although most weakness resolves within minutes of injury, there are times when neurapraxia is delayed in its presentation.

Diagnosis of burners depends mostly on history and physical exam; often, further testing is not necessary. It is critical to exclude any bilateral or associated leg symptoms that would indicate a more central cause, such as transient quadriparesis. In such cases, or with repetitive injury or chronic symptoms, further evaluation may be helpful in confirming the diagnosis. Plain X-rays of the cervical spine, including flexion and extension lateral views, and an MRI may be indicated in these cases. Electromyelogram (EMG) studies evaluate the conduction of electric impulse from nerve to muscle unit and can often help pinpoint the area and degree of nerve injury. However, there is usually at least a 3–4-week delay between injury and the onset of changes in nerve conduction that are perceptible by EMG [36].

Treatment of burners consists of pain control, rest, and regular reexamination until pain and neurologic symptoms have resolved. Rest from sports until complete resolution of symptoms is important to reduce risk of more severe injury. Because stingers are so common in tackling sports and recurrence rates are approximately 20%, prevention is important. Adjustment of tackling technique, use of protective equipment, and focus on a conditioning program that emphasizes cervical and upper trunk strength for a "chest-out posture" are all ways to try to prevent recurrent stinger syndrome. [34].

Fractures and Traumatic Instability

Trauma from athletics is an important cause of acute cervical and thoracic spine fractures. A recent study estimates that 23% of pediatric cervical spine fractures are a result of sports-related trauma [37]. Although these fractures are relatively uncommon, they can have devastating neurologic consequences. Therefore, knowledge of the diagnosis and management of these fractures is critical in limiting progression of neurologic injury.

Acute cervical fractures are more frequently associated with serious neurologic injury; therefore, any athlete with acute neck pain must be promptly evaluated and immobilized on the athletic field. Recently, recommendations on pad and helmet removal have changed. It is now recommended that protective equipment be removed prior to athlete transport to the hospital. This change in thinking is based on the idea that equipment removal should be performed by providers with the highest level of training who is, in most cases, the athletic trainer or sports medicine physician. Recommendations to remove chest protection also allow for chest access, which is critical for patients with respiratory or cardiac arrest [38].

Injuries to the cervical spine may be divided into upper and lower (subaxial) spine. Upper

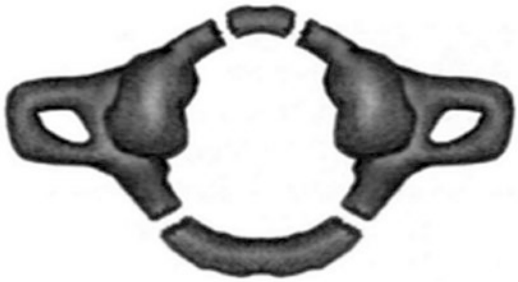

Fig. 5.7 Jefferson's fracture involves the ring of C1 and may involve the anterior and posterior arch

injuries refer to the occiput, C1 and C2 levels, whereas the subaxial spine involves C3 and below. Injuries to the atlanto-occipital juncture are uncommon but occur more frequently in children because of the incompletely developed articulation here [39]. These are frequently life-threatening at the scene.

Jefferson fractures involve the ring of C1 and result from axial loading injury [40]. These fractures may involve the anterior and posterior arch (Fig. 5.7). If the transverse ligament is involved, this will be demonstrated on the open-mouth odontoid view with greater than 7 mm of lateral mass overhang. These fractures may also be seen on the lateral view, along with widening of the predens space. Posterior arch fractures are the more common type of Jefferson fracture and usually heal with a bony or fibrous union. Burst fractures are less stable fractures and consist of fractures of both the anterior and posterior arches with involvement of the transverse ligament. Because these fractures are unstable, they may lead to both neurologic and vascular compromise. Management of stable atlas fractures is usually nonsurgical, with the implementation of bracing. Follow-up flexion and extension views of the atlantodens interval are necessary to establish the integrity of the transverse ligament. Unstable fractures or those progressing to non-union may require surgical stabilization and permanent removal from contact sports.

Axis (C2) fractures are most commonly of the odontoid or the dens, and they account for approximately 20% of all cervical spine fractures [41]. The incidence of axis fractures is on the rise; however, the increase is seen mostly in the elderly population [42]. This usually occurs from an extension injury mechanism. The dens is the superior portion of the axis, which protrudes upward and articulates with the atlas (C1). Fractures of the dens occur at the apex (type I), the body (type II), or basilar (type III) aspect of the vertebral body and are usually a result of direct trauma to the head in contact sports (Fig. 5.8). Type II fractures are associated with a higher rate of nonunion. Most commonly, the fractured fragment will displace anteriorly with posterior angulation of the dens [43]. Stable dens types I and III fractures are often managed non-surgically with traction followed by halo or hard cervical collar immobilization for 8–12 weeks (type I) or 6 weeks (type III). Type II is somewhat more controversial, but if there is any displacement or if there is any failure to maintain stability, surgical stabilization is needed [44, 45].

The Hangman's fracture is another type of axis (C2) fracture, which is also caused by a hyperextension and compression injury to the pedicle or pars interarticularis of C2 (Fig. 5.9). It is therefore more appropriately termed a traumatic spondylolisthesis. This injury is less common in children who are more likely to sustain a dens fracture through the synchondrosis of the dens. This fracture is most commonly a result of forced hyperextension with compression of the neck, such as diving and motor vehicle windshield impact. This fracture may cause an anterior displacement of C2 on C3. Diagnosis is made with plain radiographs (particularly the lateral view), followed by CT scan of the cervical spine. Stable undisplaced fractures may be treated with 3 months of semirigid collar immobilization (Miami J or Philadelphia collar) [46]. Unstable fractures are treated with halo or surgical stabilization.

Subaxial cervical and thoracic compression fractures may be classified using the Denis three-column theory (Fig. 5.10) [47]. The anterior column consists of the anterior longitudinal ligament with the anterior half of the vertebral body including the anulus fibrosus. The middle column consists of the posterior half of the vertebral body with the anulus. The posterior column comprises the posterior arch and stabilizing ligaments. Involvement of a single column indicates stability,

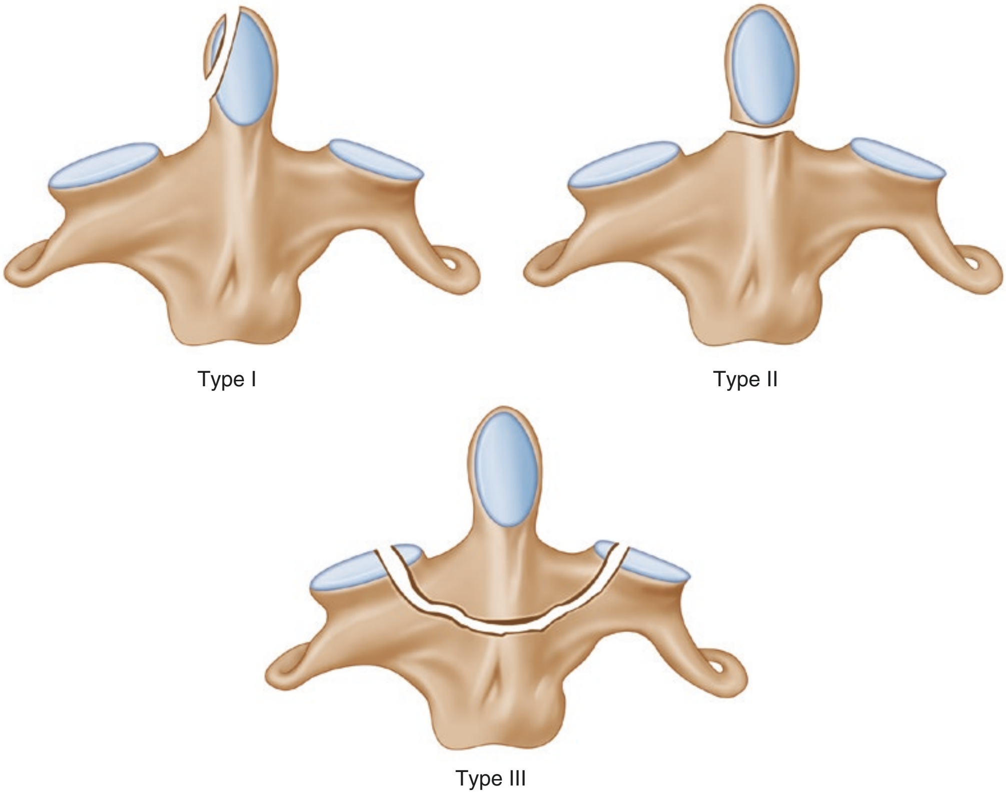

Fig. 5.8 Odontoid fracture is a result of direct trauma to the head in contact sports

Fig. 5.9 Hangman's fracture is caused by a hyperextension and compression injury to the pedicle or pars interarticularis of C2

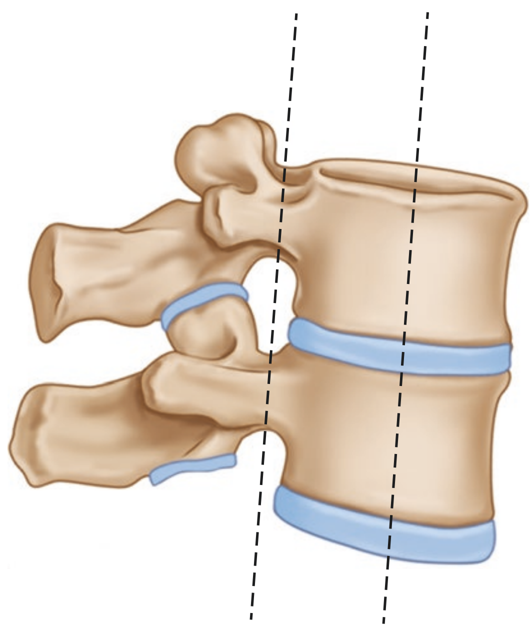

Fig. 5.10 Subaxial cervical and thoracic compression fractures may be classified using the Denis three-column theory

whereas two-column involvement (any middle column involvement) would indicate instability. This may involve neurologic instability and/or mechanical instability with deformity progression. Plain lateral X-rays that demonstrate an anterior compression fracture of 25% or less would indicate stability. It is also important to carefully assess the middle and posterior columns, where only a widening of the interspinous space may indicate three-column involvement and severe instability. As the compression approaches 50%, involvement of the posterior arch is more likely and best demonstrated on a CT scan. The Subaxial Cervical Spine Injury Classification (SLIC) and severity scale by the Spine Trauma Study Group is another important tool aiding spine surgeons in treatment planning for subaxial cervical spine injuries. The classification and severity score is based on the importance of three factors related to the management of cervical injuries: morphology, neurological status, and the integrity of the disco-ligamentous complex (DLC). Given the wide range of possible injury patterns, the SLIC score is helpful in treatment decision-making [48].

Cervical flexion injuries may be subdivided into compression and distraction mechanisms. Cervical compression-flexion fractures are the most common fractures of the cervical spine and are caused by axial loading forces applied to the head, often with neck flexion. These comprise approximately 36% of lower cervical injuries [47]. This injury is seen in tackling sports where the head is used to tackle, as well as in sports such as diving. Compression fractures are classified as stages I through V. Stage I fractures have simple rounding of the anterior superior vertebral body (Fig. 5.11). Stage II fractures are more compressed, with a beaking appearance of the anterior vertebrae. Stage III represents an anterior inferior teardrop type of fracture and may indicate instability. Stage IV and V represent the teardrop fracture with increasing displacement [49]. These injuries are demonstrated on the lateral radiograph. However, a CT will help define the extent of a fracture. An MRI is useful with stage III injuries to define disc and ligament components of instability. Stable stage I and II lesions, as well as some stage III lesions, may be immobilized in a rigid cervical collar for 10–12 weeks. Before discontinuing the collar, healing should be demonstrated on radiographs, including flexion and extension views, to assess stability. Stage IV and V, as well as some stage III injuries, will require traction and either halo immobilization or surgical stabilization.

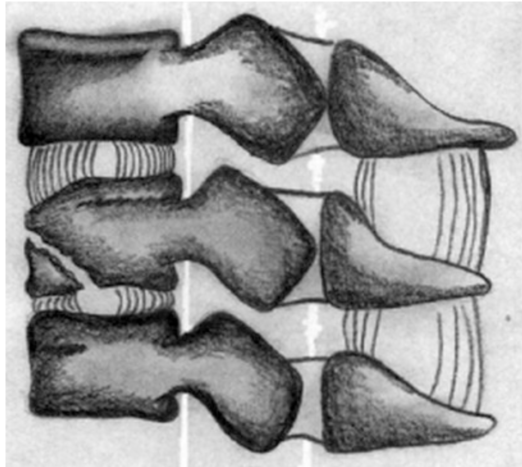

Fig. 5.11 Compression flexion injuries. Stage I fractures have simple rounding of the anterior superior vertebral body

Flexion-distraction injuries comprise a spectrum of injuries with variable amounts of flexion and distraction, as well as rotation. A simple flexion-distraction injury will demonstrate posterior element ligamentous disruption with widening of the spinous processes or facet subluxation. This will be demonstrated on lateral X-rays with subtle spinous process widening (the occult injury of McSweeney). When flexion is combined with rotation, a unilateral facet dislocation may be present. This is often stable and demonstrated on a lateral radiograph with 25% displacement of the vertebral body, along with nonparallel facet joints at the same motion segment. This may be seen in a full nelson maneuver in wrestling. A more extensive flexion-distraction injury is a bilateral facet dislocation with 50% displacement of one vertebral body at the motion segment, with parallel facets demonstrated on the lateral radiograph [50]. This is unstable, with involvement of the anterior anulus and posterior ligamentous structures.

Treatment for a simple flexion-distraction injury with mild widening of the interspinous space may be treated with a rigid cervical orthosis for 6 weeks, with care to assess flexion and extension stability before discontinuation of the collar [51]. Unilateral and bilateral facet dislocations require immediate reduction with traction and, often, surgical stabilization. An MRI may be considered before reduction if there are signs of disc herniation, which could worsen neurologic injury during the maneuvers [52].

Compression fractures with a direct axial load produce burst fractures, with fracture fragments possibly being displaced into the spinal canal. This is a classic catastrophic gridiron football and ice hockey injury that occurs when the head is slightly flexed and an axial load is applied, as seen with spearhead tackling in football or an ice hockey check into the boards. This type of unstable fracture may result in permanent neurologic sequelae and thus should be immobilized promptly pending surgical evaluation [47, 53, 54]. Prevention of this injury is paramount by banning spearhead tackling and maintaining a heads-up posture in ice hockey [55].

Extension injuries may occur with compression, as well as distraction, and may produce injuries to the pedicles, articular pillars, and laminae. These may be associated with anterior ligamentous injury to the anulus, rendering them more unstable. Stable unilateral posterior arch fractures with no anterior involvement may be treated with a cervical orthosis. More extensive injuries involving the soft tissue supports should be considered for halo or surgical stabilization [56].

Thoracic vertebral compression fractures are also associated with axial loading of the spine, usually when it is in flexion. Although the neurologic complications are often less frequent than in cervical compression fractures, it remains important to immobilize the spine with a backboard until the diagnosis can be confirmed. Athletes with thoracic vertebral compression fractures may present with upper back pain with or without paresthesias of the trunk or upper extremities.

If a thoracic compression fracture results in less than 25% loss of vertebral body height, the fracture is usually stable. However, as the fracture approaches 50%, the likelihood of posterior arch involvement increases and should be assessed with a CT scan [57]. If there are any neurologic symptoms, even transient, an MRI is useful to assess cord and soft tissue injury. Minimal compression injuries with no posterior arch involvement may be immobilized in a thoracolumbosacral orthosis (TLSO) for 6–12 weeks until pain-free. Return to sports, however, is delayed until the bracing period is completed and the athlete has regained full strength and range of motion, with attention to extension strengthening. More severe compression fractures, which are associated with instability and neurologic deficits, may require longer immobilization or surgical intervention. Athletes with no neurologic deficits and mild vertebral compression may return to contact sports when healed. If internal fixation is employed to stabilize the fracture, contact sports are often contraindicated thereafter.

Cervical and Thoracic Disc Disease

Cervical disc disease accounts for approximately 36% of all spinal disc disease [58]. This may be an acute soft tissue herniation of the disc or more of a degenerative disc-osteophyte complex at the neuroforamina. Acute soft tissue cervical disc herniations are less common than degenerative disc disease in the athletic population, particularly in the adult. The anulus is quite deficient at the posterolateral corner near the uncovertebral joint, which disrupts the normal lamellae of the anulus. This is anterior to the neuroforamina. As such, the well-hydrated nucleus in the younger individual may violate the attenuated anulus during rapid flexion or rotation that is accentuated with an axial load. This may occur with noncontact and contact sports, particularly tackling sports, as well as wrestling. Acute minor protrusions may cause an acute torticollis or wryneck, whereas a more significant herniation will produce a frank radiculopathy.

Conversely, a degenerative disc with osteophyte formation at the uncovertebral joint, and subsequent zygapophyseal joint degenerative changes, may also produce radicular symptoms. This is referred to as a hard disc herniation [59]. This may occur with repetitive coupled lateral flexion and rotation, as well as flexion and extension [60]. The most common levels are the C5 through C6 and C6 through C7 levels.

MRI imaging is quite good at defining the spacial soft tissue relations of a disc herniation. However, a CT scan can be quite helpful in defining the elements of the hard disc involvement. It is also helpful in the patient that is unable to have an MRI. However, the interpretation must carefully correlate with the clinical symptoms. Approximately 15% of 20-year-olds and about 85% of 60-year-olds will demonstrate some disc degeneration [61]. An EMG may be helpful in delineating the level of neuroimpingement, as well as detecting comorbid peripheral impingement.

Cervical disc herniations can be managed conservatively with rest, nonsteroidal anti-inflammatory drugs (NSAIDs), short courses of tapering corticosteroids, and analgesics. A soft cervical collar can be used for temporary pain relief and to remind the athlete to rest. Early therapy centers on pain control with traction, modalities, and postural biomechanics. When neurologic symptoms and pain have improved, a gentle, progressive physical therapy program can be instituted to restore range of motion and improve cervical stabilization. At times, a cervical epidural injection may be quite helpful to reduce radicular symptoms [62]. As the athlete progresses, the sports-specific phase of rehabilitation addresses the full, closed-chain upper trunk and cervical stabilization musculature, along with the biomechanics of the sport. This conservative management course is most often quite successful in managing cervical radiculopathy [63]. Nonetheless, surgical intervention is indicated in cases with refractory radicular pain, a progressive motor deficit, or signs of spinal cord involvement. Most often this is an anterior discectomy with fusion [64]. Return to sport will be discussed later in the chapter.

Thoracic disc herniations are uncommon and represent approximately 1% of all symptomatic disc herniations [65]. The lower thoracic spine (T8–11) is more prone to herniation because this is the transition zone from the less flexible upper thoracic spine, with fixation of the rib cage, to the more flexible lower thoracic spine, with free-floating ribs. These patients often present with acute onset of midline thoracic pain, with or without radicular symptoms in the chest or abdomen. MRI is the study of choice to assess the degree of disc protrusion. The clinician must have a high index of suspicion for a herniation because as many as 11–13% of adults have asymptomatic thoracic disc herniations [66]. As with the cervical spine, the clinician must ascertain the safety of the cord. In the absence of progressive neurologic symptoms, treatment is conservative. Extension strengthening is started as tolerated by the athlete. Return to play is allowed when the athlete is pain-free and strength and flexibility are fully restored. Follow-up is indicated to ensure that myelopathy does not develop.

Other Causes of Acute Neck and Upper Back Pain

The most common cause of acute-onset neck and upper back pain in the adolescent athlete is muscle strain or contusion. This type of injury is often the result of either a direct blow to the muscle mass, resulting in contusion and spasm, or an abrupt isometric contraction of a muscle, resulting in muscle tear. Although these injuries can initially be debilitating, most may be managed conservatively with rest, moist heat, gentle massage, muscle relaxants, and NSAIDs. Athletes may return to play when pain symptoms resolve. It is important that the clinician recognizes that muscle spasm may be a sign of further underlying spinal injury. Therefore, patient education about reasons to return for evaluation, such as neurologic symptoms or persistent pain, is imperative.

Chronic Injuries

Cervical Disc Degeneration

Cervical disc disease was previously addressed, along with acute disc herniation. However, one specific pattern of overuse in the gridiron football athlete should be recognized. Repetitive axial loading of the cervical spine is seen in gridiron football players who repeatedly tackle using the top of the head as the initial point of impact, the now illegal maneuver called “spear tackling.” This leads to a more insidious injury pattern of narrowing of the cervical spinal canal and loss or reversal of normal cervical lordosis, predisposing the athlete to permanent neurologic impairment. Athletes with spear tackler’s spine should be kept out of contact sports until the normal lordosis is restored, neck pain or neurologic symptoms resolve, and there is no demonstrated spinal stenosis [67].

Cervical Facet Syndrome

Cervical facet pain is common in the general population. It represents about 25% of axial neck pain as verified by selective injection techniques [68]. It has been demonstrated to cause pain in 54% of whiplash patients [69]. Asymmetrical motions in sports may acutely or chronically impact the hyaline cartilage surface of these joints. Gridiron football impact, such as a tackle to a wide receiver, may mimic the motion of whiplash. Certain ballet dance patterns may repetitively load these joints. Since the facet joints couple lateral flexion and rotation to the ipsilateral side, any cyclical motion to the side may overload the joint’s resilience. Another mechanism of injury may occur in a cyclist with an improperly fitted bike, causing hyperextension of the neck to maintain road visibility. This hyperextension will also overload the facet joint complex. These patients will present with posterior cervical pain, along with possible radiation to the interscapular region or occipital region. Examination will elicit facet and paraspinal tenderness. Spurling extension maneuvers will produce axial neck pain. Plain films with oblique views may demonstrate osteophytes from the facets. An MRI may demonstrate capsular and ligamentum flavum hypertrophy.

Treatment should be initiated with NSAIDs, gentle pain-free range of motion, and modalities such as ice, electrical stimulation, and ultrasound. Muscle activation techniques and joint mobilization may also be helpful. As the acute pain subsides, the athlete should initiate isometric, followed by dynamic, exercises that emphasize the chest-out posture for the upper trunk. Finally, a full resistive cervical strengthening program with attention to the chin-back posture is undertaken. Infrequently, a cervical facet injection may temporarily reduce the pain to allow better rehabilitation [70]. Highly resistant symptoms may benefit from a radiofrequency ablation of the medial branch of the dorsal ramus of the spinal nerve innervating the facet joints. This has been shown to be 71% effective in the treatment of whiplash patients [71].

Scheuermann’s Kyphosis

In the adolescent athlete, repeated flexion of the thoracolumbar spine may cause Scheuermann’s kyphosis, which may result in a painful deformity. This abnormality is defined on X-ray as three contiguous vertebrae with 5° of anterior wedging, irregular endplates, and a Cobb angle of at least 45° [72]. When this occurs in the thoracolumbar region, the athlete may present with thoracolumbar kyphosis and lumbar hypolordosis. This is often called atypical Scheuermann’s or lumbar Scheuermann’s. This is thought to occur because of repetitive flexion forces applied to the soft growth cartilage of the vertebral epiphyseal endplate. This is a fixed deformity, in contrast to juvenile roundback deformity, which is flexible and responds to an extension-strengthening program. This has been particularly noted in the young athlete participating in 400 h per year of many sports but especially gymnastics, swimming, and wrestling [73]. These deformities are best detected clinically on physical examination while having the athlete forward flex the thoracolumbar spine.

In the adolescent athlete with Scheuermann’s changes, bracing is quite effective if there is spinal growth remaining. This can be assessed by a Risser score of the iliac crest apophysis. For thoracic involvement with curves less than 50°, observation and extension exercises are indicated. Bracing is initiated for curves greater than 45–50°. At 60–70°, surgical intervention is considered. For curves above T7, a Milwaukee brace is used. A TLSO with upper chest support is utilized for curves with an apex below this level. Thoracolumbar Scheuermann's may be treated with a TLSO brace in 15° of extension. In patients with significant Scheuermann's kyphosis necessitating surgery, MRI is recommended to evaluate for concomitant thoracic disc disease on MRI that could impact surgical planning (Fig. 5.12) [74].

Fig. 5.12 MRI showing atypical Scheuermann's (thoracolumbar juncture endplate changes with flattening of the spine)

Scoliosis

Adolescent idiopathic scoliosis is common in the young female athlete. Scoliosis is classified according to the age when it was identified. Infantile scoliosis presents before 3 years of age. Juvenile scoliosis manifests between 3 and 10 years of age. Adolescent idiopathic scoliosis presents between 10 years of age and skeletal maturity [75]. Minimal curves have equal gender frequency. However, more severe curves have a female to male ratio of 4:1 [76, 77]. Adolescent scoliosis occurs in 2–3% of the population. However, minor curve asymmetries have been noted more often in some sports such as ballet, with a reported 24% prevalence in young dancers [78]. Repetitive asymmetric torque forces may contribute to this phenomenon. This may also be seen in swimming, serving, and throwing sports and in rhythmic gymnastics [79]. Other factors contributing to this sports curve asymmetry may include delayed menarche, small body habitus, and intense prepubertal training [80].

Adolescent scoliosis should not initially be ascribed as the cause of back pain. Other etiologies must be considered that may coexist with or cause the scoliosis. Consideration should be given to tethered cord, tumors, spondylolysis, syrinx, and disc herniation [81]. This may indicate the need for a spinal-screening MRI. However, curves that present in later adolescence with Risser scores over 2 have been associated with back pain [82]. The Risser score refers to the plain X-ray finding of the AP pelvis in regard to the maturation of the iliac crest apophysis, which appears from lateral to medial. The score refers to the most advanced quadrant of ossification, with Risser 1 being the first quadrant, Risser 2 the second, Risser 3 the third, and Risser 4 showing complete apophyseal cap ossification. A Risser 5 refers to the fusion of the cap to the ileum.

The Risser score, along with the curve magnitude, age, and maturity, indicates the risk of curve progression. For example, a curvature of less than 20° and a Risser score of 0–1 have a 22% risk of progression. Conversely, the mature patient with the same curve has a 1.6% risk of progression [83]. Other risk factors for curve progression include magnitude of curve at presentation, premenarche, and the presence of double curves [84].

Consideration should be given to a limb length discrepancy causing a nonfixed curve, which corrects with a lift. If a minor curve is felt to be secondary to sports participation, the athlete may benefit from cross-training and core stabilization. Although exercises are not accepted as solo treatment, an investigation has demonstrated the benefit of trunk strengthening with attention to rotary exercises [85]. At the very least, core strength and flexibility may prevent mechanical injury.

Those curves less than 25° are observed with repeat X-rays every 4–6 months, unless they manifest sudden changes. The immature athlete with a curve of 25° is usually treated with a brace, such as the Boston brace, which is worn 16–23 h per day. The Charleston brace is a nighttime brace. The Boston brace has shown less curve progression in some studies [86]. The athlete may opt to play without the brace for a couple of hours [87]. Curves that exceed 40–45° have a high risk of progression and should be considered for surgical intervention. With instrumentation and fusion, much athletic activity is allowed and encouraged. However, contact sports are contraindicated.

Congenital Anomalies

Klippel-Feil Syndrome

Klippel-Feil syndrome refers to a spectrum of congenital abnormalities associated with fusion masses of the cervical spine. These fusions are often incidentally detected but require some consideration for involvement in contact sports. This syndrome may be classified into three categories. Type I involves a massive cervical spine fusion. Type II involves a one- or two-level fusion. Type III includes both types I and II, with associated thoracic or lumbar spine fusions. Other associated congenital abnormalities include hearing disorders (both conductive and sensorineural); cardiac abnormalities, such as ventricular septal defects; and urologic defects [88]. Scoliosis and Sprengel's deformity are often associated. Sprengel's deformity involves an osteocartilaginous connection of the scapula to the cervical spine.

Although the classic triad is a short neck, low hairline, and decreased range of motion, this only occurs in about 40% of cases. Often, this will present incidentally or with mild motion loss, which usually involves the axial rotation component. With respect to contact sports, the major issues are instability and stenosis. Instability is most severe with fusions that involve the craniocervical and C1–C2 junction. Stenosis is often a concern at a free level between two fusion masses [89].

Evaluation should include lateral flexion and extension views to detect instability. An MRI is very useful in defining the amount of stenosis and associated craniocervical involvement such as basilar impression. A flexion and extension MRI may be useful in borderline cases to define functional stenosis. Thoracic and lumbar plain radiographs will detect fusion masses at these lower levels. Other evaluations include audiometric, renal ultrasound, and cardiac auscultation (further evaluation as indicated).

Direct contact sports are contraindicated with C1–C2 fusions, craniocervical fusions, and any associated fusions with instability or significant stenosis. Consideration should be given to avoiding involvement in sports that require repetitive extreme motion, as the free disc spaces may be predisposed to premature degeneration.

Os Odontoideum

Os odontoideum is a nonunion of the dens to the axis at the level of the synchondrosis. Although originally thought to be a congenital abnormality, it is now considered a nonunion from previous overuse stress at the level of the synchondrosis, which is at the base of the dens [90]. Because atlantoaxial stability is largely maintained by the transverse atlantal ligament behind the dens, this integrity is violated and represents a contraindication to contact sports participation. This should not be confused with a small benign apical ossicle, the ossiculum terminale, which is above the transverse atlantal ligament.

Radiographic evaluation should include lateral flexion and extension views with attention to three findings of instability [91]. A posterior atlantodens interval (PADI) of less than 13 mm indicates instability and neurologic decline. Two other findings between C1 and C2 include greater than 5 mm of translation or 20° of angular rotation. Surgical stabilization should be performed in these circumstances. MRI imaging is very useful in determining cord compression [92].

Other odontoid abnormalities include rare aplasia and hypoplasia and associated ligamentous laxity. These may be associated with Down syndrome, Morquio syndrome, and other skeletal dysplasias. Full imaging evaluation, as previously discussed, is indicated to evaluate neurologic compromise.

Return-to-Play Guidelines

The team physician is often called upon to clear an athlete to return to sports after a specific injury to the cervical and thoracic spine. As a rule, the athlete must be pain-free without neurologic symptoms and demonstrate a full range of motion and strength. However, there may be structural defects that the physician must assess for appropriateness to participate in contact sports. Watkins has created risk categories that are very helpful in determining return to play. He has classified these as minimal risk, moderate risk, and extreme risk [93]. Minimal risk implies little more risk than the sport would normally involve. Moderate risk implies a reasonable possibility of recurrent injury and neurologic injury. Extreme risk implies a high risk of permanent damage; therefore, athletes should be discouraged from participating in contact sports.

Extreme-risk injuries include a Jefferson fracture, unless it is completely healed with no demonstrated instability on dynamic radiographs and no symptoms. A partially or fully ruptured transverse ligament of the axis, unhealed odontoid fracture, unhealed hangman's fractures, and unhealed flexion injuries of the interspinous ligaments with separation on flexion radiographs are all examples of extreme-risk injuries. Also included are fractures or dislocations that have demonstrated incomplete bony healing, ligamentous instability, neurologic deficit, pain, stiffness, or residual spinal stenosis. Other conditions include cervical myelopathy, occiput-C1 fusions, C1–C2 fusions, C1–C2 rotary instability, basilar invagination, Arnold-Chiari malformation, multilevel Klippel-Feil fusions, two episodes of cervical neurapraxia, symptomatic disc herniation, three-level spine fusion, cervical involvement of ankylosing spondylitis, rheumatoid arthritis, or diffuse idiopathic skeletal hyperostosis (DISH).

Moderate-risk injuries include disc herniations that demonstrate symptomatic radiculopathy, previous single episode of cervical neurapraxia that is symptom-free, a healed posterior single-level fusion, three or more burners, and a healed two-level anterior fusion.

Minor-risk injuries include healed undisplaced fractures, asymptomatic disc herniations without central spinal stenosis, single-level Klippel-Feil, or healed surgical fusion and two previous burners.

Another difficult aspect of decision-making is the return of an athlete to contact sports who has suffered a transient neurologic deficit and demonstrates some central spinal stenosis. Watkins developed a rating system to assist in this decision-making process. The rating takes into account the amount of canal narrowing, extent of neurologic deficit, and the length of symptoms (Table 5.1).

By adding these three scores, a total number of six or less would be a mild episode; a score of 6–10 would indicate a moderate-risk episode; and a score of 10–15 would indicate a severe episode [93]. This is a guideline in managing the return-to-play decision. Any neurologic deficit would preclude the athlete from returning to sport, regardless of score.

Prevention

Prevention revolves around conditioning, sports technique, and proper equipment. Cervical spine and upper trunk strengthening are important to

Table 5.1 Watkins neurologic deficit rating system for return to play

Canal narrowing	Rating
>12 mm	1
>10 and <12 mm	2
10 mm	3
8–10 mm	4
<8 mm	5
Neurologic deficit	
Single-arm symptomatic	1
Bilateral upper extremities	2
Hemi-arm and leg symptoms	3
Transient quadriparesis	4
Transient quadriplegia	5
Duration of symptoms	
<5 min	1
<1 h	2
<24 h	3
<1 week	4
>1 week	5

Source: Rogala et al. [75]

absorb the forces in contact sports. It is generally felt that upper back postural strength imparts a chest-out posture for better cervical stability. Isolated cervical strengthening for the longus colli, extensor, and rotational stabilizers is important. Attention to sports technique has been demonstrated to diminish severe cervical spine injuries. Specifically, this was shown with the abolishment of spearhead tackling. Heads-up ice hockey also accomplishes this by avoiding impact on a straightened spine. Proper equipment may help with burners in gridiron football. Well-fitted shoulder pads that prevent lateral flexion may be useful to avoid recurrent burners.

Clinical Pearls

- The cervical and thoracic spine houses the central spinal cord.
- The clinician treating injuries to these areas should have a full understanding of the anatomy and the implications of injury to the various areas.
- Neurologic and mechanical stability must always be assessed.
- Protective equipment should be removed prior to transport if possible.
- Sport-specific biomechanical loads to the spine must be understood to determine injury patterns.
- Preseason conditioning and specific sports techniques can help prevent injury, such as avoiding spearhead tackling in gridiron football and encouraging heads-up ice hockey.
- Any neurological symptoms should preclude return to sport.
- Athletes with extreme-risk injuries or conditions, such as incompletely healed fractures or spinal stenosis, are at high risk for permanent injury and should be discouraged from participating in contact sports.

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6 Lumbar Spine Injuries

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As children train with increasing intensity in highly competitive sports, new patterns of injury are emerging. These patterns are distinct from those observed in adults [1–3]. Low back pain is identified in 10–15% of participants in youth sports in general [4, 5] with this percentage being even higher in certain sports. Studies reveal that 15–20% of young artistic gymnasts [6], 27% of college football players [7], and up to 86% of rhythmic gymnasts [8] complain of low back pain.

The etiology of low back pain in young athletes differs significantly from that seen in the adult population [5, 9]. Injuries to the pars interarticularis are more common in younger athletes [5]. Although disc-related problems are prevalent among adults, only 11% of children and youth with back pain have symptoms referable to the disc [10]. The discs in children are well hydrated, firm, and solidly attached to the adjacent vertebral end plate [2, 11], leading to a different pattern of injuries.

Structural problems are relatively common in adolescent athletes with low back pain [1], therefore, earlier and more thorough investigations may be indicated in this age group, compared with adults presenting with low back pain. Idiopathic pain is much less common among younger athletes than among adults [12, 13]. In one series of physically active individuals between 12 and 18 years of age who presented with low back pain, only 6% had symptoms caused by lumbosacral strain, compared with 27% of adults [10]. Young athletes with persistent low back symptoms should be investigated appropriately for more severe injuries such as spondylolysis or spondylolisthesis before receiving the diagnosis of a simple "back strain."

Injuries in all age groups occur either as a result of acute traumatic events or from repetitive microtrauma [2, 14]. In younger athletes, more sinister causes of low back pain, such as infection, neoplasm, inflammatory conditions, and visceral dysfunction, need to be considered as well [2]. Trauma is still the most common cause of low back pain, with high-energy contact sports such as football or rugby producing acute injuries and sports such as gymnastics, figure skating, and dance resulting in overuse injuries from repetitive flexion, extension, and torsion [2].

Anatomy

The lumbosacral spine typically consists of five lumbar segments, five fused segments of the sacrum, and four fused segments of the coccyx. Common anatomic variants include a sacralized fifth lumbar vertebra or a lumbarized first sacral

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L. J. Micheli, L. Purcell (eds.), *The Adolescent Athlete*, Contemporary Pediatric and Adolescent Sports Medicine, https://doi.org/10.1007/978-3-319-56188-2_6

segment [15]. A common developmental defect seen in the lumbar spine is spina bifida occulta, which is usually of little clinical relevance in isolation and may be considered a normal variant [16].

Each lumbar vertebra can be divided into anterior and posterior elements. The anterior elements include the vertebral body, intervertebral discs, and vertebral end plates [17]. The portions of the vertebrae between the superior and inferior articular facets are referred to as the posterior elements [18]. The posterior elements include the facet joints and pars interarticularis, as well as the pedicles, lamina, transverse processes, and spinous processes [17]. These structures are injured when extension and torsion forces are applied to the spine.

Figure 6.1 shows the anatomic structure of the discovertebral joint in the child. The intervertebral disc consists of a central core called the nucleus pulposus. This gel-like substance is contained by the anulus fibrosus, which makes the disc resilient to compressive forces and able to function as a shock absorber [17, 18]. The cartilaginous epiphyseal plates or "end plates" form the interface between the disc and vertebral body [17, 19]. A cartilage ring apophysis that circumscribes the end plates is firmly attached to the intervertebral discs via Sharpey's fibers. This ring apophysis eventually fuses with its vertebral body, but until that time, this junction is vulnerable to injury [11]. Disc herniation into the vertebral body at the ring apophysis may prevent this fusion from occurring, resulting in a limbus vertebra (Fig. 6.1) [9].

The sacroiliac (SI) joints connect the lower spine to the pelvic ring and transfer forces between the trunk and the lower extremities [17]. The SI joints have a synovial portion inferiorly and a ligamentous portion superiorly [20]. The iliolumbar ligament traverses the superior portion of the joint [20].

Clinical Evaluation

History

A complete history and physical examination are necessary when evaluating a young athlete with pain in the lumbar region. Although trauma (acute or overuse) is most frequently encountered in young athletes with low back pain, other conditions including infection, tumor, and rheumatologic disorders must be considered as well [3, 10]. Key points on history will help determine the nature of the injury or may give clues to the presence of a more serious underlying condition.

Onset of symptoms should differentiate between acute trauma and a more gradual, insidious onset of pain. Duration, location, quality, and severity of pain should be determined, along with associated neurologic symptoms and aggravating factors. "Red flag" symptoms, which may be associated with more sinister causes of low back pain such as infection, tumor, or arthritis, include fever, malaise, weight loss, morning joint stiffness, and night pain [18, 21].

The type of sport or physical activity must be determined, along with the volume of training and level of competition [1]. History of disordered eating, nutritional deficiencies, menstrual irregularities, chronic fatigue, increased frequency of infections and illnesses, and previous stress fractures may suggest an associated diagnosis of "Relative Energy Deficiency in Sport" (RED-S) syndrome. RED-S, which encompasses features of the older term, "female athlete triad," places the athlete at increased risk of stress fractures [22]. Further discussion of RED-S is beyond the scope of this chapter (see Appendix D). A past or family history of HLA-B27-associated conditions, such as (juvenile) ankylosing spondylitis, psoriatic arthritis, inflammatory bowel disease, or Reiter's syndrome, may be enlightening [23]. Review of systems may identify symptoms suggestive of a visceral or systemic etiology of low back pain.

Physical Examination

Physical examination should begin with observation of gait and posture. The patient should be observed in both flexion and extension of the spine. Pain in the lumbar region on forward flexion may suggest muscle spasm or strain or may indicate injury to the anterior elements of the spine. Extension of the spine will provoke pain in

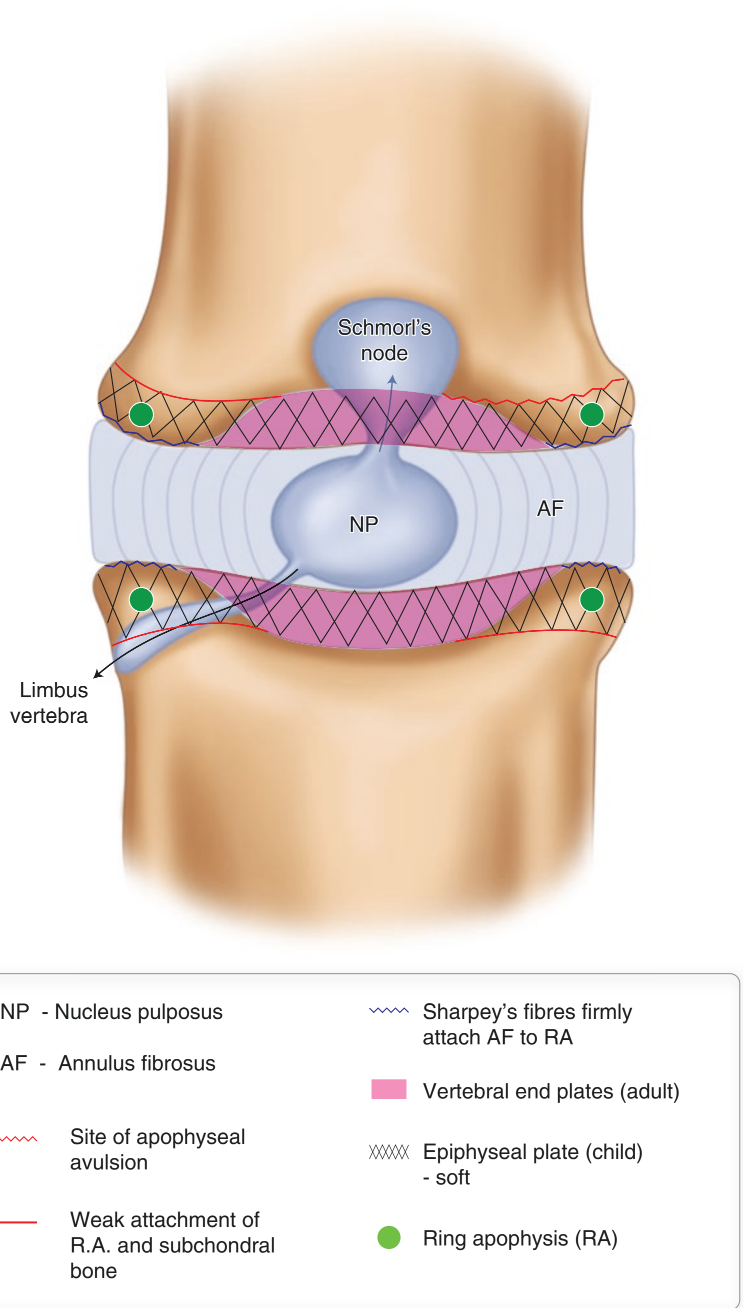

Fig. 6.1 Intervertebral disc and adjacent vertebral bodies. Concentric fibers of the anulus fibrosus surround the soft, jelly-like nucleus pulposus. The epiphyseal growth plate in childhood gives way to the vertebral end plate in the skeletally mature spine. The cartilaginous ring apophysis eventually fuses with the vertebral body, leaving a raised rim around the periphery. The ring apophysis is strongly adherent to the annulus fibrosus via Sharpey's fibers. Weakness at the attachment of the ring apophysis to the subchondral bone contributes to vertebral apophyseal avulsion injuries. This weakness also permits herniation of the nucleus pulposus through this junction, producing limbus vertebrae. In children, herniation through the soft epiphyseal plate leads to Schmorl's nodes, characteristic of Scheuermann's disease

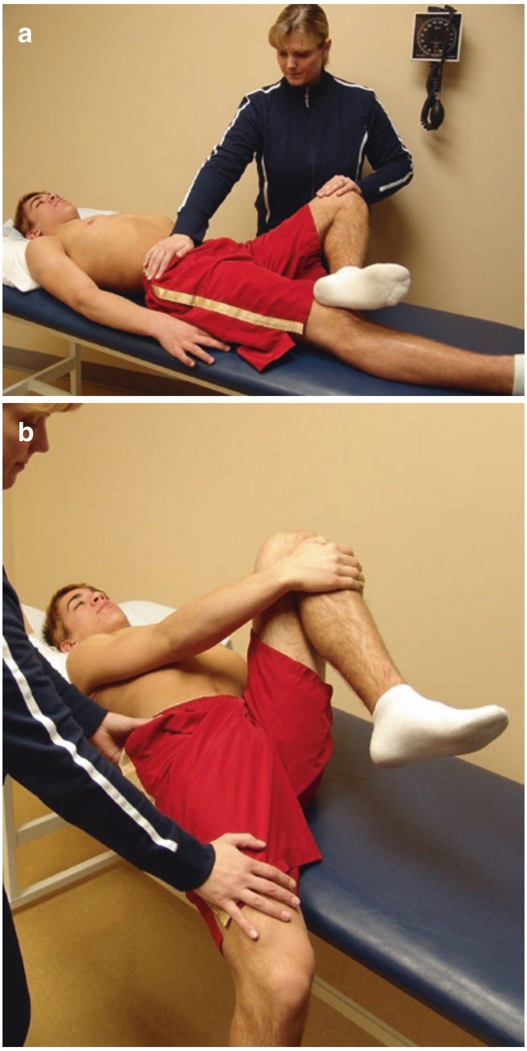

Fig. 6.2 (**a**) FABER test: with the athlete supine on the examining table, the leg is placed in a "figure 4" position and pressure is applied to the knee and contralateral ASIS. (**b**) Gaenslen's test: with the patient lying supine at the edge of the examining table, one knee is flexed maximally, and the other leg is extended over the edge of the table. Both tests assess sacroiliac joint symptoms

posterior element injuries and SI joint conditions. FABER (flexion-abduction-external rotation) test, also known as Patrick's test, and Gaenslen's test can aid in localizing the pain to the SI joint (Fig. 6.2). Areas of pain should be noted.

A screening neurologic exam, including sensation, strength, and reflexes of the lower extremities, should be conducted. Slump test and straight leg raise test for neural tension should be performed. Pain in the lumbar region, which radiates down the leg on the affected side, is consistent with nerve root irritation or impingement caused by disc herniation [24] or spondylolisthesis [25].

Low back pain is much more frequently associated with structural abnormalities in children than in adults. In the young athlete, muscle spasm or tenderness should never be attributed simply to muscle strain until other etiologies have been ruled out. Finally, if history is suggestive of visceral pathology, abdominal examination should be performed, and costovertebral angle tenderness evaluated.

Risk Factors

Several factors distinguish growing athletes from adults. Many experts feel that during rapid growth, soft tissues are unable to keep pace with the rate of bone growth. This results in muscle imbalances and a reduction in flexibility [2, 26], both of which place the young athlete at greater risk of injury.

Growth cartilage, which is present only in the skeletally immature individual, is particularly vulnerable to injury [5]. With repetitive flexion, the intervertebral disc of the young athlete may herniate through the anterior portion of the ring apophysis [2, 9, 11, 17], which is a secondary center of ossification, circumscribing the vertebral end plates. The presence of growth cartilage along the iliac crest apophyses may also produce symptoms of low back pain.

The variability in size and skeletal maturation among children of the same chronological age poses additional risks to young athletes. Most youth sports teams group children by age. As a result, on the same Bantam Hockey team, ages 13–14, the skeletal age and physical development may range from 11 to 16 years [27]. The smaller, skeletally less mature participants face significant risk from contact with bigger players.

The volume of training influences the risk of injury. Gymnasts who train 15 h or more per week have a much higher prevalence of spine abnormalities on magnetic resonance imaging (MRI) (57%) compared with those who train less than 15 h per week (13%) [28]. It is difficult to determine the optimum amount of training for young athletes, because variability in the rate of development may also represent variability in risk of injury. All members of the same sports team may not tolerate equivalent volumes of training. Certain overuse injuries present with greater frequency in athletes undergoing a rapid growth spurt [29]. This suggests that as a young athlete grows and matures, the volume and intensity of training that his or her body can tolerate may vary. Additionally, poor technique, which is a risk factor for injury at any age, may be of particular concern among younger athletes whose muscular development may be more advanced than neurologic development [30].

Other risk factors for low back injury include hip flexor tightness, increased femoral anteversion, thoracolumbar fascia tightness, abdominal weakness, genu recurvatum, and increased thoracic kyphosis. Each of these contributes to low back injury by increasing lumbar lordosis and placing additional stress on the posterior elements of the spine [5]. Hamstring tightness has also been associated with increased incidence of low back pain in general [31] and, more specifically, with spondylolysis [18].

Injuries of the Posterior Elements of the Spine

Sports that involve repetitive extension and torsion of the spine, such as gymnastics, figure skating, diving, and dance [32], place the athlete at increased risk of injury to the posterior elements. Weight lifting and contact sports, such as football and ice hockey, also have an increased association with posterior element injuries [33, 34].

Athletes with injuries, either acute or overuse, that involve the posterior elements of the spine typically present with pain on extension. Twisting motions may also precipitate pain in these patients. The athlete may describe tightness in the low back or hamstrings. The pain may be diffuse over the lumbar region, particularly in the setting of significant associated muscle spasm, or the athlete may be able to localize the pain to one side of a single vertebral level. Associated neurologic symptoms such as weakness, numbness, or tingling in the lower extremities may also be present. Any young athlete, particularly one involved in a high-risk sport, who presents with extension pain in the lumbar region requires a thorough history and physical examination, as well as early investigations to rule out significant pathology such as spondylolysis or spondylolisthesis.

Spondylolysis and Spondylolisthesis

Spondylolysis, from the Greek words "spondylos" (spine) and "lysis" (break), refers to a defect of the pars interarticularis. Although congenital or developmental defects ("dysplastic spondylolysis") exist, most cases of spondylolysis and spondylolisthesis are isthmic [35] in adolescence. These are stress fractures caused by repetitive extension and torsion of the lumbar spine. In a study of 327 high school rugby players, 72.5% of those with radiographic evidence of spondylolysis had coexisting low back pain [36], which supports the contention that pars defects are not innocuous. In one study, 47% of athletes presenting with back pain to Boston Children's Hospital were found to have spondylolysis. The most common level of involvement is L5 [37–39].

Spondylolisthesis is the forward translation of one vertebra on the next caudal segment [35]. The grade of spondylolisthesis is based on the percentage of slip of one vertebral body in respect to the next caudal segment. A slip of 0–25% is grade I, 25–50% is grade II, 50–75% is grade III, and >75% is classified as grade IV [40]. Athletes are at a low risk for progression of spondylolisthesis. This clinical entity is less common than simple spondylolysis [1]. Unilateral spondylolysis may lead to increased stress and possible fracture of the contralateral side [41]. When bilateral pars defects are present, there is limited restraint to forward motion of the affected vertebral segment, resulting in a slip. The peak age for development of a slip is during the adolescent growth spurt. Slips rarely progress after adolescence [42]. Slip angle is determined by drawing a line along the posterior border of the sacrum. The angle between the inferior border of L5 and a line drawn perpendicular to the posterior border of the sacrum forms the slip angle [43]. An increased slip angle (>45° to 55°), representing the degree of kyphosis at the lumbosacral junction, is associated with greater risk of progression [35, 44, 45].

Risk Factors

There is a genetic predisposition for spondylolysis among certain ethnic groups. Whereas the prevalence is reported to be approximately 5% by 7 years of age [46] and 6% in the adult population in general [35], the prevalence of spondylolysis among the Inuit in Northern Canada is reported to be high as 20–50% [46].

Upright posture and repetitive loading of the posterior elements of the spine through extension and torsion appear to place the athlete at increased risk of spondylolysis [35]. Sports that involve repetitive hyperextension loading of the spine are associated with increased risk of spondylolysis among athletes complaining of low back pain [2, 47, 48]. Among female competitive gymnasts, the rate of spondylolysis is 11% [49]. In a 1998 study by Perugia and Rossi of athletes with low back pain, 42% of divers, 28% of wrestlers, and 16% of gymnasts were shown to have spondylolysis on plain radiographs [47].

Factors that increase lumbar lordosis and increase stresses on the posterior elements of the spine place the young athlete at greater risk of spondylolysis and spondylolisthesis. Tight hip flexors tilt the pelvis by contracting the anterior portion of the hip joint (Fig. 6.3). Young dancers with increased femoral anteversion may "cheat" by increasing their lumbar lordosis to augment the degree of turnout of the lower extremities (Fig. 6.4) [5, 25]. Athletes with weak abdominal musculature will have difficulty stabilizing the lumbar spine in neutral. A tight thoracolumbar fascia may produce a tethering effect in the lumbar region, resulting in increased lordosis. An increased thoracic kyphosis is frequently accompanied by lumbar hyperlordosis. Genu recurvatum will tilt the pelvis into a hyperlordotic posture [5]. Finally, there is an association between spina bifida occulta and spondylolysis [42].

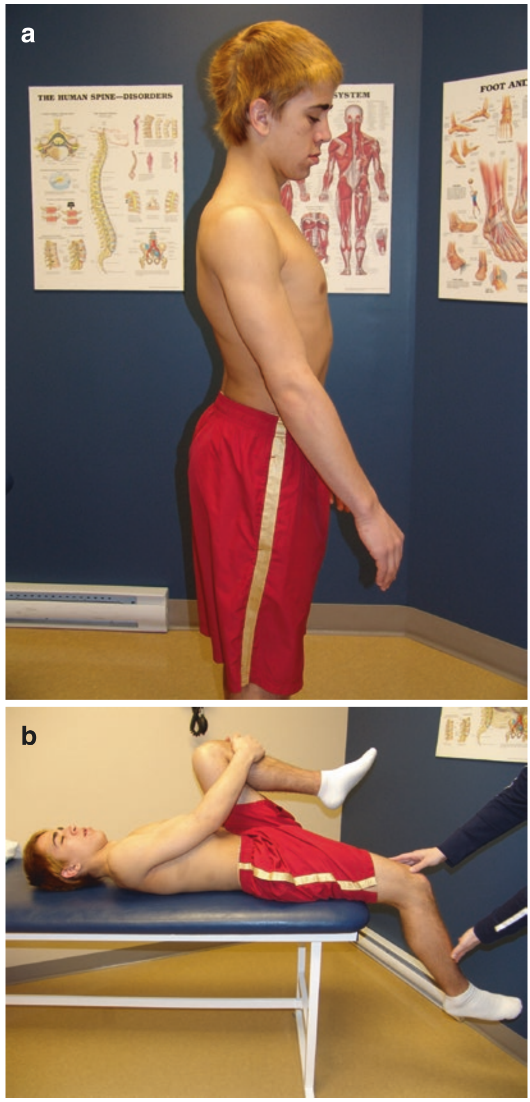

Fig. 6.3 (**a**) Increased lumbar lordosis increases risk of lumbar spine injury. (**b**) Tight hip flexors may increase lordosis

Presentation

Young athletes with spondylolysis characteristically present with pain on spine extension [32]. Onset is usually insidious, with symptoms increasing over months [35]. Affected athletes may have a milder degree of discomfort on spine flexion associated with a sense of tightness in the lumbar muscles. There is frequently an associated reduction in flexibility of the ipsilateral

Fig. 6.4 (**a**) A young dancer with good lumbar posture. (**b**) Same dancer who is now increasing apparent hip turnout by increasing lumbar lordosis

hamstrings described by the patient [32, 50]. This is particularly true among dancers and gymnasts who are often very aware of any changes in flexibility. Affected individuals may complain of pain with impact, for example, during running or jumping activities, or with body contact in football or hockey. There may be accompanying radicular symptoms, such as radiating pain, numbness, or weakness [21, 51], particularly in the setting of higher-grade (grade III or IV) slips [52]. These symptoms may make the diagnosis of spondylolysis more difficult because they may also be present in the setting of disc herniation.

Clinical Examination

Typical features of spondylolysis and spondylolisthesis on examination include lumbar hyperlordosis, ipsilateral paraspinal muscle spasm, and mild discomfort with tightness of the hamstrings on forward flexion of the spine [50]. There is focal pain on provocative hyperextension of the spine. Pain on extension localizes the pathology to the posterior elements, whereas single-leg extension, which is a very sensitive test for spondylolysis, further localizes it to the affected side (Fig. 6.5) [2, 32].

Fig. 6.5 Single-leg extension helps to localize pain to the side of the spondylolysis when standing on the ipsilateral leg

Radicular signs are less common in the younger athlete but may accompany injuries to the pars [9]. Strength, sensation, and reflexes of the lower extremities must be evaluated. Abnormal findings may be detected in the setting of nerve root irritation associated with spondylolysis or, more frequently, with spondylolisthesis. Neural tension signs may also be present [9].

Focal tenderness over the site of the bony lesion is usually present. Overlying paraspinal muscle spasm may make localization of tenderness more difficult; however, the point of maximal tenderness usually corresponds with the level and side of the spondylolytic lesion. A step-off at the lumbosacral junction may be palpable in the presence of a slip [9, 35].

Investigations

Lumbar pain that has been present in the young athlete for at least 3 weeks warrants further investigations [4]. Imaging with plain radiographs is the initial step in investigating a possible spondylolysis [21]. X-rays, including anteroposterior (AP), lateral (± coned lateral), and oblique views, are often recommended. The AP view most commonly identifies other anatomic variants or developmental defects that may be associated with greater incidence of spondylolysis. Spina bifida occulta (Fig. 6.6), although clinically insignificant in isolation, is seen more frequently in patients with spondylolysis [2, 42]. Transitional vertebrae (sacralization of L5 or lumbarization of S1) may also be seen in spondylolysis [2]. The lateral view may demonstrate a lytic lesion or spondylolisthesis (Fig. 6.6) [21]. Coned lateral X-ray at the level of the suspected spondylolysis will identify some lesions missed on regular lateral view [35, 53]. Oblique views are used to demonstrate the pars interarticularis (Fig. 6.6). While traditionally included in the evaluation of spondylolysis, some authors [5, 54] discourage the use of oblique views, which demonstrate spondylolysis in only 1/3 of cases due to the orientation of the X-ray beam to the lesion [55]. In a 2013 study by Beck et al. [54], there was no additional diagnostic value with the addition of two oblique views to AP and lateral radiographs, but ionizing radiation effective dose was increased by 75% [54].

Recent developments in digital X-ray detectors have brought digital tomosynthesis (DTS or VolumeRAD™) into the evaluation of lumbar spine pathology [56]. Images are acquired as an X-ray tube moves through a limited angle sweep with a stationary detector behind the patient [56]. In a recent study of DTS in the evaluation of ankylosing spondylitis, the mean radiation dose for exams of the lumbar spine was 35.8 mGy [57]. This approximates the radiation dose for a conventional series of AP (15 mGy) and lateral (27 mGy) digital radiographs (DR) of the lumbar spine [58]. The authors of the study found that DTS detected more subtle spinal damage, including facet joints, than conventional radiographs [57]. A study comparing DTS and DR for pediatric spinal imaging concluded that digital tomosynthesis visualized most critical structures as well or better than conventional radiographs and in some cases may obviate the need for a higher radiation dose CT scan [59]. At the Children's Hospital in Winnipeg, Canada, digital tomosynthesis is the first-line imaging modality in the evaluation of spondylolysis. This is due to the sensitivity of DTS in conjunction with low radiation doses similar to or only slightly larger than conventional radiograph series of the lumbar spine (Reed M, unpublished data). It is the author's experience that DTS is more sensitive than conventional radiographs with oblique views at detecting defects of the pars interarticularis (Fig. 6.7).

Following conventional radiographs or digital tomosynthesis, a single-photon emission computed tomography (SPECT) bone scan helps to identify bony lesions in which active bone turnover is occurring [50]. A simple planar bone scan may fail to identify an active spondylolytic lesion. SPECT images are superior to planar bone scan in the investigation of spondylolysis. SPECT images are superior to planar bone scan in the investigation of spondylolysis. (Fig. 6.8) [60].

McCormack and Athwal [61] described a "spondylolysis mimic" which is a vertebral articular facet fracture in a young gymnast. The clinical presentation was identical to that of spondylolysis. Although planar bone scan was normal, SPECT

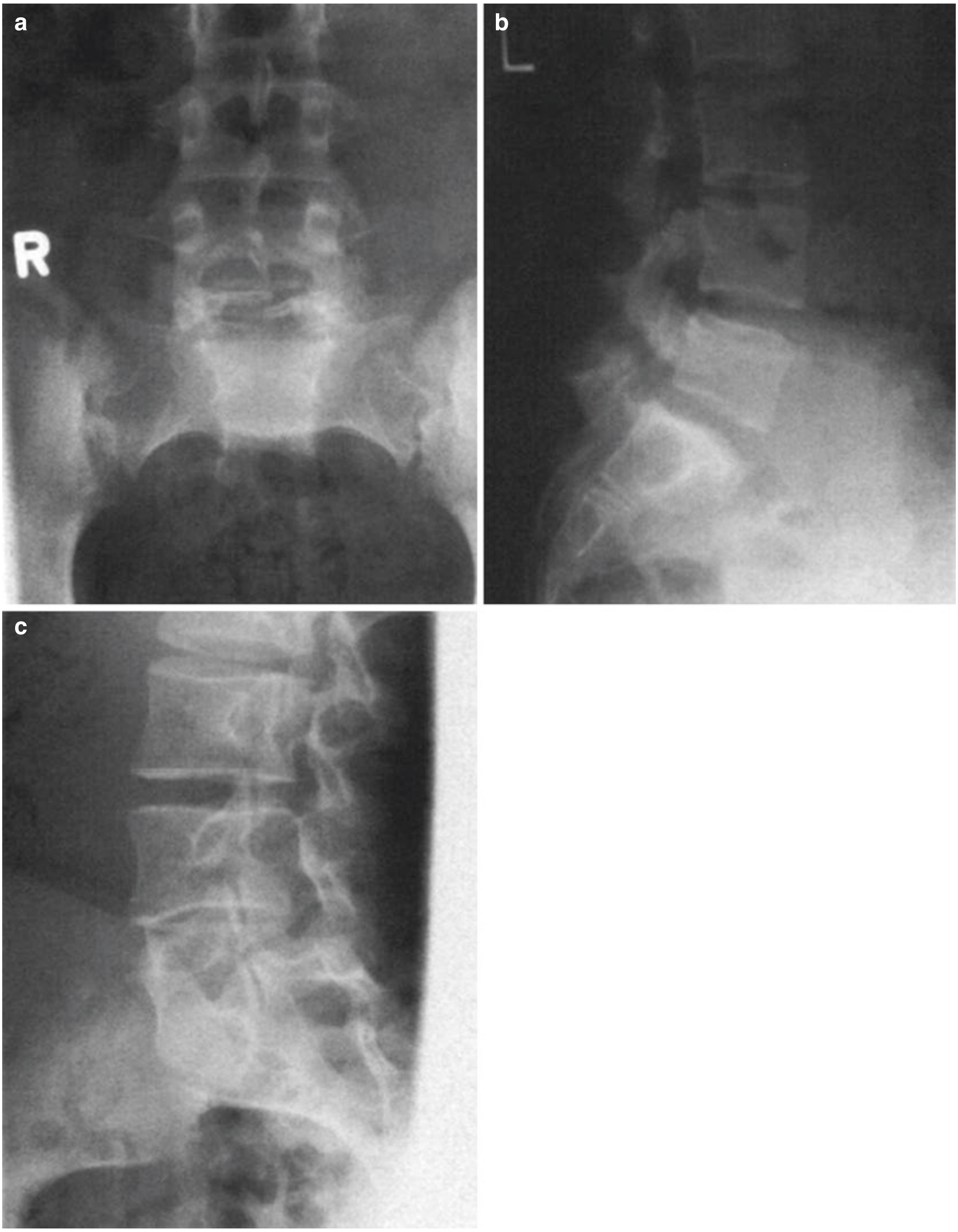

Fig. 6.6 Plain radiographs in spondylolysis. (**a**) Spina bifida occulta noted on anteroposterior view. (**b**) Lateral radiograph shows pars defect and associated grade 1 spondylolisthesis. (**c**) Oblique radiograph demonstrates spondylolysis

images revealed abnormal uptake in the posterior elements of the spine. Only on CT scan were the authors able to determine that the pathology was localized to the facet, rather than the pars interarticularis. With SPECT-CT, better anatomic localization may obviate the need for further imaging

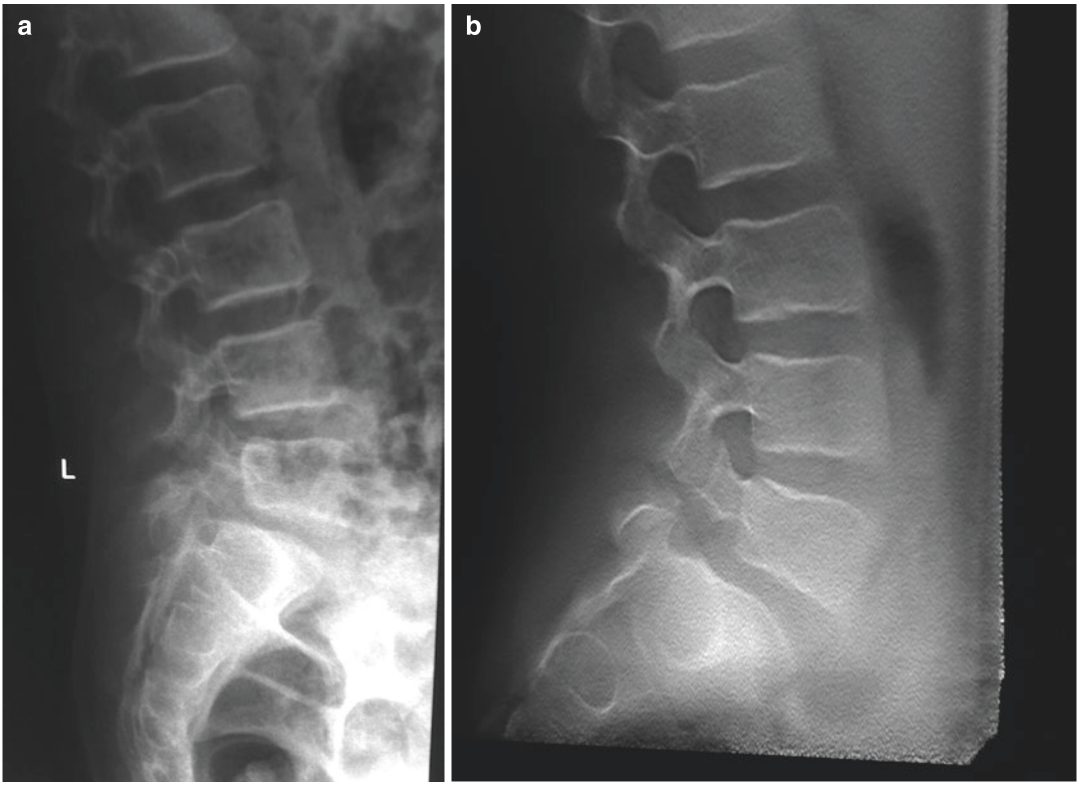

Fig. 6.7 (**a**) Plain lateral radiograph of the spine reveals grade 1 spondylolisthesis, but the pars lesions are not visualized. (**b**) Digital tomosynthesis of the same athlete reveals a clear lysis of the L5 pars interarticularis

Some clinicians elect to perform CT scans on all patients with abnormal uptake on SPECT scan [37]. CT is very sensitive in identifying true stress fractures of the pars interarticularis but may fail to identify very early lesions, which are considered "stress reactions." Some sclerosis may be identified in this circumstance; however, CT may be entirely normal [37]. Because of the additional radiation involved in CT scanning, the author's practice is to subject only those patients who are not responding to treatment to CT scanning. In this setting, the CT scan is used to identify the persistence of a lytic defect and to gather additional information regarding further healing potential. It is important to note that recent advances in CT technology that have significantly reduced the effective radiation dose delivered in lumbar spine studies may make CT more acceptable as an early imaging modality in spondylolysis. Spondylolytic lesions with sclerotic, well-corticated margins (inactive lesions) are unlikely to progress to further bony union; however, some experts have found external electrical stimulation to be of benefit in this situation [62–64]. MRI, because of the lack of ionizing radiation involved, is a desirable investigation for young athletes. Using CT as the "gold standard," MRI has 92% sensitivity in identifying pars lesions [65]. MRI has the advantage of being able to detect early stress reactions not seen on CT scans [65, 66]. The main limitation of MRI in the diagnosis of spondylolysis is in the detection of fractures in the upper lumbar levels and in the setting of incomplete fractures with marked surrounding sclerosis (inactive) [66].

Management

For the young athlete with low back pain caused by a metabolically active spondylolysis, initial management is activity modification. Any activities that provoke pain must be avoided. These activities may include running, jumping, exten-

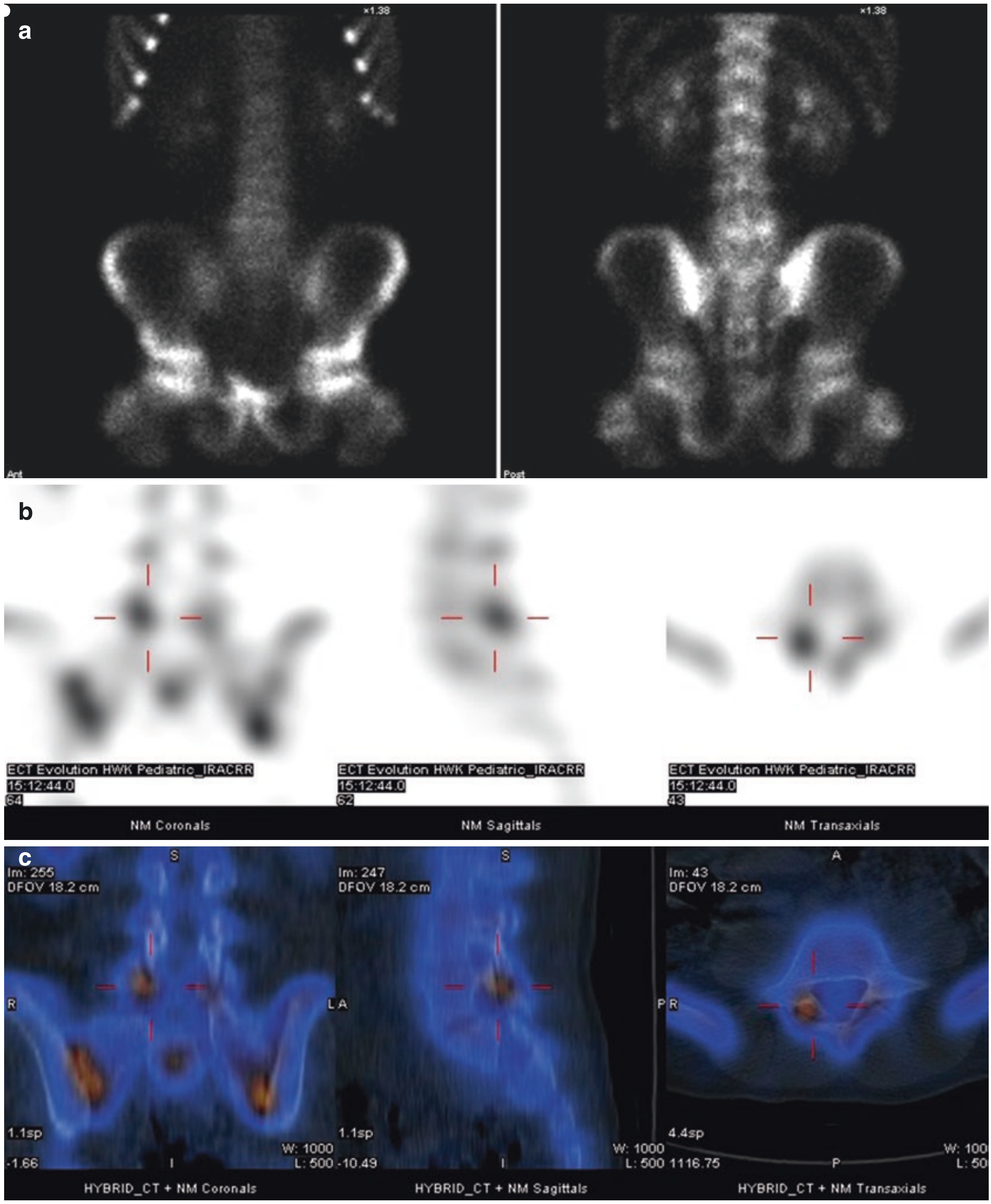

Fig. 6.8 Technetium-99 bone scan in spondylolysis. (**a**) Planar images are less sensitive than SPECT and may miss abnormalities of the pars interarticularis. (**b**, **c**) SPECT and combined SPECT-CT images clearly reveal abnormal uptake in posterior elements

sion, torsion of the spine, and body contact. A program of daily home exercises should begin immediately. This program should include strengthening of the abdominal muscles and hip flexors, hamstring stretches, and antilordotic exercises for the lumbar spine [38]. Physiotherapy may be necessary to ensure exercises are performed correctly. Improper techniques, such as increasing lumbar lordosis to increase turnout in ballet, must be corrected as well.

The use of bracing incites debate among specialists, because no prospective, randomized controlled trials have directly compared bracing versus non-bracing in spondylolysis. Some authors recommend early use of custom thoracolumbar orthoses to protect the injured spine by limiting extension and rotation [5, 50, 67]. Anderson [68] studied the intensity of uptake on SPECT scan and timing of brace use in spondylolysis with respect to symptom resolution and concluded that earlier implementation of bracing in the more active stage of spondylolysis (greater intensity of uptake) is associated with better resolution of symptoms [68]. Others feel that spondylolysis can be treated successfully with simple activity restriction in conjunction with physiotherapy, without mandatory rigid bracing [69] or with bracing being reserved for those not responding to activity restriction alone [70]. A large, prospective randomized controlled trial of bracing versus non-bracing in the treatment of spondylolysis would help settle this controversy definitively.

d'Hemecourt et al. found that 80% of young athletes treated with a rigid thoracolumbosacral orthosis (TLSO) and structured physiotherapy program were able to return to full sports participation without a brace and with no, or only occasional, pain associated with vigorous activity [38]. Kurd [67] found an even higher rate of return to sport, concluding that all patients in their series of 486 youth with spondylolysis were able to return to their pre-injury level of physical activity following TLSO, rest, and physiotherapy for 3 months. Sakai [71] found that 100% of very early-stage spondylolysis (stress reaction without visible fracture line on CT) demonstrated bony healing with an average of 2.5 months of conservative treatment including rest and TLSO brace. In early-stage spondylolysis (hairline fracture visible on CT), rest and bracing resulted in bony healing in 94% of patients over an average of 2.6 months. Bony healing was less likely (80%) in the progressive lesions (gap seen at fracture site) and took slightly longer (3.6 months). None of the terminal-stage lesions healed with conservative management [71]. The brace, typically at 0° of lordosis, helps prevent spine extension and torsion. Although evidence suggests that such bracing may not actually immobilize the lumbosacral junction [72], the brace does serve to limit extension and rotation, which are movements that can exacerbate the condition. Athletes are permitted to return to training in the brace as soon as pain subsides. The brace prevents the athlete from performing techniques with spine extension, such as "laybacks" in figure skating or "walkovers" in gymnastics, or minimizes the degree of extension in dance techniques such as arabesques. Only pain-free activities in the brace are permitted.

External electrical stimulation is a promising treatment modality in the setting of non-united inactive spondylolysis. In a small series of only two patients, one group of investigators [63] found that application of an external electrical stimulator during sleep allowed for bony union of spondylolytic lesions that were previously unhealed by a full course of bracing and activity modification. Vrable [64] published a case of a 15-year-old male gymnast who achieved complete union of chronic bilateral spondylolytic lesions, inactive on bone scan, following implementation of external pulsed electromagnetic field (PEMF) bone stimulator. In addition to the PEMF, bracing and physiotherapy were incorporated into treatment. Complete healing was attained within 12 weeks of treatment. In an unpublished study by d'Hemecourt in 2010 [73], 56 patients with spondylolysis were treated with antilordotic bracing at 0°. Thirty of these subjects also used electrical stimulation. Half of those in the brace-only group achieved bony healing, compared with two-thirds of those in the brace plus electrical stimulation group [73]. Low-intensity pulsed ultrasound appears to improve rate of bony healing in progressive-stage spondylolysis [74]. Although bone stimulation is not approved for use in chronic non-union spondylolysis, the safety profile from approved use of PEMF following lumbar fusion surgeries suggests no significant risks to this treatment modality [64]. Further research is necessary in this area before electrical stimulation can be recommended on a more routine basis for recalcitrant spondylolytic lesions.

A combination of clinical assessment and various imaging modalities has been used to determine the point at which healing of spondylolysis has occurred. Radiographic healing appears to be less important than clinical resolution of symptoms with return to previous level of physical activity [67]. One recent study found no correlation between radiographic healing at initial management and pain ratings or return to sport at a mean of 8 years follow-up [39]. Bone scans remain positive for some time, even after healing has occurred. CT may help determine the stage of healing [1, 21]; however, it is the author's preference to base healing on clinical parameters, reserving the additional ionizing radiation of CT scan for those in whom clinical resolution is delayed. MRI may also prove to be useful in the future, but at this point, the best indicator of healing is clinical assessment. A patient who has resumed full activities out of any brace used in treatment and without recurrence of pain should be considered clinically healed. Patients with spondylolisthesis should be monitored until skeletal maturity to ensure no further slip occurs. Coned standing lateral X-rays every 3–4 months during rapid growth will detect any progression of the condition. All patients who experience a recurrence of pain after treatment has concluded should be reevaluated immediately to assess the status of the spondylolysis or spondylolisthesis.

Cauda Equina Syndrome

One potential complication of spondylolisthesis is cauda equina syndrome, a compression of nerve roots below L1 [75]. Other conditions, such as dislocations of the spine or large posterocentral intervertebral disc herniations, may also lead to cauda equina syndrome [75]. This syndrome is characterized by lower motor neuron deficits with variable sensorimotor, reflex, bladder, bowel, and sexual dysfunction [75]. Symptoms suggestive of cauda equina syndrome, such as "saddle anesthesia" with bowel or bladder dysfunction, necessitate immediate surgical intervention [21].

Posterior Element Overuse Syndrome

Once spondylolysis has been ruled out, the diagnosis of posterior element overuse syndrome should be considered. This is not, in fact, a single clinical entity but represents injury to one or more of the following posterior elements of the spine: muscle–tendon units, ligaments, joint capsules, and facet joints [2]. The inferior articular facets of one vertebra articulate with the superior articular facets of the next caudal segment to form the facet joints, which are also known as apophyseal joints. Posterior element overuse syndrome is also referred to by other names, including hyperlordotic back pain, mechanical low back pain, and lumbar facet syndrome [1, 2, 11].

Risk factors for posterior element overuse syndrome include weak abdominal muscles, lumbar hyperlordosis, tight hamstrings, tight thoracolumbar fascia, limited lumbar motion, and training errors [2, 11].

Presentation and Clinical Examination

Young athletes with this condition present with symptoms and signs similar to those of spondylolysis. They complain primarily of pain on extension or rotation of the spine. Common physical findings include pain on rising from flexion [76] and pain on provocative hyperextension. Paraspinal muscle tenderness may be present [2, 76]. Nerve root signs are not typical features of posterior element overuse syndrome. Focal tenderness is present over the lower lumbar spine, adjacent to the midline. Facet joint injection with anesthetic can confirm that pain is originating within the facet joint [17]; however, this is seldom required in young athletes with low back pain. Transitional vertebrae, with pseudoarthrosis between the lateral spinous process and the iliac wing (Bertolotti's syndrome), may result in focal pain and tenderness, mimicking spondylolysis [17].

Management

Treatment consists of a daily home exercise program that, in more recalcitrant cases, is carried out under the supervision of a physiotherapist. Abdominal strength exercises, antilordotic exercises, and stretches of the hamstrings and thoracolumbar fascia should be included in the rehabilitation program [2]. Ice and nonsteroidal anti-inflammatories (NSAIDs) may help reduce pain and associated inflammation. Pain-free activities are permitted. This typically excludes extension and rotation of the spine. In the case of persistent pain, despite the aforementioned measures, the use of a soft lumbar support brace or an antilordotic brace may provide some relief [17].

Low Back Pain Related to Injuries of the Pelvis

Sacroiliac Joint Dysfunction

The sacroiliac, or SI, joint is a frequent site of discomfort in active individuals. Forces between the trunk and the lower extremities are transmitted across the SI joints [9, 17]. Motion within the SI joint is quite limited, but excessive or reduced motion can lead to pain in the joint [6]. Altered mechanics in the lumbar region, which result from other lumbar pathology, can apply stress to the SI joints if muscle spasm is present. Leg length discrepancies may also contribute to SI joint pain [5].

Inflammation of the SI joint occurs in various conditions: the HLA-B27 seronegative spondyloarthropathies such as juvenile ankylosing spondylitis, Crohn's disease, and psoriatic arthritis, as well as infectious causes, such as Reiter's syndrome. The differential diagnosis of SI dysfunction also includes stress fracture of the sacrum [5, 50].

Presentation and Clinical Examination

Athletes with SI joint pain present with symptoms similar to those of spondylolysis. Pain is usually exacerbated with spine extension. Symptoms may be due to a single traumatic fall onto the ischium or may be secondary to other injuries or biomechanical stresses that cause repetitive asymmetric pelvic motion [1, 11, 17]. Physical examination findings confirm pain in the lower lumbar or buttock region with extension, often localizing to the affected SI joint on single-leg extension. Poor pelvic stability may be noted on Trendelenburg testing. Weakness of the gluteus medius muscles allows the pelvis to rock side to side with ambulation, thereby placing additional stress across the SI joints. Tests for SI joint mobility may detect hyper- or hypomobility of the joint, leading to increased pain. FABER (Patrick's) test [9] and Gaenslen's test [77] may be positive (Fig. 6.2). Hopping on the affected side produces pain in the presence of a sacral stress fracture [78].

With the athlete prone, focal tenderness may be elicited over the affected SI joint. Careful distinction must be made between SI joint tenderness and tenderness of the posterior elements of the lumbar spine. Pseudoarthrosis between the lateral spinous process and the iliac wing in Bertolotti's syndrome may result in focal pain and tenderness near the superior portion of the SI joint [5]. Chronic stress to the iliolumbar ligament at the superior portion of the joint can lead to focal pain and tenderness at this site. Trendelenburg sign is typically positive on the affected side.

Investigations

If symptoms persist for more than 3 weeks, plain radiographs of the lumbar spine and pelvis may be warranted. Anatomic variants that place the SI joints under additional stress may be detected (e.g., transitional vertebrae). Abnormalities of the SI joint related to sacroiliitis associated with seronegative spondyloarthropathy include erosions, joint surface irregularities, and sclerosis. Digital tomosynthesis appears to have a higher sensitivity than conventional radiographs for detection of early bone changes around the SI joint in ankylosing spondylitis [79].

Technetium-99 bone scan will detect the rarer stress fractures of the sacrum [50, 78] and may detect abnormal uptake associated with sacroiliitis. Some caution should be exercised in interpreting the results because the SI joints may have some degree of increased uptake in the skeletally immature individual. Bone scan should be able to differentiate between Bertolotti's syndrome and spondylolysis [5].

MRI may be useful in distinguishing between SI joint dysfunction/inflammation and sacral stress fractures by more precisely defining the anatomic location of the abnormality. It has the added ability over bone scan to rule out bone or soft tissue tumors and lacks ionizing radiation [78]. In a series of 21 runners with sacral stress fractures, 15 subjects underwent MRI, all of whom had abnormalities at the site of the fracture (9 were full stress fractures, 6 showed marrow edema only) [78].

In the appropriate setting, blood work may be warranted to screen for sacroiliitis resulting from one of the seronegative spondyloarthropathies. Erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP) will be elevated, whereas rheumatoid factor (RF) and antinuclear antibodies (ANA) will be negative. HLA-B27 may be positive due to frequent association of this histocompatibility antigen with the seronegative spondyloarthropathies [80].

Management

Treatment of SI joint dysfunction involves ice, NSAIDs, bracing, activity modification, and physiotherapy. Physiotherapy may involve mobilizing a hypomobile SI joint [81] or stabilizing the pelvis in the setting of a hypermobile joint. Pelvic stabilization is essential, particularly if weakness of the gluteus medius is present. Hip girdle and lower abdominal strengthening exercises may attenuate forces transmitted to the affected area while improving running mechanics [78].

Ice and NSAIDs will help reduce pain and any associated inflammation present in the region. Bracing of the SI joints will assist with stabilization of the joints temporarily and may reduce stress across the joints. Activities should be limited to those that do not provoke pain. Treatment may take a few weeks to a few months until the athlete becomes asymptomatic. Leg length discrepancies should be corrected, to reduce abnormal stresses across the SI joints [17]. For sacral stress fracture, some authors suggest a period of non-weight bearing until ambulation is pain-free (1–2 weeks), followed by nonimpact activities for 6 weeks [78], whereas others recommend a period of partial weightbearing for 4–6 weeks [5]. In Fredericson's series, all 21 athletes with sacral stress fractures began a return-to-running protocol within 8–12 weeks of diagnosis and returned to full pre-injury training levels by 3–6 months [78].

Iliac Crest Apophysitis

Growth cartilage is present along the crest of the ilium in the skeletally immature athlete. Low back pain in the adolescent may be caused by traction of the gluteus medius, tensor fascia lata, lumbar paraspinals, the iliac portion of the iliopsoas muscles, and oblique abdominal muscles on the iliac crest apophysis [82]. Pain may be localized to one area of the iliac crest or may be more diffuse. Resisted contraction of the abdominal oblique muscles on the affected side will reproduce pain when symptoms extend laterally and anteriorly along the iliac crest. Treatment of this condition involves application of ice for pain relief and reduction of associated inflammation. Athletes should avoid activities that provoke pain, with particular attention to running and impact activities [82]. Exercises to stretch and strengthen the core trunk muscles will help prevent recurrence of symptoms. Once symptoms have settled and strength and flexibility deficits have been addressed, the young athlete may slowly return to pre-injury levels of activity [82].

Injuries of the Anterior Elements of the Spine

Lumbar (Atypical) Scheuermann's

Scheuermann's disease, first described in 1920 [83], refers to a thoracic kyphosis in which three or more consecutive vertebral segments are wedged 5° or more anteriorly [9]. Other radiographic findings include Schmorl's nodes, which are caused by herniation of the intervertebral disc through the vertebral end plates (Fig. 6.1) and irregularity of the vertebral end plates [2, 9].

In sports involving rapid flexion, such as gymnastics, weight lifting, American football, rowing, and diving, injuries of the vertebral end plates may occur in the region of the thoracolumbar junction [1, 2, 11, 18]. In contrast to classic Scheuermann's disease, lumbar or "atypical" Scheuermann's is associated with a flat back [2, 22]. Although there is no associated anterior wedging of the vertebral bodies, atypical Scheuermann's has other features in common with the classic form: end plate irregularities, Schmorl's nodes (Fig. 6.9), and vertebral apophyseal avulsions [5], as well as disc space narrowing [84].

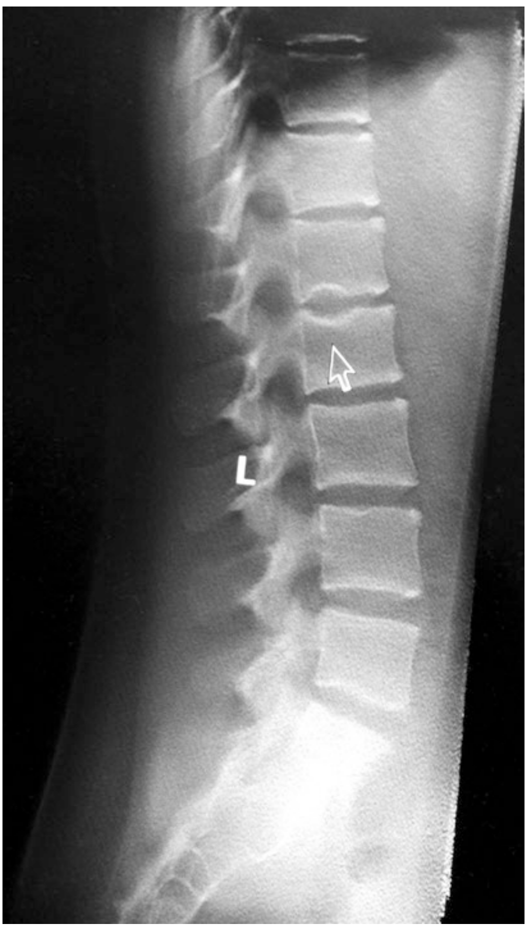

Fig. 6.9 Schmorl's node and loss of lumbar lordosis in atypical or lumbar Scheuermann's

Presentation

Athletes presenting with lumbar Scheuermann's tend to have mid-back pain that is exacerbated primarily by flexion of the spine and relieved by rest [2, 18, 85]. Pain is usually insidious in onset and affects athletes in sports requiring repetitive flexion and extension of the spine. Neurologic symptoms are not a typical feature of this condition.

Clinical Examination

On examination, young athletes with lumbar Scheuermann's demonstrate a reduced lumbar lordosis and thoracic kyphosis ("flat back") [2, 9, 22], mid-back tenderness [85], tightness of thoracolumbar fascia and hamstrings, and pain on forward flexion of the spine [2, 11]. Diagnosis of atypical Scheuermann's is based on the clinical findings described above and is confirmed on plain lateral radiographs.

Management

Once the diagnosis is made, the young athlete should begin an extension-based rehabilitation program to improve spinal stabilization, increase abdominal strength, and address tight hamstrings and thoracolumbar fascia [2, 9, 17, 22]. Bracing at 15–30° of lordosis unloads the affected vertebral elements to reduce pain [2]. This may facilitate return to play, sometimes within 1–2 months, as long as the athlete remains pain-free [17, 22, 86]. Braces may be worn either full time [2] or during the day [86] until pain subsides. In higher-risk sports such as gymnastics, gradual return to training may take 3–6 months following initiation of treatment [2]. Pain-free cross-training helps maintain overall conditioning to facilitate return to full training once symptoms abate [86].

Vertebral Body Apophyseal Avulsion Fracture ("Slipped Vertebral Apophysis")

Injury to the ring apophysis, also known as slipped vertebral apophysis, may occur as a result of rapid flexion, extension, and torsion of the spine [2]. Slipped vertebral apophysis occurs in skeletally immature youth before the ring apophysis has fused with the vertebral body [9, 19]. This fusion usually occurs by 18 years [11]. Compression or traction forces can result in avulsion of the ring apophysis from the vertebral body through this area of weakness in the immature spine [9]. The fractured cartilaginous apophyseal ring may displace posteriorly into the spinal canal, along with a portion of the intervertebral disc [9, 11]. Lower lumbosacral intervertebral levels are most commonly affected, and apophyseal avulsions are usually associated with a central disc herniation [11].

Presentation

Avulsion occurs most frequently in sports that require repetitive lumbar flexion, such as wrestling, gymnastics, weight lifting, and volleyball [9, 11]. Apophyseal avulsion fracture may present with features similar to a disc herniation (e.g., pain with coughing, sneezing, spinal flexion) [9, 11], although numbness and paraesthesias are usually absent [11].

Clinical Evaluation

Physical findings in an athlete with an apophyseal avulsion fracture are similar to those seen in disc herniation [11]. There is limited lumbar flexion and extension. Paraspinal muscle spasm and tenderness is often present [9, 11]. Straight leg testing and nerve tension signs may be positive [9, 19], but neurologic exam is typically normal [11].

Investigations

Lateral radiographs may reveal an ossified fragment in the canal [11]. Additional tests include CT and MRI. CT will better identify the fractured apophysis and its adjacent piece of bone, which may be missed on MRI [9, 11, 19].

Management

Initial management includes activity modification and nonsteroidal anti-inflammatories (NSAIDs) [9]. Bracing may also be helpful for certain patients [2, 11]. Return to sport is permitted when normal flexibility and strength have been regained [2]. In the presence of significant neural compression, surgical excision of bony fragments from the spinal canal may be required [9, 11].

Disc Herniation

Lumbar disc herniation is uncommon among adolescents in general; however, young athletes are more likely to present with this condition [73]. The intervertebral disc is subject to compressive, rotational, and shear forces [3] such as those seen in football, basketball, soccer, running, gymnastics, ice hockey, tennis, and weight lifting [11]. In the adult, a common cause of low back pain is tearing of the anulus fibrosus as the nucleus pulposus herniates posterolaterally through the weakest point of the annulus [11]. The intervertebral discs in the young active individual are well hydrated, in contrast to the discs of adults. Whereas adults typically develop herniation of the nucleus pulposus through the anulus in response to applied forces, children are more likely to herniate through the softer cartilaginous end plates [85] that are firmly affixed to the disc and into the underlying cancellous bone. This produces the typical "Schmorl's nodes" seen in classic and atypical Scheuermann's disease. In children, herniation of the disc into cancellous bone beneath the ring apophysis may also occur, resulting in a limbus vertebra [87].

Disc herniations similar to those seen in the adult population do occur in young athletes, but these make up a much smaller proportion of all low back pain in children and adolescents [9]. Disc herniations are more commonly encountered in adolescents than in children [11]. Sports that involve repetitive flexion with axial loading or repetitive rotational motions may predispose the athlete to disc herniation [9].

Presentation

Athletes with disc herniation present with low back, buttock, hip, or hamstring pain. Pain is exacerbated by forward flexion of the spine and often aggravated by cough or sneeze, which increases the intradiscal pressure [1, 3, 9, 11]. If the disc herniation impinges upon an adjacent nerve root, sciatic symptoms may be present. In this situation, pain will radiate from the lumbar region into the ipsilateral buttock and possibly the posterior thigh region. In young athletes, symptoms are more likely to be restricted to the hip and buttock compared with adults who more frequently experience sciatic symptoms radiating down the leg [2, 11]. Although frank neurologic deficits are thought to be rare in younger patients, there may be associated weakness or numbness in the lower extremity of the affected side [9]. Among youths with lumbar disc herniation severe enough to require surgery, Sarma et al. [88] found that 57% had motor deficit at time of presentation and 71% had sensory disturbances. Loss of bowel or bladder control or saddle anesthesia should prompt further evaluation for cauda equina syndrome [9, 11].

Fig. 6.10 Slump test: one knee is extended and the neck is flexed, reproducing lumbar pain with radiation into the extended leg if nerve root impingement is present

Clinical Examination

Clinical findings of disc herniation include limited trunk flexion caused by pain that may radiate down the affected leg, weakness of specific muscle groups in myotomal distribution, and numbness in the involved dermatome; however, altered reflexes, muscle weakness, and atrophy are less frequent findings in the adolescent with disc herniation [2]. The affected nerve root is usually just inferior to the disc that is herniated (i.e., fifth nerve root in L4–L5 disc herniation) [11]. Slump test and straight leg raise test will reproduce symptoms (Fig. 6.10). Paravertebral muscle spasm with sciatic scoliosis and an antalgic gait may be noted [2, 11]. Asymmetry of hamstring flexibility may be noted as well [2, 11].

Investigations

Investigations should include plain radiographs of the lumbosacral spine. Although the degenerative changes and disc space narrowing associated with disc disease in adults are not typical features in young patients, other osseous abnormalities are more commonly encountered [9, 11]. Avulsion fracture of the ring apophysis may be seen in young athletes with radicular symptoms [2, 9]. Plain radiographs or digital tomosynthesis assist in differentiating between the clinical picture of disc herniation with nerve root impingement and spondylolisthesis with nerve root impingement. Because treatment of these two conditions is very different, this is an important distinction to make. Noninvasive tests can help determine the nature and extent of the injury. CT scans can differentiate between herniated discs and slipped vertebral apophyses, while MRI can determine if neurocompressive lesions in the canal are present [2, 9, 11]. Some authors advocate MRI after 6 weeks if disc herniation is suspected, but patient is not responding to conservative measures [14]. White blood cell count, sedimentation rate, and bone scan should be considered in the presence of severe pain and systemic symptoms to rule out disc space infection [2].

Management

Treatment of disc herniation necessitates rest from vigorous physical activity, with a particular caution against spine flexion, twisting, and high-impact and heavy lifting [1]. Proper back mechanics for lifting must be reviewed with the patient. Ice and NSAIDs can help reduce pain and inflammation [1, 9, 11]. Physiotherapy in the acute stage is aimed at reducing pain, inflammation, and secondary muscle spasm. Modalities and lumbar traction may be of benefit. Symptoms usually improve within a few weeks. Once acute symptoms have abated, exercises may be added to the regimen. Hamstring stretches and core strength and stability are essential elements of treatment [1]. Abdominal muscle and paravertebral muscle strength exercises help maintain a neutral spine [11]. Strong trunk musculature appears to be associated with reduced stress on the discs during lifting [89]. Although immobilization with bracing is discouraged in the adult population, a rigid polypropylene thoracolumbar orthosis at 15° of lordosis may help unload the affected disc and reduce associated muscle spasm in young athletes who are not responding to other conservative measures [2, 9, 11, 85]. This often facilitates an earlier return to light training [2]; however, return to vigorous sports training should be delayed for 6–12 months following diagnosis [11]. Epidural corticosteroids may be used to reduce inflammation around the disc in those athletes who have ongoing restrictions due to pain [1, 9, 85]. This treatment may be considered after approximately 6 weeks if symptoms persist [90].

As in the adult population with discogenic back pain, clinical signs and symptoms of impending cauda equina syndrome, such as saddle anesthesia, bowel or bladder dysfunction, or severe or progressive motor loss, necessitate emergent referral for surgical intervention [11, 85].

Other Causes of Low Back Pain

Low back pain in the young athlete is not always caused by injury. Inflammation, infection, and neoplasm can present with low back pain. Visceral disorders can also present with pain in this region [11]. "Red flags" such as fever, weight loss, night pain, and malaise in a patient with low back pain should lead the clinician to rule out more sinister causes for the symptoms [1, 2, 11]. Morning stiffness associated with sacroiliac pain should prompt consideration of juvenile ankylosing spondylitis [1, 2, 11].

Seronegative Spondyloarthropathies

The seronegative spondyloarthropathies are a group of inflammatory conditions that may affect the spine and SI joints. "Seronegative" refers to the absence of rheumatoid factor. HLA-B27 is often positive in these conditions [80]. The seronegative spondyloarthropathies encountered in young patients include juvenile ankylosing spondylitis, psoriatic arthritis, and enteropathic arthritis. Reiter's syndrome, which is a reactive arthritis, falls within this category as well.

Presentation

Affected individuals present with low back pain and morning stiffness that lasts more than 45–60 min [2, 17]. Pain is often localized to the SI joints. There may be a history of pain at the insertion points of tendons (entheses). Other systemic conditions may be present on history, such as psoriasis or inflammatory bowel disease. A family history of psoriasis, inflammatory bowel disease, or ankylosing spondylitis may also be present.

Clinical Examination

Physical examination features include tenderness over the SI joints, positive SI joint stress tests (FABER test and Gaenslen's test), and pain on extension of the spine. A modified Schober's test assesses decreased lumbar mobility. This test is performed by placing a measuring tape against the lumbar spine. The 10 cm mark is placed at the level of the posterior superior iliac spine (PSIS), with marks made on the skin 10 cm above and 5 cm below the initial mark. The patient is asked to flex the spine. In a normal spine, there should be at least a 5 cm increase between the top and bottom skin marks with flexion. Skin should be examined for evidence of psoriasis. Patients with SI joint pain should be examined for tenderness caused by inflammation of the Achilles tendon, patellar tendon, and plantar fascia insertions to bone (enthesitis). In individuals with seronegative spondyloarthropathy, pain at these sites previously may have been attributed to apophysitis, such as Sever's apophysitis or Osgood–Schlatter apophysitis. Apophysitis is an overuse injury that affects the growth cartilage at the insertion of tendons in skeletally immature individuals. Chronic effects of persistent enthesitis include bone edema and overgrowth, formation of enthesophytes, bone bridging, subcortical bone cysts, and erosions at tendon insertions [23].

Investigations

Laboratory investigations should include CBC, ESR, and CRP. Rheumatoid factor is absent. Over 90% of patients with ankylosing spondylitis are positive for HLA-B27 [80]; however, because this test is expensive and quite time-consuming, it should not be used as a screening test for all patients who present with SI joint pain.

Plain radiographs may be normal or may show abnormalities of the SI joints. Erosions, joint surface irregularities, and sclerosis may be detected. More recently, digital tomosynthesis has been used to identify more subtle joint damage in ankylosing spondylitis, particularly within the lumbar facet joints [57]. Bone scan will typically reveal increased radionuclide uptake within the affected SI joints. Enthesitis and apophysitis may be clinically difficult to differentiate; therefore, additional imaging, such as ultrasound or MRI, may be of diagnostic benefit [23].

Management

In most cases, children or adolescents with suspected juvenile ankylosing spondylitis should be referred to a pediatric rheumatologist for ongoing management. Other referrals that may be appropriate include ophthalmology, to assess for uveitis, and gastroenterology, if there is suspicion of inflammatory bowel disease.

Discitis

Low back pain associated with systemic symptoms, particularly fever, in a young athlete should prompt consideration of discitis or tumor [2, 11]. There may be a history of ear infection or upper respiratory tract infection several days before onset of back symptoms [11]. Discitis, or inflammation of the intervertebral disc, may present with low back pain that is exacerbated on forward flexion of the spine. Pain does not typically settle with conventional measures such as rest, ice, NSAIDs, or stretching [1]. Discitis is most commonly encountered in children younger than 8 years old [91], although a bimodal distribution of incidence peaks between 6 months and 4 years and again between 10 and 14 years of age [92]. Young children may refuse to bear weight [11, 93]. Although severe back pain, high fever, and signs of bacteremia may accompany discitis, the typical presentation is much less dramatic, particularly in younger children [92, 94]. Back ache, stiffness, and low-grade fever are commonly encountered at this age [94]. Physical exam frequently reveals paravertebral muscle spasm, stiffness in spinal movements with decreased range of motion, pain on flexion of the spine, and less commonly straight leg raise signs [11].

Investigations

In the presence of symptoms or signs suggestive of discitis, laboratory and imaging investigations should be obtained. Plain radiographs may demonstrate disc space narrowing with sclerosis or erosions of the adjacent vertebral end plates [90, 92–94]; however, these findings are often absent for the first 2–4 weeks after onset of symptoms [90–92, 94, 95]. Bone scan and contrast-enhanced MRI can detect the presence of discitis early in the course of the disease [90, 95], often within 1–2 days of onset of symptoms [92]. ESR and CRP are generally elevated, whereas white blood cell counts may be normal or only mildly elevated [90–92, 95].

Management

Although *Staphylococcus aureus* is the most commonly encountered organism in discitis [91, 93], both blood cultures and disc space needle aspiration often yield negative cultures [92]; therefore, empiric treatment for *S. aureus* is often initiated after blood cultures alone [11, 91]. Bracing and/or bed rest can help reduce pain [11, 92, 96], and most young athletes may resume exercise in 4–6 weeks if they are asymptomatic [11].

Vertebral Osteomyelitis

Hematogenous spread of bacteria to the vertebral body can lead to osteomyelitis of the spine. Infection may also spread directly from discitis [93]. Transdiscal spread may result in involvement of two adjacent vertebral bodies [92]. The mean age of presentation of vertebral body osteomyelitis is 7.5 years [97]. The clinical presentation is similar to that of discitis in children; however, fever may be more significant.

Investigations

Imaging with plain radiographs may show rapid loss of disc height and adjacent lysis of bone [92]. Bone scan demonstrates increased uptake within the affected vertebra. MRI and CT have also been used to detect vertebral osteomyelitis [92]. The positive predictive value of MRI is comparable to that of bone scan in the acute setting; however, MRI has the advantage of clearly distinguishing between discitis and vertebral osteomyelitis [98].

Management

As in discitis, *S. Aureus* is the most common infectious agent implicated in vertebral osteomyelitis. Treatment with antibiotics should continue for at least 4–6 weeks [93], until ESR has normalized [99, 100].

Spinal Neoplasms

Although an infrequent cause of low back pain in children and adolescents, tumor should be considered in the differential diagnosis [1, 99], particularly when “red flag” symptoms are present. Intractable back pain, pain at night, fever, malaise, and weight loss should prompt the clinician to look for more sinister causes of low back pain, including benign and malignant tumors [1, 3, 90, 96].

Benign lesions that may affect the spine include osteoid osteoma, osteoblastoma, eosinophilic granuloma, and aneurysmal bone cyst [90, 96]. Osteoid osteoma and osteoblastoma typically present with night pain that is alleviated by aspirin or NSAIDs [96]. Primary malignancies such as osteogenic sarcoma and Ewing’s sarcoma can present with lesions in the spine [90]. Metastatic lesions seen most frequently in the spine include neuroblastoma and rhabdomyosarcoma [101]. Other metastatic lesions such as lymphoma, leukemia, and Wilms’ tumor, may present with low back pain [96].

Investigations

Screening laboratory investigations, including CBC, ESR, and urinalysis, should be considered where there is clinical suspicion of tumor as a cause of low back pain in the young athlete [102]. Radiographic findings that suggest a malignant process include thinning and destruction of pedicles, vertebral body collapse, and expansile lesions with a soft tissue mass [103]. Bone scan will detect bony abnormalities, including those caused by osteoid osteoma and other neoplasms [11, 96, 103]. Further imaging with CT scan or MRI will better identify and localize the lesion. Referral to oncology for further work-up and management is necessary.

Scoliosis

Idiopathic scoliosis does not typically cause back pain in the young athlete. In patients presenting with painful, rapidly progressing scoliosis, other conditions must be sought, including benign and malignant tumors, disc herniation, spondylolisthesis, and infection [1]. In one study of adolescents with lumbar disc disease, 29% were found to have scoliosis [88]. Individuals in whom scoliosis is reversed (i.e., convex right in the lumbar region or convex left in the thoracic region) should be more closely evaluated for other causes for the curvature. Such conditions include muscle spasm caused by underlying lumbar injury or spinal neoplasms [102].

Prevention

The key to prevention of overuse injuries of the lumbar spine is the recognition of risk factors. These risk factors may be identified during preparticipation evaluations. A child who experiences a rapid growth spurt may be more vulnerable to certain conditions of the lumbar spine; therefore, a decrease in training at such times may reduce the risk of injury. Although there is no set volume of training that is safe for all young athletes at all stages of development, parents and coaches should watch for increasing complaints of pain. This may suggest that the athlete's body is unable to tolerate the present levels of stress imposed by the sport.

The nature of certain sports increases the risk of lumbar spine injury in young athletes. Walkovers in gymnastics and laybacks in figure skating place a considerable stress on the posterior elements of the spine. Children involved in such sports should be advised to limit the number of repetitions of movements involving back hyperextension during practices if they begin to experience low back pain. To assist this group of athletes, a core-strengthening program may be beneficial. Athletes with lumbar hyperlordosis should begin an exercise program aimed at reducing their lordosis. This may involve posture exercises, as well as stretches for tight hip flexors. Athletes should be instructed to stretch tight hamstrings to reduce the risk of low back pain.

Proper technique may prevent some injuries of the lumbar spine. For example, young male dancers should be instructed on proper techniques for lifting their partners to prevent discogenic low back pain. Figure skaters should be instructed to extend through their entire spine, rather than "hinging" in the lower lumbar region to help prevent spondylolysis.

Finally, an important factor in prevention of lumbar spine injury is the recognition that low back pain is not simply "a part" of some sports. Low back pain is not "normal"—it most frequently indicates the presence of stress on the tissues. If this stress is not reduced and the lumbar spine is not allowed to recover, more serious overuse injuries may ensue.

Return-to-Play Guidelines

Lumbar pain in young athletes may be caused by a wide variety of etiologies, and the stresses placed on the lumbar spine vary from sport to sport. Return-to-play recommendations must take into account the specific diagnosis, the type of sport or physical activity, the age and skeletal maturity of the child, and the level of cooperation of the coaches and parents in providing modified activities for the young athlete.

In general, very few overuse injuries of the lumbar spine and sacrum require complete rest from physical activities. In most situations, young athletes may continue to participate to some degree in their chosen sports, as long as they avoid movements or activities that aggravate symptoms or continue to apply undue stress at the site of injury. For younger children who may not maintain a pain-free level of activity on their own, or for those athletes who notice pain only after cessation of their activities, more specific restrictions may be advised.

For injuries of the posterior elements, including spondylolysis, spondylolisthesis, and posterior element overuse syndrome, athletes may continue modified, pain-free sport participation. For these athletes, extension, spine torsion, and impact activities are often curtailed until symptoms subside. It is the author's practice to use bracing (custom thoracolumbar orthoses for spondylolysis/spondylolisthesis; off-the-shelf lumbar support braces for posterior element overuse syndrome) to facilitate earlier return to play. Sport participation gradually increases as healing progresses and symptoms abate. Once the athlete is at full, pain-free sport participation in the brace, with a benign clinical examination, bracing is weaned. This may be after a few weeks for posterior element overuse syndrome or a few months in the case of spondylolysis or spondylolisthesis [1, 17].

Pain originating from the sacroiliac joint and iliac crest apophyses may be managed with modified activities and progression to full training as symptoms permit; however, sacral stress fractures require an initial period of partial or non-weight bearing. These individuals can generally begin a graded running program within 8–12 weeks and return to full training by 3–6 months [78].

Symptoms will help guide return-to-play recommendations in young athletes with injuries to the anterior spinal elements. As described for posterior element injuries, bracing may assist in returning athletes to training when rest and avoidance of inciting activities are unsuccessful. Similarly, return to play for athletes with atypical Scheuermann's may be facilitated within 1–2 months by bracing if this permits pain-free training. Sports that involve more aggressive, repetitive flexion and extension of the lumbar spine (e.g., gymnastics) may require a more protracted treatment period before the athlete returns to full training [2].

After disc herniation, activities are often significantly restricted for a few weeks until the acute symptoms of pain and secondary muscle spasm have subsided. Use of a rigid polypropylene thoracolumbar orthosis at 15° of lordosis for 3 months, or until symptoms subside, may help the adolescent athlete resume daily activities and light training [2, 9, 11]. Affected athletes must have a full, pain-free range of motion with normal strength before returning to full sport participation [11]. Most patients have improved enough symptomatically by 4–6 weeks to allow return to noncontact sports [14]. Full return to sports can be anticipated within 8–12 weeks in most children or adolescents with lumbar disc herniation [14]; however, return to vigorous sports participation may be delayed for 6–12 months in some patients [11]. Those with significant pain not responding to conservative measures by 6–12 weeks should be referred for possible surgical intervention [14].

Clinical Pearls

- The young athlete who presents with lumbar symptoms should be taken very seriously, as there is a greater likelihood of associated structural pathology in younger individuals.
- "Lumbar strain" or other nonspecific conditions should only be entertained as diagnoses of exclusion.
- The etiology of low back pain in skeletally immature athletes is different from that of adults, and management of specific conditions often differs. Even the clinical presentation of the same condition and response to treatment may be dramatically different in younger athletes compared with adults.
- The sport and intensity of training responsible for development of symptoms may give clues to the underlying etiology of low back pain.
- Diagnostic imaging plays a significant role in the evaluation of lumbar spine pathology. Efforts should be made to minimize ionizing radiation, particularly in younger athletes.
- When dealing with young athletes, the physician must also consider more serious, atraumatic conditions in the differential diagnosis of low back pain. "Red flags" for such conditions include fever, weight loss, morning joint stiffness, and night pain.

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7 Thoracoabdominal Injuries

Hamish Kerr, Brady Bowen, and Deborah Light

Intrathoracic and Intra-abdominal Injuries

A soccer player sustains trauma to his abdomen in a collision with an opponent. The player is taken out of the game, only to return within 2 min feeling little ill effect. He is noted to be coughing but is able to continue. After the game, he is complaining of left upper quadrant abdominal pain. The athletic trainer relates that the player has had a recent upper respiratory tract infection.

Did the player sustain a splenic rupture because of underlying splenomegaly, caused by infectious mononucleosis, or is this an abdominal wall hematoma or muscle strain? Alternatively, could the coughing be indicative of an intrathoracic injury, such as a pneumothorax?

This scene illustrates the difficulties involved in diagnosing injuries to the chest and abdomen. Unless there is a low threshold to pursue investigation, athletes may suffer serious consequences. Injuries to the chest and abdomen are often more subtle in presentation than other injuries, such as an acute ligament rupture. Thoracoabdominal injuries are uncommon, and catastrophic events can occur if an intra-abdominal or intrathoracic injury is unrecognized. Awareness of the organs that can be injured, and how such injuries may present, is the best defense against missing potentially life-threatening thoracic and abdominal trauma [1].

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Anatomy

The thorax contains the heart, the great vessels, and the lungs. The lungs are surrounded by two layers of pleurae protected by the ribs and the thoracic musculature. The diaphragm divides the thoracic and peritoneal cavities with a variable position throughout respiration [2]. The expulsive motion of the diaphragm can raise the right crus to the level of the fourth anterior costal cartilage. Importantly, the abdominal contents may be raised well into the chest and exposed to chest wall trauma.

The peritoneal cavity contains solid organs, such as the liver, spleen, and pancreas, plus hollow viscous organs, including the stomach and the small and large intestines. Also in this area are the lower ribs, the abdominal wall musculature, vascular structures, the bladder, and retroperitoneal organs and spaces.

L. J. Micheli, L. Purcell (eds.), *The Adolescent Athlete*, Contemporary Pediatric and Adolescent Sports Medicine, https://doi.org/10.1007/978-3-319-56188-2_7

Clinical Evaluation

Thoracic Injury

Athletes with a thoracic injury may present with chest wall pain and, often, shortness of breath. Inspection for ecchymosis can also be helpful with intrathoracic injuries incurred in sport. Pulmonary auscultation is essential for assessment for lung pathology. Cardiac auscultation may be indicated for myocardial contusion or arrythmias. Further examination may include palpation for tenderness over a suspected rib fracture.

Abdominal Injury

Athletes can present with an immediate onset of pain or a more insidious onset [1]. Athletes who have a history of a high-risk mechanism, such as a rapid deceleration or high-energy impact, or who have continuous, persisting abdominal pain should be examined.

Physical exam should begin with the measurement of vital signs, which may be normal or reflect a state of shock. Inspection for ecchymosis and tenderness on abdominal palpation helps detect the potentially affected organ. Abdominal wall muscular contusion can be difficult to distinguish from intra-abdominal injury. Contusions are usually only tender over the area of sustained injury, and pain may be evident with contraction of the underlying muscle. Conversely, intra-abdominal injuries may elicit tenderness from various angles of palpation.

Among athletes with significant abdominal trauma, 50% will have a negative initial exam, so reexamination can be crucial. One estimate is that 20% of patients with an acute hemoperitoneum have an initial benign abdominal exam [3].

Liver or spleen injuries can bleed, causing intra-abdominal irritation and pain. Pain is often mild, without palpable tenderness. Injuries to hollow viscera and the pancreas cause peritonitis, often resulting in severe pain. Initially, this is localized to the site of injury. Peritoneal signs, such as referred tenderness and loss of bowel sounds, are found with progression of intra-abdominal injury. Auscultation for bowel sounds can be misleading, as the presence of bowel sounds does not exclude injury. Walking or coughing can also precipitate pain. Retroperitoneal injuries may occur without peritoneal signs when there is minor trauma. Hematuria is often the only clinical manifestation of renal trauma.

Coexisting Injuries

It has been well recognized that lower chest wall trauma places the upper abdominal organs at risk for injury. Most commonly, a blow to the lower left chest wall can result in an injury to the spleen [1]. Conversely, several case reports exist in the literature of abdominal impact resulting in an intrathoracic injury, such as a pneumothorax. One such report by Roberts [4] described an ice hockey player who was checked into the boards and sustained an impact over his left lower ribs. Initial concern for a splenic injury proved unfounded, and he was allowed to return to the game. However, he was too uncomfortable to continue, and assessment afterward revealed a 15% pneumothorax on chest x-ray. Hence, pulmonary injury from abdominal trauma can occur without disruption of the diaphragm. Diaphragm rupture is uncommon but is usually left sided (70–90%), as the liver appears to protect the right side.

Diagnostic Assessment

Laboratory investigations, including serial determination of hematocrit, diagnostic imaging, and diagnostic peritoneal lavage (DPL), can be performed in a hospital setting. DPL has become less commonly performed with the increased availability of diagnostic ultrasound and computed tomography (CT). A chest x-ray is usually indicated. An erect view is helpful to exclude air under the diaphragm, suggesting bowel perforation.

An emerging imaging modality for chest and abdominal trauma is diagnostic ultrasound, which has useful applications in the evaluation of thoracic trauma and may be a better diagnostic tool than supine x-ray for pneumothoraces and lung contusions [5–7].

Abdominal CT scan after blunt trauma has 67% sensitivity in its ability to predict the need for surgery in a pediatric population [8]. The negative predictive value was 98.7% in the same study. A combination of clinical exam and CT scan did not miss any significant injuries. Serial examination may be performed in a hospital setting. CT scan alone may miss clinically significant injuries.

CT is the best choice for imaging solid organs such as the liver and spleen [9] and remains the gold standard in evaluating blunt abdominal trauma in hemodynamically stable patients [10–13] though diagnostic ultrasound has advantages. While ultrasonography is not as sensitive for intra-abdominal trauma, does not provide as much anatomic detail, does not allow for injury grading [14], and remains operator dependent, it does have a role, for instance, in the hemodynamically unstable patient [15, 16]. Hoffman et al. described a sensitivity of 85% and a specificity of 99% in detecting intra-abdominal injuries [16], while Berkoff suggests sensitivity of 60% (95% CI 49–70) [17]. Ultrasound visualizes free intraperitoneal fluid well, though it may not identify the injured organ [18]. Conditions identified on ultrasound in unstable patients will eventually require CT to identify the injury and to guide management [18]. The use of abdominal ultrasound for evaluation of unstable patients has been described by the term "focused assessment with sonography for trauma" (FAST) [19]. The FAST examination aims to recognize peritoneal fluid/blood, which typically arises from a solid organ injury. A hypotensive athlete who has suffered abdominal trauma with a positive finding on a FAST examination has a higher likelihood of operative management [17, 19–26].

Treatment

Field treatment for shock, before and during transfer to a trauma center, is essential when shock is detected. Intravenous access with a large-bore cannula should be established at two sites with rapid infusion of 0.9% saline, rather than dextrose-containing fluids.

Current surgical goals are for organ salvage and repair, rather than removal of injured intra-abdominal organs. Indications for removal revolve around uncontrolled bleeding, particularly when associated with coagulopathy. In such circumstances, the risks of surgery are outweighed by the benefit of achieving hemostatic control, with a low likelihood of control being achieved any other way. Once stabilized, discharge with home observation is often practical. However, caution is required regarding delayed rupture of the spleen at 7–10 days.

Thoracic Injuries

Thoracic injuries generally result from rapid deceleration or high-energy impacts, which occur most frequently in high-speed, high-energy contact sports, such as bicycling, skiing, football, hockey, and boxing [15]. Statistically, adolescents have a higher incidence of penetrating thoracic trauma relative to younger children, who have higher rates of blunt thoracic trauma [27]. Road traffic accidents and pedestrian injuries have been reported as the leading cause of thoracic injuries, with sports-related injuries occurring much less frequently [28]. However, evolution of "extreme sports" may increase the potential for high-energy impacts and may be especially dangerous in the setting of remoteness from immediate medical attention. In one study, 6.1% of injured snowboarders sustained chest trauma, whereas only 2.7% of skiers had similar injuries [29].

Lung Injuries

Pneumothorax

This is the most common intrathoracic injury after blunt thoracic trauma [30]. Among all children who sustain high-energy thoracic trauma, approximately one quarter to one third will develop a pneumothorax [31, 32]. Pneumothorax related to sporting activity or injury is relatively uncommon. Spontaneous occurrences have been reported in a number of sports such as soccer [33] and weight lifting [34]. Pneumothorax as a result of blunt trauma during sports generally involves deceleration of the athlete's thorax against a moving or a stationary object, as has been reported in skiing and snowboarding [35], bicycling [36], football, and ice hockey [37].

Tension pneumothorax occurs in 1–2% of patients with a spontaneous pneumothorax [38]. Pneumothorax results from the loss of air from the lung into the pleural space. If no mass effect is caused by this air, the injury is referred to as a simple pneumothorax. However, if the loss of air into the pleural space continues, tension can result with concomitant shift of the mediastinum away from the side of the pneumothorax. Such a tension pneumothorax requires immediate decompression with a needle into the chest cavity and, optimally, by a tube thoracostomy. If this is not done, the continued pressure and mediastinal shift will lead to respiratory compromise by inhibition of airflow into the working lung and to cardiac compromise by a reduction in venous return to the heart.

Pneumothorax, whether simple or tension, can occur spontaneously from rupture of a bleb, from a sudden compressive force to the chest with a resulting rupture of the lung parenchyma, or from a displaced rib fracture that penetrates the lung. Both simple and tension pneumothoraces are associated with tachypnea, dyspnea, and sudden chest pain, though these findings may be quite subtle with a simple pneumothorax. Of those with spontaneous pneumothorax, up to 87% will present with chest pain and 43% with shortness of breath [39].

On examination, a simple pneumothorax may present with a small shift of the mediastinal structures to the side of the pneumothorax, whereas tension pneumothorax is associated with a shift to the opposite side. Physical examination may also demonstrate decreased breath sounds on auscultation and hyperresonance to percussion on the side of the lesion. Tension pneumothorax is also associated with tachycardia, neck vein distension, and hypotension.

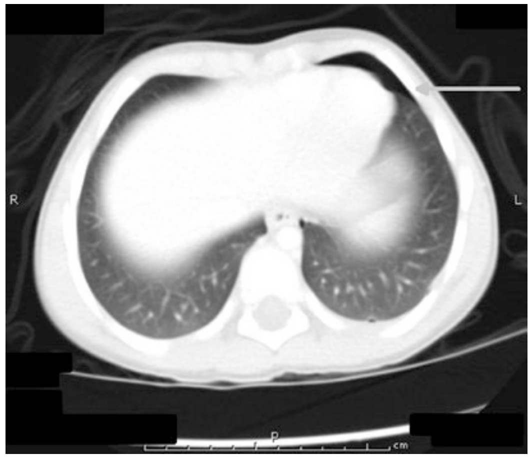

Fig. 7.1 Left pneumothorax. Courtesy of David Mooney, MD, Children's Hospital, Boston, MA

The diagnosis is confirmed by chest x-ray, but as noted previously, tension pneumothorax should not await chest x-ray for treatment. Figure 7.1 illustrates a CT of a left pneumothorax which remains the gold standard for diagnosis. Ultrasound has gained increased interest given its growing availability, feasibility, and lack of radiation exposure, of particular importance in the pediatric population. Though investigation is ongoing, studies have suggested improved sensitivity and comparable specificity of ultrasound compared to supine chest x-ray for detecting pneumothorax [40, 41]. One study demonstrated that prehospital critical care providers were able to learn the techniques, correctly diagnose, and retain the skills needed to identify sonographic signs suggestive of a pneumothorax [42], a practice that could be applied by appropriately trained sports medicine physicians [17].

Tube thoracostomy and suction at −20 cm H_2O are all that is required for the treatment of most pneumothoraces. Thoracoscopic talc pleurodesis has been shown to be an effective intervention in recurrent or persistent spontaneous pneumothoraces [43]. The athlete can resume normal activity within a few days of discharge or as other injuries allow. Occasionally, a small, simple pneumothorax of 20% or less can be treated without tube thoracostomy if the patient is asymptomatic and has no other injuries. This approach requires careful observation and repeat chest x-ray to document stability. Regardless of treatment type, recurrence rates of primary spontaneous pneumothorax are reportedly high in children, up to 54% [44]. Return to physical activity should be delayed until complete resolution of the pneumothorax [45]. Symptoms of primary spontaneous pneumothorax often resolve within 24 h, even prior to resolution of the pneumothorax [46]. Therefore, return to play should be determined on a case-by-case basis. Current guidelines recommend avoidance of air travel within 2–3 weeks following a pneumothorax, due to concern that a volume of air trapped in the pleural cavity may expand and develop into a tension pneumothorax in the lower cabin pressure of a commercial airplane in flight [47].

Pulmonary Contusion

Pulmonary contusion is a bruise of the lung associated with hemorrhage and edema into the lung parenchyma [15]. It can result from a sudden deceleration in which the lung strikes the chest wall, from a concussive blow to the chest that compresses the lung or from a displaced rib fracture [30]. Children appear prone to this injury in the absence of a rib fracture because of the compressive nature of the rib cage [31]. As a result, the force of impact is transmitted to the lungs, rather than being absorbed by the ribs, which may not fracture. It is important to identify pulmonary contusion, as some patients will go on to develop pneumonia or acute respiratory distress syndrome (ARDS).

Patients present with cough, hemoptysis, and dyspnea. Exam shows diminished breath sounds, crackles, or both. Chest x-ray findings vary from fluffy, patchy infiltrates to consolidation and are diagnostic in 85–97% of patients [48, 49]. The extent of pulmonary contusion on CT scan can help to predict the risk of developing ARDS [50]; however, the role of CT in the pediatric patient with chest trauma remains controversial [51]. Ultrasound is emerging as an alternative diagnostic tool in thoracic trauma and may be a useful alternative to CT for assessment of the extent of pulmonary contusion [7].

Fluid intake should be minimized, if possible, to reduce pulmonary edema. Supportive ventilation is necessary in severe instances. Pulmonary contusion after athletic injury is usually self-limited, without long-term sequelae. Once resolved, an athlete can resume training but should do so gradually, because exercise tolerance and pulmonary reserve will be reduced.

Hemothorax

Hemothorax may result from injury to the lung parenchyma or any of the intrathoracic vessels that may be lacerated by a traumatic rib fracture. In the setting of trauma, a pneumothorax may accompany this hemorrhage, causing a hemopneumothorax. Clinically relevant hemothoraces occur in 14% of children sustaining blunt-force chest injury [31]. Blood in the thorax is often asymptomatic, unless the volume is large. In this instance, hemothorax can present similarly to tension pneumothorax, with decreased breath sounds and hypotension. Dullness to percussion is noted over the area of pooled blood. Treatment involves supporting ventilation and circulation with intravenous fluids and then placing a chest tube once transferred to an appropriate setting.

Cardiac Injuries

Commotio Cordis

Commotio cordis is a cause of sudden cardiac arrest resulting from blunt, nonpenetrating trauma to the precordium. It is often of apparently low energy and results in cardiac arrhythmias in the absence of any structural injury to the heart or surrounding tissues [52]. The epidemiology of commotio cordis has been studied in the United States over the last several decades with the use of a commotio cordis injury registry, first described by Maron et al. in 1995 [52–55]. Most cases occur in teenage males, with a mean age of 15 years, and it has been speculated that the more compliant chest cage of younger athletes may make them more susceptible to these impacts. Over half of reported commotio cordis events occur during organized competitive sports, with the remainder occurring during practice or daily activities. The majority of blows resulting in commotio cordis are the result of a small projectile impacting the chest, such as a baseball, lacrosse ball, or hockey puck, while the rest are from bodily contact [56].

Animal models have been developed that suggest a specific and rare combination of circumstances is required to produce commotio cordis [57–59]. An impact must occur directly over the precordium, with a small enough surface area to transmit all of the energy from the collision to the heart [52, 59]. If this occurs exactly at the time of ventricular repolarization, just before the peak of the T wave, there is a 10–20 ms period of susceptibility that can result in ventricular fibrillation [54, 57–60]. In animal models, when a blow occurs outside this time, other arrhythmias may result, including heart block or bundle branch blocks [57].

Commotio cordis had previously been thought to have a high fatality rate with a low likelihood of reversal, despite the lack of structural injury [52, 53]. However, with increasing awareness and availability of automated external defibrillators (AEDs) at sporting events and in the community, the percentage of patients who survive commotio cordis has increased from 10 to 15% before 2000 to greater than 50% during the period from 2006 to 2012. Predictors of survival are prompt defibrillation and occurrence in a competitive event (during which rapid response and AED availability are more likely) [56].

Protective equipment such as chest guards and softer "safety balls" have been used to try to prevent blunt cardiac trauma, but evidence that such equipment prevents commotio cordis is lacking [61]. The most recent registry report at the time of this writing indicated that almost 40% of commotio cordis victims were wearing chest protectors at the time of the event, suggesting that current equipment may not offer sufficient protection [56]. In some cases this may be due to incomplete coverage of the precordium, or migration of equipment during movement [52, 54], but commercially available chest wall protectors failed to prevent ventricular fibrillation in an animal model of commotio cordis despite complete coverage of the cardiac silhouette [62]. For survivors of commotio cordis, a comprehensive cardiac work-up is necessary to rule out structural defects, conduction abnormalities, or other cardiac diseases that could have led to arrhythmia or arrest. Return-to-play decisions depend on the presence of underlying cardiac disease and should occur in consultation with a cardiologist. Some experts suggest avoiding return to sports with risk of chest impact after a commotio cordis event, at least until an older age [55].

Cardiac Contusion and Other Blunt Cardiac Injuries

In the setting of thoracic trauma, structural injuries to the myocardium must be considered. Such injuries may range in severity from contusion to free wall or septal wall rupture, valvular injury, and coronary artery or great vessel injury [63, 64]. Cardiac contusion (also referred to as contusio cordis) may result from a direct blow to the chest or from a rapid deceleration of the heart, causing it to strike the rib-sternum complex. Most injuries occur to the right ventricle, due to its proximity to the anterior chest wall. It has been reported in contact sports [65–67] but is more common in high-speed events such as motor vehicle accidents.

If blunt cardiac trauma is suspected due to mechanism or associated injuries, patients should be referred for further diagnostic testing. The use of cardiac enzymes for diagnosis and prognosis of cardiac contusion has been a topic of debate in the literature [68–73] and is complicated by the fact that there is no agreed-upon gold standard for comparison. Creatine kinase (CK) and creatine kinase-myocardial band (CKMB) have not shown diagnostic utility [68]; however, the combination of a normal cardiac troponin and normal electrocardiogram (EKG) is predictive of the absence of clinically significant cardiac trauma [70–72]. Most experts recommend obtaining an EKG and cardiac troponin if cardiac trauma is suspected, and further evaluation such as echocardiography should be obtained if the results are abnormal. Patients with EKG abnormalities or elevated troponin should be monitored for 24–48 h, as most dysrhythmias will occur during the first 24–48-h period after injury [64, 69, 70, 74, 75].

In the absence of EKG or troponin abnormalities, asymptomatic patients can resume normal activities as other injuries allow.

Chest Wall Injuries

Rib Fractures

Acute Rib Fractures

Rib fractures are considered the most common serious injury of the chest wall [76, 77]. Children are more vulnerable to intrathoracic injuries than adults, even in the absence of rib fracture, because of the increased elasticity and flexibility of their thoracic cage, which allows energy to be transmitted to the intrathoracic structures [78]. A fracture of the rib in a pediatric patient is more likely to be associated with other more significant injuries than in adults [79] and should increase clinical suspicion of other intrathoracic or intra-abdominal trauma.

Rib fractures can be divided into upper zone (first four ribs), midzone (ribs 5–8), and lower zone fractures (ribs 9–12) [80]. The most commonly fractured ribs from direct impact in any age group are the midzone ribs [77]. Fractures of the upper zone or lower zone ribs, multiple fractures, and flail segments are less likely to be isolated injuries than other patterns of rib fractures and may result in injury to surrounding structures [76, 80]. Acute traumatic impact fractures of the first and second rib are often associated with neck trauma and vascular injuries, as well as pneumothorax, lung laceration, and hemothorax. Direct impact fractures of the lower ribs may injure the kidneys, liver, or spleen. Splenic trauma has been reported in up to 20% of left lower rib fractures and acute liver trauma in up to 10% of right lower rib fractures [77]. Fractures of the first rib and the floating rib are generally thought to be more common in sports [76]. Isolated fractures of the first rib were initially described primarily as stress fractures or overuse injuries in athletes or physical laborers [81–83], though more are being reported in contact sports participants.

First rib fractures in sports may also occur from indirect trauma as a result of forceful opposing muscle contraction [83] and have been reported in tennis players, surfers, windsurfers, rowers, dancers, gymnasts, and basketball players [84–90]. Fractures from indirect trauma occur with hyperabduction of the arm and falling on an outstretched arm, as well as sudden muscle contraction [83, 84, 91, 92]. The intercostal muscles and serratus anterior pull inferiorly, while the scalene muscles pull superiorly. The anterior scalene muscle produces bending forces at the subclavian sulcus, which is the usual fracture site [93].

Floating lower rib fractures may also occur with indirect trauma [76]. They are caused by avulsion of the attachments of the external oblique muscles and latissimus dorsi muscles with sudden contraction [76]. These types of fractures have been reported in baseball players and batters [76, 94].

The diagnosis of acute rib fractures is often indicated by a history of a traumatic event. The pain may initially be diffuse and gradually localize over the affected rib. Direct palpation, deep inspiration, coughing, twisting, or flexion to the side may exacerbate the pain. If there is accompanying lung or pleural injury, there may be subcutaneous emphysema. While these findings should prompt evaluation for rib fracture, clinical examination alone is not sensitive for detecting many rib fractures [95]. First rib injury may be particularly challenging, as palpation of the first rib is difficult.

A chest x-ray is often sufficient to establish the diagnosis and exclude other diagnoses, such as a pneumothorax or hemothorax. Dedicated rib series are more sensitive than conventional chest x-ray for detection of rib fracture, though their utility in minor chest trauma is debated [96, 97]. Patients with significant chest trauma should be referred to the emergency department for evaluation with a CT scan, which can also assess for associated intrathoracic and intra-abdominal injuries. An emerging diagnostic modality in the assessment of acute rib fracture is thoracic ultrasound. Some early studies suggest that ultrasound is effective and may be more accurate than x-ray in detecting rib fractures in the acute setting [95, 98–100]. Ultrasound is also useful and potentially more accurate than x-ray in the assessment of other injuries associated with rib fractures, including pneumothorax and pulmonary contusion [5–7].

The majority of rib fractures heal with rest. The goal of therapy for uncomplicated rib fractures is pain relief, improvement of ventilation, prevention of worsening injury, and a safe return to sport. Pain is usually controlled with oral analgesics. Ice may also be used. Deep breathing should be encouraged to prevent atelectasis. Taping is controversial and may lead to increased splinting, pulmonary complications, and atelectasis. Activities should be modified until symptoms resolve, and training should be resumed gradually. Return to play should only be considered in patients whose symptoms resolve and who have minimal pain with palpation.

Rib Stress Fractures

Stress fractures are relatively uncommon in the ribs as compared to the lower extremities, but they have been described in youth and adult athletes [101–103]. Most published information on rib stress fractures is in the form of case reports, with such reports indicating that these injuries occur predominantly in the first rib or in the middle ribs [102, 104].

First rib stress fractures have been reported mostly in overhead sports such as baseball, basketball, tennis, and weight lifting [81–83, 89, 104–106], as well as in surfers, swimmers, and dancers [84, 85, 107]. Unlike with acute traumatic first rib fractures, isolated first rib stress fractures are infrequently associated with other significant injuries of the vasculature or the lung (Fig. 7.2) [93].

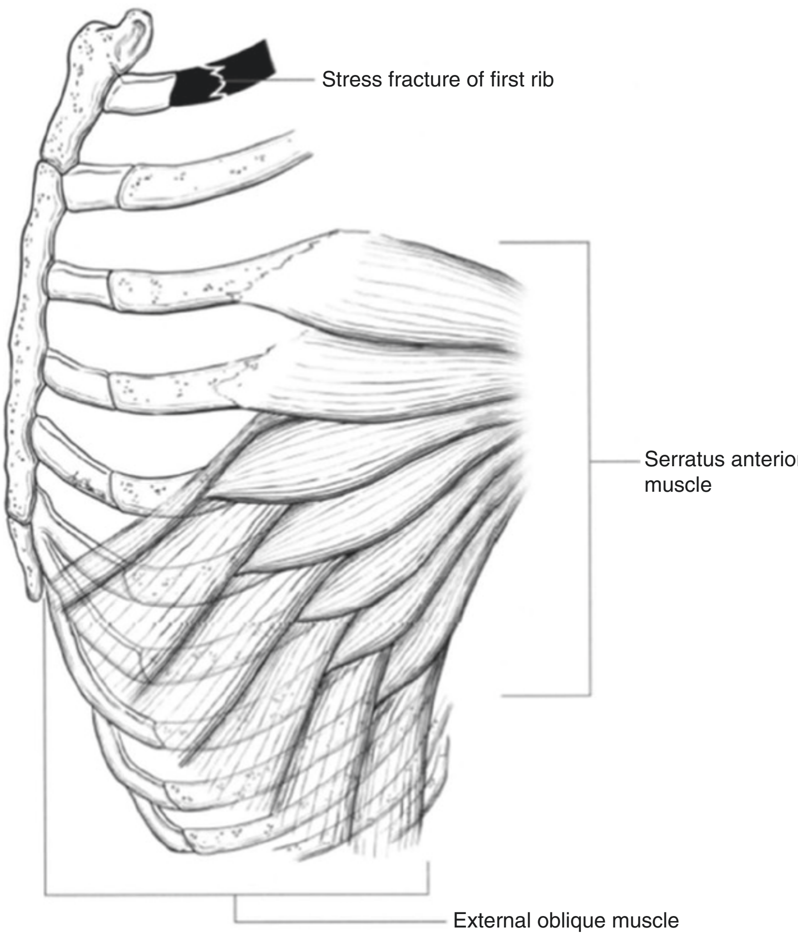

Fig. 7.2 First rib stress fracture

Stress fractures of the middle to lower ribs are reported mostly in patients who engage in swinging or pulling activities such as golf and rowing [104, 108–111]. Etiological factors associated with these sorts of fractures include improper technique, equipment problems, and lack of flexibility and strength [108, 111, 112]. Onset of symptoms is often preceded by an increase or change in physical activity or training [113]. Stress fractures of the ribs in rowers are postulated to be caused by excessive action of the serratus anterior muscle [114].

An athlete with a rib stress fracture typically presents with insidious onset of pain, either in the scapular region in the setting of a first rib fracture or with lateral, posterior, or anterior chest pain in the case of middle rib injury [93, 111]. Diagnosis is often delayed due to the nonspecific symptoms, which may be misdiagnosed initially as a muscle strain [102, 109].

In a study by Lord et al., plain radiographs revealed stress fractures in 16 cases of 19 rib fractures performed 2 weeks after the injury [109]. However, plain radiographs may initially be negative with stress fractures prior to callus formation, and diagnosis typically requires a triple-phase bone scan [101–103]. CT scans and magnetic resonance imaging (MRI) may also be useful for definitive diagnosis [115]. Rest from sport is suggested for a period of 4–6 weeks, though there is little evidence regarding the best approach to return to sport [116, 117]. Delayed union and nonunion are the most common complications of first rib stress fractures in throwing athletes. In patients with recalcitrant pain, referral to an orthopedic surgeon may be necessary [90].

Slipping Rib Syndrome

Slipping rib syndrome (also referred to variably in the literature as rib-tip syndrome, clicking rib syndrome, or rib pain syndrome) was first described in the early twentieth century and is characterized by an abnormal movement of the lower ribs resulting in intercostal nerve impingement and pain. This diagnosis has remained somewhat elusive, in part due to variation in definitions within the literature. Scott and Scott described the more inclusive "painful rib syndrome" as the clinical presentation of pain in the lower chest or abdomen, a tender spot on the lower costal margin, and reproduction of pain by pressing that spot [118]. Slipping rib syndrome may also mimic abdominal pathology, due to its common presentation with upper abdominal pain [119]. The condition typically involves the eighth, ninth, and tenth ribs. These ribs are attached to each other by fibrous tissue in adults and by cartilaginous tissue in children. It is believed that when these connections are weakened or ruptured by trauma, the ribs can slip and impinge on the intercostal nerve, producing pain [120]. Rib-tip syndrome is usually unilateral; however, it may be bilateral [118, 121]. This condition particularly affects running, vigorous arm exercise, arm abduction, and swimming [101]. It has been reported more frequently in adults but nevertheless is a cause of rib and upper abdominal pain in adolescent and collegiate athletes [122–124].

Pain is often localized to the upper abdomen, epigastrium, or inferior costal regions. Some patients report a slipping movement of the ribs or a popping sensation. Pain may vary from mild to severe and often is reproduced by movement [118]. Symptoms can often be reproduced upon clinical examination by hooking the fingers under the inferior rib and pulling anteriorly, referred to as the "hooking maneuver" [125]. A positive test reproduces the patient's pain and results in a click. Direct tenderness over the cartilage is another frequent finding. The diagnosis is clinical, and diagnostic imaging is generally not helpful, although it may exclude other conditions. Intercostal nerve blocks may be useful in establishing the diagnosis. Ultrasound has been described in adult patients as a means to observe cartilage subluxation during movement [126].

No definitive consensus exists as to the best management for slipping rib syndrome [127]. Conservative management for mild cases includes reassurance and avoidance of aggravating motions. Some patients have reported favorable outcomes with single or multiple local anesthetic nerve blocks [119, 128], and corticosteroids added to an injection may be beneficial. Surgical excision of costal cartilage for recalcitrant cases has demonstrated efficacy in both adults and children [120, 122, 129, 130].

Costosternal Syndromes (Costochondritis)

A variety of diagnostic terms have been used in this group of syndromes, including costochondritis, costosternal syndrome, and anterior chest wall syndrome. Costochondritis is a common cause of atraumatic chest pain in children and adolescents and is characterized by pain and tenderness of the costochondral junction without swelling [131]. This condition may account for 9–22% of cases of pediatric chest pain [132, 133]. The sites most typically involved are the second through fifth ribs [131]. Costochondritis may be preceded by an upper respiratory infection or by exercise that stresses the upper body, and symptoms may persist for several months [134].

Diagnosis of costochondritis is clinical, based on a history of chest pain and by exclusion of other etiologies [134]. Anterior chest wall tenderness may be localized to one or more costochondral junctions, and movement of the arm on the ipsilateral side may also reproduce the pain [131, 134].

The course is usually self-limited, and most patients recover spontaneously from the condition. Anti-inflammatory agents, ice, muscle relaxants, and injection of lidocaine (with or without corticosteroid) have been used in selected cases [134, 135]. Stretching exercises may also be of benefit [136]. Patients should be reassured of the benign course of this condition and can continue to participate in sports as tolerated.

Sternal Fractures

Sternal stress fractures have been reported in golfers, weight lifters, and wrestlers [101, 137, 138]. Acute traumatic sternal fractures are frequently seen in association with deceleration injuries and/or direct blows to the chest in adults, though a case series in children suggested that more minor blunt trauma may be a common mechanism in this age group [139]. Isolated sternal fractures from direct impact do not pose significant risk to the athlete. Injuries to the sternum have traditionally led to a search for associated cardiac, great vessel, and pulmonary injuries caused by the anatomic proximity of these structures, but associated morbidity with these injuries is low. Studies in both Europe and the United States have shown the mortality associated with isolated sternal fractures to be less than 1%, and the incidence of associated blunt cardiac injury to be low [140–142]. Nevertheless, it is important that one carefully assess the pediatric patient who presents with a sternal fracture for symptoms of other potentially associated injuries. These include pneumothorax, pulmonary contusion, and cardiac contusion.

Sternal fractures are often better seen on lateral sternal x-rays than on standard anterior-posterior (AP) chest films, because most of these fractures are oriented transversely. Standard radiographs can also be challenging to interpret in pediatric patients, due to the variable pattern of ossification centers in the sternum [139, 143]. In cases in which a fracture is questionable, CT scans are more sensitive but may not improve detection of clinically significant sternal fractures [144]. Ultrasound is a promising diagnostic tool for sternal fracture, with recent reports suggesting better accuracy than traditional radiographs [145, 146]. If intrathoracic trauma is suspected in the setting of a sternal fracture, further imaging and assessment are warranted. Otherwise asymptomatic pediatric patients with isolated sternal fracture can be safely discharged home [139].

Scapular Fractures

Scapular fractures represent less than 1% of all skeletal injuries and 5% of shoulder fractures [147, 148]. It is uncommon for scapula fractures to occur in isolation [149], and presence of a scapula fracture should prompt consideration of other thoracic injuries [150]. Fractures of the scapula are rare in athletes, with the majority of reported cases occurring in football players [147, 148, 151]. Injuries occur during tackling, when the shoulder is in abduction and the scapula is pulled away from the chest wall where it is unable to dissipate direct force.

There are eight types of scapular fractures. They are classified by anatomic location: body, glenoid rim, glenoid fossa, anatomic and surgical neck, acromion, spine, and coracoid process. The

Table 7.1 Sports-related abdominal trauma

Intra-abdominal pathology	Abdominal wall contusions	Splenic ruptures	Ruptured jejunum	Pancreatic injury	Renal injuries
No. of patients	11	4	1	1	7

Source: Ref. [152]. Reprinted with permission from Elsevier

majority of scapular fractures are body fractures [151]. Approximately 10% of fractures occur in the acromion, coracoid, and spine [115].

A scapular fracture may present with symptoms that are similar to a rotator cuff injury [151]. Cain and Hamilton reported that rotator cuff injuries were initially suspected in half of football players who were diagnosed with scapular fractures [147]. Clinical examination reveals weakness with abduction and external rotation of the shoulder. Pain and weakness in the shoulder region are exacerbated with movement. Localized tenderness, swelling, and hematoma formation over the fracture site may also be present.

Scapula fractures are often not seen on standard scapula x-rays (AP, lateral, and axillary views). In one study, 43 out of 100 scapular fractures were missed on initial radiographs [149]. Therefore, specialized views such as the scapula Y, CT, or MRI may be necessary.

Treatment of nondisplaced scapular fractures is usually conservative and involves rest from sports and physical therapy. The application of ice is recommended for the first 48 h. A sling may also be used for immobilization, along with early range of motion exercises for 2–4 weeks. Rehabilitation should then focus on strengthening, and full return to sport may take several months [151]. In severe cases, surgical fixation should be considered.

Abdominal Injuries

Ten percent of all abdominal injuries have been reported to result from sports-related trauma [152]. Football [153, 154], rugby [155], soccer [156–158], and wrestling [159] are the most common contact sports for abdominal trauma. Noncontact sports, such as downhill skiing [160–163], water skiing [164], and horseback riding [153, 165], result in high-speed deceleration mechanisms and may result in very serious injuries.

Fig. 7.3 Duodenal injury from a bicycle fall. Courtesy of David Mooney, MD, Children's Hospital, Boston, MA

A retrospective cohort study of Swedish children by Bergqvist et al. [153, 166], involving 348 injuries over 30 years, revealed 7.1% of abdominal trauma was sports related (Table 7.1). Sports involved were ice hockey (eight cases), skiing (six cases), soccer (five cases), pole vaulting (one case), and gymnastics (one case).

The same study contrasted recreational cycling with organized sport and found 12% of abdominal trauma in children was related to this pastime. In addition to the pathologies detailed in Table 7.1, there were liver injuries, a mesenteric rupture, muscle lacerations, a stomach rupture, and colon injuries with cycling. Ballham [167] showed that bicycle injuries had a higher injury severity index than other sports. Pediatric bicycle injury data from Puranik [168] of 211 children under 15 years old revealed 9% had internal organ injuries. The handlebar imprint can sometimes be seen along the upper edge of the abdomen (Fig. 7.3) [169]. Bicycles [170–172] and other types of sports-related vehicular use may result in the same patterns of abdominal injury that are seen in automobile accidents.

Splenic Injury

Injuries to the spleen can result from a direct force to the abdomen, especially the left upper quadrant, and from a sudden deceleration when the hilum is torn or by displacement of lower left rib fractures. Any of these mechanisms are possible in high-speed or contact sports.

The mechanism of splenic injury was explored in a study of downhill skiers [173]. In high-velocity or high-impact collisions, e.g., with a tree, a chairlift pole, or a snow fence, multiple trauma was always present (fractures or damage to multiple organs). Skiers were unable to move at the scene, and splenectomy resulted in five out of six cases (83%). With low-velocity or low-impact collisions, often just a single organ was involved. Such injuries resulted from falls on ski trails, on moguls, or on tree stumps or rocks. Presentation in these cases was often delayed for hours, while the individual continued skiing. Splenectomy was necessary in 5 of 12 cases (42%).

Machida et al. [29] found a significantly higher abdominal injury rate in snowboarders compared to skiers. Injuries to the kidney, liver, and spleen were seen in both. In snowboarders, riding mistakes after jumping and subsequent falls were responsible for 31.6% of the abdominal traumas. Skiers were more likely to have a collision as the mechanism for their abdominal injury.

Physical exam is neither sensitive nor specific for splenic injury. Therefore, patients with a concerning mechanism or pain should undergo diagnostic imaging. The most important determinant of nonoperative management of splenic rupture is hemodynamic stability, including hematocrit. Nonoperative management of splenic injuries consists of careful hemodynamic monitoring, frequent physical and laboratory examination, and, most importantly, strict bed rest. Given a stable course, a CT scan should be repeated after 5–7 days and should show stabilization or improvement of the injury. Rest and avoidance of contact sports are recommended for up to 4 months after injury. This is determined largely by the severity of the injury seen on CT and its resolution. Nonoperative splenic management seems to be more successful in children (90%) than in adults (70%) [174].

Epstein-Barr Virus, Infectious Mononucleosis, and Splenomegaly

By age 30, 90% of the population has been exposed to the Epstein-Barr virus, which causes infectious mononucleosis [175]. This may frequently be unrecognized, particularly in children. From 1 to 3% of college students are affected each year [176]. The peak incidence is in 15–24-year-olds.

A study using physical exam alone reported splenomegaly in 8% of patients with infectious mononucleosis [177]. In comparison, a study utilizing ultrasonography demonstrated that 100% of patients with infectious mononucleosis had an enlarged spleen; physical examination detected the abnormality in less than 20% of the same cases [178]. These studies indicate that physical exam alone is an insensitive tool to diagnose splenomegaly in the setting of infectious mononucleosis.

During bouts of mononucleosis, spleen length increases by 33% and peaks between 2 and 4 weeks from onset of symptoms [178]. Comparison with normative anthropomorphic measurements with ultrasound should be used to guide recommendations for return to sport after infectious mononucleosis [179–181].

Infectious mononucleosis causes the splenic architecture to become distorted, making the spleen susceptible to rupture from any increased abdominal pressure, even from sneezing or coughing. Splenic rupture in infectious mononucleosis occurs in 0.1–0.2% of cases, with the highest estimate being 0.5% [182]. The timing of this complication is predictable, being noted in the first 3 weeks of the illness. Splenic rupture is unusual beyond 3 weeks from the onset of symptoms (headache, sore throat, and fever). The prodromal period is not considered when determining the onset of the illness.

Splenic rupture is associated with abdominal pain, left shoulder pain (Kehr's sign), or periscapular pain. Left upper quadrant abdominal tenderness may or may not be accompanied by peritoneal signs, such as generalized tenderness, guarding, and rebound tenderness. Indicators of hypovolemia, such as tachycardia and hypotension, are worrisome signs. This complication fortunately is often not fatal. Splenectomy is necessary in some instances, although nonoperative management is often successful [183]. Treatment should be individualized. There is no evidence to suggest corticosteroids reduce spleen size or shorten the duration of the illness [184].

The appropriate time to allow an athlete with infectious mononucleosis to resume his or her activity is determined by the duration of symptoms, as well as the presence of splenomegaly and risk of splenic rupture. There is concern that contact trauma may precipitate splenic rupture. In a 1976 survey of college team physicians, the respondents identified 22 cases of splenic rupture. At the time of the trauma, 41% of these were diagnosed with infectious mononucleosis. Seventeen of the student athletes were participating in football [185]. Most splenic ruptures in the setting of infectious mononucleosis, however, are spontaneous, not the result of contact.

Return-to-play recommendations in the literature have been varied [186]. To protect the enlarged spleen, which should probably be assumed to be present in all cases [184], all strenuous activity should be avoided for the first 21 days. At this point the athlete may start a graded aerobic program, avoiding contact, if the athlete is asymptomatic, afebrile, and does not have a palpable spleen. At 4 weeks, if the signs are equivocal or the athlete is at high risk for collision, an imaging study such as ultrasound should be considered [187]. It should also be noted that normal spleen size has been directly correlated with athlete size; hence, a large athlete with an appropriately sized spleen may be mistakenly diagnosed with splenomegaly if the splenic volume/body mass is not considered [180, 188].

Hepatic Injury

With the evolution of CT scanning, recognition of minor liver injuries has been enhanced. Although the spleen was previously asserted to be the most commonly injured intra-abdominal organ, the incidence of liver injuries may be similar [189]. This is not surprising considering the large size, soft substance, and unprotected position of the liver. Injury can result from a direct blow, especially to the right upper quadrant, a sudden deceleration, or by displacement of right lower rib fractures. Hepatomegaly results in an increased risk of injury, not only because of the increased size but also because an enlarged liver is softer than normal. Therefore, hepatomegaly is a contraindication to high-speed or contact sports.

The mechanism of injury, especially for lower rib fractures, is much more important than the physical exam to suggest a possible liver injury. Right upper quadrant abdominal tenderness, an abrasion/contusion over the right upper abdomen, right shoulder pain, or hemodynamic instability may be present. A CT scan is warranted with any appropriate mechanism. The typical appearance of a liver laceration is illustrated in Fig. 7.4. Unstable patients should have an immediate laparotomy. However, even high-grade injuries can be managed nonoperatively despite an imposing CT appearance, if the patient is hemodynamically stable.

Renal Injury

The kidney is the most commonly injured intra-abdominal organ in some sports, such as rugby. Renal injuries may be relatively asymptomatic, even with repeated blows, such as in boxers, or they may result in renal contusions causing microscopic or gross hematuria. Occult hematuria without radiographic evidence of injury is extremely common in several sports. It is present in 25% of boxers [164], college football players [190], and distance runners [191]. Kidney trauma from a direct blow is particularly common in football and rugby. Twenty-five percent of renal

Fig. 7.4 Hepatic injury. Courtesy of David Mooney, MD, Children's Hospital, Boston, MA

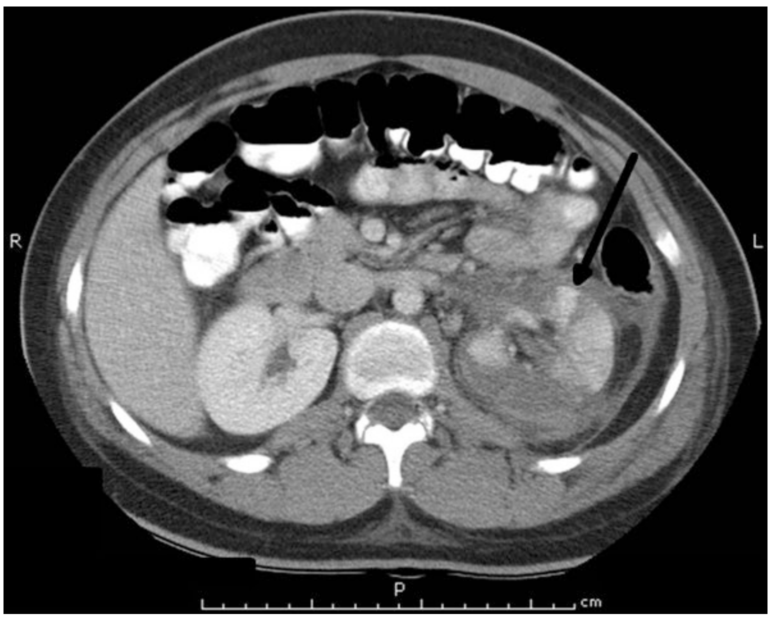

Fig. 7.5 Left kidney injury. Courtesy of David Mooney, MD, Children's Hospital, Boston, MA

injuries and 40% of renal pedicle injuries do not demonstrate hematuria [192]. An injury to the kidney is shown by CT in Fig. 7.5.

Gross hematuria should be evaluated in the hospital. Nonoperative management is appropriate as long as the athlete is not in shock, there is no expanding hematoma, and no free extravasation of urine seen on intravenous contrast CT. Complete healing is essential before return to sports. Most renal injuries heal within 6–8 weeks. Microscopic hematuria may persist for 3–4 weeks after injury.

Younger patients require special attention, as renal injury is more common than splenic or hepatic injury. Up to 30% of renal trauma in children is related to sport. This may be caused by a proportionally larger kidney size or a lack of musculoskeletal protection [8].

Pancreas

The pancreas is injured in 1–2% of abdominal trauma. A forceful blow to the upper abdomen is the most common mechanism of injury [155, 158]. For instance, a bicycle fall where the handlebar twists and “spears” the child may be the presenting history [1, 169]. As with other internal organs, there are often minimal obvious physical signs of damage. Patients can develop nausea, vomiting, and abdominal pain up to 48 h later. Typically, the pain radiates to the back. CT is the most useful imaging modality.

Bowel Injury

Bowel injury is infrequent and most commonly occurs as a result of a forceful blow to a small area over the small intestine. Physical findings may be limited. An erect chest x-ray may reveal air beneath the diaphragm, although CT is the most sensitive diagnostic imaging modality.

Groin Pain and Injuries

This is one of the more difficult problems to diagnose in athletes, especially if chronic. Soccer, hockey, hurdling, and skiing are sports where groin injuries are especially common [193]. The etiology is most commonly soft tissue injury, contusion or hematoma, and muscle-tendon strain. However, consideration of inguinal hernia, bursitis, and nerve entrapment is warranted.

Additionally, there is evidence evolving in the literature regarding the sportsman’s hernia [194]. This is a tear in the transversalis fascia in the posterior inguinal floor that Hackney [195] describes as an “incipient direct inguinal hernia.” The mechanism of injury is aggressive abduction in specific athletic situations, such as cutting maneuvers. Sportsman’s hernias are particularly common in sports such as soccer and hockey, where athletes frequently change direction at high speed [195–197]. The sportsman’s hernia is resistant to conservative therapy, and symptoms will recur after a period of rest. The key physical exam finding is tenderness at the pubic tubercle. This injury does not typically show up on routine imaging. Surgical repair of the inguinal floor will return approximately 90% of patients to full activity without pain [194].

Prevention

Thoracoabdominal trauma is uncommon in pediatric athletes. Certain injuries may be preventable. Sport-specific safety equipment should be worn to minimize the risk of injury. For instance, chest barriers and safety balls in baseball may have decreased (though not eradicated) the risk of commotio cordis [52]. An AED should be present at venues.

Conditioning is also important. Appropriate core strength, including the entire trunk, will maximize protection in contact sports and minimize overuse stress in noncontact sports. Attention to proper sports technique can also minimize the possibility of overuse.

Return-to-Play Guidelines

Onsite return-to-play decisions should be based on pain resolution, unless a minor abdominal wall injury is considered likely. Vital signs should be normal and peritoneal signs absent. Further, players should be able to exercise without an increase in symptoms.

Athletes who have sustained a solid organ contusion require a normal CT scan 2–3 weeks before being allowed to return to practice. Lacerations and subcapsular hematomas require longer periods of recovery because of the greater architectural damage sustained; hence, a prolonged period of healing is necessary. If an organ has to be removed, full tissue postoperative healing takes 6–24 weeks. Strenuous activity should therefore be postponed for 6–8 weeks and contact sports for 12–24 weeks, although advice varies by surgeon.

Rib injuries should be considered on a case-by-case basis, but return to sport is usually possible in 4–8 weeks. Tullos and Erwin described a baseball pitcher who was asymptomatic with a first rib injury at 3 weeks and was able to return to pitching with a pain-free nonunion [94]. The athlete with a sternal fracture can return to play when he/she can compete in a pain-free manner. If the patient engages in contact sports, a flank jacket or other similar device can be used to protect the injury.

Clinical Pearls

- It is essential, when assessing an athlete who has sustained trauma to the thorax or abdomen, to maintain a high level of suspicion for internal injury.
- There may be no external sign initially, and serial physical examinations are crucial.
- If a significant injury is suspected, the athlete should be transferred to a setting where CT imaging and advanced medical care are available.
- Rib fractures may be traumatic from direct impact or secondary to acute muscle contraction. They may also occur as a stress injury.
- Fractures of the first four ribs or the last two ribs, multiple fractures, and flail segments may result in injury to surrounding structures.
- Scapular fractures are unusual in sports and are often missed initially.

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8 Adolescent Shoulder Injuries

Nathaniel Cohen and Treg Brown

Injury to the adolescent shoulder poses a unique challenge to the sports medicine team. To determine best practice patterns, the team must utilize an evidenced-based approach. These young athletes sustain injuries caused by both acute, traumatic events and chronic overuse patterns. These injuries affect both osseous and soft tissue structures. Some of the injuries encountered are unique to this age group.

With growing numbers of adolescents participating in sports and increasing pressure to perform, shoulder injuries in this young age group have steadily risen. Acute injuries resulting from a fall or collision are seen in all sports, but are particularly prevalent in collision, contact, and extreme sports, such as football, hockey, gymnastics, and skateboarding. Year-round competition and sports-specific training have further contributed to the rise in overuse injuries seen in this young patient population. Participation in sports such as baseball, softball, tennis, and swimming create potential repetitive overuse injuries of the shoulder. Forty to eighty percent of swimmers and 50–95% of baseball players demonstrate signs and symptoms of shoulder dysfunction [1]. The incidence of shoulder pain in youth baseball pitchers has a frequency of 32%, and nearly one third of 298 pitchers reported shoulder symptoms over the course of two seasons [2].

The current body of scientific literature regarding the athletic adolescent shoulder is limited. Therefore, extrapolation of research findings on the adult overhead athlete will be necessary. As physicians continue to improve and refine the diagnosis and surgical intervention for the athletic shoulder, physical therapists and athletic trainers have been challenged to develop creative rehabilitation programs to care for these athletes. Understanding the epidemiology, functional anatomy, basic science, normal and abnormal biomechanics, pathophysiology, and a variety of therapeutic approaches are vital to achieving success when working with the adolescent athletic shoulder.

Functional Anatomy

Adolescent athletes are faced with a triumvirate of predisposing factors for shoulder injury. Open physeal plates, joint laxity, and underdeveloped musculature are three unique aspects of the developing body [3]. When combined with trauma or the stresses of overhead activity, these factors can result in a host of shoulder injuries unique to the skeletally immature athlete. To better recognize these injuries, an understanding of normal development is

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L. J. Micheli, L. Purcell (eds.), *The Adolescent Athlete*, Contemporary Pediatric and Adolescent Sports Medicine, https://doi.org/10.1007/978-3-319-56188-2_8

paramount. As embryologic development ends, shoulder anatomy progresses such that the shoulder is fully developed and the structures are identical to the adult shoulder. Skeletal maturation may continue well into the second decade of life, and it is during this time that the stress of overhead activity will remodel the humerus. Ossification of the humeral head is accomplished by three centers: one for the humeral head and one for each tuberosity [4]. This area accounts for approximately 80% of the growth of the upper extremity. The epiphyseal plates at these sites are weaker than the surrounding ligaments, so adolescents are more likely to sustain avulsion fractures while more mature athletes would sustain tendon or ligament injuries [5]. Normal skeletal development continues through adolescence, culminating in proximal humeral physeal closure in girls by 14–16 years of age and in boys by 16–21 years of age.

As development occurs, the type III collagen is progressively converted to the more stable and "soluble" type I collagen found in adults. The increased level of type III collagen in the young athlete explains why young people with shoulder instability are more prone to recurrent instability compared with older people [6]. The developing shoulder also undergoes considerable adaptation from the stress of sports. As the shoulder continues to develop, the head is inclined and retroverted relative to the shaft. Osseous and soft tissue changes have been shown to occur both radiographically and by simple range of motion comparisons of the dominant and nondominant shoulders. The normal angle of humeral retroversion in the adult population varies markedly, but has been found to be increased in the dominant shoulder of baseball pitchers [7–10]. This variability should be kept in mind when evaluating the young overhead athlete.

The superior biceps-labrum complex is a structure of significant importance to the overhead athlete. The superior portion of the labrum inserts directly onto the biceps tendon, and the biceps tendon inserts on the supraglenoid tubercle [11]. Huber and Putz describe the superior and inferior portions of the labrum and the surrounding glenohumeral ligaments and tendons as a periarticular fiber system (PAFS), forming a basket of fibers around the neck of the scapula and constituting a functional unit (Fig. 8.1) [12]. Morphologically, the fibers of the upper portion

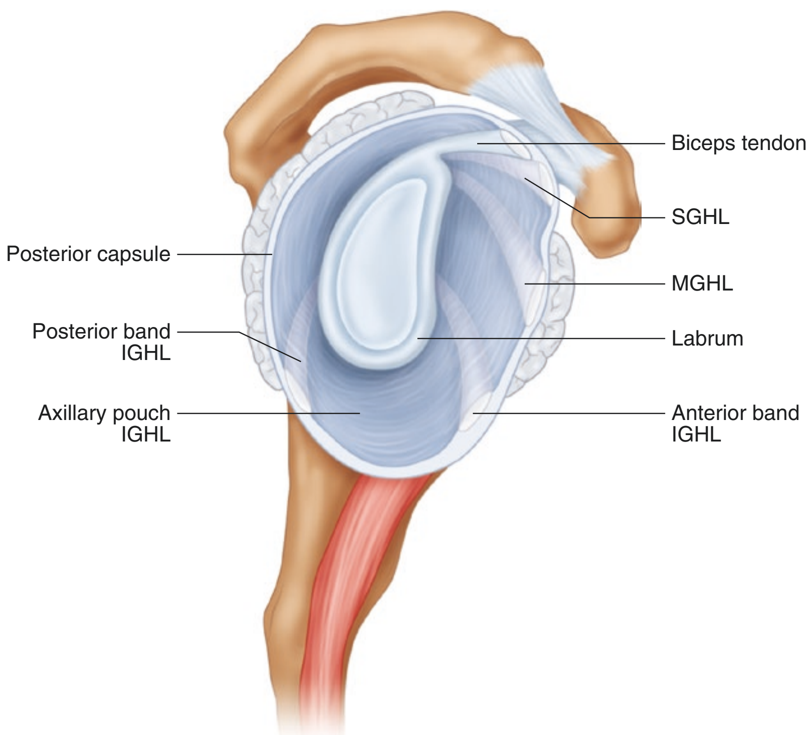

Fig. 8.1 Schematic of glenoid fossa, labrum, biceps tendon, and glenohumeral ligaments

of the PAFS are indistinguishable from those of tendons [10]. Clinically, tendons are designed to handle tensile forces. Therefore, the superior portion of the PAFS may be adapted to handle the tensile forces of deceleration as opposed to the shear stress that occurs in maximum external rotation (overhead sports).

The shoulder joint capsule, in combination with the labrum, reinforces the glenohumeral joint. The shoulder capsule has three primary bands or thickenings, termed the glenohumeral ligaments (superior, middle, and inferior). These "tissues" and the glenohumeral ligaments, in particular, provide static stability to the glenohumeral joint, allowing it to reach extreme angles of mobility, while preventing subluxation or dislocation. The inferior glenohumeral ligament (IGHL) supports the humeral head much like a hammock, with the bands reciprocally tightening as the humeral head is rotated in the abducted position [13]. It is the primary restraint to AP translation in the abducted, externally rotated position [13, 14]. The superior glenohumeral ligament and rotator interval provide stability against inferior and posterior forces with the arm adducted. AP translation is restricted by the middle glenohumeral ligament in the abducted arm. The posterior capsule limits posterior translation when the arm is forward flexed, internally rotated, and adducted. Joint concavity provided by the glenoid socket and accentuated by the labrum provides further stability.

The rotator cuff is the "workhorse" of the shoulder. As in the adult, the adolescent rotator cuff has three main functions: glenohumeral stabilization, rotation of the humerus, and assisting with elevation of the upper extremity. The rotator cuff consists of the subscapularis, supraspinatus, infraspinatus, and teres minor muscles and their tendons. The subscapularis inserts onto the lesser tuberosity, whereas the remaining tendons insert onto the greater tuberosity. Optimal performance of these dynamic stabilizers requires proper functioning of the deltoid and periscapular stabilizers (trapezius, levator scapulae, serratus anterior, and rhomboids).

The rotator interval is a complex anatomic region that plays an important role in the normal function of the shoulder. It is the triangular space between the subscapularis and supraspinatus tendons and the base of the coracoid process. It is roofed by the rotator interval capsule which is reinforced externally by the coracohumeral ligament (CHL) and internally by the superior glenohumeral ligament (SGHL). It is traversed by the intraarticular biceps tendon.

Clinical Evaluation

History

A thorough history and physical exam is critical to effectively diagnose shoulder injuries. A physician must take a detailed history from the athlete regarding the events surrounding the injury, whether traumatic or atraumatic. This should include, but is not limited to, the following: date of onset of symptoms, the mechanism of injury, the location of the pain, the presence of any mechanical or instability symptoms, previous injuries or surgeries, and previous and immediate management of the injury. Questions pertinent to the overhead athlete include practice and competition level, number of repetitions, and where in the "overhead motion" pain occurs. Particular focus should be placed on the amount of training in which the athlete is participating, including the number of games and practices, as well as if the athlete has had any chance to recover. For throwing athletes, pitch count per game and innings pitched will provide insight into the potential risk of overuse injuries.

Physical Examination

Physical examination consists of observation, range of motion, strength, palpation, and special tests, which should confirm the working hypothesis determined from the history. Exposure of the entire shoulder region is mandatory. The shoulder and periscapular region should be inspected and compared to the contralateral shoulder for any signs of asymmetry, atrophy, discoloration, or deformity. Palpation of key bony and soft tissue structures should be performed in a systematic fashion. These structures should include the sternoclavicular (SC) and acromioclavicular (AC) joints, clavicle, acromion, scapula, greater tuberosity, deltoid, and proximal bicep tendon.

Range of Motion

Range of motion should be assessed in all planes, and any deficits or painful arcs of motion should be noted. Both active and passive ranges of motion should be evaluated. The supine position will better enable the clinician to stabilize the scapula, and thereby better assess true glenohumeral motion. The examination may be modified to a sport-specific injury if the history warrants. External and internal rotation measurements have been utilized as an indirect measure of the status of a thrower's shoulder (Fig. 8.2). Meister et al. examined the differences in range of motion in an adolescent male baseball population (8–16 years of age) to determine developmental changes [15]. Range of motion differed significantly between the 8-year-old and 16-year-old groups. Differences between the dominant and nondominant shoulders grew larger as the age of the group increased. Interestingly, total shoulder motion decreased as the athletes aged, indicating decreased soft tissue laxity. Differences in range of motion in the throwing shoulder can occur with differing levels of competition (Table 8.1). Werner et al. documented similar, but increased, shoulder ranges of motion in adolescent windmill softball pitchers [16]. This was felt to be caused by the increased generalized ligamentous laxity found in females. Marked internal rotation deficit combined with a generalized loss of motion is a sign of glenohumeral internal rotation deficit (GIRD).

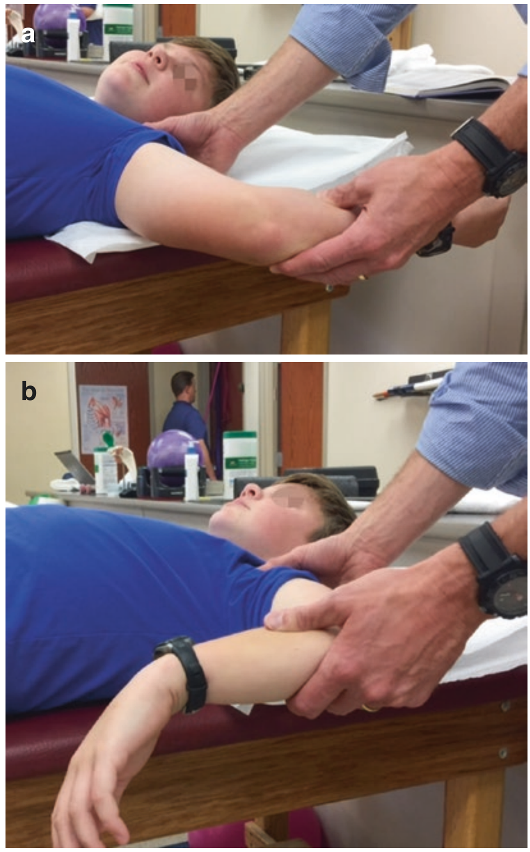

Fig. 8.2 (**a**) Passive external rotation range of motion of the glenohumeral joint in the supine position with scapular stabilization. (**b**) Passive internal rotation range of motion of the glenohumeral joint in the supine position with scapular stabilization

Table Comparison of external and internal rotation range of motion in three levels of baseball competition

Level	Passive ER/IR	Max ER
Pro	121–137°/62°	184°
College	107–160°/48°	158°
Youth	120–148°/44°	163°

Maximum external rotation data from our lab during the actual pitching motion

Strength Testing

Strength testing should be performed with the athlete seated facing the examiner. Resistance is then provided to assess supraspinatus strength (thumb down abduction in the plane of the scapula), infraspinatus (external rotation with the arm adducted), and deltoid (abduction with the arm at the side). Grade of strength and any associated pain with these tests should be noted.

Special Tests

A thorough ligamentous stability examination will often require examining the patient in the supine position if any guarding or apprehension is present. Several "special" tests are utilized to discern the presence of any instability. Anterior instability is by far the most frequent type of instability pattern encountered, and it may easily be assessed performing a standard apprehension relocation maneuver (Fig. 8.3). This is a useful test and easily mastered in a brief period. The load and shift maneuver is also useful for evaluating anterior and posterior instability patterns (Fig. 8.4). This exam requires complete relaxation of the patient, and the findings should always be compared to the contralateral shoulder. A useful grading system for this examination is as follows: grade 0, no translation; grade 1, translation up to the glenoid rim; grade 2, translation onto the rim (subluxation); and grade 3, translation over the rim (dislocation). The O'Brien's test has been described as a useful adjunct in the diagnosis of superior labral (SLAP) injuries that are often found in conjunction with a variety of instability patterns (Fig. 8.5). Unfortunately, false positives are common, often representing the presence of an AC injury, bicep tendinitis, or

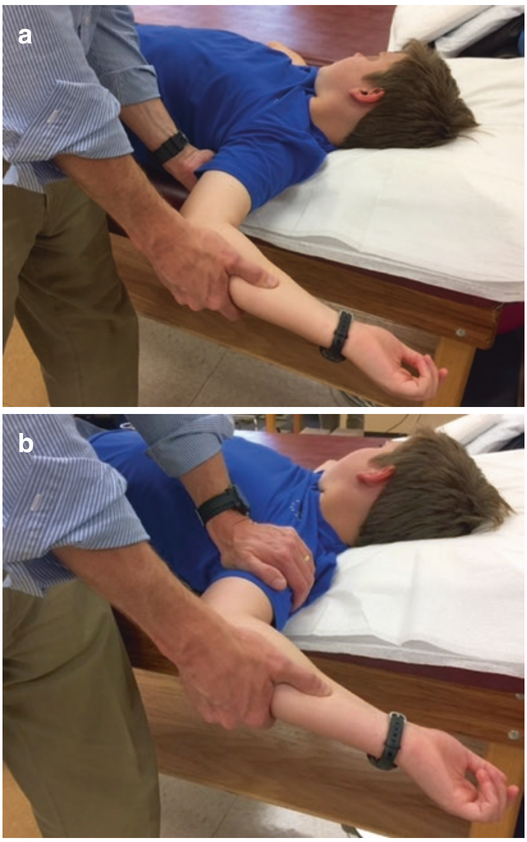

Fig. 8.3 (**a**) Anterior apprehension test for anterior instability. Patient's glenohumeral joint is passively moved into external rotation until guarding is demonstrated (+) or capsular end feel is reached (−). (**b**) Relocation test for anterior instability. After a (+) apprehension test, a posteriorly directed force is applied to center the humeral head in the glenoid fossa, and apprehension disappears with a concomitant increase in passive external rotation range of motion

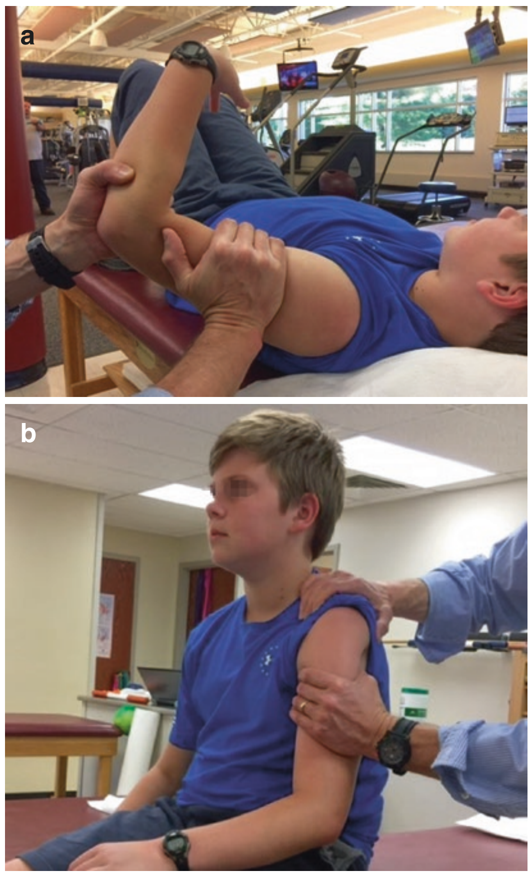

Fig. 8.4 Load and shift maneuver is useful for evaluating anterior and posterior instability patterns. Gentle force is applied to the humeral head to center it on the glenoid fossa, and an anteriorly or posteriorly directed force is applied to determine instability. It may be performed supine (**a**) or seated (**b**)

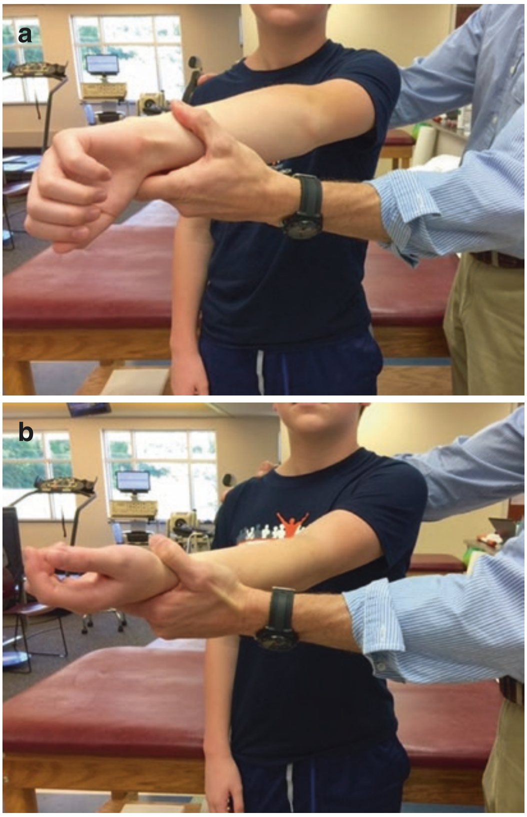

Fig. 8.5 (**a**, **b**), The O'Brien's test has been described as a useful adjunct in the diagnosis of superior labral (SLAP) injuries that are often found in conjunction with a variety of instability patterns

posterior instability. Palpation of the bicipital groove and pain with resisted external rotation may also show biceps and superior labral pathology [17]. Pain with the apprehension maneuver and relief with the relocation maneuver may be a sign of internal impingement. Pain with posterior load and shift may help to elicit symptoms in patients with posterior shoulder instability.

The sulcus test may be performed either seated or supine and, again, requires complete relaxation of the patient. The examiner should grasp the elbow of the patient on the affected side. A longitudinal force is then exerted, pulling the elbow away from the shoulder, toward the ipsilateral hip. The development of a sulcus immediately distal to the lateral edge of the acromion indicates a positive test. This test evaluates for the presence of inferior laxity and rotator interval injuries. The exam should be performed with the arm in the neutral position and repeated in full external rotation (ER). If the sulcus sign remains positive with the arm in full external rotation of the glenohumeral joint, a rotator interval injury should be suspected; however, bilateral sulcus signs are often indicators of generalized ligamentous laxity. All patients suspected of having generalized laxity should be inspected for hyperextension of the elbows and metacarpal-phalangeal joints and hyperflexion of the first carpometacarpal/wrist joint.

Impingement tests are performed to evaluate the rotator cuff and subacromial bursae. These tests are performed with the athlete seated. The classic Neer impingement sign and Hawkins sign are good indicators of subacromial inflammation, and they should be correlated with appropriate strength testing to better evaluate for rotator cuff pathology. An "impingement test" (subacromial injection of local anesthetic) may be performed when there is a question regarding the source of the patient's pain. Intraarticular injuries (biceps and capsulolabral injuries) will not be relieved with a subacromial injection.

The AC and SC joints should be palpated, and areas of tenderness should be noted. If an AC injury is suspected, a painful cross-arm adduction maneuver will help confirm pathology at this site. If an injury to this area remains in question, pain relief after a selective injection of local anesthetic into the AC joint may confirm the diagnosis.

Scapulothoracic Region

The scapulothoracic region should also be closely inspected. Injuries to this area are particularly prevalent in the overhead athlete. Winging and scapular dyskinesia should be sought. Unfortunately, direct observation of scapula position and orientation has proven elusive in the overhead athletic population. Myers et al., studying an adult population, demonstrated significantly increased upward rotation, internal rotation (IR), and retraction of the scapula during humeral elevation [18]. They concluded that throwing athletes have a different resting scapular position and orientation than their nonthrowing counterparts. At what point during development these adaptive changes occur has not been determined. However, it is important to note that differing scapular positions between dominant and nondominant shoulders in the overhead adolescent athlete may be a normal adaptation. These changes should be distinguished from Sprengel's deformity, a rare congenital malformation of the scapula.

Acute Shoulder Injuries

Traumatic injuries to the adolescent shoulder can occur during collision and contact sports, most notably from a fall on an outstretched hand or from direct contact with the ground, enclosure, or another player. Such force can result in a glenohumeral subluxation, dislocation, acromioclavicular separation, or a variety of fractures. Because of the developmental and structural differences between the young athlete and adults, the diagnosis and management of these injuries can differ.

Acromioclavicular and Sternoclavicular Separations and Dislocations

Acromioclavicular (AC) and sternoclavicular (SC) separations are rare in the young athlete. Injuries to these joints typically occur from a direct blow to the superior aspect of the shoulder or a direct lateral blow with the arm adducted. The corresponding physes for these joints fuse late, with the medial clavicular physis remaining open until 24–25 years of age [19]. Therefore, injuries to this area in children 15 years of age and younger are usually physeal fractures or pseudodislocations that are difficult to distinguish from the common adult AC separation.

AC joint injuries should be evaluated with AP views of both AC joints for comparison and an axillary view to determine the presence of any anterior or posterior positioning or intraarticular involvement. True AC separations have been classified as grades I–VI [20]. Grade I and II injuries are essentially nondisplaced injuries. Grade III injuries will demonstrate displacement of 25–100% on radiographs. These injuries should be distinguished from grade V separations, which result in significant superior displacement in excess of 100%. Grade IV and VI injuries are rare and displace posteriorly and inferiorly, respectively.

Grade I and II AC separations are treated nonoperatively. The player should be given a sling for comfort and will likely be unable to participate in contact sports for 2–3weeks. When all motion and strength have returned and pain has diminished, they may be allowed to return to play as tolerated. Management of grade III separations remains controversial, but many authors recommend a trial of nonoperative treatment initially. Injuries to the dominant arm in overhead athletes or weight lifters are exceptions and will likely benefit from early repair. Grades IV–VI require anatomic repair or distal clavicle excision and stabilization using one of many techniques described in the literature. There is a trend to using soft tissue augmentation with either allograft or autograft in patients undergoing AC reconstruction, particularly for chronic cases.

Medial physeal fractures can mimic adult SC dislocations and are more frequent than medial shaft fractures. Sternoclavicular separations are usually anterior and respond to nonoperative measures. Attempts to reduce anterior SC joint dislocations typically fail; however, these injuries tend to respond to initial activity modification and gradual return to activities as pain allows. Posterior dislocations are rare, but can result in dysphagia, dysphonia, and pulmonary and neurovascular compromise. Closed reduction may be successful. Open reduction should be reserved for open injuries and injuries with significant displacement or compromise of the neighboring vital structures. Once reduced, these injuries tend to be quite stable, and range of motion may begin after 2–3 weeks. Distinguishing between anterior and posterior dislocations can be quite difficult using routine radiographs; therefore, CT scans are routinely recommended to evaluate this injury. Physeal fractures of either the AC or SC joint should be treated with a sling for 2–3 weeks, followed by gradual progression of physiotherapy. Return to play can be expected in 4–6 weeks.

Clavicle Fractures

Fractures of the clavicle are one of the most common fractures seen in this age group. Nondisplaced fractures are typically treated with sling immobilization for 3–4 weeks with pendulum exercises starting at 2–3 weeks. The healing capacity of younger skeletally immature athletes allows for considerable displacement and deformity to occur with little to no residual sequelae. As the athlete reaches skeletal maturity, the healing capacity diminishes, and consideration may be given for surgical fixation of fractures with significant shortening, displacement, or established nonunions [21]. Nonunions, although infrequently seen in adolescents, are another indication for open reduction and internal fixations (Fig. 8.6a–c). In the adult literature, better results have been seen with open reduction and internal fixation of displaced clavicle fractures [22]. While there have not been similar large-scale studies in adolescents, there appears to be an emerging trend for operative fixation of displaced fractures. Adolescents have shown good results with operative fixation of displaced clavicle fractures. Open fractures or fractures causing tenting of the skin are absolute indications for surgery. Return to play for these injuries requires clinical union of the fracture site and pain-free, normal range of motion.

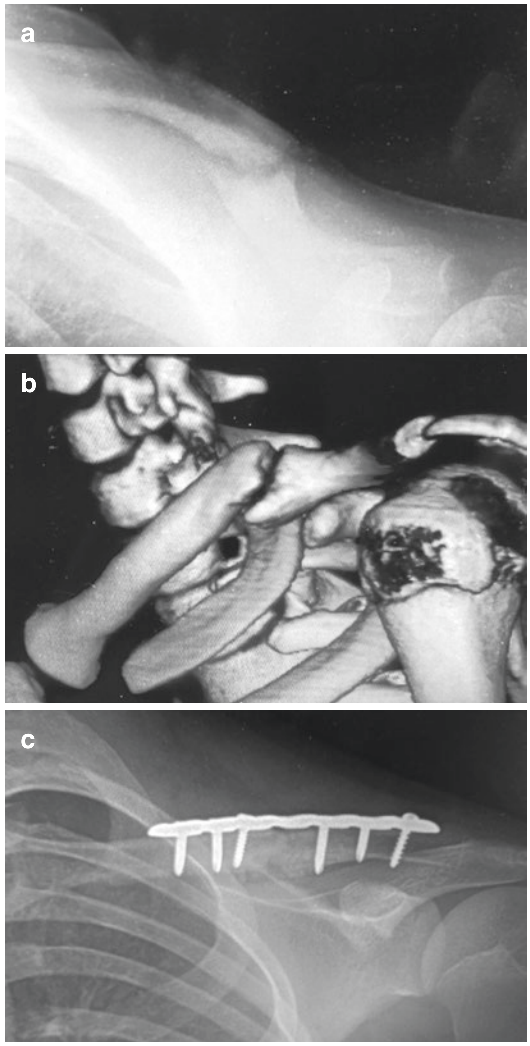

Fig. 8.6 A 13-year-old male with an 8-month-old clavicle nonunion. (**a**) AP with 10° tilt and (**b**) CT scan 3D reconstruction demonstrate no bridging callus. (**c**) AP radiograph of clavicle after locking plate fixation and autogenous bone grafting

Proximal Humerus Fractures

Fractures of the proximal humerus in the skeletally immature athlete usually occur at the physes. These fractures may be missed on routine AP views; therefore, a standard trauma series consisting of AP, scapula Y, and axillary lateral views should be obtained when evaluating any patient with a suspected shoulder injury. Salter-Harris type II fractures are most commonly seen (Fig. 8.7a–c). These fractures have tremendous remodeling capability and are typically treated nonoperatively in a sling and swathe. Proximal humerus fractures with associated lytic areas likely represent a simple bone cyst that should be evaluated further. Unstable or significantly displaced fractures require closed reduction and percutaneous pinning. If a closed reduction is not possible, then open reduction should be performed as soft tissue interposition of the biceps tendon in the fracture site has likely occurred. A sling and swathe for 3–4 weeks and early range of motion will result in return to play as early as 8 weeks.

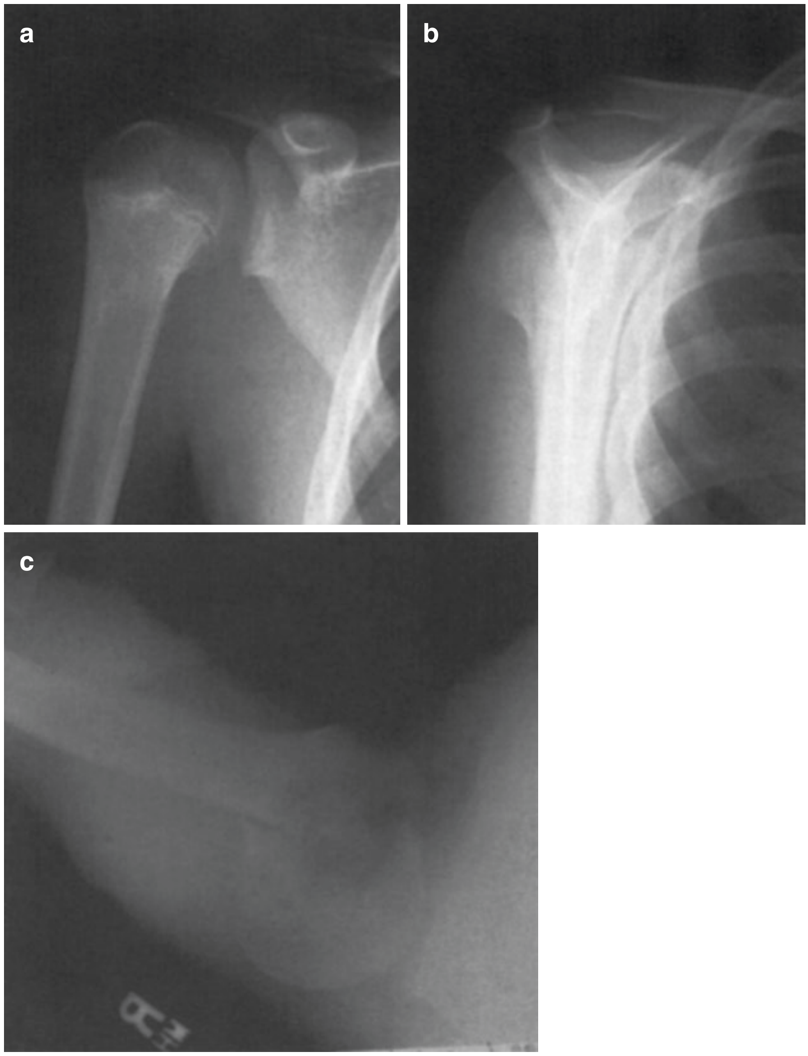

Fig. 8.7 A 12-year-old basketball player with severe pain after a fall onto an outstretched arm. (**a**) AP radiograph and (**b**) scapula Y views are nondiagnostic for injury. (**c**) Axillary lateral view shows obvious Salter-Harris fracture of the surgical neck

Glenohumeral Dislocation

Glenohumeral instability encompasses a wide spectrum of shoulder disorders. A discussion of glenohumeral instability requires proper classification by the physician, distinguishing between an actual dislocation, a subluxation episode, and a subtle microinstability. The instability pattern must then be characterized as anterior, posterior, or multidirectional in nature. Finally, the etiology of the instability should be defined as traumatic or atraumatic. Patients with an atraumatic etiology should then be further classified as exhibiting involuntary versus voluntary instability. Only after the shoulder disorder is properly classified will the physician be able to accurately diagnose and treat the young athlete.

Shoulder dislocations and subluxations are common in the older adolescent athlete, and their frequency approaches that of adults. The extreme degree of mobility seen in the glenohumeral joint is likely to blame. Furthermore, the elastic nature of the immature, capsuloligamentous structures can exacerbate the problem. On the contrary, athletes younger than 10–12 years of age rarely sustain a true dislocation; instead, they are more likely to have a fracture at the weaker, open proximal humeral physis [23].

Traumatic instability typically develops after a fall or injury with the arm in an abducted and externally rotated position. Anterior instability is the most common pattern. Traumatic injuries may result in tears or plastic deformation of the capsuloligamentous structures and/or labrum. The anterior-inferior glenohumeral ligament and labrum are the most commonly injured structures and are termed Bankart lesions. Numerous investigators have studied these injuries and have noted the high recurrence rate for anterior shoulder instability in this age group. Marans et al. reported the results of 21 adolescent patients with traumatic anterior shoulder dislocations and reported a recurrence rate of 100% [24]. Deitch et al. retrospectively evaluated the outcome in 32 patients between the ages of 11 and 18 years with radiographically documented anterior shoulder dislocations. All patients were immobilized from 1 to 8 weeks, and 24 of them received supervised physical therapy. Nonetheless, instability recurred in 75% of patients [25]. A study by Kirkley et al. found a recurrent dislocation rate of 60% in first-time dislocators under the age of 30 years [26].

Athletes sustaining an acute, traumatic anterior dislocation will often hold the affected extremity in an abducted and externally rotated position. A prominence in the anterior joint region and hollow space in the posterior subacromial area are often present. The axillary nerve may be injured, and it should be thoroughly evaluated before initiation of any treatment. Radiographs should be obtained for anyone suspected of having a dislocation or subluxation event. These studies should include the standard shoulder trauma series mentioned previously, and they should be performed before any reduction. This is particularly important in the skeletally immature child who is more likely to have a physeal fracture that clinically mimics a dislocation. Post-reduction radiographs should always be obtained to confirm an adequate reduction. If the diagnosis remains in doubt, a magnetic resonance arthrogram (MRA) can be quite useful to detect capsulolabral injuries, occult glenoid fractures (bony Bankart lesions), and posterior or anterior humeral head impaction fractures (Hill-Sachs and reverse Hill-Sachs lesions). MRA is also useful in detecting the less common humeral avulsion of the glenohumeral ligament (HAGL lesion).

Posterior dislocations are seen far less frequently than anterior dislocations. There is no available data to determine the exact incidence of this injury in the adolescent population; posterior dislocations in children are limited to case reports only [27]. Posterior shoulder instability most frequently occurs in a position of forward flexion above 100°, with the shoulder in mild internal rotation and slight adduction. This position is commonly achieved in weight training, hockey, and blocking in football. These injuries may also follow a direct blow to the anterior aspect of the shoulder as occurs with contact sports. Posterior dislocations are more difficult to diagnose on clinical exam. The arm is usually held across the body in full internal rotation and adduction. These patients will have pain with any attempts at motion and have an inability to externally rotate. These forms of instability can be missed by x-ray unless an axillary view is obtained.

The treatment for athletes with shoulder instability continues to evolve. There is controversy surrounding the treatment of first-time dislocations, the timing of in-season dislocations, the type of operative treatment for optimal stabilization, and the treatment of recurrent dislocations. Many first-time "dislocators" are initially placed in a sling, for comfort, and are counseled regarding the natural history of this injury and high incidence of recurrent dislocations in this young, athletic population. Conservative management is directed toward restoring full range of motion and strength through a supervised physical therapy program. Emphasis is placed on rotator cuff and periscapular strengthening. Overhead athletes should progress through an interval throwing program before returning to play [28]. There have recently been some reports of decreased recurrence rates treating first-time dislocators in an external rotation sling [29]. Although this technique is promising for initial nonsurgical management, some studies have challenged this. In addition, patients often find this to be a challenging position in which to be immobilized.

There are some surgeons who have advocated a more aggressive approach to treating first-time shoulder instability. A prospective randomized study has shown a decrease in recurrence rates in those patients stabilized operatively after an initial dislocation [30, 31]. In addition, studies have shown that patients suffering even one dislocation have a higher rate of subsequent glenohumeral osteoarthritis [32].

In collision and contact athletes with anterior instability involving their dominant arm, and for those athletes with recurrent anterior or posterior instability, surgical stabilization is a consideration. Treatment is tailored to each athlete, with some midseason athletes being allowed to return to play upon regaining full motion and strength, with the plan to proceed with surgery upon completion of the season. It has been shown that athletes can return to finish their season. However, they are at risk for further dislocation or subluxation [33].

Early surgical repair can be considered for collision, contact, and throwing athletes sustaining an acute anterior dislocation in the dominant shoulder [31]. This treatment approach reflects the findings of studies demonstrating significantly reduced re-dislocation rates with operative stabilization when compared to nonoperative measures. Lawton et al. performed a retrospective review of 70 shoulders in 66 patients, aged 16 years and younger, with shoulder instability [28]. At a 2-year follow-up, those individuals treated with conservative management including physical therapy had a 60% success rate, whereas 40% went on to have surgery. In the surgical group, 90% felt they were performing at the same or higher levels of competition and work. Bottoni et al. also recommended surgical stabilization for their series of young patients with acute, traumatic, first-time anterior shoulder dislocations [31]. They noted that of the 12 patients treated nonoperatively, 9 went on to have recurrent instability (75%), whereas only 1 out of 9 treated operatively (11%) recurred. These studies emphasize the need for further large, long-term studies of this injury [34].

There remains controversy regarding optimal surgical treatment. The majority of these injuries may be corrected through an arthroscopic approach. Certain factors can optimize chances of success with an arthroscopic repair, including having more than two points of suture anchor fixation, posterior labral stabilization, and addressing the capsule at the time of labral repair [35].

An open approach should be considered for those contact athletes with bony Bankart lesions and/or large impaction fractures (Hill-Sachs deformities) of the humeral head. In addition, patients who have failed prior arthroscopic repair may be considered for open treatment as well. Other candidates for open repair are those patients with bony lesions after recurrent instability. Open repair can consist of an open capsular shift as popularized by Neer [36], or a Latarjet bone-block reconstruction [37].

Significant glenoid and humeral bone loss has been shown to be a risk factor for failure of arthroscopic shoulder stabilization. There is an emerging concept of describing glenohumeral defects as “off-track” and “on-track,” referring to the degree of bipolar bone loss with recurrent instability. “Off-track” shoulders, in which the Hill-Sachs lesions engage with the glenoid defect, are at risk for recurrent dislocation if the bony issues are not addressed [38, 39]. In this case, the bone loss must be corrected. General guidelines for arthroscopic repair include glenoid defects <15% of the total width. If there is a bony lesion of greater than 25% or a large fracture, then an ORIF or Latarjet procedure should be considered [40].

After surgery, the patient is placed in a sling and swathe for 2–4 weeks. Physical therapy for passive range of motion is begun the first week after surgery and is slowly progressed until full motion is achieved by 12 weeks. Strengthening is begun on the second visit and steadily progressed over the ensuing 12 weeks, at which point more sport-specific activities are emphasized. Progressive weight training continues, and the athlete is allowed to return to collision or contact sports after a minimum of 4 months if all goals have been met. Overhead athletes, and pitchers in particular, may require 6–9 months to return to play.

SLAP Lesions

Injuries to the biceps-superior labrum complex can occur from a variety of occurrences, including falls on an outstretched arm, traction pulls from lifting, a direct blow to the shoulder, and overuse [41–43]. These injuries have been termed “SLAP” lesions, describing their “superior labral anterior-posterior” location. Tennis, volleyball, baseball, and windmill softball pitchers are all at risk of developing a SLAP injury over time. These injuries are rare in the young athlete, but their incidence increases in late adolescence.

Athletes with a SLAP injury will often complain of pain in either the anterior or posterior aspect of the shoulder, usually during the later cocking and early acceleration phases of throwing [44–46]. They occasionally describe a “clicking” or “catching” sensation, and the active compression or “O’Brien” sign is often positive. Posterior capsule contracture is the most common cause for shoulder pain in the young overhead athlete, and it can accompany labral injuries. Internal rotation should therefore be assessed and compared to the contralateral shoulder.

Plain radiographs are typically normal. If the clinician strongly suspects the presence of a labral injury, a MR arthrogram of the shoulder may be useful. Connell et al., utilizing conventional MRI and using arthroscopy as the gold standard, concluded that MRI had a sensitivity of 98%, specificity of 89%, and an accuracy of 95% for detection of superior labral tears [47]. However, this level of accuracy has been difficult to reproduce by other clinicians [48], and these findings can be seen in asymptomatic overhead athletes [49, 50].

Initial treatment for SLAP injuries consists of an initial course of relative rest and early physical therapy [46, 51]. Patients sustaining a SLAP lesion secondary to a compressive injury, such as a fall onto an outstretched arm, should avoid closed chain exercises to minimize compression and shear stresses to the healing labrum. Patients with a peel-back mechanism should avoid excessive external rotation while the lesion is healing. However, they may need stretching of a tight posterior capsule [13]. The “sleeper stretch” is useful for stretching a tight posterior capsule and may be performed supine or standing (Fig. 8.8).

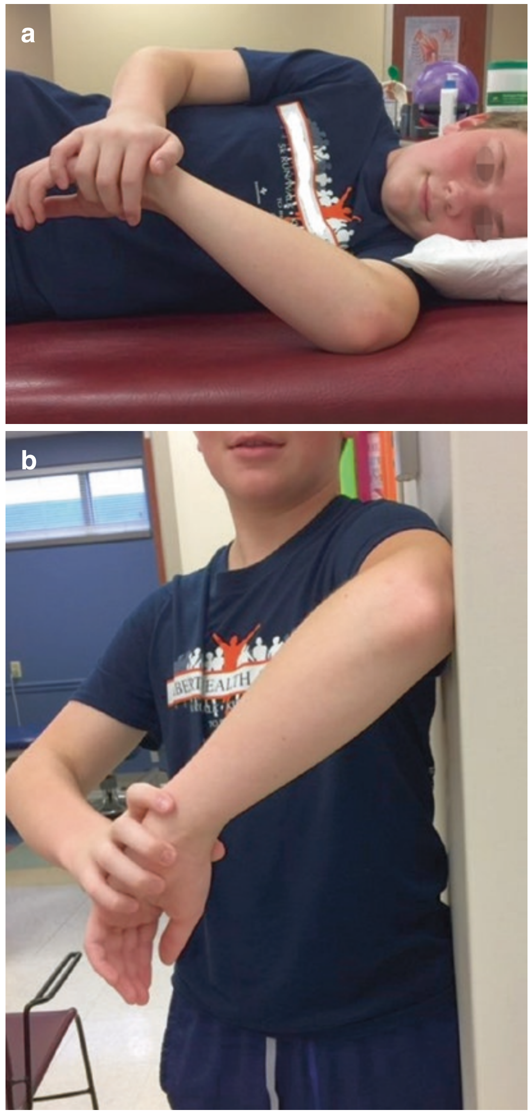

Fig. 8.8 Posterior capsule contracture may be addressed with a “sleeper stretch” in the lateral decubitus position (**a**) or while standing against a wall (**b**)

There are seven key exercises we utilize in the early stages of shoulder rehabilitation for the scapula and rotator cuff musculature: seated press-ups, push-up plus, rows, scaption, side-lying external rotation, prone shoulder extension with external rotation, and prone horizontal abduction with external rotation [52–54]. When painless range of motion and full strength are achieved, the athlete is progressed to a “reentry to sport” program, documenting the number of throws, swimming yards, or tennis strokes and the athlete’s response to these sessions. Pain before and during activity necessitates a return to rehabilitative activities, whereas pain after activity that resolves in a few hours with cryotherapy allows the athlete to continue through the program.

Athletes that have failed an adequate course of conservative treatment may require surgical treatment. Partial, stable tears of the superior labrum should be debrided, whereas complete, unstable tears are repaired. Repair usually involves arthroscopic stabilization of the repair using suture anchors. Care must be taken not to overtighten the shoulder, as this can negatively impact a throwing athlete. Physical therapy will usually parallel the nonoperative rehabilitation program. A return to overhead sports is prohibited for a minimum of 4–6 months post-operatively.

Rotator Cuff Injury

The incidence of complete rotator cuff tears in the adolescent population has been reported to be as low as 0.8–1.0% of patients of all ages diagnosed with a cuff tear [55, 56]. This low rate is attributed to the absence of degenerative changes in the tendon, as is often present in the elderly. Perhaps more importantly, the tensile strength of the young, healthy tendon is greater than bone. This explains the still infrequent, but more common, finding of an avulsion fracture of the greater or lesser tuberosity after a traumatic injury [57]. Because of the physiology of the young shoulder, pitchers may also develop a "Little Leaguer's shoulder" rather than an isolated cuff tear [58]. Young pitchers will occasionally sustain an overuse rotator cuff tear; however, the injury is typically preceded by a more traumatic event [46, 47, 59, 60].

Physical exam will reveal pain with impingement testing and weakness of the rotator cuff, most commonly the supraspinatus tendon. Tenderness over the greater or lesser tuberosity may also be present. The patient should also be evaluated for a concomitant labral injury. Routine radiographs, including AP, scapula Y, and axillary lateral views, should be obtained. MRI is reserved for those athletes with persistent, atypical pain or weakness after a fall, or those failing a protracted course of conservative treatment. It is quite useful for diagnosing supraspinatus and infraspinatus tears; however, accurate diagnosis of small subscapularis tears remains problematic.

Rotator cuff strains and small, partial-thickness tears should initially be treated conservatively. This treatment should include a physical therapy program focusing on rotator cuff and scapular strengthening, as previously mentioned. The athlete should be restricted from overhead sporting activities. An initial course of nonsteroidal anti-inflammatory medication may be helpful. Restoration of a swimmer or thrower's range of motion, rotator cuff and scapular strength and endurance, and an elimination of pain are achieved before a return to overhead activities.

Surgical intervention is reserved for those patients who have failed a long course of conservative treatment or those athletes with MRI confirmation of a full-thickness rotator cuff tear. Surgery should begin with a thorough examination under anesthesia, followed by diagnostic arthroscopy. Partial-thickness tears estimated to be <30–40% in thickness at the time of arthroscopy may be debrided, whereas larger tears should be repaired. In the rare event that a complete rotator cuff tear is encountered in an adolescent, it should be repaired. If no rotator cuff tear is seen at the time of arthroscopy, a secondary impingement syndrome because of underlying instability is likely. In this setting, a selective arthroscopic capsulorrhaphy and subacromial bursectomy are performed, as described below. A selective capsular plication technique is recommended to address the instability.

Chronic Overuse Shoulder Injuries

Overuse injuries of the shoulder continue to plague youth and adolescent athletes. Numerous studies show that repetitive injuries are extremely common. Makhni et al. found that 23% of youth baseball players in their study group had a previous overuse injury [61]. Fleisig et al. showed in a 10-year prospective study that there is an approximately 5% chance of developing a serious injury

Table 8.2 Maximum pitch counts and required rest periods

		Required	Rest	Pitches		
Age	Daily maximum pitches	0 Days	1 Day	2 Days	3 Days	4 Days
7–8	50	1–20	21–35	36–50	N/A	N/A
9–10	75	1–20	21–35	36–50	51–65	66+
11–12	85	1–20	21–35	36–50	51–65	66+
13–14	95	1–20	21–35	36–50	51–65	66+
15–16	95	1–30	31–45	46–60	61–75	76+
17–18	105	1–30	31–45	46–60	61–75	76+

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that required shoulder or elbow surgery or retirement from throwing [62]. Overuse correlates very strongly with injury. Pitchers who threw more than 100 innings per season had a 3.5 times higher rate of injury than those who did not throw more than 100 innings [62]. In softball, Skillington et al. found an increase in shoulder fatigue, pain, and weakness in those players who pitched in consecutive games [63]. Early sports specialization has been seen to be an independent risk factor in adolescents participating in sports, even after adjusting for age and number of hours playing [64].

With the growing awareness of the dangers of overuse injuries, there is an increasing awareness of the need to restrict activity in youth sports. Guidelines have been put into place to limit the number of pitches in a game. In addition, there are now recommendations regarding required days of rest between pitching outings (Table 8.2).

Fig. 8.9 Radiograph of Little Leaguer's shoulder. A 13-year-old Little League pitcher with onset of pain after routine pitch late in season. Note widening of the physis, with fragmentation along the lateral aspect

Little Leaguer's Shoulder

Little Leaguer's shoulder describes a clinical entity characterized by pain with throwing, in conjunction with radiographic evidence of widening of the proximal humeral physis (Fig. 8.9). This condition is typically the result of overuse in the overhead athlete, particularly pitchers. These athletes will often have mild shoulder pain for several months that increases dramatically while pitching in a game [65].

They will have tenderness over the proximal humerus and may have associated swelling. Pain and weakness are noted with resisted abduction and external rotation. Radiographs of the contralateral shoulder are useful to confirm subtle physeal widening. If the diagnosis remains questionable, a bone scan may be useful for revealing increased, asymmetric uptake in the involved proximal humerus.

The development of Little Leaguer's shoulder appears to result from the extreme, repetitive force placed across the proximal humeral physis in these young athletes. Mair et al. found that the increased external rotation and shear stress arising from the throwing motion causes adaptive changes to the proximal humeral epiphysis [66]. Furthermore, Sabick et al. used a biomechanical study to demonstrate how shear stress arising from the high torque in late cocking is large enough to lead to deformation of the weak proximal humeral epiphyseal cartilage, causing either humeral retrotorsion or proximal humeral epiphysiolysis over time [5]. Recent studies have found a correlation between Little Leaguer's shoulder and glenohumeral rotational deficit [67].

Treatment is nonsurgical and includes rest and gentle range of motion. As the pain resolves, a light rotator cuff strengthening program is begun. Pitching is not allowed for a minimum of 6–8 weeks, or until all pain has resolved. A supervised throwing program is begun, and improper pitching mechanics are corrected. If any symptoms return, the throwing program is discontinued for an additional month.

Long-term consequences are rare; however, premature physeal closure with resultant humeral length discrepancy or deformity and physeal fractures have occurred [68]. Proximal humeral epiphysiolysis or osteochondrosis of the proximal epiphysis should be sought in the skeletally immature pitcher. This condition is distinguishable by the radiographic signs of avascular necrosis or fragmentation of the proximal epiphysis in the presence of a normal-appearing physeal plate [58]. This condition is rare and has a less predictable outcome.

Glenohumeral Instability

Glenohumeral subluxation often follows a single traumatic event (recurrent traumatic instability), but may also occur as a result of overuse in the overhead athlete (atraumatic, microinstability). Young athletes with generalized laxity and no history of trauma will frequently demonstrate multidirectional instability (atraumatic MDI). Overhead athletes with multidirectional instability will commonly complain of soreness, fatigue, decreased velocity, and a decline in accuracy. Capsulolabral tears are not as commonly seen in this subgroup of athletes, and their symptoms tend to be a product of rotator cuff imbalance, overuse, and improper technique. These athletes usually present with complaints caused by secondary impingement resulting from their instability. They will occasionally relate a subluxating episode and, less frequently, have a true dislocating event [28]. Athletes experiencing subluxating events will complain of pain and "slipping" or "popping" of their shoulder. Occasionally they will describe a "dead arm" sensation after a particular throw. This sensation is brief in duration and usually precludes further pitching that day.

Athletes with recurrent subluxations or multidirectional instability (MDI) should initially be treated with 4–16 weeks of activity modification, specifically avoiding overhead throwing activities. A supervised physical therapy program focusing on rotator cuff and periscapular strengthening is begun immediately. Strengthening of the trunk and lower extremities is often neglected and should be addressed. Pitchers should be evaluated for a posterior capsular contracture, and an appropriate stretching program should be begun if present. As symptoms subside, a return-to-play program should be utilized that will ensure a slow, progressive, and safe return to functional activities. If the patient is an overhead athlete, their technique should be evaluated and corrections made before a return to their respective sport. Surgical intervention is rarely needed in this age group, particularly middle school athletes. However, when older adolescent athletes do not respond to this treatment regimen, a selective capsulorrhaphy (capsular suture plication), addressing only the capsuloligamentous structures contributing to the instability pattern, may be warranted [69]. It is imperative to first rule out a posterior capsular contracture (GIRD) as the cause of their symptoms and treat it accordingly. Superior labral tears (SLAP lesions) may also occur in this patient group and may be repaired if encountered at the time of surgery. The post-operative regimen for these athletes is similar to that described for glenohumeral dislocations, with the exception of return to play typically requiring 6–9 months in the multidirectional instability group.

SLAP Lesions/Internal Impingement/ Glenohumeral Rotation Deficit

Several theories have been proposed to explain the etiology of overuse-related SLAP injuries. Adolescent athletes demonstrate a significant amount of joint laxity, which may manifest as increased external rotation, particularly in throwing athletes [15]. Studies have shown the highest strain rate on the superior labrum to occur during the late cocking position (maximum external rotation) [70, 71]. Overhead athletes with increased external rotation in the presence of subtle instability have been found to be at risk of developing a biceps-labral complex tear [72–76]. Biomechanically, when a pitcher over-rotates (excessive ER) or horizontally abducts his shoulder in early and late cocking, shear stress develops that can damage the superior biceps-labral complex. In addition, pitchers with less than a 180° arc of internal/external rotation are particularly at risk for SLAP injury. Poor mechanics combined with posterior capsule contracture, underdeveloped musculature, or fatigue (overuse) adversely affects the dynamic stability, leading to shoulder injuries and SLAP lesions in particular [73, 76, 77].

Overuse SLAP lesions may not be entirely caused by overhead forces. Windmill softball players are also at increased risk of developing this injury despite using an underhand windmill technique. These athletes typically present with hyperlaxity or even MDI. Most notable in females, windmill softball pitchers have been found to develop distraction forces across the glenohumeral joint that are 94% of body weight [16]. This distraction force occurs as the momentum created by the windmill motion results in the arm being pulled away from the body immediately after ball release. This mechanism of injury was demonstrated by Bey et al. through the creation of unstable SLAP lesions in seven out of eight cadaveric shoulders when combining traction and inferior subluxation, as occurs during a typical windmill pitch [78]. This mechanism of injury should be remembered when examining the young softball pitcher with persistent shoulder pain.

There is also evidence that glenohumeral internal rotation deficit (GIRD) plays a role in the development of SLAP tears. Burkhart el al. [73] believe decreased internal rotation (GIRD) leads to the humeral head translating superiorly during the acceleration phase of the pitch, leading to increased forces on the superior labrum. The posterior contracture is thought to be the result of deceleration forces generated across the posterior-inferior aspect of the shoulder after ball release. The risk of developing such a contracture increases with repetitive throwing [77].

Throwing a baseball, softball, or football can cause shoulder dysfunction caused by the high rotational velocities and torques generated at the glenohumeral joint. Other sports, such as volleyball, tennis, and swimming, have unique biomechanics, but similar injury patterns. However, *internal impingement* is one overuse injury that tends to affect a disproportionate number of baseball pitchers. The exact etiology of this injury is debated, but it may represent a combination of injuries, including superior labral tears, rotator cuff injury, posterior capsule contracture, and anterior instability [79]. These athletes complain of pain while throwing and note a decrease in control and speed with their pitches. They will also occasionally complain of a "dead arm" sensation [5]. On physical exam they will have a positive apprehension relocation test, pain with resisted external rotation, and a positive O'Brien sign. Internal rotation is often limited as well and should be compared to the contralateral shoulder.

Conservative management follows those principles discussed for anterior instability and SLAP lesions. Once the overhead athlete regains painless full range of motion and rotator cuff strength, they may progress through an interval throwing program. Once completed, the athlete undergoes biomechanical analysis. Recommendations should be made providing specific drills to correct biomechanical issues. The athlete must complete all aspects of the conservative management program before returning to competition.

Absolute indications for operative treatment include MRI evidence of an unstable SLAP lesion or full-thickness rotator cuff tear. Both of these indications are relatively rare in the skeletally immature athlete. Relative indications include failure of 4–6 months of conservative treatment as outlined. SLAP injuries are surgically treated as previously discussed. Partial-thickness rotator cuff tears <50% in thickness are debrided, and larger tears are repaired. Repair of the SLAP lesion will typically address any concomitant instability. Some authors feel a selective anterior-inferior capsulorrhaphy should be performed as well [80]. However, before any capsulorrhaphy is considered, the surgeon should first ensure that a posterior contracture is not present. In these instances, it may be necessary to address posterior capsular contracture with a posterior-inferior capsule release if they have failed an appropriate posterior capsule stretching program [77]. The post-operative course is similar to that described for SLAP lesions and anterior instability. The basic principles of therapy are directed toward achieving full range of motion, full strength, no swelling, and no pain. This will create a foundation for the athlete to begin a functional exercise progression. Sports-specific activities and interval throwing programs will then enable the athlete to return to their preinjury level of function, often requiring 6–9 months for the overhead athlete.

"Secondary" Impingement Syndrome

The adolescent shoulder may be more susceptible to overuse injuries than the adult shoulder. Smaller muscle mass, decreased muscular endurance, and increased tissue laxity may lead to microtraumatic injuries. The overhead athlete is particularly susceptible to this mechanism of injury. These athletes often participate in daily practices or games and may play on more than one team during the course of the year—a perfect recipe for overuse injuries. Characteristically, overuse injuries are manifested as "secondary" impingement in the subacromial space. Here, contact between the superior humeral head and inferior surface of the acromion process can inflame the bursa, rotator cuff, and bicep tendon. This abnormal contact occurs when the static and dynamic stabilizers are no longer able to properly balance the glenohumeral joint. Glenohumeral instability is the most common cause for this imbalance. Athletes demonstrating generalized joint laxity are particularly susceptible and will often develop MDI that is frequently mistaken for pure "outlet" impingement. These athletes appear to primarily have a rotator cuff injury when, in reality, their rotator cuff symptoms are a result of underlying instability. If the laxity and subsequent instability are not recognized and addressed, the rotator cuff is placed at a disadvantage by performing activities related to overhead motion, while concomitantly maintaining congruency of the glenohumeral joint [76]. As the instability continues, more demands are placed on the rotator cuff, resulting in inflammation with possible progression to an undersurface tear over time.

The young athlete will nearly always describe a history of repetitive overhead throwing, serving, or swimming. If such a history is not offered, it should be pursued with questions pertaining to number of practices and competitions per week, the duration of sport-specific training, number of teams they participate on, and number of pitches, serves, or laps performed leading up to or immediately preceding the injury. Patients will complain of anterolateral shoulder pain that increases with overhead activities. On exam, they demonstrate pain with provocative impingement testing, although significant weakness is not typically found [68]. The apprehension and relocation exam is usually abnormal, prompting further evaluation with load and shift testing. A positive sulcus sign is also helpful for detecting underlying MDI. Standard radiographic studies are typically normal. Patients that have not responded to an appropriate conservative treatment program or are suspected of having a rotator cuff tear may require MRI evaluation. Increased signal in the subacromial space and distal supraspinatus tendon is not uncommon and may represent tendonitis and impingement; however, false positives in the overhead athlete are common.

Rotator cuff impingement in the young adolescent will typically respond to 4–16 weeks of conservative therapy. Many of the athletes have underlying instability of the glenohumeral joint, and therefore the treatment program is identical to that discussed in the instability section. A gradual reentry to sport program is initiated, documenting the number of throws, swimming yards, or tennis strokes and the athlete's response to these sessions. Pain before and during activity necessitates a return to rehabilitative activities, whereas pain after activity that resolves in a few hours and with cryotherapy allows the athlete to continue through the program. A baseball or softball player that is asymptomatic while batting but develops pain during throwing will often respond to conservative management. When following an appropriately designed conservative rehabilitation program, these athletes may demonstrate improvements with as few as 4–6 treatments.

Surgery is considered only after the patient has shown no improvement after a minimum of 6 months of conservative treatment. Surgery entails an exam under anesthesia, followed by a diagnostic arthroscopy. Tears of the labrum and rotator cuff are treated as previously described. In the presence of a relatively normal arthroscopic exam, but clinical instability, a selective capsulorrhaphy is performed addressing only the area of instability. A suture plication technique is preferred. A subacromial bursectomy is often helpful, but an acromioplasty is not indicated in this age group.

Prevention

Returning the injured overhead athlete to their preinjury level of competition can be difficult at times. Unfortunately, numerous studies focusing on the normal mechanics in baseball and windmill softball pitching found the shoulder undergoes potentially damaging forces on every pitch [5, 16, 80]. It is therefore critical to prevent injury from occurring, rather than treat it after the fact. Numerous studies have been conducted to determine effective measures to prevent injuries in the overhead athlete. Lyman et al. found young pitchers had a lower incidence of injury when they were limited to throwing no more than 75 pitches per game and 600 pitches per season [2]. Curveballs, sliders, screwballs, and forkballs are associated with higher incidence of injury and should be discouraged in children under 14–15 years of age. In addition, young pitchers should be removed from the game if demonstrating any signs of fatigue and should not be allowed to participate in more than one league at a time [2]. Proper pitching mechanics should be taught early and year-round conditioning encouraged, with emphasis also placed on core strengthening and posterior capsule stretching for pitchers in particular [80].

There are several critical instants during overhead throwing motions, and some are shared by baseball, football, and softball. Core and leg strength is of critical importance. Balance point, occurring at the end of the wind-up phase, is unique to baseball pitching. If the pitcher does not achieve a solid balance point, the legs and trunk will not be in sync with the upper extremity, placing greater stress on the shoulder and elbow to achieve ball velocity. Keeping the hand on top of the ball during the early cocking phase and restricting the arm from moving behind the body in late cocking minimizes the stress placed on the anterior capsule and is a characteristic shared by all three sports. Taking an adequate stride length is also important. This ensures that the legs and trunk are in sync with the arm and the athlete can take advantage of the explosiveness of the body to impart force to the ball with the least amount of stress to the shoulder. This underscores the importance of lower extremity and core strengthening in the adolescent overhead athlete.

Return-to-Play Guidelines

Adolescent athletes must achieve certain clinical or impairment goals before completing a functional exercise progression. This includes achieving full range of motion at the shoulder and thrower's range of motion in the overhead athlete. They must demonstrate full strength throughout the rotator cuff, scapula, and prime movers of the shoulder girdle, as well as core and lower extremity strength and power. Pain and effusion must be eliminated. The functional exercise progression consists of sports-specific activities and practice drills that will mimic the stresses the athlete will encounter in competition. For the overhead athlete, an interval throwing program, or long toss program, must be completed for position players, and an additional mound interval throwing program must be completed for pitchers. The athlete must also demonstrate appropriate mechanics for their respective sport to minimize the risk of reinjury and to enable them to achieve peak performance. Achievement of all the impairment goals and completion of the interval throwing program will ensure that the athlete can return to full competition as quickly and safely as possible, with minimal risk for reinjury.

Clinical Pearls

- There are numerous conditions that can affect the adolescent athlete's shoulder.
- Overuse injuries occur more frequently than acute, traumatic injuries. Most of these injuries can be prevented.
- When an injury does occur, early recognition and conservative care will allow a safe return to sport in the majority of cases. Conservative treatment revolves around a well-structured and supervised physical therapy program for many of these injuries.
- Sport-specific return-to-play programs enable a safe and efficient return to competition and a long, healthy career.
- When surgical intervention is needed, recent advances in surgical techniques allow the majority of procedures to be performed arthroscopically.
- The sports medicine specialist is in a unique position to educate coaches, parents, and athletes on preparation, prevention, training, and participation to minimize the risk of shoulder injury.

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Elbow and Forearm Injuries

9

Anthony Luke, Margaret Lo, and Marc R. Safran

Introduction

The elbow and forearm create a fascinating joint complex. It is a highly congruous joint that provides a wide range of motion required for function, including sports, yet is inherently stable. The adolescent athlete has the added dimensions of growth and development, which can affect forces around the joint, motor function and can be the source of multiple potential problems [1]. The elbow has a complex maturation process, developing from multiple ossification centers, which can complicate the diagnosis and treatment of injuries. As a growing individual is able to perform with greater speed, strength, and endurance, the loading forces, torques, and risk of injury increase [2, 3].

Injuries to the elbow and forearm can result from overuse or acute trauma. Throwing sports, such as baseball [4], lead to frequent elbow problems. Overuse elbow injuries are also commonly seen in athletes who use the upper extremities and are involved in repetitive training, such as gymnastics [5, 6], weight lifting, tennis [1, 7], and golf [8]. Trauma, typically a fall on the outstretched arm, can result in fractures and dislocation. Fractures in the upper extremity in children most frequently involve the radius and ulna, followed by the hand and carpal bones and then the distal humerus [9].

Anatomy

Bony Anatomy

The elbow joint is made up of the articulations between the humerus, ulna, and radius. The forearm is composed of the radius and ulna with its proximal and distal articulations, as well as its overlying muscles and soft tissue structures. The distal humerus has two major articulating surfaces: the trochlea, which articulates with the coronoid and olecranon of the ulna, and the capitellum, which opposes the radial head. The elbow joint can be divided into three articulations: (1) the radiocapitellar joint, (2) the ulnohumeral joint, and (3) the proximal radioulnar joint. The ulnohumeral joint allows flexion and extension, while the radiocapitellar and radioulnar joints allow supination and pronation of the forearm,

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L. J. Micheli, L. Purcell (eds.), *The Adolescent Athlete*, Contemporary Pediatric and Adolescent Sports Medicine, https://doi.org/10.1007/978-3-319-56188-2_9

with the radius pivoting around the ulna. The bony hinge of the elbow provides osseous stability with its greatest contribution below 20° and greater than 120° of flexion, while between these ranges, the ligaments and capsule provide greater degrees of contribution stability [10]. Children often demonstrate hyperextensibility of the elbow associated with capsular and ligamentous laxity [11, 12].

Ossification Centers

The growth plates are areas of vulnerability from traction or shearing forces which makes the elbow vulnerable to fracture and apophyseal injuries. The development of the elbow occurs from multiple ossification centers that follow a predictable order of formation. This pattern of growth can help assess bony maturity, based on their appearances on X-ray [13]. They appear in the following order: **C**apitellum (age 1–2 years), **R**adial head (age 3 years), **I**nternal (medial) condyle (age 5 years), **T**rochlea (age 7 years), **O**lecranon (age 9 years), and External (lateral) epicondyle (age 10 years in girls and 11 years in boys) (mnemonic **CRITOE**) (Fig. 9.1). The medial epicondyle apophysis begins to ossify then fuse at approximately 7 years and 15 years of age for males and 4 years and 13 years of age for females [14]. Eighty percent of the growth of the humerus occurs at the proximal end. Therefore, there is less potential for remodeling at the elbow if fractures should occur at the distal humerus [12].

Ligament Complexes

On the medial aspect of the elbow, the ulnar collateral ligament (UCL) complex is composed of three ligaments: anterior oblique, posterior oblique, and transverse (Fig. 9.2). The anterior oblique ligament is functionally divided into anterior and posterior bands. The anterior band is responsible for most of the stability of the elbow and is most prone to injury with acute or repetitive valgus strain.

On the radial side of the elbow, the lateral collateral ligament (LCL) complex is composed of the radial collateral ligament (RCL), the lateral ulnar collateral ligament (LUCL), the accessory lateral collateral ligament (ALCL), and the annular ligament (AL) which wraps around the radial head [15]. The LCL complex is the main ligament responsible for withstanding varus and external rotatory stress in the elbow. The LUCL has been shown to help control posterolateral rotatory motion about the elbow [16]. Injuries involving the LCL at the humeral insertion primarily involving the LUCL and the RCL produce maximal rotatory instability [17, 18].

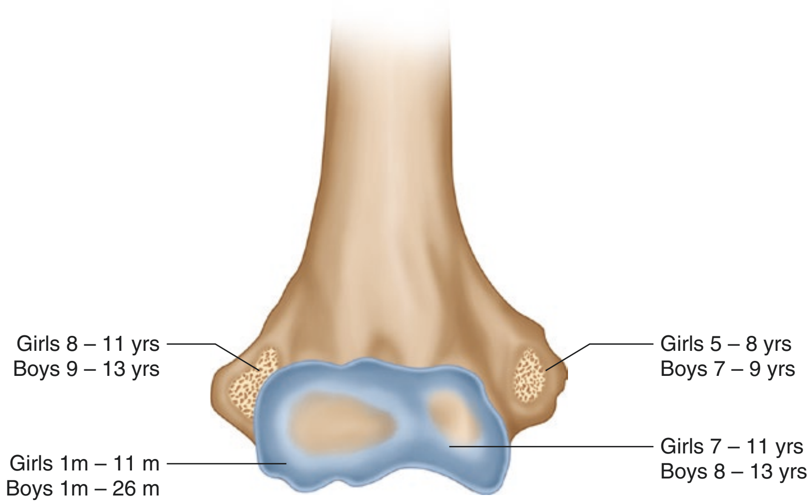

Fig. 9.1 Elbow ossification centers and their roentgenographic appearance according to age (From Bradley JP. Upper extremity: elbow injuries in children and adolescents. In: Stanitski CL, DeLee JC, Drez D Jr, eds. Pediatric and adolescent sports medicine, Vol 3. Philadelphia: WB Saunders, 1994: 244, with permission)

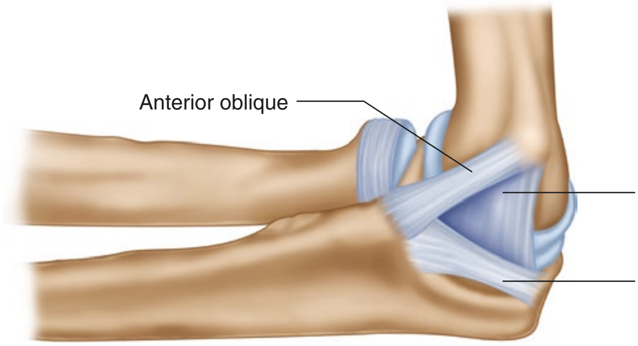

Fig. 9.2 The ulnar collateral ligament complex (From Safran MR. Elbow injuries in athletes: A review. Clin Orthop 310: 260, 1995, with permission)

Muscle Tendon Units

Muscles that cross the elbow contribute a compressive joint reaction force. The joint reactive forces of the anterior and posterior muscles (biceps, brachialis, brachioradialis, and triceps) provide stability to the joint by compressing the congruous joint [19]. The lateral elbow is also statically and dynamically stabilized by the extensor and supinator muscles [20]. The common extensor muscle group inserts onto the lateral epicondyle and is composed of the extensor carpi radialis brevis, extensor digitorum, extensor digiti minimi, extensor carpi ulnaris, extensor pollicis, and the supinator. The supinator muscle, abductor pollicis longus, extensor pollicis longus and brevis, and extensor indicis muscles originate from the ulna and radius to compose the deep extensors of the forearm. The flexor-pronator group provides some dynamic stability to the medial elbow, but its role is minor [21]. The common flexor group includes the pronator teres, flexor carpi radialis, palmaris longus, and flexor carpi ulnaris. The flexor digitorum superficialis and profundus, flexor pollicis longus, and pronator quadratus make up the deeper muscles of the forearm.

Neurovascular Structures

The ulnar nerve is the neurologic structure most commonly injured in sports due to its superficial course. The ulnar nerve passes behind the medial epicondyle and lies over the ulnar collateral ligament. It is anterior to the medial triceps and fairly mobile, allowing it to slide out of the cubital tunnel in some patients. The median nerve travels with the brachial artery under the ligament of Struthers in the medial arm, into the antecubital fossa medial to the biceps, then under the bicipital aponeurosis and pronator teres [22]. The radial nerve passes from the posterolateral arm toward the anterior aspect of the elbow at the level of the distal third of the humerus. It divides into the superficial radial nerve and the posterior interosseus nerve, which is the deep branch. The posterior interosseus nerve supplies the extensor muscles of the forearm and runs in close proximity to the radial neck and under the supinator, passing the arcade of Frohse where it can occasionally become compressed [23].

After the age of 5 years, the capitellum is only supplied by one or two blood vessels, which act as end arteries. Anastomoses interconnecting the metaphysis, epiphysis, and diaphysis form by the age of 19 years when the growth plate has closed, to bring blood supply to the capitellum [24–26]. It has been suggested that repetitive valgus stress on the elbow during a period when the capitellum has its most vulnerable blood supply, for example, from repetitive throwing or gymnastic maneuvers, can cause microtrauma to these vessels which may lead to osteochondroses [27].

Clinical Evaluation

History

In the evaluation of an upper extremity injury in an athlete, it is important to obtain information about the patient's age, hand dominance, side of involvement, position played, duration, and nature of symptoms. Most athletes will complain of pain, instability, or lack of function. In throwers, this may be described as not being able to throw the ball as far or as accurately, or in other sports like tennis or volleyball, not hit the ball as hard. Loss of range of motion is common in children with acute or overuse injuries and may be due to pain, capsular contracture, effusion, or internal joint derangement. Mechanical symptoms such as catching or locking suggest an intra-articular pathology such as a loose body, chondral injury, or osteochondritis dissecans. Patients may complain of instability of the elbow with hard throwing or pushing up with the arms from a seated position. If neurologic symptoms are reported, such as paresthesias or weakness, the distribution of symptoms may indicate whether the injury is more central involving the neck or brachial plexus or if a peripheral nerve is affected.

The mechanism of injury, as well as activities that exacerbate and alleviate the symptoms, is useful for narrowing the differential diagnosis. A fall on the outstretched hand usually has different consequences and pathologies than an atraumatic problem with gradual onset from repetitive overuse. Instability of the elbow most often occurs with hard throwing or weight bearing loading such as push-ups or gymnastic maneuvers. For patients who are throwers, the style of throwing, mechanics, types and volume of throws/pitches, velocity, accuracy, and any training errors should be noted [7]. One should determine which phase of throwing produces symptoms. Pain during cocking and late acceleration suggest ulnar-sided pathology due to valgus stress, while pain during deceleration and follow through are suspicious for posterior impingement and stress injuries of the olecranon [10]. The location of symptoms can help focus the examiner toward the most probable diagnoses [28]; for example, posterior pain typically occurs during hyperextension.

Physical Exam

Observation, Palpation, and Range of Motion (Look, Feel, Move)

The elbow should be examined for deformity and areas of ecchymosis and swelling. Patients with a fracture or dislocation will usually present with significant tenderness, swelling, and deformity. The sulci on either side of the olecranon should be observed for intra-articular effusion, with the lateral gutter being most easy to evaluate for intra-articular swelling. The carrying angle can be observed in the relaxed, extended position.

Several superficial landmarks can be palpated, including the lateral and medial epicondyles, the olecranon, the radial head, the capitellum, the distal biceps insertion into the radial tubercle, and the ulnar nerve. The ulnar collateral ligament, which lies under the flexor carpi ulnaris can be palpated for tenderness. The olecranon and the epicondyles form an isosceles triangle. The posterior aspect of the olecranon can be checked for tenderness. The ulnar nerve can be palpated in the posterior aspect of the medial epicondyle area followed by flexion and extension of the elbow to see if the nerve subluxes or dislocates.

Range of motion can be checked with active and passive assessments of elbow flexion, extension, and forearm supination and pronation. Average motion includes flexion from 0° to 145° ± 10°, with pronation and supination at about 80° and 85°, respectively [29]. Lack of extension can suggest an internal derangement or chronic flexion contracture.

Stress Tests

The UCL is best tested with the elbow in approximately 70° of flexion. There are several stress maneuvers to test the functional integrity of the UCL including the valgus stress test, the milking maneuver, and the moving valgus stress test.

Valgus stress testing can be performed with the elbow flexed to approximately 30°. Though the test has often been described with the forearm in pronation, cadaveric studies suggest that the valgus laxity of the elbow is most pronounced with the forearm in neutral rotation [19] (Fig. 9.3).

The "milking maneuver" can be performed with the arm in more flexion, ideally at 70°, with the valgus force applied by supporting the elbow and tractioning the thumb, similar to milking a cow (Fig. 9.4). This position recre-

Fig. 9.3 Valgus stress test. The patient's wrist and hand are fixed, and a valgus stress is applied with the patient's elbow at 30°

Fig. 9.4 Milking maneuver. The "milking maneuver" is performed with the arm at 70°, with the valgus force applied by supporting the elbow and tractioning the thumb, similar to milking a cow

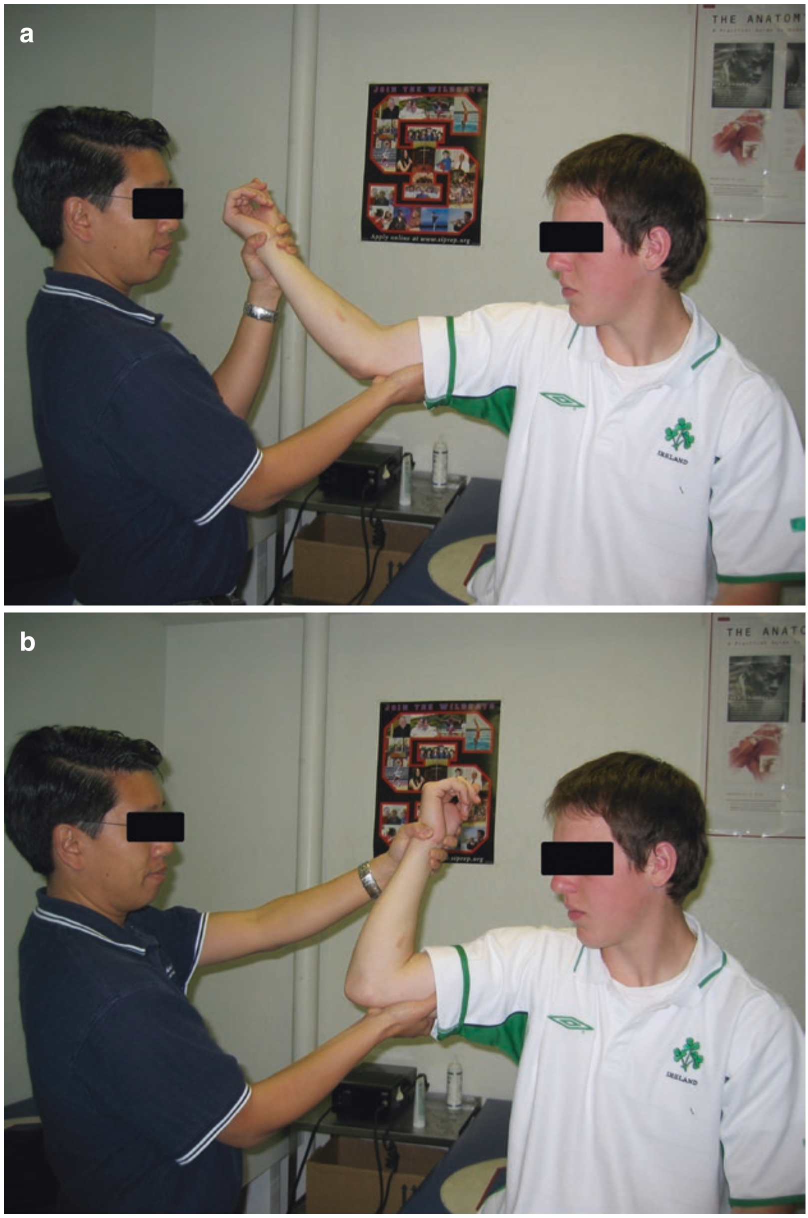

Fig 9.5 Moving valgus stress test. (**a**) With the patient sitting with the shoulder abducted to 90°, the examiner applies a valgus force to the elbow until the shoulder is fully externally rotated. (**b**) While maintaining the valgus torque, the examiner quickly extends the elbow to approximately 30°. A positive test reproduces pain at the UCL, typically occurring maximally between 120° and 70° of flexion

ates the valgus throwing position and helps hold the shoulder in external rotation, reducing the effect of shoulder rotation on the assessment of the UCL [30].

The "moving valgus stress test" has been described by O'Driscoll et al. (Fig. 9.5) [31]. With the shoulder abducted to 90°, the examiner maintains a valgus force to the elbow until the shoulder is fully externally rotated and then quickly extends the elbow from full flexion to approximately 30°, similar to the acceleration phase of throwing. In a positive test, the athlete describes the reproduction of pain at the UCL that the patient has with activities, which typically occurs maximally between 120° and 70° of flexion as the elbow is extended. The test is reported to be 100% sensitive and 75% specific with a small sample of patients [31]. Varus stress testing is performed by flexing the elbow to 30° with the forearm in full pronation and applying a

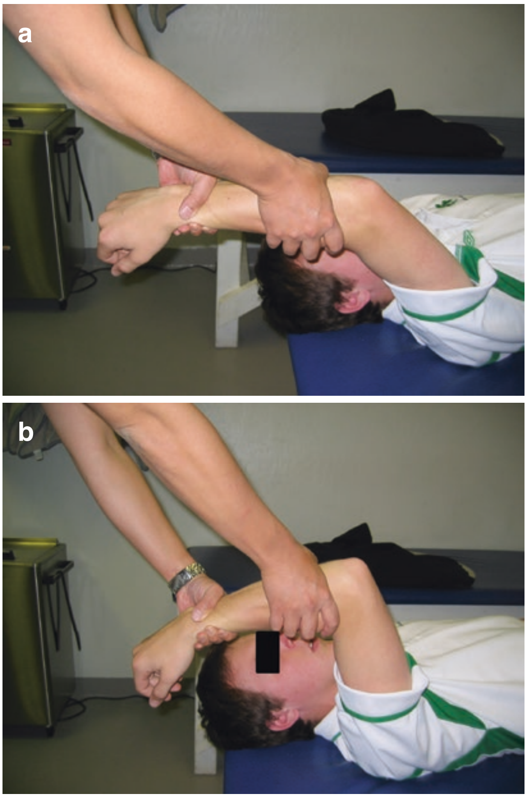

Fig. 9.6 Pivot shift. (**a**) With the athlete lying supine with the arm overhead, the elbow is supinated, and a valgus and axial force is applied to the elbow. The athlete may complain of pain or apprehension. (**b**) Starting in extension, the elbow is flexed with a reduction "clunk" occurring typically at 40°–70° of flexion

varus force to the lateral elbow. Pain or laxity indicates a positive test, though varus laxity is exceedingly rare [32]. The lateral pivot-shift apprehension test is the most sensitive test for reproducing posterolateral instability of the elbow (Fig. 9.6). This test allows for the radial head to sublux posterolaterally as the elbow rotates around the axis of the UCL with the applied forces [33].

Provocative Tests

The valgus extension overload test involves quickly placing the athlete's elbow in maximal extension with the forearm pronated [10]. Valgus stress in hyperextension that accentuates the pain suggests posterior impingement of the olecranon in the olecranon fossa.

Resisted muscle testing is useful for identifying underlying tendinopathies. Pain over the lateral epicondyle is often demonstrated with resisted forearm supination, wrist extension, or third digit extension with elbow in full extension, if the common extensor tendon is injured. Passive wrist palmar flexion while the elbow is extended may also reproduce symptoms of lateral epicondylosis. Conversely, resisted wrist palmar flexion or pronation and passive wrist dorsiflexion/extension while the elbow is in extension can reproduce pain if the common flexor tendons are affected.

Physical examination should include evaluation of the cervical spine, bilateral shoulders, elbows, and wrists [34], as well as neurologic sensation and motor strength testing. Patients with ulnar nerve symptoms may exhibit a positive Tinel's sign over the cubital fossa as well as subluxation of the ulnar nerve with flexion of the elbow.

Examine the Kinetic Chain

A coordinated sequence of joint movement and muscle contracture is necessary to produce an efficient functional task such as pitching. For example, key events before release of the ball include generation of momentum through the lower extremities and trunk, elbow elevation and extension, internal rotation of the shoulder, and pronation of the elbow. "Dropping the elbow" which positions the elbow below shoulder level increases the tensile loads on the elbow ligaments [35] but can happen in a young pitcher due to poor technique or fatigue. Specifically assessments of core trunk stability, one leg stance and squat testing for weakness, scapular dyskinesis, and glenohumeral internal rotation deficit (GIRD) are suggested in throwing athletes [36]. The elbow simply may be the weakest link in the chain and more susceptible to injury.

Imaging

Standard radiographs of the elbow include anterior-posterior (AP), lateral, and one or two oblique views of the elbow. Radiographs of the contralateral elbow are sometimes helpful for comparison in young patients. Though comparison films are commonly ordered, two studies found that opposite side elbow films did not improve diagnostic accuracy [37, 38] and do not need to be routinely obtained. A posterior fat pad sign has been reported to be predictive of an occult, intracapsular fracture (supracondylar, radial head, olecranon) in as many as 76% of children with otherwise normal radiographs, though previous reports ranged from 6 to 29% [39]. The capitellum should not be posterior to the anterior humeral line as this suggests a supracondylar extension fracture with displacement of the capitellum posteriorly [13]. Stress radiographs performed manually or by gravity can be obtained to demonstrate ligamentous insufficiency in the UCL; however, they can be misleading [19].

Other imaging modalities may be required for the elbow. A computed tomography (CT) scan is still ideal for fractures and bone definition. Bone scan is useful to detect stress injuries of the olecranon or medial apophysis. In the setting of osteochondritis dissecans, bone scans are useful to determine bony activity and assess healing potential. However, MRI is being used more frequently for identifying stress and occult fractures without radiation [21]. MR arthrogram has a high sensitivity for complete tears estimated at 95% and 86% for partial tears of the UCL in adults [40]. MRI is still the gold standard for soft tissue pathology, though diagnostic ultrasound has been increasing in utility for soft tissue as well as fractures [41, 42].

Acute/Traumatic Elbow Injuries

Elbow Dislocation

During a fall on the outstretched hand, an axial force is applied to the elbow with other stresses, depending on the mechanism of injury. For example, the elbow can dislocate following a hyperextension, valgus, or a valgus/external rotation mechanism. These can lead to posterior dislocation, disruption of the anterior ulnar collateral ligament, or posterolateral instability, respectively [23]. In younger children aged 5–10 years, the anatomy of the distal humerus is predisposed to fracture in the supracondylar region, since the area of the bone is very thin between the olecranon fossa posteriorly, the coronoid fossa anteriorly, and the medial and lateral columns of the distal humerus [43]. Extension fractures, causing the distal fragment to displace posteriorly, occur 97.5% of the time, while flexion fractures occur much less frequently (2.5%) [44]. Elbow dislocations in children younger than 13 years of age are relatively uncommon with an incidence of 3–6% of all elbow injuries [45]. Boys are affected more than girls, and the injury usually involves the non-dominant arm (60%) [46]. Data from the High School Reporting Information Online [RIO] project suggest that 91.3% of dislocations occurred in boys' sports, with the majority of the dislocations occurring in boys' wrestling (46.1%) and football (37.4%) [47]. They noted that elbow dislocation rates were higher in competition than in practice.

The most common dislocation is posterior, with posterolateral displacement of the proximal radius and ulna articulation from the humerus and an intact radioulnar articulation [48]. In posterior elbow dislocations, the mechanism of injury is usually a fall backward with the arm in abduction and extension. Over one half of posterior elbow dislocations will have an associated fracture, with fractures of the medial epicondyle being the most common [12, 45]. Anterior elbow dislocation is rare, and divergent elbow dislocation is extremely rare. A direct blow to the posterior aspect of the flexed elbow leads to anterior elbow dislocations. Divergent elbow dislocation signifies a posterior elbow dislocation with disruption of the radioulnar articulation leading to lateral displacement of the radial head and medial displacement of the proximal ulna. Divergent elbow dislocations are caused by high-energy trauma.

A child with a posterior elbow dislocation presents with obvious elbow swelling, deformity, and forearm shortening. The patient frequently holds his or her elbow in a semi-flexed position and refuses to move the elbow secondary to pain.

Routine radiographs are usually diagnostic and must be examined carefully for associated fractures.

Non-operative treatment by closed reduction should be performed promptly after adequate pain control and muscle relaxation are established. A careful neurovascular exam must be done before and after reduction, paying special attention to the median nerve and brachial artery. After reduction, a posterior splint is used to immobilize the elbow in 90° of flexion for 2 weeks. Active range of motion is then started as early as 2 weeks to minimize the risk of fixed contracture, though stable reductions may be accompanied by earlier range of motion as pain subsides. Surgery is needed more often following elbow dislocation compared to other elbow injuries (13.6% vs 4.7%, respectively [47, 48]. Indications for surgical treatment include an inability to obtain a closed reduction, an open dislocation, or a displaced osteochondral fracture. Fractures need to be immobilized for 4–6 weeks [48].

The most serious neurologic complication is damage to the median nerve directly by the dislocation or by entrapment within the joint. Approximately 10% of patients experience neuropraxia of the median or ulnar nerve, which usually resolves within 6–8 months [43]. Late complications include loss of motion, myositis ossificans, recurrent dislocations, radioulnar synostosis, and cubitus recurvatum [48]. Initiating early mobilization 2 weeks after injury can help minimize loss of motion, which is a common complication. Recurrent instability in elbow dislocations without associated fracture is rare.

Posterolateral Rotatory Instability

Posterolateral rotatory instability (PLRI) is a common form of recurrent instability of the elbow. With a fall on the outstretched hand and internal rotation of the body, a valgus and supination moment can occur causing the posterolateral movement as the elbow subluxes or dislocates. Athletes usually present complaining of recurrent painful clicking, snapping, and/or locking of the elbow following a dislocation, trauma, or elbow surgery [33]. The injury is associated with tearing of the LCL complex, in particular the LUCL, with recurrent episodes of instability due to the ulna and radius rotating posteriorly as a unit [49], particularly the radial head subluxating posterior to the capitellum [49]. The posterolateral pivot-shift apprehension test is the most sensitive test for reproducing the patient's symptoms (Fig. 9.6) [33]. Radiographs may demonstrate a small flake fracture of the coronoid process, which suggests a shear fracture from an elbow subluxation or dislocation [33]. Stress radiographs with the arm supinated and slightly flexed with the lateral elbow against the X-ray cassette may demonstrate the rotatory instability [48]. MRI can be helpful in identifying LCL injuries directly. MRI can also be useful to identify osteochondral injury to the capitellum which may result in problems for a young athlete [48]. In one series, 8 out of 44 patients requiring surgical reconstruction, usually following a dislocation, were under 18 years of age [49]. The LUCL can be repaired if the LCL has been directly avulsed from the lateral epicondyle, and any associated osteochondral defects should be addressed during surgery [50]. Otherwise, reconstruction of the LUCL is performed for chronic ligament insufficiency [49]; however, traditional ligament reconstruction in skeletally immature patients may pose a risk to the lateral humeral condylar and epicondylar physes [51].

Medial Epicondyle Avulsion

The medial epicondyle can avulse following acute valgus stress involving the UCL and/or sudden contraction of the flexor-pronator group. Medial humeral epicondyle fractures account for 20% of all elbow fractures that occur in children [48, 49]. X-rays of the elbow are usually first line for imaging; however, they are not very reliable on measuring the displacement of the avulsion [52]. Woods and Tullos have classified medial epicondyle avulsions into types 1, 2, and 3 [48]. Type 1 fractures are described as large avulsions involving the whole epicondyle and affect athletes under 14 years of age. These avulsions do not result in elbow instability. Type 2 injuries involve avulsion of the epicondyle and the anterior band of the UCL. Type 3 injuries are fragments smaller than the epicondyle and usually occur in the adolescent athlete.

Indications for surgical treatment are controversial, as both surgical and non-operative treatments have demonstrated success with healing and return to play [48]. Non-operative treatment typically involves long arm casting in neutral forearm position for 2–4 weeks at 70–90° followed by protected motion with a hinge brace for at least 6–8 weeks [52]. Josefsson and Danielsson have reported on long-term follow-up of conservatively treated patients with medial epicondyle fractures. They found 31 out of 35 healed with fibrous non-union with good function and range of motion [46]. Similarly, in a long-term retrospective study from Italy, 42 patients with medial epicondyle fractures with displacement between 5 and 15 mm which occurred between 8 and 15 years of age were followed for an average of 34 years after injury [53]. Sixteen of 19 patients who were treated conservatively with casting at 90° for 4 weeks demonstrated good results and function, which was similar to ORIF and better than excision. Physical therapy to restore motion should be started at 6–8 weeks, with forearm flexor strengthening after bony union has been achieved [52].

Different authors have described indications for surgery. Osbahr et al. described non-operative treatment for displacement <5 mm without valgus instability and operative treatment for displaced fractures >10 mm [54]. Between 5 and 10 mm of displacement would be treated based on patient/surgeon preference [54]. Many clinicians believe that displaced medial epicondylar avulsions of more than 2–5 mm in the dominant arm of a throwing athlete should be treated surgically, though no studies exist to determine if the outcomes and abilities truly are better with surgery in this group. Certainly, if there is associated valgus instability, entrapment of the fragment in the joint, and/or ulnar nerve dysfunction, then surgery is indicated, as originally described by Woods [55]. Cruz et al. suggest operative repair should be considered if the fracture is displaced >75% and non-operative treatment if displaced <25% [52]. Treatment for displacement between 25 and 75% displacement is based on the demand of the athlete, with high demand throwing athletes managed more aggressively with surgery [52]. Stepanovich et al. described 12 patients from a series of 140 patients with displaced humeral epicondyle fractures who returned for long-term follow-up an average of 3 years post-treatment, comparing operative fixation with closed management. Both groups were comparable in terms of age, length of follow-up, dominant side injured, and sports involvement pre-injury; however, 50% of the surgical patients presented with an unreduced elbow dislocation, with higher rates of fracture union and return to sport following surgery, though both groups had similar objective and subjective outcome measures [56].

Forearm Fractures

Forearm fractures can occur in young athletes following angular loading with rotational displacement. A Monteggia fracture is a fracture of the ulna with a dislocation of the radial head due to rupture of the proximal radioulnar ligaments. These injuries are frequently misdiagnosed as an isolated ulna fracture. As such, all patients who present with an ulnar fracture should have their elbow assessed clinically, and radiographically, to avoid missing the concomitant instability of the radial head. Nightstick fractures are transverse fractures of the ulna from direct trauma. Galeazzi fractures involve a fracture of the distal radius with a disruption of the distal radioulnar joint, though this usually presents in preadolescent athletes.

The athlete will typically present with pain, swelling, and deformity over the fracture site, though a mildly displaced fracture may not be obvious. A careful neurovascular assessment must be performed to rule out complications of forearm fractures including nerve injury and compartment syndrome. If an athlete complains of both elbow and wrist pain with an isolated ulna fracture, a dislocated radial head should be ruled out. Long-term complications following a Monteggia fracture include persistent valgus instability, cubitus valgus, elbow stiffness, and arthritis. Those with a distal radius fracture should be assessed for pain at the wrist to rule out distal radioulnar joint injury. A poorly treated Galeazzi fracture may result in chronic wrist pain, limited motion, and arthritis from ulnocarpal impaction.

X-rays of the forearm should be assessed for alignment. Specifically, drawing a line through the central axis of the humeral shaft and the head of the radius should intersect the capitellum at all positions of the elbow. In a Monteggia fracture, in younger patients, the ulnar fracture usually involves the coronoid process or is just distal to it [57].

While treatment of forearm fractures in adults is operative, pediatric forearm fractures are usually treated conservatively [58]. To reduce the fracture and dislocation, gentle longitudinal traction and the opposite force from the mechanism of injury are typically applied. The radial head usually dislocates laterally or anteriorly in young athletes and can be reduced with flexion, supination, and direct pressure [49]. Initially, a sugar-tong splint can be applied around the fractured forearm to avoid the risk of developing compartment syndrome from bleeding. Once the acute swelling has ceased, treatment involves a long arm cast initially at approximately 110° to avoid rotation of the forearm, rather than using a short arm cast. The forearm is casted in the neutral position rather than in supination or pronation [59]. Molding the cast may be needed.

Open fractures, unstable fractures, and severely malaligned fractures require surgical attention. Advantages of open reduction with internal fixation are more stable and anatomic healing and the ability to start earlier range of motion, for example, in treating isolated lateral condyle fractures. If the angulation of the fracture is more than 10°, then it may require operative fixation to enable healing. Some angulation may be accepted especially if there is growth remaining; however, rotational deformities have much less capacity for remodeling [59]. Also, proximal radial and ulnar fractures have less potential for remodeling since the distal growth plates are responsible for over three-quarters of the longitudinal growth of each bone, respectively [58]. In Monteggia fractures, the ulnar fracture alignment should be restored for proper healing, since the radioulnar joint congruency is usually achieved once the ulna is realigned [57]. A systematic review suggested that open reduction with ulnar osteotomy with or without annular ligament reconstruction is the most commonly performed procedure resulting in reduced pain and elbow deformity. Plates used to repair a forearm fracture are best left in place, especially if the individual is involved in a contact sport [59]. While Galeazzi equivalent fractures are not common in the adolescent population, surgical attention may need to be considered. Long-term complications to be aware of and evaluated regularly include premature epiphyseal closure, length discrepancies, or joint incongruency.

Chronic/Atraumatic Injuries

"Little League Elbow"

"Little Leaguer's elbow" is a term that has been misrepresented throughout the literature, as it has been applied to medial apophysitis, osteochondritis dissecans, Panner's disease, and any other elbow pain in a young thrower. The use of this term should be avoided, and the specific diagnosis should be used. Classically, Little Leaguer's elbow is a medial apophyseal injury that affects young baseball players, usually pitchers, around 9–12 years of age [60]. As early as 1965, the radiographic appearance of the elbows of 80 California Little League pitchers aged 9–14 years has shown abnormal changes, with 39 elbows (49%) reported to demonstrate medial epicondylar apophyseal fragmentation [61]. Excessive, repetitive throwing at an early age is felt to be the cause of these changes. As the adolescent throwing athlete matures, the forces generated by the upper extremity can lead to overuse injuries. During the late cocking and acceleration phases of throwing, the ulnar collateral ligament sustains high-tension valgus stress, while a compressive force is applied over the radial head and capitellum [1]. Medial epicondylitis and medial epicondyle apophysitis can occur in the prepubescent athlete, while ulnar collateral ligament injuries occur in the older thrower. Medial apophyseal avulsion, radial head hypertrophy, or avascular changes in the capitellum (osteochondritis dissecans) are adaptational or pathological changes that occur in the immature elbow [1, 4].

Medial Apophysitis

Repetitive valgus overload can lead to microtrauma in the apophysis of the medial epicondyle. Athletes will present with medial elbow pain or decreased throwing velocity. They may present with or without flexion elbow contracture. Athletes with elbow pain may show some widening of the medial apophysis and/or medial epicondylar fragmentation before epiphyseal closure on X-ray in younger athletes around 9–13 years. Recurrent traction on the UCL attachment to the inferior medial epicondyle leads to these changes [62]. As the physis is weaker than the ligament itself, the physis is subject to these valgus stresses, and instead of UCL injury, the physis becomes damaged, and apophysitis ensues. Bone scan and MRI will demonstrate marrow edema, physeal widening, and irregularity of the medial apophysis representing stress injury or possible stress fracture [63]. Treatment usually involves relative rest from valgus loading activities such as throwing. Anti-inflammatories and ice are commonly used, though long-term evidence of benefit is not available. Non-displaced stress injuries to the medial epicondyle respond well to conservative treatment, with no functional deficits [4].

Ulnar Collateral Ligament Injury

There has been an epidemic increase in UCL reconstruction surgeries, demonstrating these elbow injuries are increasing due to overuse [64]. UCL injuries are reported most commonly in throwing athletes such as baseball players (especially in pitchers); however, they also have been observed in other throwing sports including water polo, javelin, tennis, and volleyball [65]. A study of Little League World Series pitchers observed that out of 638 adolescent pitchers, 62 played professionally in the minor leagues [56] or major leagues [6, 66]. While only 28 continued to pitch professionally, the three players needing UCL reconstruction (a.k.a. "Tommy John surgery") were all pitchers, with some concern that they had exceeded pitch counts [66].

When the growth plate is no longer the weakest link, repetitive valgus stress can produce tensile forces on the medial elbow leading to microtrauma of the UCL. Factors leading to overuse include velocity, power, and the repetitious nature of the throwing motion [7, 67]. Pain during the acceleration phase of throwing, at ball release during delivery, or pain at point of impact hitting a baseball or tennis ball is the common complaints [68]. Due to the chronic nature of UCL instability, patients may also present with symptoms of ulnar nerve irritation or loose bodies [7]. Patients typically have point tenderness 2 cm distal to the medial epicondyle over the mid-substance of the UCL. Two to 3 days after an acute injury, ecchymosis may develop in the medial joint line. Valgus loading stress maneuvers can demonstrate any ligament insufficiency. The elbow has the most valgus laxity when the forearm is in the neutral position, and cadaver sectioning showed that transection of the anterior oblique ligament demonstrated laxity at all ranges [18].

Plain radiographs are needed to evaluate for possible medial epicondyle fracture and/or instability. A relative increased widening of 2 mm or more at the medial joint space compared with the unaffected elbow on valgus stress anterior-posterior radiographs is considered pathologic [25]. A stress ultrasound test can be helpful identifying an UCL injury, which shows a joint gaping more than 1.5 mm compared to the normal side (sensitivity 81% and specificity 91%) [69]. Adding an MR arthrogram in addition to the ultrasound increased the sensitivity of detection to 96% and specificity to 99% [69]. MRI can also be useful in identifying a torn UCL [70, 71]

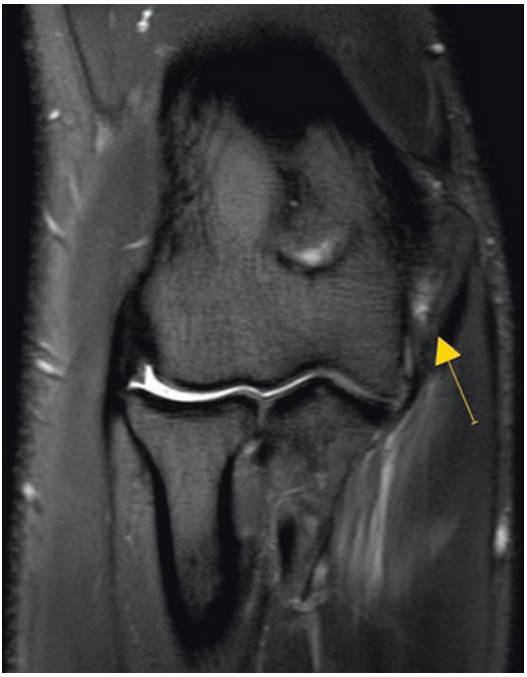

Fig. 9.7 Coronal MRI of a partial ulnar collateral ligament tear in a 17-year-old catcher

(Fig. 9.7); however, some radiologists prefer an MR arthrogram.

Initial treatment for UCL tears is conservative. Non-operative treatment consists of rest, anti-inflammatory medication, and ice. After the pain is controlled, physical therapy should be initiated. Approximately 6 weeks after the initial injury, the elbow should be reevaluated [25]. If the elbow stability is improving, a structured rehabilitation and a return to throwing program can be followed. In a study of 31 throwing athletes with an average age of 18 years who had a UCL injury, 42% were able to return to their previous level of play at an average of 24.5 weeks (13–54 weeks) of conservative management [72]. A more recent study suggested that MRI findings of distal UCL tears, especially when high grade, have a high risk of failing non-operative treatment. Of the two third of athletes who were successfully treated with non-operative management, 81% had proximal UCL injuries [25, 73–75].

There is a growing trend for surgical treatment for UCL injuries. A survey of media members revealed many misconceptions regarding UCL reconstruction, including that surgery was performance enhancing and overestimations of the expected return to activity [74]. In fact, Cohen showed only 52% of professional baseball pitchers were able to return to play at the same or higher level following UCL surgery [76]. However, surgical treatment has been demonstrated to be successful at returning athletes to their previous level of competition, making it a viable option with a growing trend in these surgeries occurring in patients between 15 and 19 years of age [76].

Surgical treatment options include UCL repair or UCL reconstruction [63]. Surgical UCL reconstruction has been performed, preferentially using autologous grafts of the palmaris longus or gracilis [7, 66, 77]. Petty, Fleisig, and Cain Jr. suggest that indications for surgical treatment are more complex in the adolescent than in the adult, since teens tend to display more significant signs and symptoms related to a given injury, and they have better healing potential. For these reasons, they feel that conservative management has a higher chance of being effective in the adolescent than the adult for UCL injuries [78]. In the early 1990s, both Jobe and Andrews demonstrated the outcomes of surgical reconstruction were consistently more superior to repair [68, 79]. However, in 2008 Savoie reported excellent results in a series of young throwers with UCL injury treated with primary UCL repair [80]. Savoie used suture plication with repair to bone drill holes ($n = 9$) or suture repair to bone using anchors ($n = 51$) in 60 throwing athletes of high school age. Fifty-eight of the 60 patients were able to return to sports within 6 months of the surgery. Complications in this series included four failures and three patients with transient post-operative ulnar neuropathy symptoms that resolved spontaneously [80]. A literature review also reported excellent results with surgical repair, with a return to sports rate of over 87% [66]. Generally, for young throwers with UCL injury, the trend is to repair the UCL if it is avulsed from one insertion or the other. For mid-substance tears in young athletes, UCL reconstruction is preferred. For adults, there is usually more intra-substance damage and change prior to UCL rupture, so reconstruction is generally recommended in this group of throwing athletes. Return to play for the throwing athlete requires progression through phases and is overall successful to return athletes to their previous level of competition [81].

For other athletes, like wrestlers or water polo players with acute UCL injuries, non-operative treatment is initiated with bracing and early ROM and then strengthening. If symptomatic valgus instability persists, then reconstruction may be considered; however, this is uncommon.

Osteochondritis Dissecans of the Capitellum

Osteochondritis dissecans (OCD) is a progressive form of osteochondrosis of the capitellum involving focal injury to subchondral bone leading to a loss of structural support for the overlying articular cartilage [25]. OCD typically affects the dominant extremity of adolescents and young adults with onset of symptoms between 11 and 16 years of age. Most cases are seen in high-level athletes who experience repetitive valgus stress and lateral compression across the elbow (i.e., overhead throwing athletes, gymnasts, weight lifters) [25, 34, 82, 83]. The lesion only affects a portion of the capitellum. Loose bodies and articular surface deformation can develop [84]. Elbow OCD lesions are graded from I to IV based on the integrity of the articular cartilage and the stability of the subchondral bone [85].

The etiology of OCD is unclear. Most authors believe that repetitive microtrauma in the setting of a tenuous blood supply is the primary mechanism of injury [12, 75, 86]. Genetic factors, trauma, and ischemia have also been proposed [25, 87, 88]. The histopathology of OCD is consistent with findings of subchondral bone osteonecrosis [25, 89].

Patients typically present with a gradual onset of lateral elbow pain and flexion contracture in the affected arm, more often the dominant one. The pain is intermittent, aggravated by activity, and relieved by rest. Elbow swelling may develop, as well as locking, popping, and catching of the elbow as loose bodies form. On physical exam, there may be tenderness to palpation and crepitus over the radiocapitellar joint. Loss of 10–20 degrees of extension is common, and mild loss of flexion and forearm rotation may also be seen [24, 34, 89].

Fig. 9.8 Osteochondritis dissecans of the capitellum in a 15-year-old baseball pitcher

Characteristic plain film findings of elbow OCD include a focal area of radiolucency and rarefaction in the subchondral bone in the anterior aspect of the capitellum (Fig. 9.8). Early OCD can appear as flattening of the capitellum without fragmentation, typically in children around 11 years of age [87]. More advanced and/or older lesions become fragmented [90] and may have a sclerotic border or demonstrate loose bodies on radiographs.

MRI is the preferred method in the evaluation of OCD lesions since it is both sensitive and specific [91]. MRI demonstrates the extent of the OCD lesion more accurately and also identifies loose bodies that may not be seen on plain film, as well as the integrity of the articular cartilage overlying the area of bony rarefaction, helping dictate

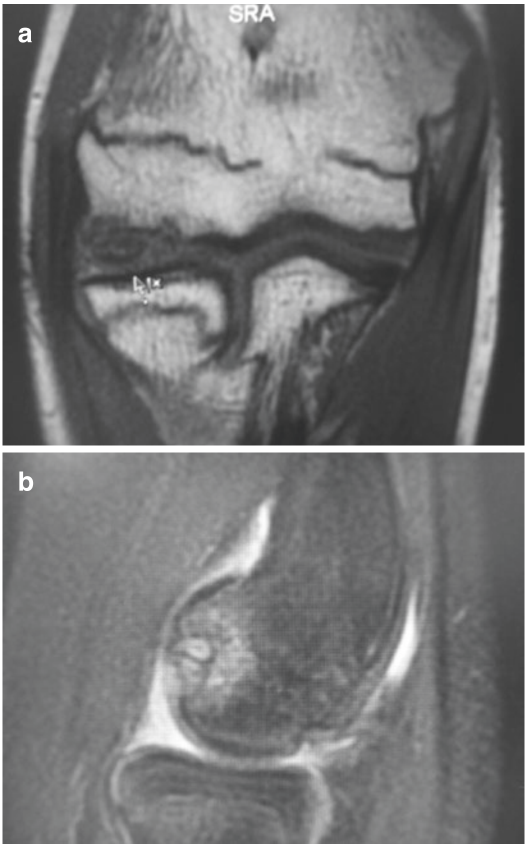

Fig. 9.9 MRI. (**a**) Coronal view (T1-weighted film) and (**b**) sagittal view (T2-weighted film) of an osteochondritis dissecans of the capitellum (Photos by Lisa Lattanza, MD. Used with permission)

Table 9.1 Classification of osteochondritis lesions of the elbow

Grade	Arthroscopic findings	Treatment
Grade 1	Smooth but soft, ballotable articular cartilage	If symptomatic, undergo drilling
Grade 2	Fibrillations or fissuring of the articular cartilage	Lesions not responding to non-operative treatment should undergo removal of all affected cartilage back to a "stable" rim and then abrasion chondroplasty of the underlying bone
Grade 3	Exposed bone with a fixed osteochondral fragment	Removal of the osteochondral fragment and abrasion chondroplasty
Grade 4	Loose but undisplaced fragment	Removal of the osteochondral fragment and abrasion chondroplasty
Grade 5	Displaced fragment with resultant loose bodies	Abrasion chondroplasty of the exposed crater with diligent search of the remaining elbow joint for loose bodies, which should be removed. Any associated osteophyte or synovitis in other elbow compartments should be removed. An early ROM and strengthening program should begin ASAP post-operatively

Source: Adapted from Baumgarten TE, Andrews JR, Satterwhite YE. The arthroscopic classification and treatment of osteochondritis dissecans of the capitellum. Am J Sports Med. 1998;26(4):520–3. Reprinted with permission of Sage Publications, Inc.

treatment (Fig. 9.9). CT scans can also help define bony anatomy and identify loose bodies. Bone scintigraphy is very sensitive for identifying osteoblastic activity or increased vascularity at the site of an OCD lesion; however, it is non-specific and is less useful in diagnosis [34]. Ultrasonography can also facilitate the assessment of capitellar lesions [88]. Baumgarten et al. have proposed an arthroscopic classification of OCD lesions that parallels the MRI classification, based on integrity of the articular cartilage (Table 9.1) [83].

The prognosis of OCD of the capitellum and choice of conservative or surgical management depend on the patient's age and the severity of the original lesion [34], in particular, symptoms, size of the lesion, and stage of the lesion, specifically the integrity of the cartilage surface. To provide the best outcome, early detection and appropriate treatment are imperative. Small, non-displaced lesions in younger athletes with intact articular cartilage on MRI are best managed conservatively with rest, ice, and NSAIDs, particularly if the bone scan demonstrates increased bony activity. Serial plain films should be obtained to follow resolution of disease. Unfortunately, many may not heal [12, 91]. Prevention through activity modification and education is an important and effective management strategy [24]. Proper education of athletes, parents, and coaches about this problem is crucial as development of a loose body from continued sports participation can lead to permanent symptoms and disability.

The prognosis for more advanced lesions and older athletes, particularly when the articular cartilage is not intact, the bone scan is cold, or if loose bodies are present, is less favorable. Even after 6 months of rest, 13 of 24 athletes still had pain during activities [92]. Indications for surgical treatment include persistent symptoms despite conservative management, symptomatic loose bodies, articular cartilage fracture, or displacement of the osteochondral lesion. The surgeon must assess the size, stability, and viability of the fragment and decide whether to remove the fragment or attempt to surgically reattach it. Most fragments cannot be reattached and therefore are excised followed by local debridement. Subchondral drilling may be performed to encourage healing with early stage lesions [34, 92–94]. When lesions are loose and not reparable, arthroscopic loose body removal with abrasion arthroplasty or drilling of the defect may be recommended to allow fibrocartilaginous tissue to fill the defect. Lewine et al. described their series of 21 adolescent athletes after arthroscopic loose body removal, drilling, and microfracture with 61.9% nontender and radiographic resolution in 50% at 2 years of follow-up [85]. Fourteen (66.7%) returned to their primary sport. In advanced stage OCD, another option is internal fixation of unstable in situ OCD lesions with osteochondral autograft transplantation surgery (OATS) to repair the defect using bone cartilage plugs from non-weight bearing areas of the knee [90, 95]. A series form Hennrikus et al. described healing in 20 out of 26 subjects under 15.3 years of age with lesions smaller than 13 mm in diameter identified as indicators of better success [95]. On average, 86.6% of patients are able to return to sport following surgery for advanced OCD [96].

Panner's Disease

Panner's disease is an osteochondrosis of the capitellum. Age, pain onset, and the radiographic appearance of the lesion help differentiate between Panner's disease and OCD [91]. It is a self-limiting, benign process that involves the entire ossification center and commonly occurs in children between the ages of 4 and 10 years of age [94]. The dominant extremity is usually involved.

Children typically complain of several weeks of a vague, dull, aching pain over the lateral elbow of the dominant extremity that is exacerbated by activity and relieved by rest [24, 25, 34, 93]. On physical exam, there is usually a 10–20-degree loss of extension and maximal palpation tenderness over the radiocapitellar joint. Edema and effusion are rare [25]. Typical radiographic findings in Panner's disease include demineralization of the capitellum with poorly defined cortical margins, fissuring, and/or fragmentation of the entire capitellum [97]. Abnormal development of the radial head may also be observed. CT is occasionally helpful to further define bony pathology; MRI is very sensitive and useful in the early detection of Panner's disease [24, 26]. Follow-up plain films show healing with consolidation, but persistent flattening of the capitellum may occur.

Treatment is conservative and involves rest, activity modification, avoidance of valgus stress, maintenance of range of motion, ice, and NSAIDs. A prolonged period of healing of up to 3 years is common. Long-term clinical and radiographic results are excellent. In most patients, there are no long-term sequelae or residual deformity [34].

Posterior Impingement, Olecranon Stress Injury, and Apophysitis

Many sports require the elbow to forcefully extend to generate force or to lock out the elbow, leading to valgus extension overload. During throwing, the olecranon is loaded and can impinge in the olecranon fossa when the elbow is extended during acceleration and follow through [1]. This is accentuated in the face of valgus laxity of the elbow. In order to stabilize the elbow, it is often locked in full extension with many gymnastics maneuvers. The olecranon can develop stress injury from impacting the olecranon fossa or from eccentric triceps traction forces [78, 98, 99]. If a growth plate is present, widening may occur leading to apophysitis. Rarely, the epiphysis can acutely displace [78]. Wilson has recommended radiographing the elbow at 110° of flexion with the arm lying on the cassette, and the beam angled 45° toward the ulna to better demonstrate osteophytes in the posteromedial elbow which are commonly seen with valgus extension overload [13, 98]. MRI is the best test to identify degenerative changes, apophysitis, or developing stress fracture. Initial treatment is directed toward symptom control, activity modification, and physical therapy. If symptoms persist despite rest, arthroscopic debridement can be considered [99]. Care is taken not to remove more than just the osteophyte, as excessive bony removal has been associated with ulnar collateral ligament insufficiency.

Treatment

Initial Management

Traumatic injuries including fracture and dislocation are treated initially by protecting the arm in a splint until it can be assessed by an orthopedic surgeon. A posterior splint can ideally keep the elbow at 90° with the hand supinated until assessed, which is the position of function for the elbow. Emergency attention is required if there is neurovascular compromise, a joint dislocation, an open fracture, or a severely displaced and unstable fracture. As a rule of thumb, intra-articular fractures that involve more than a 2 mm step off or displacement may require surgical management [12]. A hinged brace is useful to protect the elbow from valgus instability while allowing flexion and extension range of motion.

Physical Therapy

Physical therapy for the elbow is often directed toward protected early range of motion. Following even severe trauma such as a dislocation, rehabilitation can be started immediately in a hinged cast brace with the elbow in full pronation [23]. Priest and Wiese concluded that elbow immobilization for as short time as possible was beneficial to regaining range of motion after dislocations in gymnasts [5]. A randomized control trial with 43 patients showed that physical therapy helped improve motion at 12 and 18 weeks post-operatively in supracondylar fractures; however, it was not shown to demonstrate differences in motion at 1 year [99]. This suggests that physical therapy of the elbow can restore good range earlier in young patients. Low-load, long-duration stretches are suggested to improve motion [100, 101]. If athletes have a persistent flexion contracture and no other internal derangement or instability, a dynamic splint may be used to help increase range of motion [101].

Sport-specific exercise can be introduced once an adequate healing period has passed after injury or surgery. Wilk et al. start an early range of motion program, including joint mobilizations, followed by strengthening exercises. Throwing programs are often introduced by 6 weeks post-injury with a gradual sequence of progressive exercises involving different distances, resistances, coordination, and proprioceptive exercises [102].

Surgery

Arthroscopic surgery in the elbow, in the hands of an experienced surgeon, has a safe and effective role in the treatment of selective pathologies. In a series from 1979 to 1995, 49 elbow arthroscopies were performed for osteochondritis dissecans (58%), arthrofibrosis and joint contracture (20%), synovitis (10%), acute trauma (10%), and posterior olecranon impingement syndrome [99]. Based on a modified Andrews elbow scoring system, 85% of patients had a good or excellent result, with 90% of the children returning to sports without limitation. Although no complications were reported in the mentioned series, potential complications including nerve injuries, flexion contracture, and infection have been identified following elbow arthroscopy in an adult population [103].

In general, surgical assessment is required for functional ligamentous instability; cartilage defects and intra-articular lesions, including loose bodies and OCD; displaced fractures; and injuries resulting in malformation causing persistent dysfunction. As a rule of thumb, fractures that have less than 2 mm of displacement are treated non-operatively [104].

Prevention

Several risk factors, including high pitch counts, pitch velocity, pitching year round, geography, loss of shoulder motion, elbow torque, sports specialization, and others, have been shown to increase a pitcher's risk for injury. Sports specialization refers to a practice in which children choose a single sport to play, spend more than 8 months of the year participating in that single sport, and often stop participation in all other sports.

To avoid traumatic and overuse elbow injuries, proper technique in a given sport should be emphasized. In a biomechanical study, Fleisig analyzed the throwing mechanics of youth, high school, college, and professional pitchers [2]. He found that the increases in joint forces and torques were most likely due to increased strength and muscle mass in the higher level athlete. The greater shoulder and elbow angular velocities produced by high-level pitchers were most likely due to the greater torques they generated during the arm cocking and acceleration phases. The valgus torque around the elbow is closely correlated with the throwing athlete's weight ($r = 0.79$) [3]. The other kinetic factors that were associated with elbow torque are maximum shoulder abduction torque and maximum internal rotation torque [3]. Younger pitchers often take a shorter stride and drop the elbow leading to less velocity overall for the pitch. This may force the athlete to "use more arm" to improve the speed. Thus, it appears that the natural progression for successful pitching is to learn proper mechanics as early as possible and build strength as the body matures [2].

Modifying training risk factors, especially type of activity and volume of activity, is useful. In a prospective, descriptive cohort study, Lyman et al. studied 472 pitchers ages 9–14 years over one season in Alabama [105]. Their study tools included pre-and post-season questionnaires, injury and performance interviews after each game, pitch count logs, and video analysis of pitching mechanics. They determined that there was an increase in elbow and shoulder injuries with cumulative pitch counts over 600 pitches per season. Breaking pitches and high pitch counts were risk factors for injuries. Thirteen- and 14-year-old pitchers had three times the number of elbow injuries when throwing the slider (OR 3.49, $p < 0.01$) [105].

Training volume and activities are important to discuss with the athlete, parents, and coaches to identify if there are any training errors or areas which can be modified. Priest and Weis recommend employing spotters, using thicker mats, and educating young gymnasts in techniques of falling. Rules should be enforced by referees and coaches, to avoid reckless play as well as dangerous training practices. Coaches should emphasize proper pitching mechanics to optimize power from the lower part of the body and to align the upper extremity properly to decrease valgus stress on the elbow.

Experts recommend that adolescent baseball players should not throw more than 80 pitches a game, should not participate in more than 8 months of competition per year, and limit their total number of pitches in competition to 2500 per year [106]. Throwing breaking pitches should not be started until after 13 years of age [106]. At least 3 days rest is recommended between outings to allow adequate recovery and to avoid fatigue. As recommendations continue to be refined, activity recommendations, including pitching, should be made based on physical maturity of the athlete rather than chronological age, since the onset of puberty varies widely, and strength and flexibility are based more on physical maturity rather than age [107].

During the pre-participation physical exam, suggestions to improve strength and flexibility in joints in the kinetic chain may help prevent injuries. A glenohumeral internal rotation deficit (GIRD) from tightness of the posterior shoulder capsule can often cause shoulder problems in throwing athletes, which subsequently move down the chain to affect the elbow. High school pitchers were also noted to have stronger internal rotators on the dominant versus their non-dominant arm on isokinetic strength testing [108, 109]. In these overhead athletes, a proper conditioning program should target stretching the shoulder and elbow, including posterior shoulder capsule stretching, and strengthening of the rotator cuff and periscapular stabilizers.

Return to Play Guidelines

An athlete should have full, pain-free range of motion before returning to sports. The athlete should be returned gradually, with limited activities early on. Following surgery, not all athletes will return to their sport, depending on the type and severity of injury. Following UCL surgery in high school baseball players, 20 out of 27 athletes returned to play after approximately 11 months [108]. Return to play with OCD and intra-articular lesions is difficult to determine. Radiographic healing is ideal, though not always possible. The athlete should be completely asymptomatic with all activity, especially if they are an overhead athlete, before returning to play. Following trauma to the elbow such as dislocation or fracture, the athlete will most likely not resume upper extremity training for at least 3 months, with full activities expected around 6 months. With most elbow soft tissue injuries and non-operative problems, adolescent athletes recover well following an adequate period of healing.

Clinical Pearls

- *Elbow pain in the adolescent athlete deserves careful attention.
- Reproducing the mechanisms that produce symptoms through physical exam maneuvers or by having them perform push-ups or throwing will help identify the problem.
- Elbow tendinopathies can still occur from overtraining, but they are much less common in adolescents than adults.
- If the adolescent athlete has persistent, reproducible pain within the elbow, osteochondritis dissecans should be ruled out. MRI can be useful to help stage the OCD lesion to determine treatment.
- When there is an effusion in the elbow and history of trauma, dislocation or occult fracture, especially involving the radial head, should be suspected.
- In fractures of the radius and ulna, carefully examine the proximal and distal radioulnar joints to rule out complex fractures.
- With almost all elbow injuries (other than some fractures), the athlete should begin protected motion early, at the latest by 3 weeks, to avoid excessive stiffness.
- Forced range of motion after trauma is discouraged in physical therapy to avoid heterotopic ossification.
- Any apophyseal avulsion or fracture with more than 2 mm of displacement is more concerning and should be evaluated by an orthopedic surgeon familiar with elbow problems.
- Fortunately, there can be good healing potential and remodeling for elbow injuries in young patients with open growth plates.

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10 Injuries to the Wrist, Hand, and Fingers

Praveen G. Murthy and Donald S. Bae

Wrist and hand injuries in the adolescent athlete present many challenges for treating physicians, therapists, trainers, and coaches. The spectrum of injuries, varying degrees of acuity and chronicity, and involvement of multiple anatomic systems (e.g., bone, ligament, tendon, and nerve) add to their complexity. Furthermore, injuries to the adolescent athlete must be managed in the context of continued musculoskeletal growth and development. The use of protective and/or assistive devices (e.g., tape, braces, splints, and casts), timing of return to play, and post-injury performance expectations must be carefully weighed in the treatment of these injuries. Finally, the psychosocial and financial consequences of these injuries cannot be ignored.

The purpose of this chapter is to review the epidemiology, prevention, and treatment of common wrist and hand injuries in the young athlete. As a comprehensive review of all injuries is beyond the scope of this chapter, emphasis will be placed on acute traumatic injuries, and particular attention will be made to those injuries requiring specialized nonoperative and/or surgical care.

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Epidemiology

Hand and wrist injuries are thought to comprise between 3 and 25% of all athletic injuries in this younger patient population [1–12]. Indeed, several published studies have suggested that hand and wrist injuries are more common in children and adolescents than adult sports participants. Potential reasons for this include the following: increased sports participation in younger athletes, the increased popularity of "extreme" sports, the inherent inability of the musculoskeletal system in younger athletes to withstand the frequency or intensity of certain sport-specific activities, the use of age- or size-inappropriate equipment, and poor supervision, coaching, and/or athletic technique [13]. Sprains are thought to be the most common injury sustained to the hand and wrist, comprising 20–50% of all injuries, followed by contusions (15–30%) and fractures (5–35%) [8, 14].

The Athlete's Wrist and Hand

Ryu et al. have established that most adult activities of daily living can be performed with 40 degrees of wrist extension, 40 degrees of wrist flexion, a

L. J. Micheli, L. Purcell (eds.), *The Adolescent Athlete*, Contemporary Pediatric and Adolescent Sports Medicine, https://doi.org/10.1007/978-3-319-56188-2_10

40-degree arc of radial–ulnar deviation, and a 100-degree arc of forearm pronation/supination [15]. However, greater ranges of wrist motion, force generation, and angular velocities are required for sports participation. Professional baseball pitchers, for example, require over 90 degrees of wrist flexion during the throwing motion [16]. In Olympic-level tennis players, maximum angular velocities of 1950 degrees/s have been recorded for wrist flexion [17]. Average mechanical loads across the wrist during pommel horse exercises in high-level gymnasts have been recorded at two times body weight, with peak loading rates of up to 130 times the body weight per second during certain maneuvers [18, 19]. Similar observations have been made in other sports, highlighting the biomechanical demands placed upon the hand and wrist during athletic activity.

Anatomy

Twenty-nine bones comprise the hand and wrist. In addition to their osteology and radiographic appearance, awareness of the location of the physes is essential for appropriate care of athletic hand and wrist injuries (Fig. 10.1). The physes of the phalanges are located proximally in the digits and the thumb, and the closure of the epiphyseal plates does not typically occur until 14–16 years of age. Conversely, the physes of the metacarpals, with the exception of the thumb, are located distally in the metacarpal neck region. The thumb metacarpal has its physis proximally, near the carpometacarpal joint.

The ossification centers of the carpal bones become radiographically apparent in a predictable pattern, beginning with the capitate at less than 1 year of age and then proceeding sequentially to the hamate, triquetrum, lunate, scaphoid, trapezius, trapezoid, and pisiform. All ossification centers are visible radiographically by the 10th year of life. The distal radial and distal ulnar epiphyses become visible by 1 and 6–7 years of age, respectively. These physes close between the ages of 16 and 18 years, at the completion of skeletal growth.

Fig. 10.1 Bones of the hand. Anteroposterior radiographic image of the normal hand and wrist in a skeletally immature patient. Note the proximal locations of the phalangeal physes. The physes of the index, long, ring, and small finger metacarpals are distal, whereas the thumb metacarpal has a proximal physis. Courtesy of the Children's Orthopedic Surgery Foundation, Boston, MA

Awareness of the appearance of these physeal zones will avoid confusion between these normal structures and possible fractures and bony injuries. Furthermore, remodeling potential, or the capacity for bony deformity to correct with skeletal growth, is dependent on the amount of remaining growth, degree of deformity, and proximity of deformity to the adjacent physis. Knowledge of the physeal location, therefore, is essential to avoid false assumptions regarding bony healing after an acute injury.

In addition to the bony structures, joint stability in the hand and wrist is conferred by ligaments. At the interphalangeal joints, the collateral ligaments restrict excessive radial and ulnar deviation. These collaterals insert broadly on both the epiphysis and metaphysis, accounting for the infrequency in which avulsion fractures of the epiphysis occur. Conversely, at the metacarpophalangeal (MCP) joints, the collateral ligaments insert on the epiphysis of the more distal phalanx. For this reason, Salter–Harris III avulsion type fractures are much more common at the MCP joint level.

Similarly, wrist stability is imparted by several extrinsic and intrinsic ligaments, which help to stabilize the carpus and allow for the efficient transmission of forces across the wrist. Although a description of these ligamentous structures is beyond the scope of this chapter, special mention will be made regarding the triangular fibrocartilage complex, owing to its frequent contribution to pain and functional limitations in the adolescent athlete.

Finally, there are a total of 25 extrinsic tendons that traverse the hand and wrist. These include three wrist flexors (flexor carpi radialis, palmaris longus, flexor carpi ulnaris), four wrist extensors (brachioradialis, extensor carpi radialis longus, extensor carpi radialis brevis, extensor carpi ulnaris), the thumb flexor and extensors (flexor pollicis longus, extensor pollicis longus, extensor pollicis brevis), extrinsic digital extensors (extensor digitorum comminis, extensor indicis proprius, extensor digiti quinti), extrinsic digital flexors (flexor digitorum profundus and superficialis), and the long thumb abductor (abductor pollicis longus). In addition to these musculotendinous units, there are 18 intrinsic muscles of the hand, including the thenar, hypothenar, lumbrical, interossei, and adductor pollicis muscles. Because of the number of musculotendinous units and the compensatory abilities of the hand, in cases of suspected injury, precise evaluation of isolated muscle function should be performed to rule out a complete tendon rupture or laceration. For example, when assessing for a possible flexor tendon injury in the finger, assessment of independent distal and proximal interphalangeal joint flexion must be made to check both flexor digitorum profundus and flexor digitorum superficialis integrity, respectively.

Clinical Evaluation

History

Treatment of any injury to the hand or wrist begins with a thorough history and physical examination. Background information, including hand dominance, type of sport(s) played, position and/or events, and level of performance, are critical to provide appropriate sport-specific care. Details of the exact mechanism of injury, including position of the hand or wrist, direction and magnitude of the applied force, and subsequent complaints of pain, weakness, and instability, will provide clues to the diagnosis. In the office setting, athletes should be asked regarding the initial on-field management of the injury in question, such as manipulation, reduction maneuvers, and splinting. Finally, inquiring whether the athlete was able to return immediately to practice or competition will provide insight on the severity of the injury.

Physical Exam

Inspection for the presence of swelling, ecchymosis, lacerations, abrasions, or wounds will help guide the examiner to the anatomic region of interest and rule out the possibility of an open fracture or dislocation. Careful palpation of all the anatomic structures in the zone of injury is essential. Musculoskeletal injuries hurt, and reproducible bony tenderness should be considered a fracture until otherwise proven. In addition to bony tenderness, all adjacent joints should be assessed for motion and stability. Finally, a comprehensive neurovascular examination is performed to assess for possible nerve or vascular injury.

The presence of angular or rotational deformity should also raise suspicion for a bony or joint injury. The principle of tenodesis is helpful in these situations. In the normal hand and wrist, passive wrist extension results in obligate passive digital flexion, with all the fingers roughly parallel, pointing toward the scaphoid tubercle. In

Fig. 10.2 Clinical photograph depicting a patient with a flexor tendon injury to the long finger due to a traumatic laceration in the palm. Note is made of loss of tenodesis effect, resulting in an extended resting position of the affected digit in relation to the adjacent fingers

cases of rotational deformity through a fracture, the affected digit will overlap or underlap the adjacent fingers. After the same principles, in patients with a flexor tendon injury, the affected digit will not passively flex with the adjacent digits in the resting position or with passive wrist extension (Fig. 10.2).

Plain radiographs should be obtained in the evaluation of any possible bony or joint injury. In addition to orthogonal views of the region in question, oblique radiographs will often identify bony injuries not readily apparent on anteroposterior (AP) or lateral projections. In cases of suspected carpal, articular, or ligamentous injury, additional magnetic resonance imaging (MRI) or computed tomography (CT) may be warranted; specific situations in which these studies are helpful are discussed below.

Wrist Injuries

Distal Radius Fractures

Distal radius fractures are among the most common injuries in skeletally immature patients, comprising between 20 and 35% of all childhood fractures [20–23]. Approximately one-third of these fractures involve the distal radial physis [24, 25]. With increases in sports participation among younger children, the incidence of forearm, wrist, and hand injuries has risen [13, 26]. In particular, increased participation in soccer, gymnastics, and snowboarding has been linked to the increased incidence of pediatric distal radius fractures over the past two decades [23, 27, 28]. Furthermore, recent analyses suggest that increased body weight may also be a contributing factor [29, 30].

Anatomy

The distal radial physis contributes approximately 80% of the longitudinal growth of the radius. For this reason, fractures of the distal radius have tremendous remodeling potential, and up to 10 degrees per year of dorsal–volar angulation may remodel with skeletal growth [31–34]. In general, younger patients with fractures close to the physis in the plane of adjacent joint motion have the greatest remodeling potential. Rotational deformities, however, have limited remodeling potential. Based on these principles, 20–25 degrees of dorsal–volar angulation, 50% translational displacement, and 10 degrees of radial–ulnar deviation may be expected to remodel with continued skeletal growth in younger patients (less than 12 years old). Conversely, older adolescents nearing skeletal maturity do not have the same remodeling capacity. In these older patients, treatment recommendations are made as would be for adults.

Clinical and Radiographic Evaluation

Patients will typically present with pain, swelling, and/or deformity of the affected wrist, typically after a fall onto the outstretched upper extremity. Plain radiographs will confirm the diagnosis and guide treatment. An understanding of the normal radiographic appearance of the skeletally immature hand and wrist is paramount (Fig. 10.1). In general, the wrist, forearm, and elbow are imaged to rule out ipsilateral injuries of the affected limb.

Distal radius fractures are generally categorized according to their anatomic location, pattern of injury, and degree of displacement, angulation, and/or rotation. These injuries may occur at the distal radial metaphysis, involve the distal radial physis, or extend into the radiocarpal joint.

Management

Distal metaphyseal fractures in skeletally immature patients are generally divided into torus or bicortical fractures. Torus, or "buckle," fractures are characteristic injuries of childhood, owing to the increased porosity of metaphyseal bone during accelerated skeletal growth. Cortical failure occurs in compression, and as a result, these injuries are inherently stable. Typically, there is little associated fracture displacement, and given the capacity for remodeling, fracture manipulation is not required. Immobilization in a short-arm cast or removable wrist splint for 3 weeks provides adequate symptomatic relief and prevents further injury. Randomized prospective studies have demonstrated that torus fractures may be effectively and safely treated with splint immobilization, removed by parents after 3 weeks with no need for subsequent clinical or radiographic evaluation [35–38]. Treatment in a prefabricated cock-up wrist splint has also been associated with higher patient- and family-rated satisfaction when compared with cast immobilization in a recent randomized controlled trial [39].

Bicortical fractures of the distal radial metaphysis may occur because of bending, rotational, and/or shear forces sustained by the wrist during injury. Displaced fractures with unacceptable alignment may be treated with closed reduction and cast immobilization. Recent prospective randomized controlled trials have shown that a well-molded below-elbow cast is as effective as above-elbow casts in the treatment of displaced injuries [40, 41]. Athletes are allowed to return to sports after confirmation of fracture healing and return of motion and strength.

The published recommendations of what constitutes "acceptable" alignment are highly variable, and there continues to be discussion and controversy regarding the indications for fracture manipulation and surgical treatment. In general, most authorities agree that up to 20–25 degrees of angulation in the sagittal plane and translational displacement of up to 50% of the cortical diameter will reliably remodel and may be accepted in patients with greater than 2–3 years of remaining skeletal growth. In older patients, up to 10 degrees of angulation in the sagittal plane and up to 10 degrees of radial–ulnar deviation may be accepted.

It is important to recognize, however, that late displacement after initial fracture reduction occurs in up to one-third of cases [42–45]. Initial displacement and periosteal disruption, inadequate reduction, poor casting techniques, resolution of soft tissue swelling, and muscle atrophy have all been implicated as contributing factors. A recent study showed that initial fracture displacement greater than 50% and inability to achieve anatomic reduction were the most important risk factors for redisplacement [45]. In skeletally mature patients, greater than 20 degrees of apex volar angulation, greater than 5 mm of radial shortening, comminution beyond the midaxial line, and intraarticular fracture extension have all been identified as radiographic predictors of fracture instability [46–49]. If the resultant deformity is deemed unacceptable, intervention is warranted.

Fig. 10.3 (**a, b**) Anteroposterior and lateral radiographs of a displaced distal radial metaphyseal fracture. (**c, d**) Anteroposterior and lateral radiographs after closed reduction and percutaneous pin fixation and subsequent bony healing. Courtesy of the Children's Orthopedic Surgery Foundation, Boston, MA

Current indications for surgical treatment include irreducible or unstable fractures, open fractures, "floating elbow injuries," neurovascular compromise, or soft tissue swelling precluding circumferential cast immobilization. Percutaneous smooth pin fixation may be performed after closed reduction to maintain appropriate fracture alignment (Fig. 10.3).

Some advocate percutaneous pin fixation for all displaced metaphyseal fractures in older children to avoid loss of reduction and need for remanipulation. However, pin fixation carries the concomitant risks of infection, neurovascular injury, and general anesthesia. Randomized, prospective studies comparing the two treatment methods cite similar complication rates and no significant outcomes differences [42, 50].

The majority of distal radial physeal fractures are Salter–Harris type II fractures and are amenable to closed reduction and cast immobilization. Closed reduction should be performed atraumatically with adequate analgesia and/or anesthesia. Because of concerns regarding iatrogenic physeal injury, repeated reduction attempts or attempts at late reduction (greater than 5–7 days from injury) are discouraged. Indications for surgical treatment include significant soft tissue swelling or concomitant neurovascular compromise (e.g., compartment syndrome or acute carpal tunnel syndrome) precluding circumferential cast immobilization or intraarticular fractures with joint incongruity (e.g., Salter–Harris III fractures).

Scaphoid Fractures

The scaphoid is the most commonly injured carpal bone, comprising approximately 70–80% of all carpal fractures, and it is most commonly seen in young males in the second and third decades of life. Despite our increased awareness of the prevalence of these injuries, the diagnosis and treatment of scaphoid fractures remain challenging, due, in part, to its complex anatomy, tenuous vascular supply, and role in wrist biomechanics. Indeed, few injuries in the adolescent athlete provide as many diagnostic challenges, treatment options, and potential complications for the treating care provider.

Anatomy

The scaphoid has a complex three-dimensional shape, resembling a peanut that is twisted and bent [51]. The majority of the scaphoid surface is covered by cartilage. For this reason, the vascularity of the scaphoid is imparted by a limited number of vessels. Seventy to eighty percent of the scaphoid's intraosseous vascularity, including the entire proximal pole, is provided by branches of the radial artery that enter the dorsal ridge of the scaphoid and travel in a retrograde fashion [52]; 20–30%, in the region of the scaphoid tubercle, is supplied by volar radial artery branches. This vascular pattern accounts for the high predisposition for scaphoid nonunions and osteonecrosis of the proximal pole after fractures of the scaphoid waist.

With radial deviation of the wrist, the scaphoid moves with the proximal carpal row into flexion. Conversely, with ulnar deviation of the wrist, the scaphoid will extend. Displaced scaphoid fractures will result in abnormal wrist kinematics, allowing the distal pole to flex while the proximal pole extends. This results in apex dorsal and radial angulation of the scaphoid fracture, the so-called humpback deformity [53]. Even with fracture healing, this flexion deformity will alter normal wrist kinematics, often leading to pain, stiffness, weakness, and progressive radiocarpal arthrosis [53–55]. As a result, bony healing in anatomic alignment is critical for restoration of function.

Clinical Evaluation

Patients will typically present with radial-sided wrist pain after a fall onto an outstretched hand. Often, the clinical manifestations are subtle, demanding careful evaluation. In addition to a thorough physical examination, specific testing of the scaphoid should be performed. Tenderness elicited from palpation of the "anatomic snuffbox" or scaphoid tubercle has been shown to be the most sensitive test for clinical diagnosis of a scaphoid fracture [56]. Axial loading the thumb across the carpometacarpal joint, the so-called grind test, may produce pain. The scaphoid compression test, in which the examiner compresses the scaphoid between the proximal and distal poles with his/her thumb and index finger, is another reliable examination maneuver [57]. In general, these clinical tests have high sensitivity but poor specificity, necessitating further workup with imaging [56].

Radiographs

Appropriate radiographic imaging should be performed in all suspected cases of scaphoid fracture (Table 10.1). Routine anteroposterior (AP) and lateral plain radiographs of the wrist alone do not suffice. Because the scaphoid normally extends and lies more parallel to the plane of the hand with ulnar deviation of the wrist, an AP view in ulnar deviation should be obtained. Furthermore, the middle third of the scaphoid may be better visualized with a 45-degree semipronated view, whereas the dorsal ridge may be best seen on a semisupinated view [58]. In addition to confirming the diagnosis, radiographs will identify fracture displacement, defined as a gap greater than 1–2 mm, a scapholunate angle greater than 60°, a radiolunate angle greater than 10–15°, or an intrascaphoid angle of greater than 45° [53, 59] (Table 10.1).

Plain radiographs may not always identify fractures, however. Treating physicians, trainers, and coaches are often confronted with a patient with radial wrist pain, but negative radiographs. Appropriate evaluation and treatment of these

Table 10.1 Radiographic evaluation of suspected scaphoid fractures

Radiographic evaluation of suspected scaphoid fractures	Anteroposterior (AP) X-ray of the wrist
	AP X-ray of the wrist in ulnar deviation
	Lateral X-ray of the wrist
	45° pronated and supinated views
	CT or MRI
Radiographic findings in acute displaced scaphoid fractures	Fracture displacement >1–2 mm
	Scapholunate angle greater than 60° on lateral view
	Radiolunate angle >10–15° on lateral view
	Intrascaphoid angle >45°
	Presence of "cortical ring sign" on AP view

patients remains a subject of debate. Traditionally, patients with scaphoid tenderness but normal x-rays were treated for 1–2 weeks in a thumb spica cast, followed by repeat plain radiographs to evaluate for possible bony injury. This approach has several limitations, particularly in the young, active working or athletic population. Unnecessary casting results in loss of work or sports participation, and repeat radiographs may not adequately visualize subtle injuries, particularly nondisplaced fractures.

Bone scintigraphy had previously been advocated in these situations; however, isotope scans may be positive in settings of synovitis or early arthrosis. In addition, bone scintigraphy will not provide information regarding bony anatomy, which is needed to make the appropriate treatment recommendations. For these reasons, early CT or MRI (Fig. 10.4) is advocated to make the diagnosis and define the fracture pattern. Indeed, studies suggest that early MRI may be more cost-effective than serial plain radiographs and cast immobilization, particularly in the younger athletic or working population [60–63]. In a comparison of advanced imaging modalities for radiographically occult scaphoid fractures, MRI has been shown to be superior to multidetector CT in detecting solely trabecular injury, while multidetector CT appears to be superior in depicting cortical involvement [64]. A diagnostic algorithm is proposed (Fig. 10.5) for the evaluation of suspected scaphoid injuries.

Nonoperative Treatment

Cast immobilization will result in successful healing in over 90% of acute, nondisplaced scaphoid fractures. However, scaphoid fractures require longer periods of immobilization until bony union is achieved, and it is not uncommon for these injuries to take 8–12 weeks to heal.

Methods of cast immobilization continue to be debated. Incorporation of the thumb into a spica cast has been advocated to eliminate forces across the scaphoid that may inhibit healing or cause displacement. Clay et al. performed a randomized prospective study of 392 patients com-

Fig. 10.4 (**a**) Anteroposterior (AP) view of the wrist in a patient with radial wrist pain. (**b**) AP view of the wrist in ulnar deviation, in which the fracture of the scaphoid waist is more apparent. (**c**) Computed tomography scan and (**d**) MRI of the wrist, confirming the diagnosis. (**e**) Post-operative AP view of the wrist after open reduction and internal fixation with a compression screw (Courtesy of the Children's Orthopedic Surgery Foundation, Boston, MA)

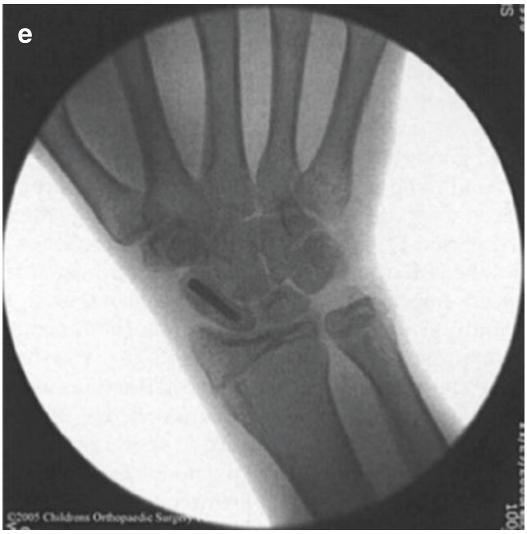

Fig. 10.4 (continued)

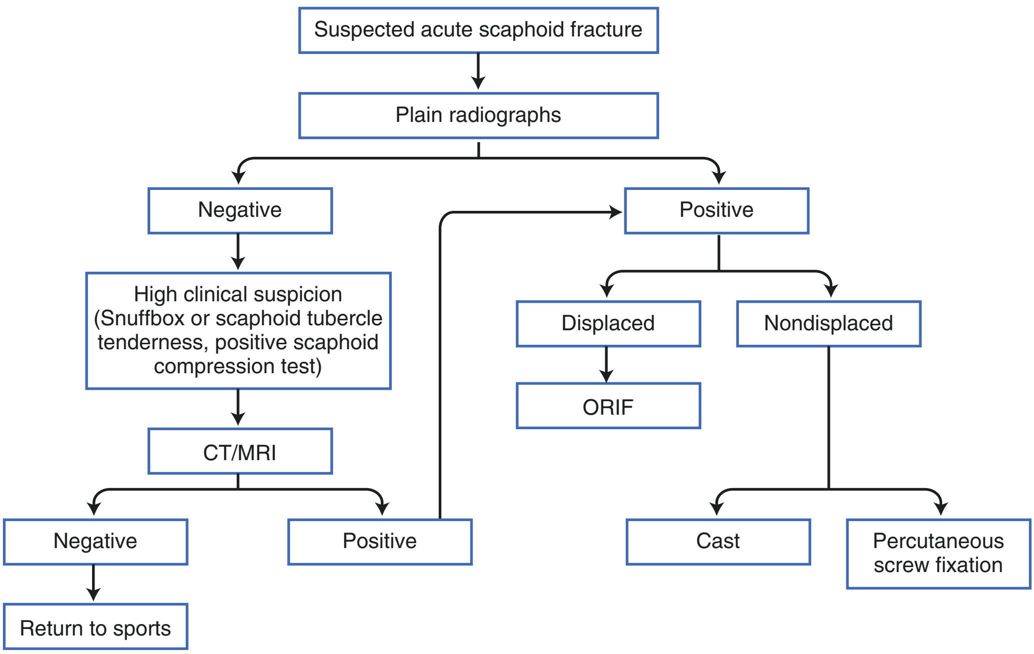

Fig. 10.5 Clinical algorithm in the evaluation of suspected acute scaphoid fracture. ORIF, open reduction and internal fixation (Courtesy of the Children's Orthopedic Surgery Foundation, Boston, MA)

paring short-arm casting with or without a thumb spica component for the treatment of acute nondisplaced injuries [65]. At the 6-month follow-up, rates of bony healing did not differ between the two treatment groups. Immobilization of the elbow eliminates forearm rotation, which has previously been shown to cause scaphoid fracture motion [66]. Gellman et al. performed a prospective randomized study comparing long- versus short-arm thumb spica casting for the treatment of acute nondisplaced scaphoid waist fractures [67]. Patients treated with long-arm casts for the first 6 weeks have a faster healing time (9.5 vs. 12.7 weeks) and lower nonunion and delayed union rate than those treated with short-arm casts alone. Finally, several biomechanical and clinical studies have evaluated the effect of wrist position on scaphoid healing during casting. Arguments have been made for wrist extension, wrist flexion, and radial and ulnar deviation. Hambidge et al. performed a prospective, randomized study comparing cast immobilization in 20° wrist flexion and 20° wrist extension [68]. No difference was found in fracture healing, although patients immobilized in flexion had restrictions in motion at early follow-up. The authors' current preferred method of casting for nondisplaced scaphoid waist fractures is short-arm thumb spica cast until clinical and radiographic healing.

It is important to remember that fractures of the scaphoid tubercle and distal pole are extraarticular and have a more robust vascular supply. Bony healing is reliable and more rapid. For this reason, short-arm thumb spica casting for 4–6 weeks in nondisplaced or minimally displaced injuries will usually suffice.

Surgical Treatment

Established indications for surgical treatment include displaced fractures of the scaphoid waist, proximal pole fractures, fractures with associated injuries (e.g., distal radius fractures and carpal instability), and fractures that have failed nonoperative treatment (Fig. 10.4).

There is a continuing debate regarding the most appropriate treatment for nondisplaced scaphoid waist fractures in the young athletes. Because of the prolonged period of immobilization often required for successful cast treatment and the risk of nonunion, some have advocated surgical fixation of nondisplaced injuries. The enthusiasm for surgical treatment has increased recently, given advances in techniques for minimally invasive and percutaneous approaches to screw fixation [69–72]. The theoretical advantages of surgical stabilization for nondisplaced fractures include more rapid healing, shorter cast immobilization, decreased risk of nonunion or late displacement, and more expedient return to sports or work.

Several studies have shown more rapid bony healing and faster return to activity with surgery. Bond et al. performed a prospective, randomized study comparing cast immobilization to percutaneous screw fixation for nondisplaced scaphoid waist fractures in young naval personnel, average age 24 years [73]. Average fracture healing time was 7 weeks in the screw fixation group, compared to 12 weeks in the casting group; return to military duty was 8 weeks compared with 15 weeks, respectively. In a similar study, Adolfsson et al. performed a randomized study of 53 patients comparing percutaneous screw fixation to cast immobilization for nondisplaced scaphoid waist fractures [74]. Although there were no differences in the rate of bony union or time to healing, patients who underwent surgical fixation had significantly better range-of-motion at the 16-week follow-up. Dias et al. performed a randomized controlled trial of 88 patients comparing short-arm casting (with the thumb left free) to screw fixation without supplemental casting or splinting [75]. Range-of-motion and grip strength were higher in the surgically treated group at 8 weeks; however, at longer follow-up, patients had equivalent motion and function. Both groups returned to work at 5–6 weeks after injury. Notably, 10 out of 44 patients in the casting group had no evidence of healing after 12 weeks of casting and ultimately required additional treatment. This high percentage of casting failures may be caused by the casting technique (i.e., failure to incorporate the thumb and/or elbow in the cast). More recently, a prospective, randomized study by McQueen et al. similarly examined 60 patients treated with either percutaneous screw fixation or cast immobilization with the thumb free [76]. Patients who were treated surgically returned to sports 9 weeks sooner than those treated nonoperatively. Radiographically, patients in the operative group had faster time to union by almost 5 weeks and a trend toward a higher rate of union [76].

Given the improvements in imaging and surgical techniques, as well as the data suggesting that early screw fixation may lead to more rapid bony healing and return to sports participation, patients with nondisplaced scaphoid waist fractures should be counseled regarding the advantages and disadvantages of cast immobilization versus screw fixation.

Return to Play

Guidelines for return to play after treatment of acute scaphoid fractures vary widely among treating surgeons [77]. Belsky et al. have recommended CT scan every 6 weeks to ensure the scaphoid is healed prior to allowing return to protected play [78]. Once there is evidence of healing (at least 50% cross-sectional bone bridging on CT scan) and the wrist is pain-free with excellent motion and grip strength, return to play is considered and pursued in a graduated fashion on an individual basis.

Other Carpal Fractures

Hook of Hamate Fractures

Hook of hamate fractures represent approximately 2–4% of all carpal fractures [79]. The hook of hamate is a bony projection of the hamate, lying just distal and radial to the pisiform (Fig. 10.6). Despite its location beneath palmar fibrofatty tissue, it may reliably be located if the examiner places the interphalangeal joint of his/her thumb on the pisiform; by flexing the interphalangeal joint, the thumb tip will fall over the hamate hook (Fig. 10.6). Anatomically, it serves as the attachment for the pisohamate and transverse carpal ligaments, origin of the flexor digiti quinti and opponens digiti quinti muscles, and forms the radial border of Guyon's canal (the ulnar tunnel). In addition, it lies in close proximity to the flexor tendons of the small and ring fingers and the sensory and deep motor branches of the ulnar nerve.

Classically, these injuries occur because of direct force applied to the hamate hook, either from a fall onto an extended wrist or from the impact of the butt of a baseball bat or racquet, which rests adjacent to the hamate's bony process [80]. Acutely, hook of hamate fractures present with localized tenderness, swelling, and ecchymosis. There may be pain with resisted small and ring finger flexion, as well as paresthesias or dysesthesias in the ulnar nerve distribution.

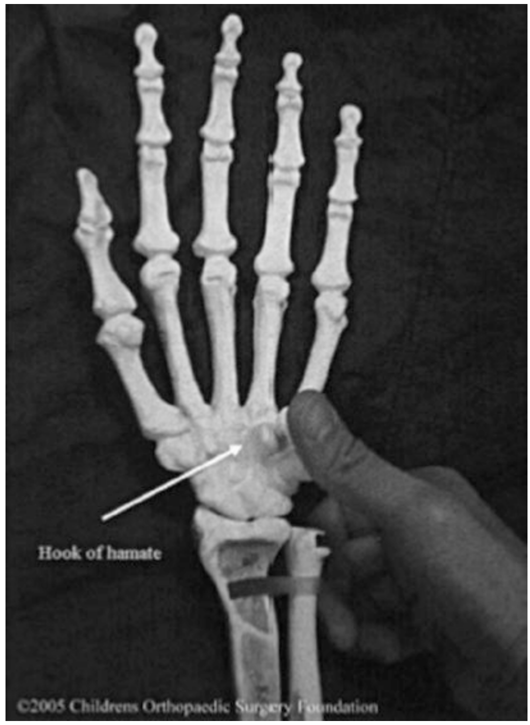

Fig. 10.6 Illustration demonstrating palpation of the hook of the hamate. The examiner places the interphalangeal joint of his/her thumb over the pisiform, allowing the tip of the thumb to fall upon the hook of the hamate (Courtesy of the Children's Orthopedic Surgery Foundation, Boston, MA)

Specific radiographic studies must be performed to confirm the diagnosis. The carpal tunnel and supinated oblique views of the wrist may be obtained to better visualize the hook of hamate in suspected cases [81, 82]. Computed tomography, however, will best provide visualization of the hook of hamate to make the diagnosis of fracture and guide treatment.

Acute nondisplaced or minimally displaced fractures may be successfully treated with splint or cast immobilization when diagnosed early

[83]. Acute displaced fractures may be treated with cast immobilization or surgery. Although a stable fibrous union may form after casting, there is a risk for development of a painful nonunion. For this reason, many have recommended either open reduction and internal fixation (ORIF) or hamate hook excision in displaced injuries [84, 85]. Several published reports have documented rapid return to sports with little, if any, disability after hook of hamate excision [80, 84–86]. Chronic hamate hook fractures may present with tenosynovitis or rupture of the flexor tendons and ulnar nerve symptoms. Although some have advocated open reduction and internal fixation with the use of bone graft, hook of hamate excision may provide the most reliable means of symptomatic improvement and expedient return to activities [87].

Dorsal Triquetrum Avulsion Fractures

Triquetral fractures are commonly seen in young athletes. Dorsal avulsion fractures may be seen after a fall onto an outstretched hand or hyperflexion injuries of the wrist. These represent avulsion of the dorsal intercarpal and radiotriquetral ligaments from their insertion on the triquetrum. Patients will typically present with dorsal wrist pain, swelling, and tenderness after a fall. Radiographs will confirm the diagnosis. A comprehensive examination is critical to rule out associated bony or ligamentous injury. In the absence of associated pathology, these may be successfully treated with a short-arm cast or splint immobilization for 3–6 weeks.

Triangular Fibrocartilage Injuries

Though descriptions of triangular fibrocartilage complex (TFCC) injuries in adults have been widespread since the 1980s, only recently has there been increased understanding of similar injuries in the pediatric and adolescent patient population [88, 89]. Although this may be attributed to increased awareness, increased sports participation in younger athletes may also be contributing to the increased prevalence. Furthermore, as the use of diagnostic tools such as high-resolution MRI become more widespread, so too may our appreciation of the frequency of these injuries [90, 91]. When present, TFCC injuries may be the source of ulnar-sided wrist pain and functional limitations in the adolescent athlete.

Anatomy

The TFCC refers to a convergence of structures on the ulnar side of the wrist that serve to support the ulnocarpal articulation and stabilize the distal radioulnar joint (DRUJ). First described by Palmer and Werner, these structures include the triangular fibrocartilage, the dorsal and volar radioulnar ligaments, the meniscal homologue, the ulnolunate and ulnotriquetral ligaments, and the subsheath of the extensor carpi ulnaris (ECU) tendon [88]. Functionally, the TFCC provides a smooth articular surface between the radius and ulna, transmits and absorbs axial loads across the ulnocarpal articulation, and contributes stability to the ulnar wrist and DRUJ. Previous studies have demonstrated that approximately 20% of the axial load is transmitted across the ulnocarpal joint in wrists with neutral ulnar variance [92]. Small changes in ulnar variance may result in significant alterations in axial loads borne by the TFCC.

Clinical Presentation

Most patients with TFCC tears present with ulnar-sided wrist pain, which is exacerbated with forceful grip and twisting-type activities, often in the setting of prior wrist trauma. It is thought that most TFCC injuries arise from axially loading of/fall onto the extended and pronated wrist [93]. The symptoms of TFCC injury may be subtle, particularly in the child or adolescent. Indeed, patients may complain of wrist pain only during specific sports-related activity and be free of pain or functional limitations during activities of daily living [89].

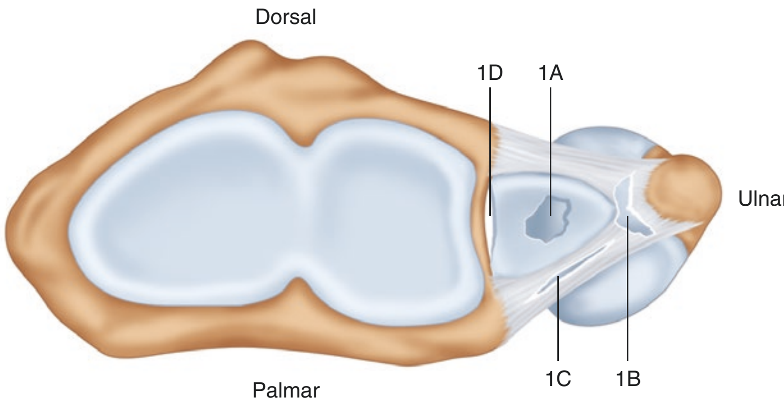

Fig. 10.7 Palmer classification of acute tears of the triangular fibrocartilage complex (TFCC). Class 1A, central perforation of the fibrocartilage disk tissue. Class 1B, ulnar avulsion. Class 1C, distal avulsion. Class 1D, radial avulsion

Physical examination findings may also be subtle. Usually there is tenderness over the ulnar aspect of the wrist. The TFCC compression test, in which the wrist is axially loaded, ulnarly deviated, and rotated, is a helpful provocative test. Stability of the DRUJ must be assessed, as TFCC disruption may be associated with DRUJ instability.

All patients with suspected TFCC injury should be evaluated with plain radiographs to identify potential coexisting wrist pathology, including distal radial fracture malunion, ulnar styloid nonunion, positive ulnar variance with ulnocarpal impaction, and DRUJ instability. As the apparent length of the distal ulna can vary with forearm rotation, standardized views should be obtained and variance measured according to the technique of perpendiculars [94]. Comparison radiographs of the contralateral wrist may be useful in these situations. MRI may be used to assess the integrity of the TFCC. Though early reports of this imaging modality noted significant limitations in the evaluation of the TFCC, the sensitivity and specificity of MRI has improved [90, 91].

The Palmer classification is the most commonly used system to describe TFCC injuries [95]. In the pediatric population, traumatic (class 1) injuries represent the vast majority of TFCC tears (Fig. 10.7); as expected, degenerative (class 2) tears of the TFCC are far less common. Injuries to the TFCC are further classified based on the location of the cartilage complex tear (Table 10.2).

Based on previously published reports, there is an apparent increased prevalence of Palmer 1B tears in pediatric patients compared with adults [89, 96]. Indeed, tears from the ulnar attachment, with or without associated ulnar styloid fractures, represent the most common variety of TFCC injuries in children and adolescents.

Table 10.2 Classification of triangular fibrocartilage tears

Class 1: traumatic	
A	Central perforation
B	Ulnar avulsion
C	Distal avulsion
D	Radial avulsion
Class 2: degenerative	
A	TFCC wear
B	TFCC wear, lunate/ulnar chondromalacia
C	TFCC perforation, lunate/ulnar chondromalacia
D	TFCC perforation, lunate/ulnar chondromalacia, LT ligament perforation
E	TFCC perforation, lunate/ulnar chondromalacia, LT ligament perforation, ulnocarpal arthritis

Tears of the radial attachment (Palmer 1D tears) represent the second most common type. Care should be made during preoperative evaluation, MRI analysis, and intraoperative arthroscopic survey to ensure accurate diagnosis of these radial-sided tears. If mistaken for a central traumatic tear (Palmer 1A), simple debridement alone may result in persistent pain, instability, and functional limitations.

Patients with persistent pain and functional limitations associated with TFCC injury despite rest, activity modification, and physical/occupational therapy are candidates for surgical treatment.

Surgical Management

In appropriate patients with peripheral TFCC tears, repair of the TFCC to its ulnar or radial attachments is recommended. Surgical repair typically consists of wrist arthroscopy, debridement of the tear, and subsequent suture fixation of the TFCC edge to either its ulnar or radial attachments [97]. Coexisting wrist pathology, such as ulnar styloid fractures, ulnocarpal impaction in the setting of positive ulnar variance, and DRUJ instability, are addressed at the time of TFCC repair.

Post-operatively, patients are immobilized in long-arm casts with the elbow flexed 90° and the forearm in supination for 4 weeks, followed by short-arm casts or splints for an additional 2 weeks. Range-of-motion and strengthening exercises are then initiated. Sports participation is allowed after there is restoration of motion and strength, typically 3 to 6 months postoperatively.

Compared to the extensive published data regarding the surgical management of TFCC injuries in adults, relatively little has been written about the results of treatment in the pediatric patient population. Terry and Waters reviewed a series of 29 children and adolescents treated for post-traumatic, surgically documented TFCC injuries at an average age of 13 years [89]. All patients presented for evaluation of ulnar wrist pain. Over three-fourths had Palmer 1B lesions. Eighty-six percent of patients had coexisting wrist pathology, most commonly being ulnar styloid nonunion, DRUJ instability, distal radial fracture malunion, and/or ulnocarpal impaction. All Palmer 1B, 1C, and 1D tears were repaired using the principles and techniques outlined above. At average follow-up of 21 months, over 85% of patients had good to excellent results as assessed by the modified Mayo wrist score, which assesses pain, motion, and wrist function [89, 96–98].

More recently, Farr et al. described their experience in 39 children and adolescents who underwent wrist arthroscopy for refractory wrist pain for greater than 3 months, at an average age of 15.3 years [99]. Of these, 80.5% of patients were found to have TFCC tears arthroscopically, though preoperative MRI only detected TFCC injuries in 26.8% of these cases. Palmer 1B tears were the most common, followed by Palmer 1D. In a subsequent study by the same group, outcomes were assessed in 12 adolescents who underwent repair of Palmer 1B tears via outside-in vertical mattress technique. At a mean follow-up of 1.3 years, patients had a significant improvement in their visual analogue scale (VAS) and mean post-operative disabilities of the arm, shoulder, and hand (DASH) score of 16, suggesting good overall functional outcome [100].

McAdams et al. also noted excellent outcomes in a series of 16 athletes who underwent arthroscopic TFCC repair or debridement, with minimum follow-up of 24 months [101]. Mean mini-DASH scores improved from 47.3 to 0, and return to play averaged 3.3 months [101].

The Gymnast's Wrist and Ulnocarpal Impaction

Repetitive axial loading of the wrist during sports participation may cause growth disturbance of the distal radial physis in skeletally immature athletes, leading to relative ulnar overgrowth and altered wrist biomechanics. As noted previously, a change in ulnar variance by 2 mm can increase the axial loads borne across the ulnocarpal joint from 20 to 41% [92]. This may lead to ulnar wrist pain, TFCC tears, and DRUJ instability.

This constellation of findings is commonly seen in gymnasts because of the repetitive weight bearing performed with the wrist in dorsiflexion. Indeed, studies of high-level gymnasts have demonstrated a higher incidence of ulnar-positive variance and distal radial physeal stress changes compared to non-gymnasts [102, 103]. One recent study of 19 gymnasts at an average age of 13.3 years found radiographic evidence of distal radial physeal arrest in 65% of cases [104].

In patients with pain and functional limitations despite splinting, therapy, and activity modification, surgical treatment may be warranted. Depending on the degree of deformity and amount of skeletal growth remaining, surgery may consist of arthroscopic-assisted TFCC

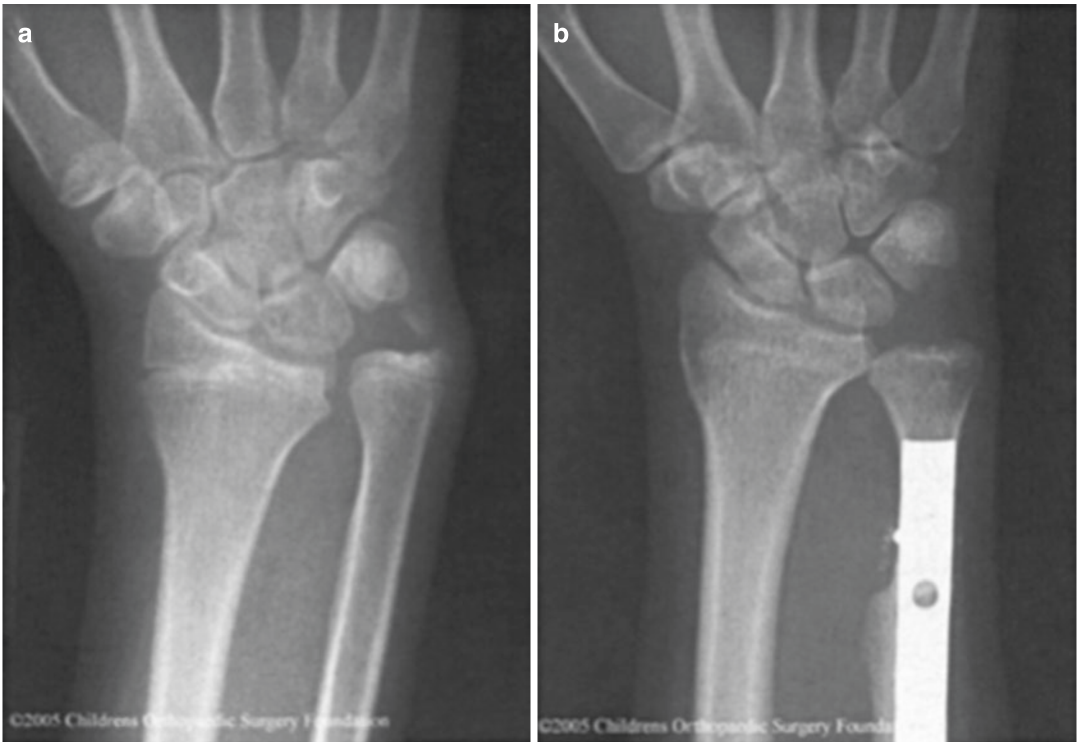

Fig. 10.8 (**a**) Anteroposterior radiograph of the wrist in a patient with ulnocarpal impaction. Note the ulnar styloid fracture nonunion and positive ulnar variance. (**b**) AP radiograph after ulnar styloid nonunion excision and ulnar-shortening osteotomy (Courtesy of the Children's Orthopedic Surgery Foundation, Boston, MA)

repair, distal ulnar epiphysiodesis, ulnar-shortening osteotomy, corrective radial osteotomy, or combinations thereof [105, 106] (Fig. 10.8).

Hand Injuries

Metacarpal Fractures

Metacarpal fractures are common in adolescent males, with a peak incidence rate in the 10–19 year age group [107, 108]. Sports injuries represent the second most common etiology after punching injuries, with the highest number occurring in basketball and American football [108]. Although the majority of metacarpal fractures may be successfully treated with nonoperative means, care providers should have an understanding of fundamental treatment principles and indications for surgical intervention. Not all metacarpal fractures are the same, and treatment is predicated on the location of injury, digit involved, degree of associated displacement, and presence of associated injury.

Patients present with pain, swelling, and deformity after hand trauma. Fractures may occur because of direct blow or indirect trauma, such as when the limb or body pivots around a planted hand. A comprehensive physical examination is performed to assess for associated neurovascular or tendinous injury, as well as to assess the adjacent soft tissues and skin integrity.

Perhaps the most important component of the physical examination is to assess for rotational deformity of the affected digit. This may be best assessed using the principle of tenodesis, as described earlier in the chapter. In cases of a malrotated metacarpal fracture, the tenodesis maneuver may result in over- or underlapping of the affected digit with respect to the adjacent fingers. Malrotation is important to identify, as such deformity compromises hand function and does not remodel, even in skeletally immature patients. Radiographs will confirm the diagnosis; AP, lateral, and oblique views of the hand are recommended.

Metacarpal Shaft Fractures

Isolated fractures of the metacarpal shaft often demonstrate little displacement or angulation. This is, in part, caused by the presence of the intermetacarpal ligaments, which connect the distal metacarpals to one another, and the keystone configuration of the carpometacarpal (CMC) joint. Mild deformity may be accepted with no adverse effect on hand function. In addition, because of the compensatory motion present in the CMC joints of the ring and small fingers, more angular deformity may be accepted in the ring and small fingers than the index and long fingers. Most authorities agree that up to 20–30 degrees of angulation may be accepted in the ring and small metacarpals, whereas only 10 degrees of angulation or less should be accepted in the index and long metacarpals [109].

In cases of unacceptable deformity, closed reduction and cast immobilization are recommended. Casts are typically maintained for 3–4 weeks, with interval radiographs performed to confirm maintenance of acceptable alignment. Several modified cast gloves and splints have been proposed in athletes with these injuries to provide expedited return to play [110]. Although the exact form of immobilization may be modified for each individual, the principles of treatment remain the same.

Indications for surgical treatment of metacarpal shaft fractures include the following: open fractures, multiple metacarpal fractures (in which the stabilizing effects of the adjacent metacarpals are lost), rotational malalignment, and unstable fractures in which acceptable alignment cannot be maintained with cast or splint immobilization. In these situations, surgical stabilization may be accomplished by several different techniques, including percutaneous smooth wires, intramedullary wires, interfragmentary compression screws, or plate-and-screw constructs, depending on fracture pattern and associated injuries (Fig. 10.9).

Recent studies in adults suggest that athletes may return to play within 7–14 days after surgical treatment of metacarpal shaft fractures, utilizing protective bracing for an additional 3–6

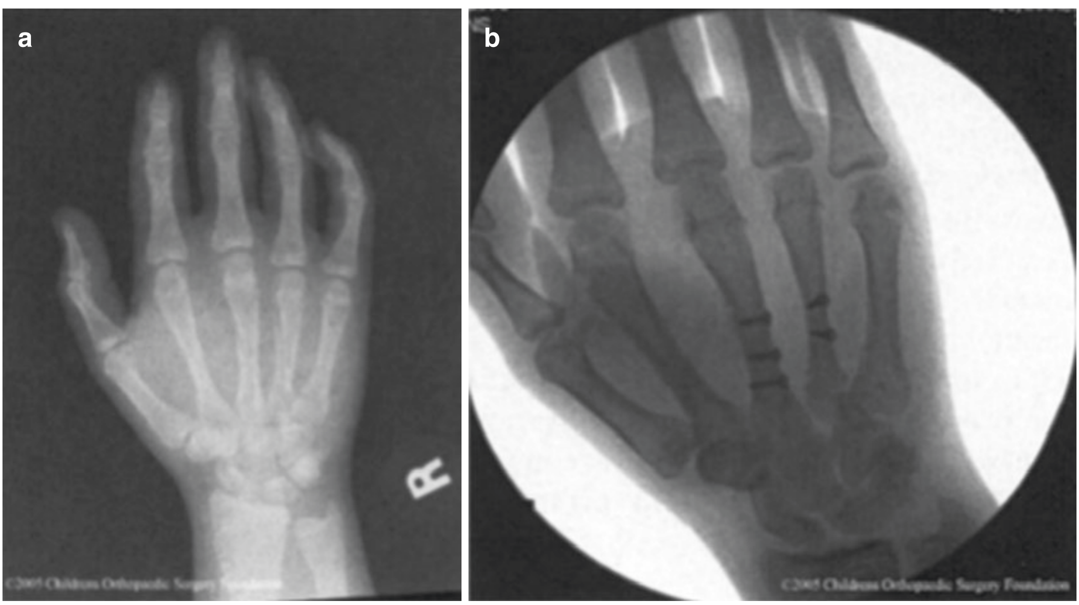

Fig. 10.9 (**a**) Anteroposterior radiograph of the hand demonstrating fractures of the long and ring finger metacarpal shafts in a 13-year-old gymnast. (**b**) Because of malrotation of the digits seen on clinical examination, as well as the fact that multiple adjacent metacarpals were involved, the injury was treated with open reduction and internal fixation using interfragmentary compression screws. The patient returned to gymnastics at 3 months (Courtesy of the Children's Orthopedic Surgery Foundation, Boston, MA)

weeks, without any detriment to wound or bone healing, implant integrity, or functional outcome [111–113]. As such, some authors recommend surgical management of metacarpal shaft fractures for certain athletes who desire earlier return to play [111, 112].

Metacarpal Neck Fractures

Fractures of the metacarpal neck are also common injuries, typically affecting the ring and small rays. Though often referred to as "boxer's fractures," these injuries are rarely seen in high-level boxing athletes. The mechanism of injury involves a direct axial load across a flexed MCP joint.

Patients will present with pain, swelling, and deformity. Radiographs will confirm the diagnosis, typically demonstrating apex dorsal angulation caused by the position of the hand during injury and the deforming forces imparted by the intrinsic muscles of the hand. Because of the compensatory motion present in the ring and small MCP and carpal–metacarpal (CMC) joints, considerable angulation may be accepted with no adverse effects on hand function. Although there is no consensus, most authorities would agree that up to 30–40 degrees of apex dorsal angulation may be accepted in the ring and small metacarpals [109]. As with metacarpal shaft fractures, less deformity may be accepted in the index and long fingers, and most authors agree that only 10–15 degrees of angulation may be accepted in these digits [109]. Depending on the specific sport and position played, angulation of the metacarpal neck may be less tolerable, as palmar prominence of a flexed metacarpal head may cause difficulty with grasping objects such as a baseball bat [114].

In cases of unacceptable angulation, closed reduction may be performed, followed by application of a well-molded cast or splint to maintain alignment during bony healing. The reduction maneuver consists of longitudinal traction, followed by MCP joint flexion and dorsally directed pressure on the metacarpal head to correct the angular deformity. Several different methods of immobilization have been recommended, though none has been shown to be superior [115–118]. Multiple studies of extraarticular metacarpal neck fractures treated with various cast configurations (with the MCP joint flexed or extended, with the interphalangeal [IP] joints included, or with the IP joints free) have demonstrated no difference in alignment, bony healing, final range-of-motion, or grip strength [115, 116, 118]. A recent prospective, randomized trial compared cast immobilization to a soft wrap with buddy taping in 68 metacarpal neck fractures with angulation less than or equal to 70° and found no difference in outcomes [117]. Furthermore, a Cochrane Review examined five randomized studies comparing a variety of treatment modalities, including casting, functional bracing, or buddy taping, and found excellent outcomes in all cohorts regardless of the type of immobilization [118].

Indications for surgical treatment include the presence of angular or rotational malalignment refractory to closed reduction and immobilization. Options for surgical stabilization include percutaneous smooth wire fixation or formal open reduction and internal fixation. In these instances, early range-of-motion exercises are recommended to avoid long-term stiffness.

Metacarpal Head Fractures

Metacarpal head fractures are intraarticular injuries. If there is more than 25% of articular surface involvement or any evidence of articular surface incongruity, surgical treatment is recommended to reconstitute the MCP joint.

Phalangeal Fractures

Patients with phalangeal fractures will typically present with pain, swelling, and deformity after direct or indirect hand trauma. In young athletes, these injuries are commonly seen in contact or ball sports. Again, evaluation for possible rotational malalignment must be performed. If the patient is unable to make a fist or flex the affected digit, the tenodesis maneuver may be utilized. AP, lateral, and oblique radiographs of the affected digit are recommended to confirm the diagnosis. Fractures are classified according to location, displacement, angulation, and malrotation. The presence of intraarticular extension or comminution should be noted.

Extraarticular fractures of the distal phalanx commonly occur after crushing injuries. In the absence of associated wounds or nail bed injuries, tuft fractures may be treated symptomatically, with the expectation of clinical healing in 4–6 weeks. Splinting or taping may allow for better symptomatic control and earlier return to sports. Fractures involving the distal phalangeal shaft are typically stable and may be treated according to similar principles. In rare instances, unstable shaft fractures with excessive angulation may be treated with closed reduction and percutaneous pin fixation.

Displaced physeal fractures of the distal phalanx are typically treated with closed reduction and splint immobilization. Careful examination of the affected digit is paramount, as the presence of an associated nail bed laceration may signify an open fracture (Seymour's fracture) [119, 120]. In these injuries, surgical treatment with nail plate removal, irrigation and debridement of the fracture site, open reduction, and nail bed repair are recommended to ensure bony healing and prevent complications of infection and growth disturbance.

Fractures of the middle and proximal phalangeal shaft are treated according to their fracture stability. Stable fractures that are minimally displaced may be treated with buddy-taping or splinting and early digital mobilization. Serial radiographs are recommended, however, to detect late displacement. In fractures with excessive angulation (greater than 10°) or any malrotation, closed reduction with or without surgical stabilization is recommended [109, 121] (Fig. 10.10). Types of surgical fixation will depend on the fracture location, pattern, and degree of deformity. Early referral to a hand surgeon is recommended in these instances. As with metacarpal shaft fractures, recent studies have suggested that surgical fixation may allow earlier return to play, though this remains controversial and the decision to operate should be made on a case-by-case basis [111, 112].

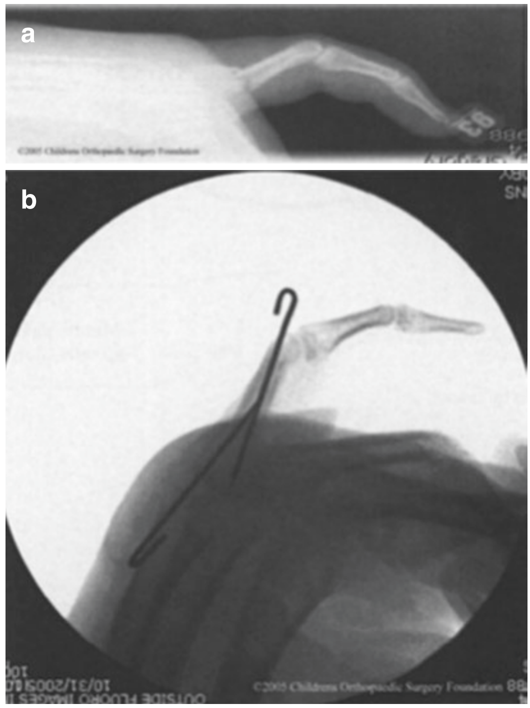

Fig. 10.10 (**a**) Lateral radiograph of the small finger depicting a proximal phalanx fracture with apex volar angulation in a 16-year-old football player. (**b**) This injury was treated with closed reduction and percutaneous pin fixation. Pins were removed after 3 weeks, and the patient returned to sports 6 weeks after surgery (Courtesy of the Children's Orthopedic Surgery Foundation, Boston, MA)

Articular fractures of the phalanges merit special attention. Nondisplaced unicondylar fractures may heal with immobilization alone; however, these injuries are prone to late displacement and must be evaluated with serial radiographs to ensure healing in proper alignment. Any displaced or comminuted articular fractures of the middle or proximal phalanx warrant hand surgery consultation and consideration for operative treatment.

Proximal Interphalangeal Joint Dislocations

The proximal interphalangeal joint (PIP) is the most commonly dislocated joint, particularly

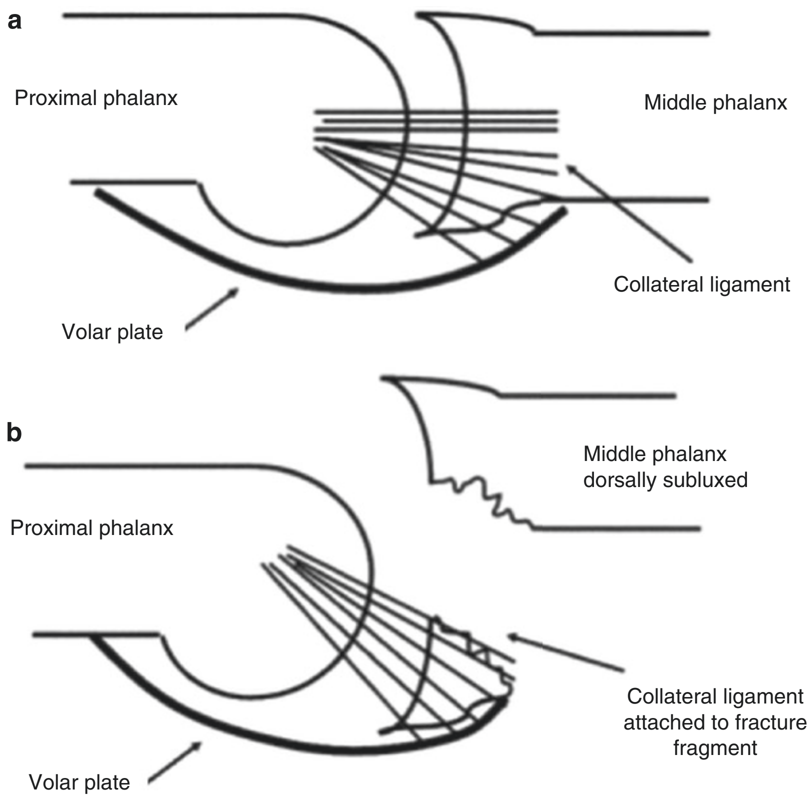

Fig. 10.11 (**a**) Schematic diagram of the PIP joint depicting the course of the collateral ligament and volar plate. (**b**) Schematic diagram of an unstable PIP joint fracture dislocation; with a large fracture fragment, little or no collateral ligament remains attached to the middle phalanx, resulting in joint instability (Courtesy of the Children's Orthopedic Surgery Foundation, Boston, MA)

among participants in contact and ball sports [122, 123]. Patients will present with acute pain, deformity, and limitations in digital motion after a "jamming" or "catching" injury. An axial load combined with hyperextension of the fingertip typically results in a dorsal dislocation of the middle phalanx.

Knowledge of the functional anatomy of the PIP joint is needed to understand treatment principles (Fig. 10.11). The PIP joint is a diarthrodial joint that relies on adjacent soft tissue for stability. The collateral ligaments arise from the concave collateral recess along the radial and ulnar aspects of the proximal phalanx and pass distally and palmarly to insert on the volar and lateral aspects of the middle phalanx. The palmar-most fibers of the collateral ligaments blend in with fibers of the volar plate. The volar plate is a stout ligamentous structure that forms the floor of the PIP joint and serves to resist PIP hyperextension. Dorsally, the central slip of the extensor apparatus inserts on the base of the middle phalanx and is responsible for extension at the PIP joint.

Initial management of a dorsal PIP dislocation consists of reduction of the obvious deformity via traction and flexion of the dorsally dislocated digit. Often, reduction is performed on the field by the athlete, teammate, coach, or trainer. Subsequent pain, swelling, and diminished range-of-motion of the affected joint are the norm.

A careful evaluation of the dislocated PIP joint is required to rule out associated injury, guide post-injury activity, and assess criteria for return to sports participation. Radiographs of the affected digit, including a true lateral view, are essential to assess post-reduction joint congruency and to evaluate for associated fractures.

Treatment is predicated on joint congruency and stability. In cases of pure dislocations without associated bony injury, if a congruently reduced joint is confirmed on radiographs and the joint is stable on examination, management may consist of edema control and buddy taping to an adjacent finger for 3–6 weeks. Early motion is initiated to decrease the risk of long-standing joint stiffness. Athletes may return to practice or competition with appropriate protective taping or splinting.

In the setting of dorsal PIP fracture–dislocations, treatment is again dependent on joint congruency and stability. In cases of a small avulsion fracture from the palmar base of the middle phalanx in an otherwise reduced and stable joint, buddy taping and early motion may be initiated. If the associated fracture comprises a greater portion of the articular surface of the middle phalanx, a considerable portion of the collateral ligament insertion will insert on the displaced fracture fragment (Fig. 10.11). As a result, the PIP joint may be reducible but will subluxate or dislocate as the joint moves from a flexed to extended position. In these situations, a dorsal extension-block splint may be used to maintain joint reduction but allow for some protected motion. This splint is typically used for 4–6 weeks, with incremental increases in extension over time until full extension is achieved.

In those patients with fracture–dislocations in which there is substantial articular involvement and reduction cannot be achieved or maintained, even in extreme flexion, surgical treatment is recommended. Surgical treatment may comprise open reduction and internal fixation of the bony fragment. If the fracture is comminuted or irreparable, the bony fragment may be excised, and the volar plate advanced to reconstitute joint congruity and stability. In these cases, athletes may expect to remain out of sports participation for a minimum of 4–6 weeks, until adequate bony and soft tissue healing has occurred and digital motion has been restored.

Volar fracture–dislocations of the PIP joint are less common and represent avulsion of the central slip from the dorsal base of the middle phalanx. If closed reduction is successful, these injuries may be treated with PIP extension splinting for 4–6 weeks. Again, in cases where reduction cannot be achieved or maintained due to large fracture fragments, surgical management is indicated.

Gamekeeper's Thumb

Sprains and tears of the ulnar collateral ligament (UCL) of the MCP joint of the thumb are known as "gamekeeper's" or "skier's" thumb. These injuries result from extreme radially directed force imparted onto the thumb MCP joint, typically during a fall onto an abducted thumb.

The UCL is comprised of two distinct ligamentous expansions, the proper and accessory collateral ligaments. The proper collateral ligament arises from the metacarpal head and inserts on the palmar aspect of the proximal phalanx. The accessory collateral ligament, which is contiguous with the proper, runs more palmarly and attaches to the volar plate [124, 125]. In flexion, the proper collateral ligament—and to a lesser degree, the dorsal joint capsule—serves as the primary restraint to radial deviation and palmar subluxation of the MCP joint. Conversely, in full extension, the accessory collateral ligament and volar plate are the primary restraints to valgus deviation. When both the accessory and proper collateral ligaments are disrupted, a complete tear results.

In complete tears, the UCL is commonly avulsed from the base of the proximal phalanx and retracts proximal and superficial to the adjacent aponeurosis of the adductor pollicis. In this position, the retracted end of the UCL may be palpated as a tender mass along the ulnar aspect of the UCL, the so-called Stener lesion [125]. Because of interposition of the adductor aponeurosis, the UCL is no longer in proximity to its bony insertion and will not heal with immobilization alone.

Patients typically present with pain, tenderness, swelling, and ecchymosis around the ulnar aspect of the MCP joint after a fall or valgus injury to the thumb. Anteroposterior, lateral, and oblique radiographs of the thumb should be obtained to rule out fracture or dislocation. In the absence of bony injury, stress testing is performed to distinguish between a partial and complete UCL tear. Excessive laxity to valgus stress with the MCP joint both flexed and extended signifies a complete UCL tear. Although there is great variation in what constitutes "normal" MCP laxity, average valgus laxity is 6° with MCP extension and 15° with MCP flexion [126]. Although there is some debate as to what constitutes excessive or pathological laxity, most authorities would agree that 30° or more of val-

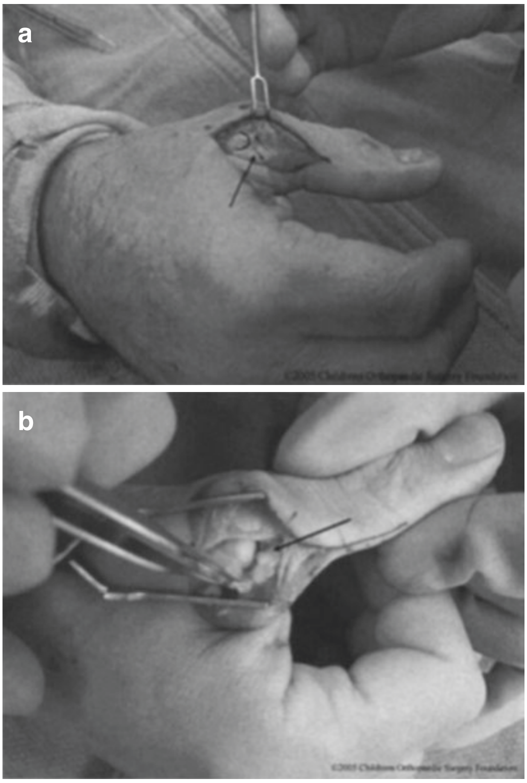

Fig. 10.12 (**a**) Intraoperative photographs depicting a Stener lesion. The retracted distal end of the collateral ligament (outlined) lies superficial and proximal to the adductor aponeurosis (arrow). (**b**) After the adductor pollicis is incised and retracted, the collateral ligament (held in forceps) may be repaired to its bony insertion along the base of the proximal phalanx (arrow) (Courtesy of the Children's Orthopedic Surgery Foundation, Boston, MA)

gus laxity, or greater than 15° compared to the contralateral thumb, suggests complete ligamentous disruption [124].

Immobilization of the thumb in a thumb spica splint or cast with the interphalangeal joint free for 4–6 weeks is recommended for partial tears. This is followed by range-of-motion and strengthening exercises and return to activities. However, in cases of complete UCL tears when a Stener lesion is present, surgical treatment is recommended (Fig. 10.12). Post-operatively, the thumb is immobilized in a thumb spica cast for 4 weeks, followed by a thumb spica splint for an additional 2 weeks to allow for ligament healing.

In skeletally immature patients, avulsion fractures of the ulnar base of the proximal phalanx may occur, rather than purely ligamentous injuries. Although these injuries are most accurately described as Salter–Harris III fractures of the proximal phalanx, they are the pediatric equivalent of the "gamekeeper's thumb" (Fig. 10.13). Surgical treatment using smooth pin fixation is recommended in these instances to restore articular surface congruity and provide for MCP joint stability. A thumb spica cast is applied for 4 weeks, at which point the Kirschner wires are removed if there is adequate radiographic bony healing. Splint immobilization is utilized for an additional 2 weeks, followed by range-of-motion and strengthening exercises.

Return to play is generally allowed after 4–6 weeks using a fabricated hand-based thumb spica orthosis for support, to be weaned as pain, range-of-motion, and strength improve [127]. In a recent study of 18 collegiate football players who underwent surgical repair of thumb UCL injuries, skill position players returned to play at an average of 7 weeks post-operatively [127]. Non-skill position players were allowed to play and practice in a thumb spica cast as pain allowed and returned to play at an average of 4 weeks.

Mallet Finger

Also known as "baseball" or "drop" finger, mallet fingers are so named because of the characteristic appearance of the digital tip, with the flexed distal IP (DIP) joint resembling the end of a hammer [128] (Fig. 10.14). This deformity is caused by a disruption of the extensor tendon mechanism in the region of the DIP joint, typically resulting from an axial load and/or sudden DIP joint flexion moment imparted on the extended fingertip.

When identified in a timely fashion, the acute mallet finger without associated laceration, fracture, or joint instability may be successfully treated by splinting the affected DIP joint in full extension for 6–8 weeks, followed by splinting at nighttime and during athletic activity for an additional 2–4 weeks [128–130]. The PIP joint need not be immobilized. Although several different custom and commercially available splints are

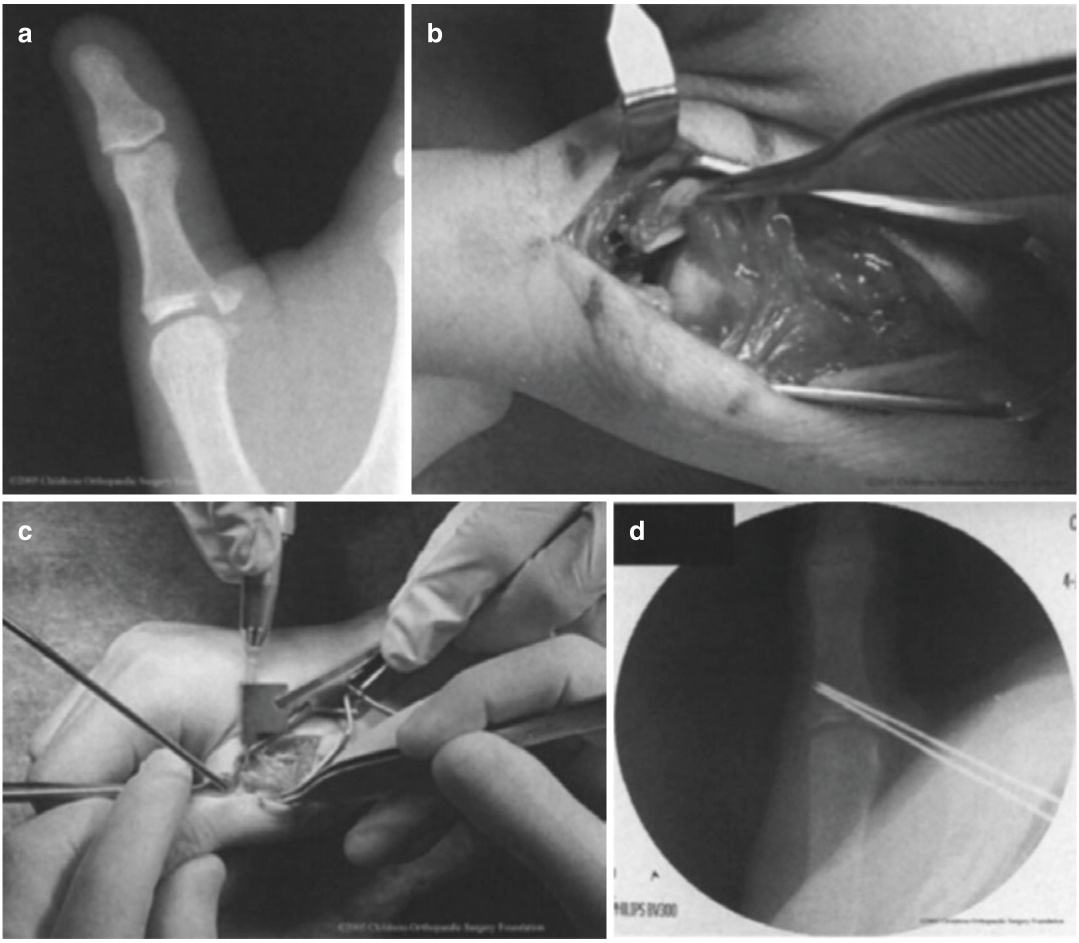

Fig. 10.13 (**a**) Radiograph depicting a Salter–Harris III fracture of the base of the thumb proximal phalanx, the "pediatric gamekeeper's" injury. (**b**) Intraoperative photograph demonstrating the fracture fragment (held by forceps) with its attached ulnar collateral ligament. (**c**) Reduction and internal fixation is performed with smooth wires. (**d**) Post-operative radiograph depicting anatomic reduction and a congruent thumb metacarpal phalangeal joint (Courtesy of the Children's Orthopedic Surgery Foundation, Boston, MA)

available, adherence to these treatment principles results in successful healing of the extensor tendon mechanism and correction of the mallet finger deformity in the vast majority of patients [131, 132].

Young athletes may also present with "mallet fractures," in which the extensor tendon insertion is avulsed from the dorsal base of the distal phalanx with a bony fragment. A lateral radiograph of the affected digit will confirm the diagnosis. When the avulsed bony fragment comprises less than 30% of the articular surface and there is no associated DIP joint subluxation, extension splinting is recommended, as previously described [133]. If there is significant articular surface involvement or palmar subluxation of the distal phalanx in relationship to the middle phalanx, surgical treatment may be considered. Percutaneous pinning, "extension-block" pinning, and formal open reduction with internal fixation of the bony fragment have all been proposed in these situations [128].

Several challenges exist, however, in the treatment of young athletes with mallet finger injuries. Compliance with full-time digital splinting is often difficult to achieve in the young, active patient, resulting in a higher incidence of failed nonoperative treatment. Furthermore, as these

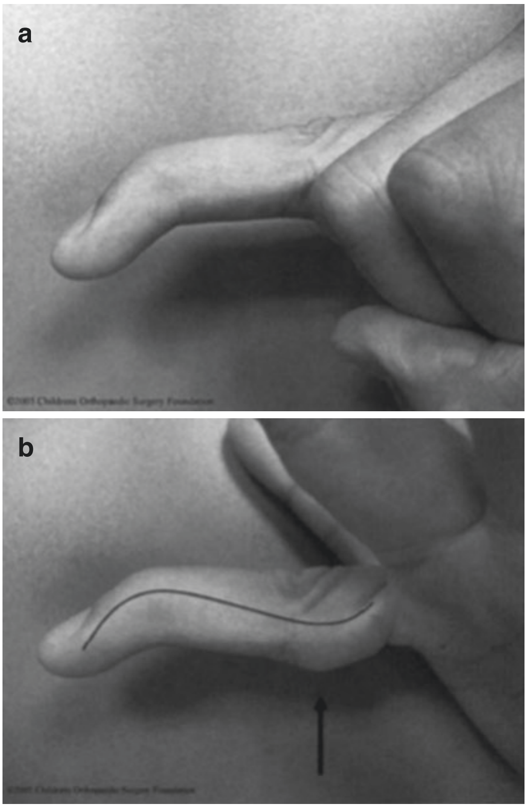

Fig. 10.14 (**a**) Clinical photograph of the mallet finger deformity. (**b**) Secondary swan-necked deformity (outlined) characterized by hyperextension at the proximal interphalangeal joint (arrow) (Courtesy of the Children's Orthopedic Surgery Foundation, Boston, MA)

injuries often arise from relatively minor trauma and do not always cause immediate functional impairment, adolescents with mallet finger injuries may not present acutely for evaluation or treatment. As a consequence, the diagnosis of mallet finger injury is often delayed beyond the acute injury period.

Several studies have supported the use of extension splinting in subacute and chronic mallet fingers [134–137]. Splinting in these situations may be successful in compliant patients and should be considered. A recent study found no difference in outcome among 45 individuals with soft tissue mallet finger who were treated with extension splinting either within 2 weeks of injury or beginning 2–4 weeks after injury [137]. Several surgical techniques have also been advocated for the treatment of chronic mallet finger deformities, including tenodermodesis, oblique retinacular ligament reconstruction, central slip tenotomy, and even DIP joint arthrodesis [138–144]. Although the technical aspects of these procedures, their indications, and results of treatment are beyond the scope of this chapter, it is recommended that patients with chronic mallet fingers failing splinting therapy be referred to a hand surgeon for consultation regarding potential treatment options.

Jersey Finger

Avulsion injuries of the flexor digitorum profundus (FDP) tendon from its bony insertion onto the base of the distal phalanx commonly occur in young athletes. These injuries typically occur during forced extension of a maximally flexed finger, such as when an athlete grabs another player's jersey while attempting to make a tackle in football or rugby; it is from this common mechanism that this clinical entity derives its colloquial name, "jersey finger" [145]. Patients will typically present with pain, swelling, and inability to fully flex the affected digit, often after a relatively innocuous injury. The ring finger is affected approximately 70% of the time [146, 147]. A careful physical examination is imperative, as active PIP joint flexion may be apparent from the intact flexor digitorum superficialis (FDS). Anteroposterior, lateral, and oblique radiographs of the affected digits should be obtained to rule out a concomitant bony avulsion, particularly in the skeletally immature.

Leddy and Packer have classified these injuries into three types, depending on the level of tendon retraction and presence or absence of a bony fragment [145]. Type I injuries are soft tissue avulsions with retraction of the tendon stump into the palm. In these instances, the vinculae have been disrupted, depriving the FDP tendon of its vascular supply and allowing for tendon retraction. Given the degree of retraction and loss of vascular supply, primary repair of the tendon avulsion is recommended within 7–10 days of injury. Delay in diagnosis and treatment leads to inability to perform a primary repair because of scar formation and contraction of the proximal muscle belly. In type II injuries, the tendon stump retracts to the level of the PIP joint. It is thought that intact vinculae help to prevent complete retraction. If the tendon is avulsed with a small bony fragment, radiographs may depict a bony “fleck” at the level of the PIP joint. Repair after 1–2 weeks may be possible because of the intact blood supply and preservation of tendon and muscle belly length. The use of cross-sectional imaging (ultrasound or MRI) has gained popularity in the recent years to help determine the level of tendon retraction in type I and type II injuries, especially when the diagnosis is delayed [136, 148]. In type III avulsions, the FDP tendon is avulsed with a large bony fragment, which is entrapped by the A4 tendon pulley. As a result, the tendon stump retracts minimally, just proximal to the DIP joint. Radiographs confirm the diagnosis. Treatment consists of open reduction and internal fixation of the bony fragment to the base of the distal phalanx, which restores the FDP tendon insertion to its anatomic location.

Avulsion injuries of the FDP tendon are not amenable to nonoperative treatment and require surgical repair. Accurate diagnosis and timely referral to a hand surgeon is critical. With prompt surgical repair and appropriate rehabilitation, near-normal restoration of digital motion and strength may be expected. However, athletes may expect to be out of sports for a minimum of 8–12 weeks.

Unfortunately, jersey finger injuries are often diagnosed late, as young athletes often will not seek immediate medical attention and continue to participate in sports, despite pain and limitations in digital motion and strength. If enough time has elapsed such that primary repair is not feasible, treatment options include flexor tendon reconstruction with free tendon graft, arthrodesis of the DIP joint, or abandoning attempts at any reconstructive procedure, particularly if the affected digit causes little functional impairment.

Prevention

There is no better treatment than prevention, and many hand and wrist injuries may be averted with appropriate preventative measures. The high incidence of wrist fractures in snowboarders and in-line skaters, for example, has prompted many to advocate the use of protective wrist guards to prevent injury. In a review of 7430 snowboarding injuries sustained over a 10-year period, Idzikowski et al. reported that approximately half involved the upper extremity and 21% involved the wrist [149]. Snowboarders who wore protective wrist guards were found to be half as likely to sustain wrist injuries compared to those without wrist protection. Ronning et al. came to similar conclusions in their prospective randomized study of over 5000 snowboarders [150]. Over three times as many wrist injuries (sprains and fractures) occurred in snowboarders without wrist braces as in those who wore protectors. No additional injuries were related to the use of the wrist braces.

Schieber et al. conducted a case–control study of over 200 in-line skaters in efforts to identify risk factors for injury [151]. Almost half of the study participants reported that they did not wear any kind of protective equipment (e.g., wrist guards, elbow pads, helmets). The odds ratio for wrist injury, adjusted for age and sex, was 10.4 for those athletes who did not wear wrist guards as compared with those who did. Similarly, the odds ratio for elbow injury was 9.5 for those who did not wear elbow pads. Similar conclusions and recommendations for protective equipment have been recommended by others, particularly for athletes involved in snowboarding, in-line skating, and skateboarding [10, 152–154].

With increased sports participation among younger children, there has been a rising awareness of the need for age- and size-appropriate equipment to aid injury prevention. Boyd et al. studied the relationship between ball size and environmental conditions and the rate of distal radius fractures among young soccer goalkeepers, highlighting this concern [13]. In this study of athletes between the ages of 6–15 years, there was a statistically significant higher rate of distal radius fracture in younger children using an adult-sized ball compared to a junior ball, during both organized and informal game settings. This study raised the question of whether some sports injuries in younger athletes may be prevented by using age- and size-appropriate equipment. Similar considerations are being applied to other sports.

Finally, there is substantial evidence that history of prior injury and inadequate rehabilitation are predominant risk factors for subsequent injury incidence in youth sports [155, 156]. When evaluating sports injuries, it is imperative to ensure not only that an injury has healed but also that the athlete demonstrates adequate restoration of strength and mechanics prior to returning to play. Family doctors and pediatricians can utilize the pre-participation physical evaluation (PPE) to identify inadequate rehabilitation of a previous injury and provide appropriate recommendations to aid in the prevention of future injuries [156].

Return to Play Guidelines

Recommendations regarding return-to-play guidelines vary according to the type of hand/wrist injury, treatment modality, acuity or chronicity, and sport-specific demands of the individual athlete. Although no universal guidelines exist, the following principles should be considered. Bony or ligamentous injuries typically require 3–6 weeks to heal; participation in practice or competition, particularly contact sports, should only be allowed if there is appropriate cast or splint immobilization of the zone of injury, including the joints proximal and distal. In cases where the injury is inherently stable, or has been stabilized with internal fixation, athletes may work on edema control, scar management, and gentle range-of-motion exercises when not participating in athletic activities. In general, full unprotected return to sports is not allowed until the athlete demonstrates full active and passive motion and near full strength of the affected hand or wrist. Athletes should be counseled regarding the potential for delayed or failed healing requiring subsequent surgical intervention inherent to all hand and wrist injuries, regardless of the measures of immobilization and protection utilized. For this reason, early referral and serial evaluations by a hand surgeon are recommended. Finally, the safety of the particular athlete and other sports participants must be considered; permission for return to play with protective devices must be obtained by the appropriate coaches, trainers, and officials.

Clinical Pearls

- Physical examination: Use the tenodesis effect to evaluate for rotational deformity and/or musculotendinous injuries to the hand. In the normal hand and wrist, passive wrist extension results in obligate passive digital flexion, with all the fingers roughly parallel, pointing toward the scaphoid tubercle.
- Radiographic evaluation: AP, lateral, and oblique views of the *specific part* of the wrist or hand should be obtained during injury evaluation. Failure to obtain appropriate imaging may result in missed diagnoses.
- Scaphoid fractures: Evaluation of all wrist injuries should include palpation of the anatomic snuffbox, palpation of the scaphoid tubercle, and the "scaphoid compression test" to assess for a possible scaphoid fracture.
- Scaphoid fractures: Consider obtaining MRI of patients with radial wrist pain and negative plain radiographs to rule out possible scaphoid fractures.
- TFCC injuries: The symptoms of TFCC injury may be subtle; patients complaining of persistent ulnar wrist pain during specific sports-related activity despite rest and strengthening should be evaluated for possible TFCC injury.
- Metacarpal fractures: Indications for manipulative reduction or surgical treatment of metacarpal fractures include open injuries, any rotational malalignment, or excessive angulation. Providers should

remember that more angulation can be accepted in neck than shaft fractures, and more deformity is acceptable in the small and ring metacarpals compared with the long and index metacarpals.
- Intraarticular fractures of the metacarpals and phalanges: All intraarticular fractures of the hand and wrist warrant early referral to a hand surgeon.
- PIP fracture–dislocations: Treatment of fracture–dislocations of the PIP joint depends on congruity of the joint reduction, joint stability, and size of the intraarticular fracture fragment. Small avulsion fractures from the palmar base of the middle phalanx in otherwise reduced and stable joints should be treated with buddy taping and early motion to avoid long-term stiffness.
- Salter–Harris III fractures of the thumb proximal phalanx: These injuries represent the pediatric equivalent of the adult "gamekeeper's thumb." Open reduction and internal fixation is recommended for displaced injuries to restore joint congruity and stability.
- Jersey finger: Careful evaluation of isolated DIP joint flexion should be performed in the evaluation of a "jammed" or "pulled" finger to rule out an FDP tendon avulsion. Early hand surgery referral should be made for all flexor tendon injuries.
- A summary of common sports-related injuries to the hand and wrist is shown in Table 10.3.

Table 10.3 Sports-related injuries of the hand and wrist

Injury	Commonly associated sports	Diagnostic modality
Mallet finger	Baseball, basketball	Mallet deformity, lack of active DIP extension
Jersey finger	Football, rugby	Resting in extension (tenodesis effect), lack of active DIP flexion
Phalangeal fractures and dislocations	Baseball, basketball	XR
Metacarpal fractures	Football	XR
Thumb UCL injury	Skiing, volleyball	TTP over ulnar aspect of MCP joint, excessive laxity to valgus stress
Hook of hamate fracture	Baseball, golf, racket sports	TTP over hamate hook, CT scan
Scaphoid fracture	Football, soccer, snowboarding	XR, MRI
Distal radius fracture	Football, soccer, snowboarding	XR
Distal radius physeal injury	Gymnastics	XR, MRI
TFCC injury/ulnar-sided wrist disorders	Gymnastics, golf, racket sports	MRI
De Quervain's tenosynovitis	Rowing, volleyball	TTP over 1st dorsal compartment,Finkelstein sign
Intersection syndrome	Rowing	TTP over 2nd dorsal compartment, crepitus with resisted wrist extension

XR X-ray (plain radiograph), *CT* computed tomography, *MRI* magnetic resonance imaging, *TTP* tenderness to palpation

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11 Pelvic, Hip, and Thigh Injuries

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Pediatric pelvic, hip, and thigh injuries are becoming increasingly more prevalent as youth participation in sports grows more common [1, 2]. The young athlete with pelvic or hip pain may present with an acute injury necessitating immediate treatment, or with chronic pain causing limitations. An acute injury may cause pain in the pelvic, hip, thigh, or even knee region. More commonly, the young athlete will have a chronic injury that will limit activities during or after sporting activities. The spectrum of injury can range from simple strains to osseous tumors [3, 4]. Apophyseal avulsions and stress fractures are the most commonly encountered skeletal injuries of the hip and pelvis in young athletes. These injuries can result in substantial amount of injury time for the young athlete. Diagnosis and treatment of the pelvis, hip, and thigh injuries is one of the most difficult clinical tasks for the sports physician and one of possibly great frustration for the young athlete. Therefore, careful clinical diagnosis with considerations of broad differentials and appropriate treatment in this age group is crucial.

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Anatomy

The hip joint has two separate and unique development patterns, the femoral head and the acetabulum, which have been well described by Ogden and Herring [5, 6]. The acetabulum is created by the normal development of the triradiate cartilage. With normal development, a congruent and stable joint is formed. Injuries to the developing triradiate cartilage could have long-lasting effects for the young athlete such as acetabular dysplasia and degenerative hip disease later in life [5, 6]. The femoral side of the hip joint has three separate ossification centers: the capital femoral epiphysis, the greater trochanter, and the lesser trochanter. The growth and progression of these ossification centers contribute to the biomechanics of the proximal femur and its injury patterns. The hip and pelvis have several apophyses, all of which have large muscle attachments (Fig. 11.1). These apophyses contain secondary ossification centers, which allow circumferential growth, but do not add to longitudinal growth of the skeleton. The secondary ossification centers appear between the ages of 11 and 15 years [5, 6]. These apophyses are weaker than the surrounding soft tissues and, hence, allow for the avulsion fractures seen in adolescent athletes, in contrast to muscle or tendon strains and tears in the older athlete.

There are several muscle groups in the thigh, including flexors, extensors, abductors, and adduc-

L. J. Micheli, L. Purcell (eds.), *The Adolescent Athlete*, Contemporary Pediatric and Adolescent Sports Medicine, https://doi.org/10.1007/978-3-319-56188-2_11

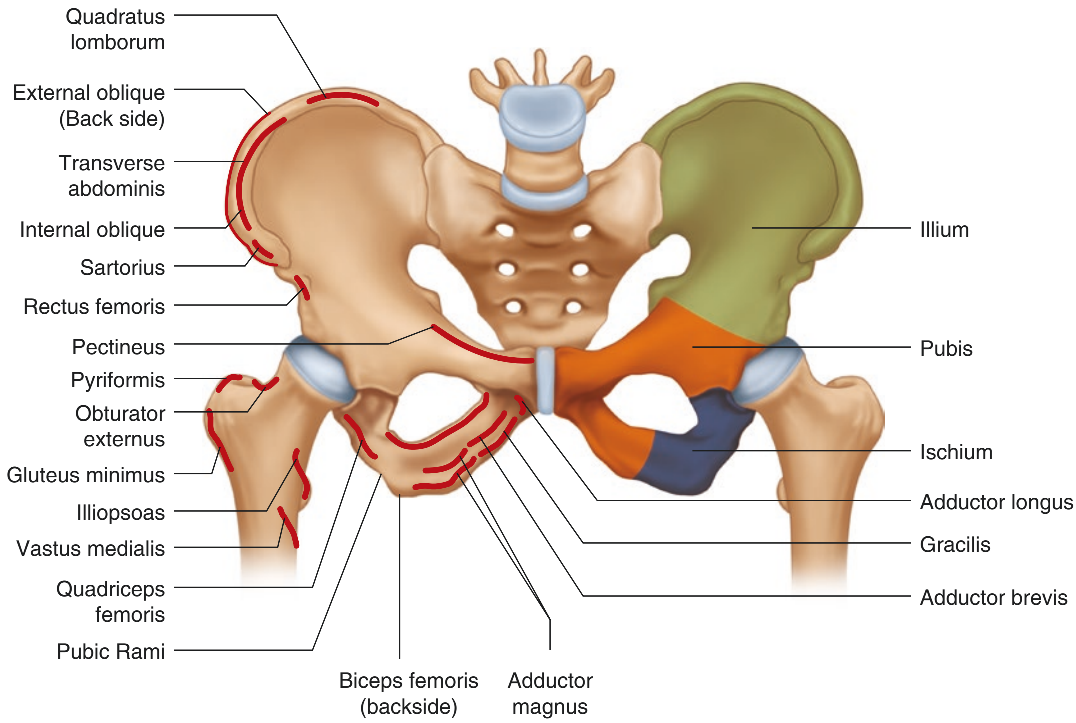

Fig. 11.1 Anatomy of the hip

tors. The quadriceps muscles (sartorius, rectus femoris, vastus lateralis, and vastus medialis) are the strongest muscles in the anterior thigh and are responsible for knee extension. On the posterior aspect, the hamstring complex is composed of three muscles: the biceps femoris (a short and long head), the semitendinosus, and the semimembranosus. The hamstrings span two joints, causing hip extension and knee flexion. The long head of the biceps, semitendinosus, and semimembranosus originate on the ischial tuberosity. In general, any muscle group spanning more than one joint is more susceptible to injury. It is also important to note that muscle injury or imbalance causes the surrounding joints to be more susceptible to injury.

Clinical Evaluation

History

The type and extent of injury to the young athlete is dependent on several factors. Eliciting details of these factors can be very helpful in making an accurate diagnosis. These factors include the patient's age, the mechanism of injury, the physiologic condition of the young athlete, and the type of sport or activity engaged in at the time of injury. The history should also evaluate potential risk factors that contribute to overuse injuries. These include inappropriate rate, intensity, and duration of training; the patient's age, to assess developmental muscle-tendon imbalances; footwear; and surface conditions [7].

Physical Examination

The sports physician on the field must be able to identify the urgency of an acute injury. Injuries with deformity, obvious dislocations, and inability to bear weight should be managed by splinting the injured limb and arranging transport to the appropriate emergency facility. Reductions should not routinely be done on the field, unless there is an obvious and serious neurovascular compromise noted in the distal extremity. The examination should include a thorough, but brief, evaluation of the alignment, stability, neurologic state, and vascular state of the pelvis and extremity. In a stable injury in the office setting, a more detailed examination can be done. Special attention should be given to the hip exam in a young patient, as well as to the determination of muscle-tendon imbalances, specific sites of bony tenderness, and extent of range of motion. When treating young athletes, who are more prone to bony avulsions and possible pathologic lesions, radiographic evaluation of the pelvis, hip, and femur should be included in the standard work-up of the injury. Magnetic resonance imaging (MRI) is very helpful to evaluate soft tissue injury and give more detail concerning bony injuries.

Acute Injuries of the Pelvis, Hip, and Thigh

Iliac Crest Contusion

Iliac crest contusion or a "hip pointer" is a common injury and, potentially, a temporarily debilitating condition. A hip pointer is a contusion of the iliac crest and the surrounding subcutaneous soft tissues. This injury is common in contact sports, such as football, rugby, and soccer, and is caused by a direct blow. Adjacent soft tissues may also be injured, causing localized pain, swelling, and difficulty with gait.

The athlete typically presents with localized pain, ecchymosis, and antalgic gait. Focal tenderness is common along the iliac crest. Because of the multiple muscle attachments of the abdominal and gluteal muscles at the iliac crest, leg elevations and muscle contractions may be painful. The diagnosis is usually made clinically, but AP and oblique pelvic radiographs can be very helpful in the young athlete to rule out apophyseal avulsions or wing fractures.

Initially, rest from aggravating activities, ice, and nonsteroidal anti-inflammatory drugs (NSAIDs) are used to treat hip pointers. In the clinical scenario of a large hematoma, an aspiration can relieve pain and possibly speed up recovery time. After the acute pain has resolved, a progressive rehabilitation program is begun that includes hip range of motion, stretching, and, ultimately, strengthening. Typical recovery time is 2–4 weeks, with return to sport when the pain has resolved and the athlete is able to perform sport-specific activities. Additional padding may be required for further protection. Myositis ossificans traumatica, muscle fibrosis, and muscle soreness are possible complications of hip pointers.

Avulsion Injuries of the Pelvis

Apophyseal avulsion fractures are common in the young athlete [8]. These avulsion fractures are secondary to either a sudden pull of the large muscle attachments on the apophysis or an excessive stretch injury of the tendon and osseous junction on an open apophysis. The apophyses of the pelvis in an immature skeleton appear and fuse later than the growth plates in the long bones. This delay in ossific maturation places the young athlete at increased risk for bony avulsion injuries. The physis is the weakest component of the immature skeleton and is more vulnerable to avulsions and direct trauma. This usually happens in adolescent male athletes between 14 and 17 years of age and in female athletes between 12 and 15 years of age, with a male preponderance [8]. Avulsions of the apophyses routinely occur during a growth spurt with corresponding tight soft tissues, making "musculoskeletally tight" athletes more prone to this injury [9].

The more common sites of avulsions are at the iliac crest (insertion of the abdominal muscles), anterior superior iliac spine (origin of the sartorius), anterior inferior iliac spine (origin of the rectus), ischial tuberosity (origin of the hamstrings), and lesser trochanter (insertion of the iliopsoas) [10, 11] (Fig. 11.1) This can occur in many different sports, but often occurs with extreme exertion, particularly in sprinters, jumpers, and kicking sports. Localized pain, swelling, and limitation of motion are common with presentation. Pain may be extreme, with point tenderness at the site of avulsion. Plain radiographs are diagnostic, but specific views, such as pelvic Judet and inlet and outlet views, may be required to identify the avulsion (Fig. 11.2).

Fig. 11.2 A proximal hamstring avulsion injury in a 15-year-old soccer player. He was injured as he flexed the lower extremity going in for a ball. This injury was missed with initial evaluation, as films were not taken. He never fully recovered from his initial injury. Upon subsequent proximal hamstring injury, radiographs were obtained and noted to have had a previous avulsion injury of the proximal hamstrings

Treatment is usually nonoperative for avulsion fractures and includes rest, ice, and avoidance of aggravating activities. Rehabilitation begins with gentle stretching and range of motion exercises with progressive strengthening [12, 13]. Return to sport is allowed after full range of motion and 90% of strength is achieved, which is usually within 4–8 weeks. For displaced ischial tuberosity avulsion fractures (more than 3 cm), open reduction and internal fixation may be required to avoid late sequelae, such as proximal hamstring syndrome and sciatic nerve irritation, and to improve hamstring strength [14, 15]. Displaced anterior inferior iliac spine avulsions may block hip range of motion if the fragment is large.

Chondral Injury of the Hip

Chondral injuries of the hip may occur in the young athletic patient and can be a source of disabling hip pain. Such injuries can be seen with trauma or underlying pathologic conditions. Traumatic history may include a frank dislocation, but more commonly involves a direct blow to the greater trochanter or a fall onto the lateral hip. In thin young athletes, the force of a direct blow to the hip is not cushioned by soft tissue and is transferred directly to the chondral surface. The resultant force can cause an array of injuries, from a superficial articular surface lesion to a full-thickness articular defect with production of a traumatic loose fragment. The cartilage damage is often at the labral junction of the acetabulum and can be associated with labral tears.

Athletes will often present with a popping sensation, pain, “locking up,” and failure to fully recover after injury. Symptoms are often mildly limiting, but become increasingly painful with movement of the hip. Mechanical symptoms, such as clicking and catching, can be common and are favorable prognostic indicators for arthroscopic treatment [16, 17]. Imaging of the hip is often helpful. Images from MRI can reveal specific injury, such as articular defects or loose fragments or simply increased bony edema, which are suggestive of trauma to the femoral head or the acetabulum. In acute lesions with intact articular cartilage, initial management should include protected weight bearing and early range of motion. If symptoms continue, or if there are loose bodies or unstable articular fragments, hip arthroscopy can be very helpful in managing the mechanical symptoms [16–19].

Adductor Injuries

Adductor strains are common and result from repetitive contractions or a sudden forceful contraction with the lower extremity in an externally rotated and abducted position. This is often seen in the soccer player who uses the medial foot for ball advancement and control. Muscular imbalance can be a predisposing factor to groin injuries [20, 21]. The athlete might complain of a sharp tearing pain with a known incident and subsequent pain with contraction of the inner thigh musculature. The adductor muscle may be tender along its course, and pain is present with resisted adduction of the leg. In acute injuries, there may be some swelling and ecchymosis at the muscular origin at the pubic symphysis.

Radiographs should be taken to exclude other causes of pubic pain, such as avulsion injuries or an intrapelvic lesion, which can be common in this age group. Images from MRI can help to identify the degree of injury to the adductor musculature, and the images correlate well with symptoms [22]. Severity of injury can be classified with a scale of I–III. Grade I strains are painful without loss of function or mobility. Grade II strains have some loss of strength and mobility. Grade III strains have complete loss of function. Treatment is conservative with rest, ice, NSAIDs, and avoidance of aggravating activities. Protective weight bearing for a few days for low-grade injuries, and a few weeks for high-grade injuries, is helpful. Physical therapy is very important and can lessen pain, as well as maintain range of motion and strength. Therapy has been shown to decrease the amount of adductor strength loss in young athletes [20] and should include stretching and strengthening. Return to sport is allowed after symptoms resolve, full range of motion is regained, and adductor strength has recovered.

Hamstring Injuries

Hamstring injuries are common in athletes and are seen in the young athlete especially during the adolescent growth spurt. Skeletal growth can outpace the muscle-tendon unit growth during the adolescent growth spurt, resulting in loss of muscular flexibility. With the immature skeleton, avulsion injuries must always be in the differential because the apophysis is the weakest portion of the hamstring complex, with the majority of the hamstrings muscles originating from the ischial tuberosity.

Injuries commonly occur with eccentric elongation during the swing and heel-strike phases. The biceps femoris is the most commonly injured hamstring muscle, most often occurring at the proximal musculotendinous junction [23]. Multiple risk factors have been described for hamstring injuries, such as previous hamstring injury, flawed technique, lack of flexibility [24], improper warm-up exercises, and strength imbalance, with the hamstring being significantly weaker than the quadriceps muscle [25]. Some studies have reported a decreased incidence of hamstring injuries in athletes who have proper strengthening, stretching, and warm-up activities [26]. Hamstring injuries are typically classified into three groups, based on severity. Grade I injuries are minor and have only a small degree of disruption of the integrity of the musculotendinous unit. Grade II injuries are more severe, with partial tearing of the musculotendinous unit, with some fibers left intact. Grade III hamstring injuries are complete tears of the hamstring musculature, with a subset of Grade III B injuries with a bony avulsion injury at the origin. Proximal, complete tears require more time to achieve full healing [27].

The young athlete may present with an acute injury or chronic pain in the proximal posterior thigh. Athletes may report a sudden tearing or popping sensation with strenuous activity, often with sprinting. With a more prolonged course, athletes may complain of a posterior thigh tightness and dull pain at the proximal hamstring origin. Physical examination may reveal posterior thigh swelling, ecchymosis, and tenderness at the proximal muscle origin, musculotendinous junction, and the muscle belly. Often, the athlete will be reluctant to fully extend the knee in an acute injury. With complete rupture, the biceps may retract distally and a mass may be noted, with a defect seen proximally [28]. Pain with passive hip flexion and resisted knee flexion is very common in the acute setting and less striking with chronic injuries. In the young athlete, plain films of the pelvis should be obtained to rule out a bony avulsion or pelvic tumors, which can be masked by chronic or recurrent injuries. An MRI is helpful when the diagnosis is unclear or in the setting of a severe injury to determine the extent of the hamstring tear and to evaluate for potential repair.

Treatment of hamstring injuries is conservative and based on injury severity. The mainstay of treatment consists of rest, ice, and compression, followed by a well-supervised physical therapy program. Hamstring stretching and strengthening should be initiated after the acute pain has subsided. The goal of therapy is to provide strength for the hamstring during its most vulnerable time of activities, i.e., eccentric elongation. Mild eccentric strengthening is most helpful in treatment and prevention [29, 30]. Return to activities is allowed when the athlete has regained full, painless range of hip motion and almost full strength. In addition, correction of muscle imbalances is of great importance in avoiding reinjury and chronic conditions. With complete hamstring rupture, surgical repair of the musculotendinous junction or the bony avulsion may be required to return the athlete to his/her previous level of sport participation [31].

Quadriceps Strain

The quadriceps can have a wide range of injury, from tendonitis to rupture of the tendon, and blunt trauma. These injuries are similar to the adult counterpart, but are less common in the young athlete. Although not common, quadriceps ruptures have been reported in adolescents [32]. These injuries can be secondary to repetitive microtrauma or overuse. More commonly, the young athlete will have an acute episode of anterior thigh pain. This is accompanied by various degrees of swelling of the thigh. MR imaging is helpful in predicting the prognosis for acute quadriceps strains [33]. Treatment is conservative, with rest and avoidance of aggravating activities. Early rehabilitation is very helpful to regain knee motion and maintain muscle tone. Return to sports is allowed after resolution of symptoms, return of knee range of motion, and adequate muscle strength.

Quadriceps Contusions and Myositis Ossificans Traumatica

Athletes engaged in contact sports often have injuries secondary to blunt trauma of the thigh. After a traumatic blunt injury, the normal healing response of hemorrhage and inflammation can lead to granulation tissue and, eventually, scar tissue formation. Athletes usually can recall a specific incident of injury and present with localized thigh pain, tenderness, swelling of the thigh, loss of knee flexion, and, occasionally, a knee effusion. Plain films are useful to rule out any bony injury initially, but might show signs of calcifications 2–4 weeks after injury. Contusions can be treated similarly to muscle strains. An effort to limit the hematoma formation should be attempted through initial use of the RICE protocol (rest, ice, compression, elevation). In addition, therapy with gentle and gradual range of motion exercises, followed by stretching and strengthening, is helpful [34–36].

A potential sequela of blunt trauma is myositis ossificans (MO), which results from significant compressive trauma to the soft tissues of the thigh. The heterotopic ossification is usually noted at the anterior aspect of the femur and suggests a more substantial injury, but rarely will it change the subsequent treatment [35–38]. In a classic study of muscle contusion and MO in young cadets, the incidence of myositis ossificans was 9–20% [34]. Incidence is thought to be much lower in young athletes, but true incidence is unknown since athletes do not routinely undergo radiography for muscle contusions [35, 37, 38]. The differential diagnosis must include infection and malignancies, such as osteosarcoma, synovial sarcomas, and chondrosarcomas. The initial radiographs might appear similar to a malignant process, but a history of recent blunt trauma, anterior location, and intact cortex suggests a post-traumatic injury. These lesions tend to stabilize radiographically in 3–4 months [39]. MR and computed tomography (CT) have been used to further analyze calcifications. The appearance of these lesions can vary depending on the maturity of the lesion [40]. Long-term limitations are rare in the young athlete. Rarely, symptoms continue and become limiting. In these rare cases after failure of conservative treatment, excision of the bony mass can be done, but preferably not until 6 months after initial injury [39].

Overuse Injuries

Stress Fractures

Stress fractures are a result of repetitive improper training or overtraining, with resultant microtrauma to the supporting skeleton, without gross mechanical misalignment or displacement [41–43]. Athletes with disordered eating, nutritional deficiencies, menstrual irregularities, and a history of previous stress fractures may have "relative energy deficiency in sport" (RED-S) syndrome. RED-S, replacing the older term "female athlete triad," places the athlete at increased risk of stress fractures [41, 42, 44, 45, Appendix D]. The prevalence and pattern of stress fractures in children differs from their adult counterparts, as does the response of the growing skeleton to the repetitive stresses applied to it [46]. Multiple risk factors will increase the likelihood of overuse injuries in young athletes, such as training errors, muscle-tendon imbalances, anatomic alignment, footwear, playing surface, nutritional factors, medical conditions, and deconditioning [46]. Usually, two or more risk factors can be identified. Training errors tend to be the most common and include rapid increase in volume or intensity of training [46]. Restrictions of the young athlete's training progression should be limited to no more than a 10% increase per week [46].

Pelvic Stress Fractures

Stress fractures in the pelvis in young athletes are quite uncommon. Stress fractures in the pelvis and hip are more commonly reported in young female distance runners or athletes involved in jumping sports [45]. Iliac crest stress injuries have been reported in young athletes as a result of repetitive training [8]. Much more commonly in this age group, stresses around the pelvis will result in frank apophyseal avulsions [47]. Stress fractures of the pubic rami (Fig. 11.3) and sacrum are the most commonly encountered and are most commonly seen in distance runners [41].

Athletes will complain of pain with weight-bearing or activity-related pain in the hip or pelvis, which decreases with rest. Localized pain to the inguinal or adductor region is common. Range of motion is often painful and limited. Axial loading and internal rotation of the extremity are likewise painful. Plain radiographs may initially be negative [48]. If suspicion of a stress fracture is high, particularly if there is persistent pain in the light of negative X-rays, bone scan or MRI should be obtained [48].

Pelvic stress fractures are usually stable and are treated conservatively with rest and protected weight bearing while symptomatic. Progressive rehabilitation with hydrotherapy can be helpful [48]. Complete recovery may take 3–5 months [41].

Femoral Neck (Hip) Stress Fractures

Femoral neck stress fractures and proximal femur stress fractures occur most commonly in endurance athletes, such as distance runners and triath-

Fig. 11.3 Axial MRI of the pelvis in a young patient with an inferior pubic rami stress fracture

letes. Femoral neck stress fractures in the young athlete with open physes are rare [49]. Occasionally, however, hip pain in the young athlete will ultimately be found secondary to a fracture of the base of the neck of the femur [50, 51]. The athlete may describe pain at the hip, anterior thigh, or groin region, as well as nonspecific muscle pain. Examination often reveals pain with axial loading. In addition, pain in the proximal thigh, pelvis, or groin can occur with internal rotation. Plain radiographs may be normal, but with a high index of suspicion, a bone scan should be obtained.

Treatment of femoral neck stress fractures depends on the location of the fracture [52]. Compression-type stress fractures involving the inferior aspect of the medial portion of the femoral neck are the most common and are inherently more stable [53]. Treatment consists of non-weight-bearing until pain resolves, with a slow, gradual return to full weight bearing. Rehabilitation with hydrotherapy for maintaining muscle mass during the partial weight-bearing period can be helpful. Tension-type femoral neck stress fractures occur superiorly at the lateral aspect of the femoral neck and are inherently unstable [54]. These are routinely treated with early surgical intervention with multiple screw fixations through the femoral neck [55, 56].

Femoral Stress Fractures

Stress injuries of the femur in young athletes are not common, representing 3–12% of the stress fractures found in this age group [51, 54]. Femoral stress fractures often occur in such sports that require cyclical loading of the lower extremities, such as endurance activities, distance running, and dancing (Fig. 11.4) [57, 58]. Stress fractures can occur anywhere in the femur, even at the distal femoral physis [59, 60]. In the young athlete, these are often compression-type stress fractures at the base of the femur.

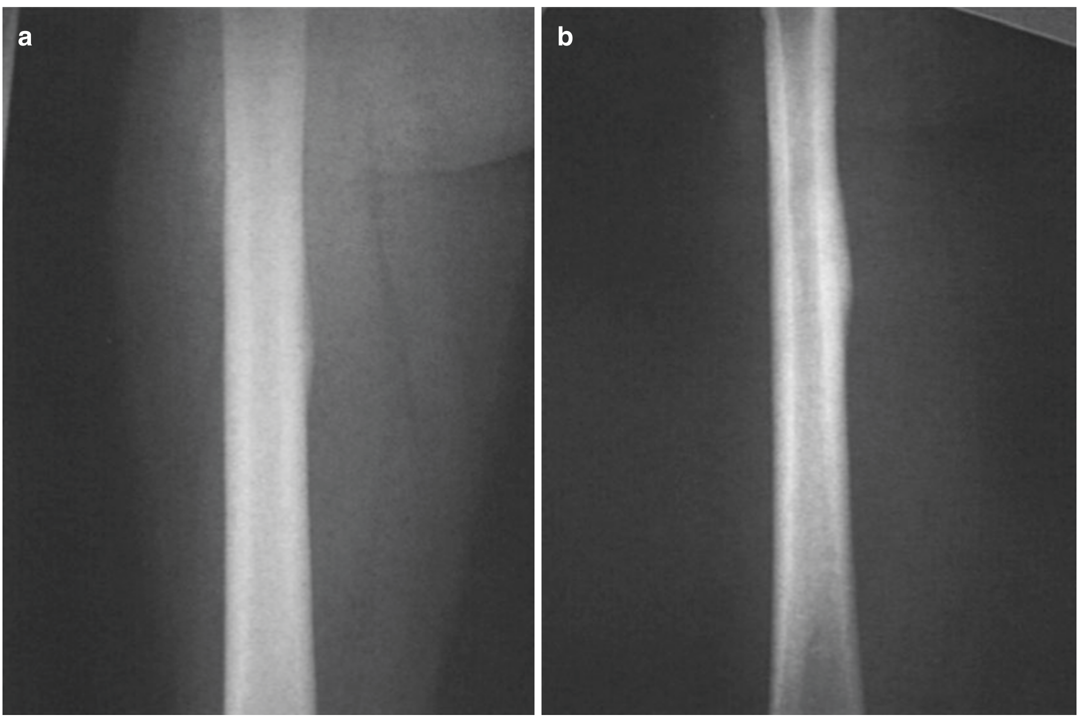

Fig. 11.4 A femoral stress fracture in a 16-year-old female cross-country runner. Her symptoms began after increasing her mileage and changing running surfaces. (**a**) Initial presentation for activity-related thigh pain. (**b**) After 6 weeks of rest with limited activities

Symptoms of a femoral stress fracture are usually activity related and are relieved with rest. Vague, dull exertional pain is often the presenting complaint. Proximal femoral neck fractures may present with referred pain to the knee and inner thigh. If the athlete presents late in the course of injury, an antalgic gait may be present. Pain with three-point stress of the femur is common, as well as pain with axial loading. Radiographic presentation of a stress fracture may differ from adults secondary to the presence of a thick periosteum [46, 61]. Because of the healing response, radiographic findings may be mistaken for a tumor [62]. Further imaging studies, such as MRI or bone scan, can be used if radiographs are negative (Fig. 11.5). Often, simple changes in training technique and intensity can allow healing in most stress fractures, but a course of modified weight bearing is required for femoral stress fractures. Cases of complete fracture displacement have been reported. Progressive protected weight bearing is advanced as the clinical symptoms abate. Usually, 6–10 weeks are required for complete healing. Return to sport can occur with complete resolution of pain and adjustment of the precipitating risk factors. Physical therapy during the recovery phase can be helpful to avoid disuse atrophy, bone demineralization, and stiffness.

Labral Tears

In the young athlete, new onset of hip pain should prompt assessment for infection, Legg–Calve–Perthes disease, developmental dysplasia, and slipped capital femoral epiphysis (SCFE) [63, 64]. After these entities have been ruled out, further diagnoses, including loose bodies, labral tears, chondral injury, and femoroacetabular impingement (FAI), should be considered [1, 65]. Labral tears are common lesions in the hip joint of young athletes. Athletes with labral tears usually present after rotational trauma to the hip joint, which can range from mild to severe. The labrum is more susceptible to tearing with underlying hip dysplasia or degeneration [66]. Tears commonly occur at the junction between the acetabulum and the labrum, and they can be associated with chondral injury [67]. Labral tears commonly occur in dancers, golfers, and activities requiring significant hip rotation.

The young athlete with a labral tear will complain of hip or groin pain and, often, report a painful clicking and catching sensation with pivoting/twisting activities, or flexed and internally rotated positions, and may be unable to obtain peak performance [68]. Examination of the athlete often reveals pain with provocative hip flexion, as well as with hyperflexion, adduction, and internal rotation while in flexion for anterior labral tears. Abduction and external rotation of the hip with the hip in extension can cause symptoms with posterior labral tears. Imaging begins with plain radiographs to assess for acetabular dysplasia. MR imaging is helpful for diagnosing labral tears, and MR arthrograms (Fig. 11.6) have been reported to have a sensitivity of greater than 90% [69].

Treatment of the young athlete with a labral tear should begin with a period of protected

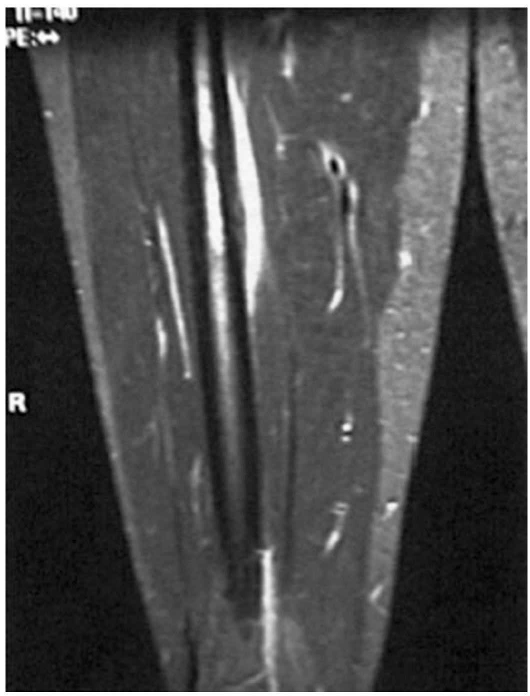

Fig. 11.5 A femoral stress reaction in a 15-year-old female distance runner. She had a history of amenorrhea, eating disorders, and right thigh pain with weight-bearing activities. A coronal MR reveals marrow edema, as well as edema in the surrounding periosteum

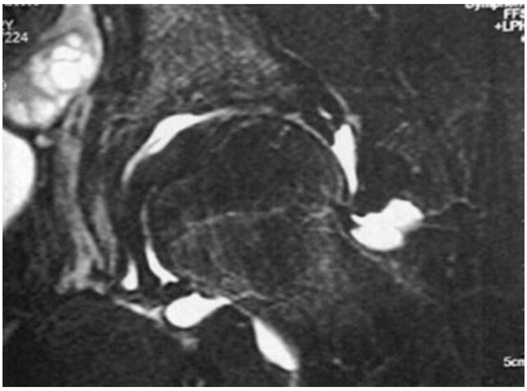

Fig. 11.6 MR arthrogram of a torn labrum in a young 14-year-old synchronized swimmer. This injury occurred after performing the splits. She had subsequent mechanical symptoms of the hip and a catching sensation with "egg-beater" swimming activities

weight bearing for 4 weeks. Only a small portion of these patients (13%) will become asymptomatic [70]. In the presence of reproducible mechanical symptoms after a twisting or axial loading event during athletics, or with high clinical suspicion, arthroscopic evaluation should be considered with persistent symptoms if therapy fails [65, 71, 72]. Most commonly, the anterior labrum is torn. The torn labrum can either be repaired or debrided arthroscopically [73]. Good outcomes have been reported after hip arthroscopy, especially in patients with preoperative mechanical symptoms [16, 70]. In addition, hip arthroscopy has been found to be a safe and efficacious treatment option for children and adolescents with hip pathology [74]. Post-operative protocols differ significantly in the literature, but should include a brief period of protected weight bearing and early onset of controlled hip range of motion exercises and strengthening activities.

Femoroacetabular Impingement

Femoroacetabular impingement (FAI) is a condition in which dysplastic or morphologic abnormalities in acetabular or proximal femoral bony structures cause impingement of soft tissues during extremes of motion [75]. This causes degeneration over time. The labrum is often involved, and patients frequently present with similar symptoms as those with labral tears. The principal complaint is pain (especially in the anterior groin), although mechanical symptoms are also often present. Patients typically cannot recall specific trauma, but rather have progressive onset of symptoms. Pain is most typically produced with hip flexion and/or adduction, so sitting for long periods of time can be uncomfortable. Athletes notice inability to perform at peak levels due to pain at extremes of motion.

Physical exam typically does not reveal any abnormalities on inspection. Gait should be observed for any signs of limp, weakness, or compensation. The FADIR (flexion, adduction, internal rotation) test is the most sensitive for detecting pathology since the anterior labrum is most often injured and acts as the source of pain. External rotation and abduction can reveal posterior labral injuries. It can also be helpful to observe active and passive arc of motion in the injured and uninjured hips since a limited arc of motion is expected in impingement. It is important to remember that there is no single sign or maneuver that will diagnose FAI; rather, the practitioner must rely on a series of findings to make the diagnosis [76].

Imaging is essential in making the diagnosis of FAI. A recent international consensus states that diagnosis of FAI requires the presence of a triad of symptoms, clinical signs, and imaging [77]. Because of the similarity between FAI and labral tears, plain films should always be obtained in any patient with complaints concerning for labral pathology. FAI is diagnosed when there is the presence of a cam lesion, a pincer lesion, or both. A cam lesion is an overgrowth of the proximal femoral neck and causes asphericity of the femoral head. Instead of a fluid ball-in-socket motion, the neck impinges on the acetabulum. A pincer lesion is an overgrowth of the acetabular rim and also causes impingement of soft tissues during motion. Both lesions may be present concomitantly. Advanced imaging can identify soft tissue, labral, chondral, or capsular injury.

Treatment consists of a trial of protected weight bearing, cessation from aggravating sports or activities, and physical therapy. The goal is to increase compliance of soft tissues and increase strength in surrounding musculature in order to offset the forces within the hip joint. If nonoperative management fails, surgery is often indicated. FAI is managed with arthroscopy and involves removing the source of impingement (i.e., restoring the natural contour of the femoral head and acetabulum) and repairing or reconstructing any soft tissues amenable for repair while debriding any that are not. Patients can reasonably expect cessation of pain and return to sport following surgery.

Osteitis Pubis

Osteitis pubis is a chronic painful inflammatory condition that affects the pubic symphysis [78]. This condition is caused by repetitive microtrauma in the young athlete with overuse of the adductors and gracilis muscles, but can result from nontraumatic etiology as well. It has been reported in athletes such as distance runners, weightlifters, fencers, soccer players, and football players [79, 80]. There is usually a gradual onset of pubic pain, which may radiate to the groin at the medial thigh region. Athletes may also complain of vague muscular symptoms and spasms of the hip adductors.

It can be difficult to distinguish osteitis pubis from an adductor strain, but focal tenderness over the anterior pubis symphysis is noted in osteitis pubis. Plain radiographs may reveal symmetrical bone resorption at the medial symphysis, widening of the symphysis, and sclerosis along the pubic rami or degenerative changes at the medial symphysis in chronic cases [1, 79, 80]. Bone scans may show diffuse increased uptake in the region.

Osteitis pubis normally responds well to conservative treatment, and it is usually self-limited. Rest, avoidance of aggravating activities, and NSAIDs are the first-line treatment options [79]. Rehabilitation utilizing hydrotherapy is usually successful, but can be prolonged, often lasting 3–9 months for complete resolution. Careful use of steroid injections under fluoroscopy can be helpful in patients who do not respond favorably to conservative treatments. More recently, prolotherapy has been used for treatment [81]. Surgical treatments have been described [72], but are rarely indicated in the young athlete. Return to sport is allowed as symptoms permit.

Sports Hernia

Sports hernia, or athletic pubalgia, is an entity that is poorly understood, is difficult to diagnose, and is often a diagnosis of exclusion in patients with groin pain. It has been defined in many different ways; however, there is consensus that injury occurs in abdominal musculature or fascia at its insertion on the pubis and is not actually believed to be a hernia. The most accepted definition is injury of the rectus abdominis insertion. However, it has also been described as injury to the adductor origin [82, 83], entrapment of the genitofemoral nerve [83, 84], or any abnormality of the fascial structures forming or supporting the inguinal canal (i.e., conjoint tendon, internal oblique musculature, or transversalis fascia) which causes a pathologic dilation of the deep inguinal ring leading to an occult hernia [85].

Sports hernias typically occur in male athletes who participate in sprinting or cutting sports such as hockey, soccer, tennis, football, or rugby. Onset is typically insidious without acute injury. The true incidence is unknown since it is difficult to diagnose and because there are many entities which cause groin pain. The classical presentation is an athlete with groin or suprapubic pain who is unable to participate at peak level, but has complete cessation of symptoms with rest [83]. Physical exam does not typically reveal any specific findings. Groin pain is a common entity in athletes, so confounding pathology may be present. Palpation of the superior pubic rami and pubic symphysis may reveal tenderness; however, this is not specific for sports hernia. The only physical exam maneuver that isolates athletic pubalgia is a resisted sit-up.

Radiography and computed tomography do not typically show pathology, but they can rule out other conditions, so plain films of the pelvis and hips should be obtained in patients with groin pain. MRI has been shown to be positive for at least one cause of groin pain in nearly all patients [86]. Therefore, unless there is clinical suspicion for a specific injury pattern, MRI may not be helpful. Nonetheless, MRI is the most accepted imaging modality in a patient with clinical suspicion for sports hernia in whom other causes of groin pain have been ruled out.

A trial of rest, NSAIDs, and physical therapy with emphasis on core strengthening may be attempted for initial treatment. However, most authors agree that sports hernias require operative intervention to achieve symptomatic relief. [83, 84, 85, 87]. This may require referral to a general surgeon depending on the preference of the treating physician. Various surgical techniques have been described including open or laparoscopic repair of myofascial structures with or without the use of mesh, attenuation of internal or external inguinal rings, release of genitofemoral nerve, or release or repair of adductor muscle origin [83–85]. Interestingly, regardless of the surgical technique employed, athletes have very high rates of return to sport within 6–8 weeks [83, 85]. This reinforces the fact that athletic pubalgia is a poorly understood condition. Nevertheless, the salient point from the body of available research is that surgery is efficacious for relieving pain and allowing athletes to return to sport.

Sacroiliitis

Sacroiliitis or sacral iliac (SI) joint sprains are relatively rare and, hence, often overlooked [88]. The sacroiliac ligaments are strong, and motion at the SI joint is limited. This joint is important in the dissipation of forces between the spine and the lower extremities [89]. Forces at the SI joint can be increased with forceful hamstring muscle contractions, sudden torsional motions, direct blows, and forceful straightening from a squatting position [89]. The young athlete will complain of low back pain in the region of the sacroiliac joint, as well as possible radiation to the buttock or thigh [65].

The athlete with sacroiliitis typically has focal tenderness over the SI joint. The FABER test (the ipsilateral hip is flexed, abducted, and externally rotated), sacroiliac compression test, and the Gaenslen's test (hyperflexion of the contralateral hip to lock the pelvis and hyperextension of the affected hip) are commonly used for diagnosis [19, 88]. Painful response from these maneuvers indicates a positive result. Radiologic evaluation is more helpful to rule out other types of pathology, such as stress fractures, tumors, infection, and inflammatory conditions, but MRI images can detect injury and abnormality at the SI joint (Fig. 11.7). Treatment includes rest, heat, and NSAIDs. A restrictive elastic bandage is often helpful after the acute phase. Steroid injections under fluoroscopy can be both diagnostic and useful in refractory cases. Healing normally takes 4–6 weeks and might require protective range of motion for healing to occur [19, 88, 90]. Rehabilitation is useful for peripelvic stability and pelvic girdle strengthening. The athlete may return to sport after resolution of symptoms, return of range of motion, and normalization of strength.

Snapping Hip

Snapping hip syndrome is a condition with a painful audible snap in the hip with flexion and extension. This is often seen in dancers and gymnasts, as well as football and soccer players. Causes of a snapping hip can include abnormal contact of the iliotibial band over the greater trochanter [91]. Localized lateral tenderness at the greater trochanter and posterior to it can be noted secondary to the inflamed trochanteric bursa. The athlete can often reproduce these symptoms voluntarily. The Ober test is often positive secondary to tightening of the iliotibial band over the symptomatic greater trochanter. The most common cause of snapping hip is usually caused by the iliopsoas tendon snapping over the pectineal prominence of the femoral neck [91, 92]. With extension of the hip, the iliopsoas tendon slides from a lateral position to a more medial position in relation to the femoral head [91]. In addition,

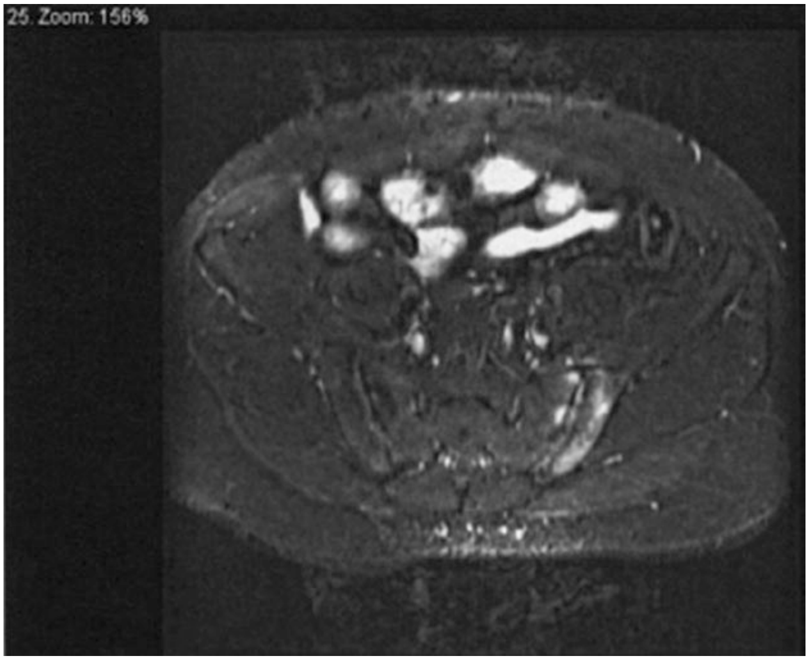

Fig. 11.7 Axial MRI of the sacroiliac joints revealing inflammation of the left sacroiliac joint

loose bodies in the hip joint, labral tears, or synovial chondromatosis of the hip joint may cause intra-articular snapping.

With a prolonged history of snapping hip, significant contracture of the hip flexors and hamstrings is often noted. Diagnosis is made on the basis of the history and can be confirmed with the physical examination. Provocative testing can be helpful for diagnosis. Progressive passive hyperflexion of the hip will cause pain, as well as resisted flexion and adduction with the leg in the figure of four positions. In addition, hyperextension and abduction of the hip with internal rotation can be painful. MR imaging can be helpful to exclude intra-articular causes of hip pain and can identify inflammation of the corresponding tendons or bursa.

The treatment for snapping hip is conservative. Rest and avoidance of aggravating activities can be very helpful. Physical therapy should include stretching of the iliotibial band and any contracture or tightness in the hip region. In addition, core strengthening can be helpful. Ultrasound and iontophoresis can be very effective in decreasing pain. Greater trochanteric bursitis can likewise be treated with ultrasound and stretching. In recalcitrant cases, an injection of a corticosteroid is helpful in relieving symptoms enough to effectively benefit from physical therapy. For refractory cases of external snapping, bursal excision and Z-plasty of the iliotibial band have been described in adolescents [93]. Internal snapping of the hip can be treated with surgical tendon lengthening for recalcitrant cases [94]. Intra-articular sources of snapping hip usually require surgical treatment with arthroscopy or an open approach if there is a large loose body of synovial chondromatosis [91]. Return to sport is allowed as symptoms permit and when strength and range of motion allow safe participation.

Proximal Hamstring Syndrome

Proximal hamstring syndrome was first described by Puranene [14]. After a hamstring injury, the inflammatory and reparative process can inflame and constrict the sciatic nerve, causing local buttock pain with radiation down the thigh. Patients often complain of gluteal or proximal posterior thigh pain, which increases with stretching of the hamstring muscle or fast running. The pain can be relentless with sitting and improves in the supine position. The ischial tuberosity is often tender, and passive stretching of the hamstring causes pain. The diagnosis is mostly made by history, but imaging studies are very helpful in ruling out other causes of buttock pain. MR images can show inflammation at the proximal hamstrings, but are often negative. Treatment is conservative, with activity modifications and NSAIDs. Physical therapy can be initiated for hamstring stretching. Injections under fluoroscopy can be used to settle the inflammatory process and allow physical therapy to be attempted. Chronic proximal hamstring syndrome often cannot be alleviated through conservative means. Surgical release of the lateral portion of the proximal hamstring tendon has been reported to have a favorable outcome [12–15].

Piriformis Syndrome

The piriformis muscle can cause compression of the sciatic nerve and is a common cause of buttock and proximal posterior thigh or hamstring pain. Piriformis syndrome is thought to be a more recognized cause of low back pain and sciatica [95]. History often reveals blunt trauma to the gluteal or sacroiliac region. Patients complain of pain in the SI joint region, at the greater sciatic notch, with occasional radiation to the lower leg. This pain is often "crampy" or described to be similar to a tight posterior hamstring. Stooping over, as well as lifting heavy objects, tends to aggravate symptoms. A palpable mass may be detected. Physical exam commonly reveals buttock pain with hip flexion, adduction, and internal rotation. It is important to rule out other more common causes of low back and radicular pain.

Imaging studies of the spine and pelvis are important to rule out other pathology. Atrophy and fibrosis of the piriformis muscle can be suggestive of piriformis syndrome [96]. Treatment of piriformis syndrome includes NSAIDs and local steroid and anesthetic injections, along with physical therapy for stretching of the piriformis muscle and local modalities to reduce pain. In recalcitrant cases, a new arthroscopic procedure releasing the piriformis has been described with immediate relief of pain and quick return to normal activities [97].

Trochanteric Bursitis

Trochanteric bursitis is secondary to irritation of the iliotibial band (ITB) or gluteal musculature over the greater trochanter (GT). Hip abductor avulsion injuries or tearing of their insertion has also been implicated with pain of the GT [98]. Continual repetitive motions, such as running, leg length discrepancy, a broad pelvis in females, and increased foot pronation, can irritate the bursa. Tenderness is found at the greater trochanter, and pain can be elicited by external rotation and adduction of the hip.

Treatment focuses on physical therapy. Anti-inflammatory medications are often helpful to allow the athlete to undergo more effective therapy. Exercises to stretch the ITB and strengthen the gluteal musculature can resolve symptoms. Often, local injection of a corticosteroid helps to allow symptomatic relief. In recalcitrant cases, a proximal release of the ITB with debridement of the fibrotic bursa can relieve symptoms [99]. Additionally, reattachment or debridement of gluteal tendons, or even a trochanteric osteotomy may be required [98]. This condition is one of irritation, and the athlete may continue to play as desired, with the aid of NSAIDs, ice, and stretching exercises.

Acquired Conditions

Slipped Capital Femoral Epiphysis

An acute slipped capital femoral epiphysis (SCFE) is an uncommon sports-related injury, but is the most common hip disorder in adolescence [100, 101]. The sports physician treating young athletes must always keep in mind that hip pathology can manifest itself with knee symptoms. In the scenario with vague knee complaints and negative findings on physical examination of the knee, hip pathology must be excluded. A SFCE rarely occurs as an acute fracture with an identified injury. More commonly, this is a chronic injury of the preadolescent and adolescent during growth spurts, secondary to mechanical failure of the proximal femoral physis during normal physiologic loading of the hip [102].

The physical examination will reveal a normal knee with limitation of internal rotation of the hip. Mild shortening of the limb is possible. With hip flexion, the leg tends to obligatorily externally rotate. Both anteroposterior and lateral plain films of both hips are indicated. Radiographs commonly reveal a widened and blurred physis and increased sclerosis of the femoral neck secondary to the posterior overlap of the epiphysis. Treatment for SCFE is surgical and involves stabilization and closure of the physis using transphyseal screws [103].

Nerve Entrapments

Nerve entrapments are not common, but are often overlooked and can cause symptoms in young athletes. These nerve entrapments should be ruled out in the differential of chronic pelvic girdle pain and can be treated definitively.

Obturator Nerve Entrapment

The obturator nerve can be compressed in multiple sites. It arises from the lumbar plexus and travels through the true pelvis. It can be compressed by pregnancy, pelvic trauma, and intrapelvic masses, such as a hematoma or infectious collection. In addition, retroperitoneal masses or collections can compress the nerve [104]. In athletes, the nerve is more at risk of compression after it exits the pelvis, by a fascial band at the distal end of the obturator canal [104, 105]. Sporting activities, including repetitive kicking, as well as lateral and twisting motions, appear to be additional factors in the development of symptoms. The athlete describes exercise-induced medial groin and thigh pain, which decreases with rest [104]. Sensation remains intact. Abductor weakness and mild muscle spasm may be present. Reproducible pain is often present with external rotation and adduction of the affected hip while standing. Diagnosis is based on the history and examination. Routine radiographs are usually normal, and MRI findings are usually within normal limits. Needle electromyographic studies in the adductor muscles often show chronic denervation patterns [106, 107].

Conservative management, consisting of rest, avoidance of aggravating activities, NSAIDs, and adductor muscle strengthening in physical therapy, should be initiated. This appears to be more helpful in acute mild cases; however, it has not been found to be helpful in chronic injuries that have resulted in denervation [104]. Surgical release is necessary to treat chronic cases of obturator entrapment and can provide permanent relief of symptoms with timely return to full activities [104].

Lateral Femoral Cutaneous Nerve Entrapment

Lateral femoral cutaneous nerve entrapment (meralgia paresthetica) is a common problem. Symptoms can present in any age group with various activities. Sports that require tight belts, pads, or bracing over the iliac crest, causing mechanical compression, are at higher risk for nerve entrapment. The lateral femoral cutaneous nerve is purely sensory, and it supplies the skin from the anterior lateral aspect of the thigh to the knee. The course of the nerve is superficial as it exits the pelvis over the lateral iliac crest. Patients complain of unilateral pain or sensory changes at the lateral thigh region. Diagnosis is mainly by history and examination. Sensory changes should be confirmatory, and a Tinel's sign is often noted just inferior and medial to the ASIS [108]. Local nerve blocks provide temporary relief and can be helpful in diagnosis and prediction of which patients with chronic symptoms might benefit from surgical release. Relief of symptoms with nerve blocks is a good predictor of successful operative management [109].

Conservative treatment includes NSAIDs and minimizing aggravating activities, such as wearing tight clothing or equipment around the hip region and long periods of standing [108]. The athlete who does not have a resolution of symptoms with conservative management may benefit from surgical decompression of the nerve, with over 90% of patients receiving complete or partial resolution of symptoms [110].

Prevention

Acute injuries of the pelvis, hip, and femur can be difficult to prevent. However, some measures can be employed. The appropriate equipment and padding should always be used during sporting activities. Many acute injuries can be prevented with proper stretching, adequate strengthening, proper warm-up, and ending training prior to fatigue. Also, addition of sport-specific balance, jumping, and plyometric exercises to the training regimen may help [111]. In addition, playing with similarly skilled athletes can avoid many acute traumatic injuries. Chronic injuries can be prevented by addressing proper training regimens and avoiding training errors. These include inappropriate progression of rate, intensity, and duration of training [7, 9, 19, 112]. Addressing anatomic factors such as lower extremity alignment, muscle-tendon imbalances of strength, endurance, or flexibility can decrease injuries [7, 9, 112]. Additional risk factors including footwear, playing surfaces, associated disease states, nutritional factors, and deconditioning can be addressed with education of athletes, coaches, and parents [7, 112].

Return to Play

Returning to play is dependent on several factors, including whether the athlete is able to return safely and effectively to sport. Before returning to sport, flexibility and strength should be within 80–90% of normal to prevent further injury and allow effective movement with activities. Therapy can be very useful to monitor and gage the athlete's readiness to return to play.

For most minor injuries of the pelvis, hip, and thigh, such as strains, bursitis, nerve entrapments, and mild avulsion injuries, a period of rest followed by appropriate therapy entailing stretching and strengthening will allow athletes to regain strength and flexibility. Sport can be resumed once the pain has subsided. Return to play after acute fractures and stress fractures must be delayed until pain has resolved, there is radiologic evidence of a healed fracture, and there has been modification of the contributing risk factor.

Clinical Pearls

- Contusions and musculotendinous injuries are the most common injuries around the pelvis and hip.
- Apophyseal avulsion fractures are common in the young athlete, particularly during growth spurts.
- The majority of these injuries can be treated successfully with physical therapy after conservative management including rest, ice, elevation, and anti-inflammatories until the athlete is functionally pain-free.
- Physical therapy should focus on return of range of motion, stretching, and strengthening before return to sports.
- Young athletes with hip pain during activities must be evaluated for more concerning causes of hip pathology, including SCFE, Perthes disease, hip dysplasia, infection, and tumor.

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12 Knee Injuries

Michelle McTimoney

Injuries to the knee are common among young athletes. Three percent of all injuries in children between 5 and 9 years of age occur at the knee. This rate is doubled in children between the ages of 10–14 (5.9%) and 15–19 (6.2%) [1]. The number of knee injuries can be partially attributed to the increase in organized youth sport.

Both acute and chronic injuries are seen in youth. Acute knee injuries occur frequently in sports such as basketball, hockey, soccer, skiing, and football. Chronic or overuse knee injuries, such as patellofemoral pain syndrome and Osgood–Schlatter disease (OSD), are seen in running and jumping sports [2]. Some knee injuries can potentially be quite debilitating if not properly managed. Therefore, it is essential that practitioners taking care of young athletes have an understanding of knee injuries that are unique to children and the anatomy that results in different injury patterns in children as compared to adults.

Anatomy

The knee joint is composed of the femur superiorly, the tibia inferiorly, and the patella anteriorly (Fig. 12.1a). The proximal fibula articulates with the proximal tibia but does not articulate with the femur. The fibula ends just distal to the joint, underneath the lateral tibial plateau. The medial and lateral prominences of the distal femur are referred to as the medial and lateral femoral condyles, and the depression between these two condyles is the intercondylar notch or trochlear groove, in which the patella articulates. The flared articular surface of the tibia is referred to as the tibial plateau. The tibial spine is a bony eminence in the center of the tibial plateau. The articular surfaces of these bones are covered with articular cartilage.

In the young athlete, each of these bones has a growth plate. The distal femoral growth plate and the proximal tibial growth plate each contribute over half of longitudinal growth for each of these bones [3]. Injury to either of these growth plates has the potential to significantly impact the growth of the young athlete. The proximal tibia also has an apophysis anteriorly called the tibial tubercle. This is the site of attachment of the patellar tendon and another location of growing bone in the tibia.

The patella is a triangular-shaped bone, with its wider base superiorly oriented. There are two apophyses at each of the superior–lateral aspects of the patella and one apophysis at the inferior pole of the patella. The quadriceps tendon attaches at these apophyses as it crosses the patella. Distally, the quadriceps tendon becomes the patellar tendon as it leaves the patella at the

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L. J. Micheli, L. Purcell (eds.), *The Adolescent Athlete*, Contemporary Pediatric and Adolescent Sports Medicine, https://doi.org/10.1007/978-3-319-56188-2_12

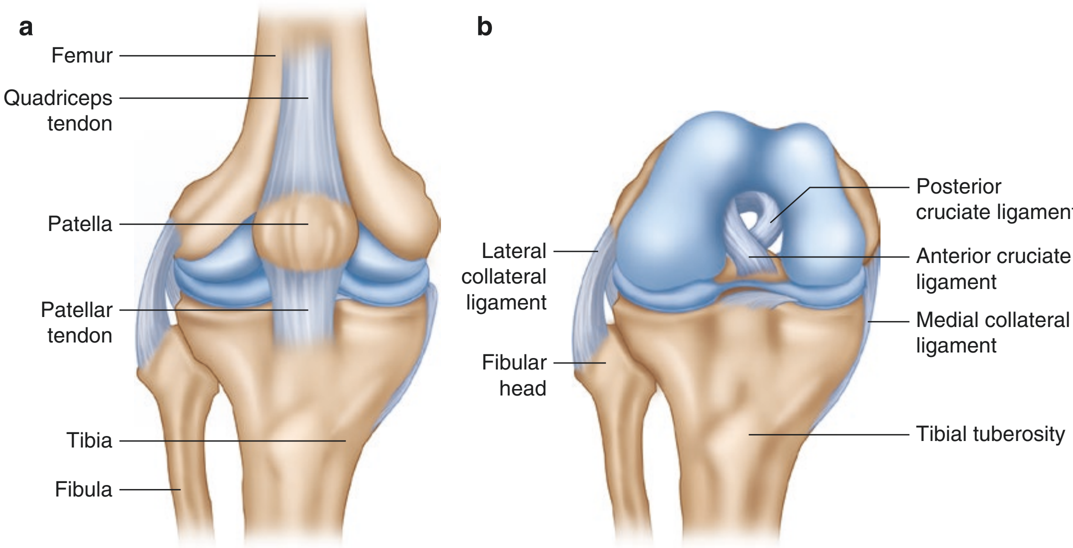

Fig. 12.1 Anatomy of the knee. (**a**) The bones of the knee. (**b**) The ligaments of the knee

inferior apophysis. These bony areas of tendinous insertion are areas of bone growth and susceptible to injury in the growing athlete. The patella functions to increase the mechanical advantage of the knee by increasing the distance of the extensor mechanism (quads and patella) from the axis of rotation through the knee joint. As a result, the quadriceps can generate a more powerful knee extension.

The quadriceps muscle group extends the knee. It is composed of the vastus lateralis, vastus medialis obliquus, vastus intermedius, and rectus femoris. The rectus femoris and the vastus intermedius run between the vastus lateralis and the vastus medialis, with the rectus femoris superficial to the vastus intermedius. The rectus femoris originates on the anterior inferior iliac spine and crosses both the hip and knee joint to insert on the tibial tubercle via the patellar tendon. The vastus lateralis, medialis, and intermedius all originate on the proximal femur and, together with the rectus femoris, insert on the patella via the quadriceps tendon.

The hamstrings are composed of the long and short heads of the biceps femoris, the semimembranosus, and the semitendinosus muscles. This muscle group originates on the ischial tuberosity. The semimembranosus and semitendinosus insert medially on the proximal tibia. The biceps femoris inserts on the head of the fibula. The hamstrings flex the knee. The sartorius and gracilis muscles originate in the pelvis, and they cross the knee medially to insert on the medial aspect of the proximal tibia. These muscles also contribute to knee flexion. The popliteus muscle originates on the distal femur, as does the plantaris and gastrocnemius muscles. These muscles cross the knee joint posteriorly and contribute to knee flexion. Laterally a tight band of fascial tissue crosses the knee as the iliotibial band (ITB). This band emanates from the tensor fasciae latae, gluteus medius, and gluteus maximus muscles. This fascial band inserts at Gerdy's tubercle, just lateral to the tibial tubercle. In knee extension, this band lies anteriorly to the lateral femoral condyle, while in flexion, it lies posteriorly.

Within the joint capsule, there are several structures important to knee function. The medial meniscus (MM) and lateral meniscus (LM) are C-shaped masses of hyaline cartilage on the medial and lateral surfaces of the tibial plateau. They function as shock absorbers, protecting the knee from high mechanical loads. The peripheral vascular zone of the meniscus extends further medially in children than it does in adults. With age, the zone of vascularization recesses. After age 10, only the peripheral one third is vascularized. The anterior cruciate ligament (ACL) originates at the medial aspect of the lateral femoral condyle and inserts in the anteromedial portion of the tibial plateau (Fig. 12.1b). It prevents the excessive anterior translation of the tibia on the femur. The posterior cruciate ligament (PCL) originates on the lateral aspect of the medial femoral condyle and crosses behind the ACL to insert on the posterolateral portion of the central tibial plateau. It prevents excessive posterior translation of the tibia on the femur. The medial collateral ligament (MCL) originates on the distal medial femoral epiphysis and inserts on the proximal tibial epiphysis. It protects against excessive valgus force. The lateral collateral ligament (LCL) originates on the lateral femoral epiphysis and inserts on the proximal fibular epiphysis. It protects the knee against excessive varus forces.

Although seldom injured in the growing athlete, it is also important to be aware of the significant neurovascular structures which course posteriorly to the knee, in the popliteal fossa. The femoral artery courses posteromedially as it becomes the popliteal artery in the popliteal fossa. The sciatic nerve becomes the posterior tibial nerve and the common peroneal nerve while still above the knee. These two nerves cross the knee posteriorly and eventually provide sensation to the plantar and dorsal aspect of the foot, respectively.

Clinical Evaluation

History

An accurate description of the presenting complaint is often the key to correct diagnosis. It is important to know whether the complaint is that of pain, instability, or swelling. The resulting effect on the function of the knee as it relates to daily activities also needs to be explored. In cases of acute injury, a description of the event is helpful. Many practitioners will find, however, that the child or youth is often unable to accurately describe the exact events of the injury. A history of inability to weight bear, swelling, locking, clicking, or giving way after the event suggests significant, often intraarticular, pathology that warrants further investigation.

Chronic complaints of knee pain are common in the pediatric athlete and may suggest overuse injuries. The location of the pain can point to potential diagnoses, such as Osgood–Schlatter disease (OSD). Knee pain can occur at the time of a growth spurt in the young athlete; therefore, enquiry into recent growth patterns may also be helpful.

It is important to assess knee complaints in the context of the athlete. Knowledge of type of sport, hours of training, recent changes in training, and training/performance goals can help guide management. Management of the injured athlete not only includes management of the injury but also of the athlete within the context of their sport. The athlete must be given guidelines on what activities are permitted, as well as what is restricted.

A review of systems must be completed to make sure that the knee complaints are not part of a bigger picture of medical illness in a pediatric athlete. A history of multiple swollen joints, night pain or sweats, unexplained fevers, or changes in weight or growth pattern suggests a possible infectious, rheumatologic, or malignant etiology, rather than a mechanical cause of knee pain.

Physical Exam

The physical examination of the knee in the young athlete begins with observation of stance and gait, looking for abnormalities of biomechanical alignment and asymmetries of gait. Abnormalities commonly observed include genu varum, valgum, or recurvatum, femoral anteversion, kissing patella, and pes planus. The range of motion of the knee must be documented and should be compared with the unaffected side. Because of the prevalence of ligamentous laxity in the pediatric athlete, full knee extension may actually include a few degrees of hyperextension, which might be overlooked if only the affected side is examined. A child should be able to flex the knee so that the heel

Fig. 12.2 Assessment for effusion. The examiner's right hand occludes the suprapatellar bursa as the left hand is used to milk any excess joint fluid across the joint from the lateral to the medial side. The presence of fluid seen medially is known as the "bulge" sign. No effusion is present in this patient (Courtesy of Bruce Carruthers, Carruthers Photography)

Fig. 12.3 Anterior drawer test. Note the examiner's hands attempting to glide the tibia anteriorly, while the patient's lower tibia is stabilized by gently sitting on the foot (Courtesy of Bruce Carruthers, Carruthers Photography)

touches the buttocks when lying prone. The knee is inspected for any bony abnormalities, such as a prominent tibial tubercle or the presence of any visible swelling. Muscle bulk should be inspected for evidence of atrophy and asymmetry. Disuse secondary to injury quickly produces significant atrophy in the quadriceps musculature.

An effusion can be assessed by milking the joint fluid superiorly on the medial aspect of the patella. Next, the suprapatellar communication is occluded with one hand, while the other is used to compress the space just lateral to the patella (Fig. 12.2). An effusion is present if a bulge of fluid can be appreciated on the medial side of the patella as the effusion is forced from the lateral joint space to the medial joint space. Any effusion in a child is significant and must be evaluated further.

Palpation is performed looking for tenderness of any bony structure. Areas of bone growth may be tender to palpation, as in OSD or Sinding–Larsen–Johansson disease (SLJD). The articular surface of the medial and lateral femoral condyle is easily palpated with the knee in flexion. Tenderness may suggest an osteochondral injury. The joint line is palpated for tenderness that may occur with meniscal injuries.

The patellar tendon can be palpated along its length for tenderness. The MCL is easily palpated on the medial aspect of the joint. The LCL is easier to palpate by putting the knee in a figure of four position. This brings out the LCL so it can be easily palpated between the fibular head and the lateral femoral epiphysis.

Special tests of the knee begin with the anterior drawer and Lachman. Both test the integrity of the ACL. The anterior drawer test (Fig. 12.3) is performed by having the patient lie supine with

Fig. 12.4 Lachman test. The examiner's lower hand attempts to glide the tibia forward on a stabilized femur (Courtesy of Bruce Carruthers, Carruthers Photography)

Fig. 12.5 McMurray's test. Note the positioning of the examiner's fingers along the joint line to feel any pop associated with meniscal pathology (Courtesy of Bruce Carruthers, Carruthers Photography)

the affected knee flexed to 90°. The examiner stabilizes the patient's lower extremity by sitting on the foot. The proximal tibia is held with both hands encircling it. It is essential to remind the patient to relax the hamstrings. This can be verified as the test is performed because the examiner's fingers are on the hamstring tendons. Once the hamstrings are relaxed, the examiner attempts to glide the tibia forward. A positive test is indicated by more glide on the affected than unaffected side. With experience, a "soft" endpoint is appreciated rather than the firm endpoint of an intact ACL.

The Lachman test (Fig. 12.4) is performed with the patient lying supine with the affected leg extended. This time one hand encircles the distal femur, and the other encircles the proximal tibia, again trying to glide the tibia forward on the femur. Excessive glide confirms incompetence of the ACL. Comparison with the uninjured knee is important because of the ligamentous laxity in children.

The integrity of the PCL is tested by the posterior drawer test. This is performed with the patient positioned as for the anterior drawer test. With the same hand positioning, the tibia is forced posteriorly. An injured PCL will allow for posterior translation of the tibia on the femur. Comparison with the unaffected leg is also helpful in this test.

Both McMurray's and Apley's tests are helpful for identifying meniscal injuries. For McMurray's test (Fig. 12.5), the patient is positioned supine with legs extended. The examiner holds the heel of the affected side with one hand and flexes the knee. The other hand is placed with fingers along the medial joint line and thumb along the lateral joint line. A valgus force is applied to the knee while externally rotating and extending the knee. The sensation of a click or pop in the

Fig. 12.6 Apley's compression test. A torn meniscus will produce pain when an axial load and rotation is applied (Courtesy of Bruce Carruthers, Carruthers Photography)

joint beneath the examiners hand is a positive result and may indicate meniscal pathology. Apley's compression test (Fig. 12.6) is performed by having the patient lie prone with the affected leg flexed to 90°. The heel is held, and an axial load is applied while rotating the tibia internally and externally on the femur. A torn meniscus will make this procedure painful.

The collateral ligaments are examined by having the patient lie supine on the examining table (Fig. 12.7). The affected knee is flexed slightly to 30° . The ankle can either be held with one hand (Fig. 12.7a) or, in larger patients, secured between the examiners trunk and upper arm (Fig. 12.7b). The other palm is placed first on the lateral side of the knee, and a valgus force is applied at the knee with a counterforce at the ankle. This stresses the MCL. Laxity and/or pain suggests injury to the MCL. The same procedure can be repeated with the palm on the medial surface applying a varus stress to the knee. Again, laxity and/or pain suggests injury to the LCL.

Ober's test (Fig. 12.8) is used to evaluate the tightness of the ITB. With the patient lying on the unaffected side, the affected leg is abducted at the hip. A tight ITB will prevent the hip from passively adducting past an imaginary horizontal line. This test is often positive in patients with ITB friction syndrome.

Patellar apprehension (Fig. 12.9) can be appreciated by having the patient supine on the examining table with knees extended. The examiner places both thumbs along the medial aspect of the patella with both index fingers along the lateral aspect of the patella. The quadriceps need to be relaxed for this test. While watching the patient's face, force is applied in a lateral direction with the thumbs in an effort to sublux the patella laterally. Patients who have a history of patellar subluxation or dislocation will be apprehensive as the patella is moved laterally. Many patients will report an increased sense of stability when medially directed pressure is applied to the lateral aspect of the patella while ranging the knee through 90° of movement.

Once the special tests have been completed, a neurologic examination of the lower extremity, including strength and sensation, must be performed.

No examination of the knee is complete without an examination of the hip. Many pathologies of the hip will present with pain referred to the knee because of the pattern of innervation of the hip and knee. Knee pain without physical findings at the knee is a red flag for possible hip pathology, and a thorough examination of the hip is essential!

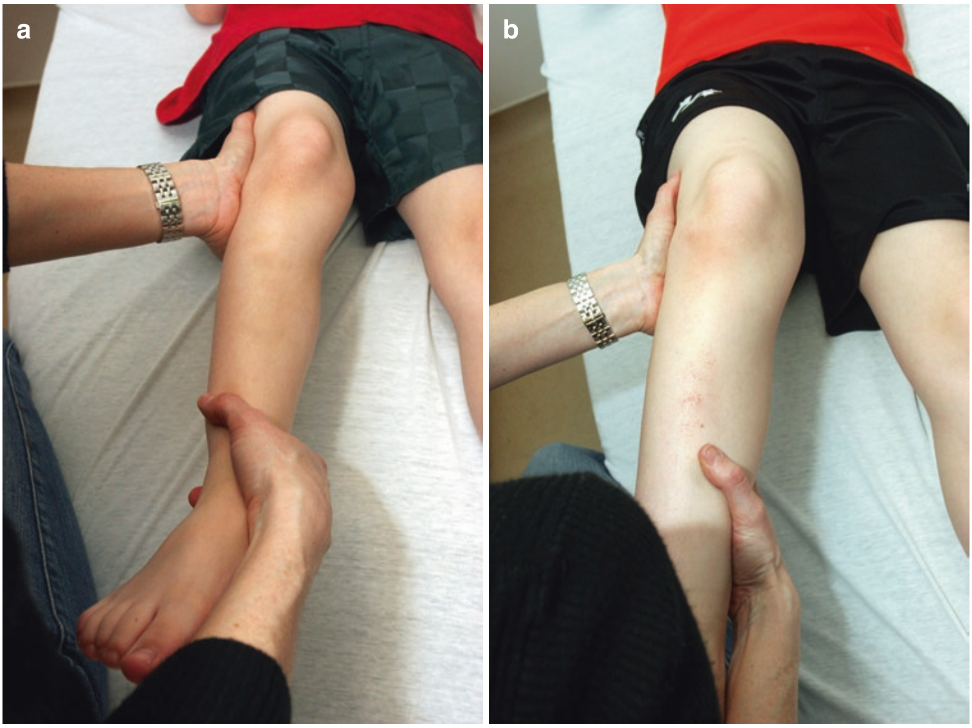

Fig. 12.7 (**a**) Medial collateral ligament stability test. Note the different techniques for stabilizing the distal tibia while valgus force is applied more proximally. (**b**) The underarm technique is helpful in larger patients when more stability is required distally (Courtesy of Bruce Carruthers, Carruthers Photography)

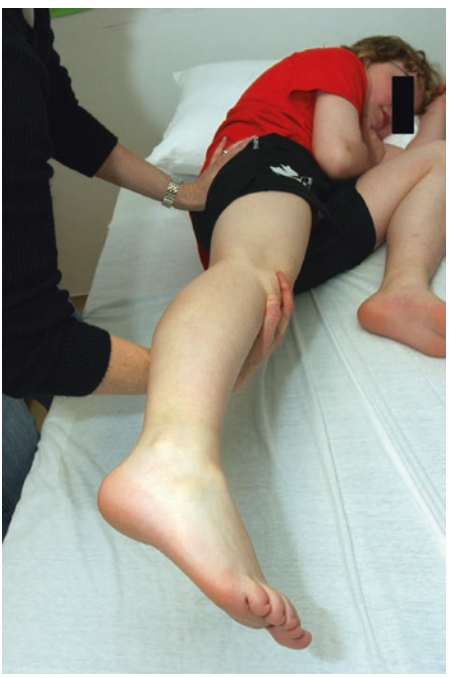

Fig. 12.8 Ober's test. In patients with a tight ITB, the extended leg will not fall past horizontally (Courtesy of Bruce Carruthers, Carruthers Photography)

Fig. 12.9 Patellar apprehension. The thumbs are used to apply a lateral pressure to the medial side of the patellar (Courtesy of Bruce Carruthers, Carruthers Photography)

Acute Injuries

Patellar Dislocation

Acute patellar dislocation lies at the most severe end of the spectrum of patellar instability. The forces that predispose the athlete to patellar dislocation include a forceful quadriceps contraction, together with a partially flexed knee and a twisting motion that displace the patella laterally resulting in significant pain, swelling, and an obvious deformity of the knee. Patellar dislocation can also result from a direct impact to the patella. The risk of patellar dislocation is highest in adolescent girls [4]. Long-term consequences include recurrent dislocations, patellar instability, cartilage injury, pain, and patellofemoral osteoarthritis [5].

Clinical Examination

There may be an obvious deformity of the knee, consistent with a laterally displaced patella. Once the patella has been reduced, there will be a hemarthrosis, decreased range of motion and tenderness (or even palpable defect) of the medial patellar retinaculum. If there is a significant defect of the patellar retinaculum, the hemarthrosis may displace from the knee joint into the quadriceps musculature resulting in an underestimation of the severity of articular injury [6]. It is difficult to assess for patellar apprehension acutely because of pain in the patellar retinaculum; however, in the subacute setting, this sign may be positive. Patellar tracking, both actively and passively, can also be assessed once the patella has been reduced or in follow-up visits. After reduction, it is essential to have the patient actively extend the knee to ensure the extensor mechanism is intact. Ligamentous testing may be difficult to assess acutely but will be normal.

Imaging includes an AP, lateral, and skyline view of the knee looking for osteochondral fractures and loose bodies. Because both plain films and magnetic resonance imaging (MRI) have a high false-negative rate for loose bodies, if clinical suspicion is high, further investigation with arthroscopy is warranted [6, 7]. The skyline view can be used to assess the congruity at the patellofemoral articulation.

Management

If the patella has not spontaneously reduced (10% of cases), closed reduction is necessary [8]. This can be accomplished by gently extending the patient's knee under mild-to-moderate sedation. Post-reduction films are obtained to look for osteochondral injury and document successful reduction. A long leg immobilizer in 20–30° of flexion is then applied for 2–3 weeks (RJ splint or immobilized double-hinged brace) [5]. Maenpaa and Lehto found that patients not immobilized had a threefold higher risk of redislocation than patients treated with immediate immobilization [9]. Weight bearing as tolerated with the immobilizer is allowed. Cryotherapy is initiated immediately. Physiotherapy is essential to restore strength to the quadriceps and knee range of motion. Limited evidence exists to support the ongoing use of a knee brace; however, many patients and physicians find subjective support can be obtained with a J-brace worn at all times during the rehabilitation phase of recovery and during sport once return to play has begun. Adolescents who are first-time dislocators are routinely treated conservatively; however, there is ongoing debate regarding the superiority of conservative vs. operative management in the adolescent [10, 11].

Recurrence is not unusual. One study found the recurrence rate after primary dislocation to be 17%; for those with multiple episodes of subluxation/dislocation, the recurrence rate was 50% [4]. Young age was positively associated with reinjury. Immediate surgery has not reduced this risk [12, 13].

Anterior Cruciate Ligament Tear

Tears of the ACL are becoming increasingly more common in young athletes. This increase is secondary to increasing athletic participation, awareness among the medical community of these injuries in children, and the capacity to diagnose these injuries with the evolution of imaging techniques [14, 15].

Prince et al. found that athletes with completely open physes were more likely to have partial tears of the ACL or an avulsion of the tibial spine than complete ACL tears [16]. Tibial spine avulsions were rarely seen in physically mature patients (4%). They also found that children suffer the same concurrent injuries as adults in ACL trauma, including torn meniscus (medial 24%, lateral 13%), sprained MCL (22%), and torn PCL (10%) [16].

Historically, ACL injuries have been reported to occur up to eight times more frequently in mature females when compared to males. However, a recent chart review at a large Pediatric Sport Medicine center demonstrated nearly equal rates between the sexes, indicating no sex difference in prepubertal children [17]. Various factors, including Q angle, shape, and size of the femoral notch, thickness of the ACL, joint laxity, hormonal influences, and training techniques, have been suggested to account for this historical sex difference in post-pubertal adolescents [18]. While research continues on defining risk factors for ACL injuries in children and adolescents, research in the area of prevention has focused on neuromuscular training programs (NMT) of the at-risk athlete. Sugimoto et al. summarize the effective components of a successful NMT program which address decreased knee flexion, increased knee abduction moment, increased ground reaction force, and asymmetric landing patterns [19]. Sportsmetrics, Prevent Injury and Enhance Performance, and Knee Injury Prevention programs have been found to lower the incidence of ACL tears [20].

The usual mechanism of injury is cutting or pivoting with a planted foot in order to stop suddenly and change direction. Alternatively, the patient may describe landing a jump on a hyperextended knee. A "pop" is often reported to have been heard at the time of injury. Severe pain and inability to bear weight ensue. Significant swelling follows within hours of the injury.

Clinical Examination

The exam may be most revealing either at the field of play before significant swelling develops or in the subacute phase of injury, once pain and apprehension have subsided. Findings include a significant effusion, a decreased range of motion, a positive anterior drawer, and a positive Lachman. Because of the frequency of concurrent injuries, it is essential to examine the patient carefully to assess the integrity of other structures. Comparison with the uninjured leg, which is used as a baseline, is necessary because of the significant ligamentous laxity present in most children. Quadriceps atrophy becomes evident within days of the injury.

Plain films of the knee (AP, lateral, notch, and skyline) are obtained to rule out concomitant osseous injury. Particularly in the youngest patients, these films must be meticulously inspected for a fracture of the tibial eminence, which accounts for 26% of all "ACL" injuries in athletes with open physes [16].

The ACL is best imaged with MRI (Fig. 12.10); however, arthroscopy remains the gold standard for assessing its integrity. It is important that the MRI be interpreted by clinicians with significant experience in this area to minimize inaccurate interpretations of the integrity of the ACL and its surrounding structures.

Management

Management of the immature patient with the ACL-deficient knee is difficult and necessitates early involvement of an orthopedist experienced in this area. Initially, weight bearing must be protected with a combination of a hinged knee brace and crutches until the quadriceps and hamstrings have regained their strength. Physiotherapy is initiated early to increase range of motion and diminish the effusion. After the initial phases of healing, more aggressive therapy can be instituted with a goal of regaining the pre-injury ratio of quadriceps to hamstring muscle strength. Sports requiring running or cutting are discouraged during these first phases of recovery.

There continues to be controversy regarding the definitive management of ACL injuries in the skeletally immature athlete. Current options include conservative management with significant activity restriction until growth has been completed followed by ACL reconstruction, traditional reconstruction in patients with minimal remaining growth and therefore minimal risk of iatrogenic growth disturbance, or early surgery

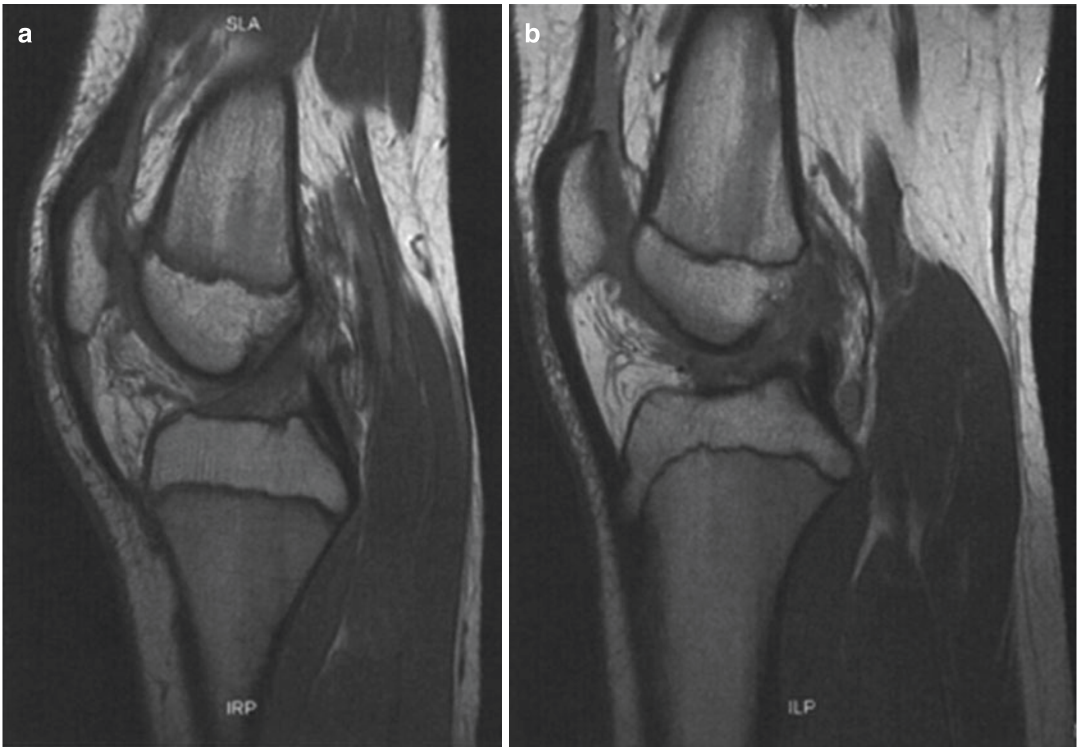

Fig. 12.10 (**a**) MRI of intact ACL. Note intact fibers extending between the anterior tibial plateau and the femoral condyle. (**b**) MRI of torn ACL. Note the mass of shredded fibers in the location of the usually linear ACL. Some buckling of the PCL can also be seen

with a physeal-sparing technique. Non-operative management leaves the patient with an unstable knee with increased risk of further meniscal and chondral injury; however, traditional operative techniques violate the immature physis to varying degrees and may result in increased risk of iatrogenic growth disturbance in the affected tibial and femoral physes. Early reports of a physeal-sparing ACL reconstruction technique documented positive functional and growth outcomes [21]. A more recent meta-analysis supports early operative intervention in order to minimize short- and long-term morbidity and maximize function [22]. In the absence of universal guidelines, each case must be considered individually in consultation with an experienced orthopedic surgeon.

Meniscal Tears

The incidence of meniscal tears in the pediatric athlete is low but increasing [23]. Tears in this population are usually traumatic after a twisting motion of the knee. Tears in children under the age of 10 are likely to be associated with a discoid meniscus [24].

The pattern of injury to the meniscus differs in the child compared to the adult, with 50–90% of tears being longitudinal in children. Displaced bucket handle tears are also common. Given normal meniscal anatomy, the MM is more likely to be torn. The relative increase in lateral meniscal tears in adolescents can be attributed to the presence of discoid LM [25].

Clinical Examination

The physical exam reveals an effusion and possibly joint line tenderness. The utility of provocative testing (McMurray's and Apley's) for meniscal pathology in children lies in the hands of the examiner. These tests can be up to 86–94% accurate when performed by experienced clinicians [26, 27] but have been noted to have accuracies as low as 29–59% in a series using multiple examiners [25, 26].

MRI has been shown to be both a sensitive and specific tool to diagnose meniscal tears. Kocher et al. found better sensitivity and specificity (79% and 92%) when looking at medial meniscal tears as opposed to lateral meniscal tears (67% sensitive, 83% specific) [27]. The increased vascularity of the pediatric meniscus may lead to false-positive interpretation by the inexperienced reader.

Management

Nonoperative treatment includes a physiotherapy program and sport modification. Twisting and cutting sports should be avoided for at least 12 weeks. Some small, stable meniscal tears may heal with such a conservative approach. More often, surgery is required. Possible operative interventions include partial meniscectomy or meniscal repair using various techniques. Meniscal repair (rather than resection as in adults) has been found to be successful in 75–100% of patients under the age of 30 [28–30]. Kocher et al. [24] reviewed several studies that suggest an increased healing potential of meniscal repairs in children compared to adults. Post-operative rehabilitation is more extensive than the non-operative protocol and includes a period of protected ROM immediately after the surgery. Return to play can be expected in 12 weeks in healed meniscal repairs with an uncomplicated post-operative course.

Collateral Ligament Injuries

Injuries to the collateral ligaments occur as a result of valgus or varus forces at the level of the knee. A valgus force to the lateral aspect of the knee may result in injury to the MCL. Less often, a varus force applied to the medial aspect of the knee may injure the LCL. MCL injuries may occur in isolation; however, an isolated injury of the LCL is unusual, and concurrent injury to the popliteus or arcuate complex should be considered [15]. Injury to the ACL and MM can occur in conjunction with MCL injury, especially in cases with a rotational component to the insulting force. Grading of collateral ligament injury is outlined in Table 12.1 [31].

Clinical Examination

The patient will be tender along the length of the affected collateral ligament. Stress testing in 30° of flexion will produce pain and, in more severe injuries, instability. If instability is evident in full extension, specifically with varus loading, injury to the posterior capsule should be considered in addition to the LCL. Isolated collateral ligament injury produces pain and instability only in flexion. With complete avulsions of the MCL, an osseous fragment at the site of origin of the MCL on the femur may be evident on x-ray (Pellegrini–Stieda lesion).

Management

Treatment of isolated collateral injuries is conservative and consists of rest and cryotherapy. If needed for comfort, a double-hinged knee brace that allows for early range of motion may be used. Physiotherapy may be helpful in maintaining strength and range of motion during ligamentous healing. Return to play is usual in 4–6 weeks for grade 1 sprains, 8 weeks for grade 2 sprains, and up to 12 weeks for grade 3 sprains (Table 12.1). A small amount of ligamentous laxity may persist, and athletes may wear the hinged brace for the first 6 months after returning to play.

Tibial Tubercle Avulsion Fracture

Tibial tubercle avulsion fractures are uncommon injuries that typically occur in well-developed adolescent male athletes nearing the end of their growth (ages 13–16) as the tibial apophysis is closing [32, 33]. These injuries make up less than 3% of all proximal tibial fractures [34] and less than 1% of all physeal injuries.

This injury happens by one of two mechanisms: (a) active knee extension through a strong

Table 12.1 Grading of MCL injuries

Grade 1	Microscopic disruption of collagen fibers, no laxity; pain with stress testing, but no laxity
Grade 2	Macroscopic partial tearing of the ligament, <1 cm opening with stress testing
Grade 3	Complete disruption of collagen fibers, >1 cm laxity with stress testing

Data sources: Mintzer et al. [28]; Diduch et al. [31]

Table 12.2 Tibial tubercle avulsion fractures

Type 1	Fracture distal to the junction of the ossification center of the proximal tibial epiphysis and tuberosity
Type 2	Fracture with extension to the junction of the proximal tibial physis
Type 3	Fracture extends into the joint through the proximal tibial epiphysis with displacement of the fracture fragment
Type 4	Fracture extension transversely through the proximal tibial physis with displacement of the fracture fragment

Each of these types is further subdivided into A (non-comminuted) and B (comminuted)

Source: Adapted from Chow SP, Lam JJ, Leong JC. Fracture of the tibial tubercle in the adolescent. J Bone Joint Surg Br 1990;72(2):231–234. Reproduced with permission and copyright of the British Editorial Society of Bone and Joint Surgery

quadriceps contraction, such as with aggressive jumping, and (b) passive knee flexion against a contracting quadriceps muscle group, as in landing after a jump from a height. Both of these mechanisms generate enough force for the strong quadriceps to overcome the strength of the fusing tibial tubercle and result in an avulsion of this fragment. Tibial tubercle avulsions most commonly occur in athletes playing basketball [32]. Although no cause–effect relationship has been found, there is speculation that OSD may play a role in the occurrence of tibial tubercle avulsion fractures [32, 33, 35]. These fractures were originally classified with the Watson–Jones classification system [36], which was later modified by Ogden et al. [37] (Table 12.2). A more recent classification system has been suggested, based on CT findings which better delineate intra-articular involvement which can be missed when using only plain films [38].

Clinical Examination

The physical examination reveals a swollen, tender bony deformity at the site of the tibial tubercle. Depending on the degree of disruption, there may be evidence of a superiorly displaced patella. The knee is often held in the position of comfort, at approximately 30° of flexion. If an effusion or hemarthrosis is present, it suggests the presence of an associated injury (ACL or meniscus) or a more severe injury with extension into the joint. The patient will be unable to actively extend the knee secondary to the interruption in the quadriceps mechanism. Although rare, care must be taken not to overlook anterior compartment syndrome which may occur secondary to disruption of the anterior tibial recurrent artery which courses anterior to the tibial tubercle [39].

Fig. 12.11 Type 3 tibial tubercle avulsion fracture. Note extension of fracture through the physis and into the articular surface. Displacement of the fragment is also present

Diagnosis is confirmed with knee x-rays. The lateral view (Fig. 12.11) is helpful in classification of the injury (Table 12.2). Often patella alta will also be evident on the lateral view.

Management

Management of tibial tubercle avulsion fractures should be guided by an orthopedic surgeon. Type 1 fractures may be treated conservatively with a cylindrical cast for 2–6 weeks. Types 2–4 are treated with open reduction with internal fixation [40]. Weekly plain films are suggested during recovery to monitor displacement of the reduced fragment [33].

If operative intervention has been necessary, resistance training may begin 6 weeks after the initial injury in an isolated tibial tubercle avulsion fracture. Patients with types 1 and 2 injuries can often return to activities in 2 months; those with types 3 and 4 fractures need 4–6 months to return to activities demanding a high quadriceps load [33]. As with all other injuries, full joint range of motion and full muscle strength must be attained before return to play. A graded return to play is recommended.

Chronic Injuries

Patellofemoral Pain Syndrome

Patellofemoral pain syndrome is associated with activities that load the patellofemoral joint in the anterior–posterior direction. The young athlete with patellofemoral pain syndrome complains of chronic vague anterior knee pain that may limit activity. Pain is aggravated with activity engaging the quadriceps. The pain decreases with rest; however, patients may complain of a vague ache or stiffness after prolonged sitting (car ride, sitting in a movie theater). This is referred to as the theater sign. There is no true swelling, locking, or giving way; however, some patients will experience impending giving way or a minor sense of instability.

Clinical Examination

The physical examination may reveal varying degrees of malalignment of the lower extremity, including internal tibial torsion, genu valgum, and pes planus. Increased Q angle is also often implicated in this diagnosis, although its significance has been debated [41]. The knee maintains full range of motion. The patella may be tender to palpation. All provocative ligamentous testing is within normal limits. Of note, children with patellofemoral pain do not have an effusion. Imaging is not usually indicated unless the diagnosis is in question or in the care of a child with patellofemoral pain and an effusion.

Management

The first-line treatment for patellofemoral pain is often physiotherapy. Crossley et al. performed a systematic review of various interventions for patellofemoral pain syndrome and found that pain was reduced with the implementation of physiotherapy; symptoms worsened when no therapy was implemented [42]. This paper found there was a paucity of evidence to support patellofemoral orthoses, taping, therapeutic modalities, chiropractic manipulation, and acupuncture in the treatment of patellofemoral pain syndrome. Despite the lack of evidence, many practitioners have found that some patients do benefit from these interventions. It is suggested that these interventions be recommended to patients on an individual basis, in conjunction with physiotherapy. A more recent review of the literature supports exercise therapy as the most effective intervention to decrease pain and improve function [43].

Return to play is based on patient symptoms. A period of relative rest from the offending activity may be helpful in the alleviation of symptoms. If an athlete is experiencing low levels of pain with activity, without increases from day to day, continuation in the sport is allowed during the rehabilitation process. When the patient's pain has subsided sufficiently to allow full participation, return to play is encouraged.

Subluxing Patella

The subluxing patella is a result of a variety of factors that lead to lateral tracking of the patella in the femoral groove during knee flexion and extension, resulting in vague complaints of instability, giving way, and anterior knee pain. Several factors may predispose an athlete to patellar subluxation. Hinton and Sharma have divided these factors into those of the host, agent, and environment [8]. Host factors include the rapid growth of adolescence that induces muscular tightness in an individual who still has the ligamentous laxity of childhood. Suggested but not proven host factors include patella alta, increased Q angle, increased femoral anteversion, excessive midfoot pronation, lateral facet dominance, deficient lateral trochlea, vertical VMO insertion, and ITB tightness [8]. The offending agent may be macrotrauma (planting the lower extremity with subsequent internal rotation and knee valgus) or repetitive microtrauma, such as the repetitive whip kick used in the breaststroke. Environmental factors include the frequency of exposure to micro- or macrotrauma, the accuracy of previous diagnoses, effectiveness of rehabilitation, and the amount of general lower extremity conditioning [8].

Clinical Examination

The lower extremity is assessed looking for evidence of malalignment (valgus, angular deformities, increased Q angle, pes planus). Patellar tracking during passive and active knee extension shows lateral movement (J-sign). Patellar apprehension is present, and tightness may be appreciated when trying to lift the lateral edge of the patella with the patient lying supine (decreased patellar tilt). Decreased bulk of the VMO compared with the vastus lateralis may be evident. There should be no effusion and ligamentous stability should be intact. The degree of generalized ligamentous laxity of the patient should also be assessed.

AP, lateral, and skyline (20–30° knee flexion) views are helpful in the evaluation of patellar subluxation (Fig. 12.12). Patella alta can be assessed on the lateral view using the method of Koshino [44] for children and the Blackburne–Peel method for adolescents [45]. The skyline view is used to assess the degree to which the patella sits in the trochlear groove, as well as the amount of "tilt" present in the lie of the patella.

Management

Identification of the primary offending agent (host, environment, agent) is essential to appropriately focus the management plan. The mainstay of conservative management is physiotherapy emphasizing the restoration of balance between medial and lateral forces acting on the patella. A quadriceps-strengthening and ITB stretching program with this focus is generally helpful within 8–12 weeks in a compliant patient.

Fig. 12.12 Patellar subluxation. Skyline view of the patella showing extreme lateral placement of the patella within the femoral groove

Evidence is lacking to support the routine use of knee orthoses; however, some physicians have found the use of a J-brace to be of subjective benefit to some patients.

An initial period of rest from offending activity is helpful while the therapy program is initiated. Once the athlete is pain-free, return to play is allowed in a graduated approach. If conservative therapy fails, referral to an orthopedic surgeon for assessment of surgical intervention is appropriate.

Iliotibial Band Friction Syndrome

With flexion and extension of the knee, the ITB slides anteriorly and posteriorly over the bony prominence of the lateral femoral condyle when the knee is at 20–30° of flexion. Repeated excessive movement of this band over the femoral condyle causes injury to the tendon, which manifests in pain and tenderness over the lateral aspect of the knee. This pain may be secondary to degenerative changes in the ITB or inflammatory changes in the associated bursa [46]. In addition to repetitive flexion and extension of the knee (which may be seen with increases in training load), risk factors may include genu varum, a prominent lateral condyle, foot pronation, and internal tibial torsion [47]. It has also been proposed that hip abductor weakness may increase thigh adduction and therefore lead to increased tension and friction of the ITB [48]. Aggravating factors include prolonged activity, such as biking or running, particularly downhill running or running on the same side of the street.

Clinical Examination

The patient's pain can often be reproduced by palpating the lateral femoral condyle as the patient's knee is moved through a 20–30° arc of flexion. A snapping sensation may be appreciated. Patients will often have a positive Ober's test. Imaging is seldom necessary if the history and physical findings are consistent. If confirmation is needed, ultrasound or MRI may be helpful [47].

Management

Conservative management is usually successful in young athletes with ITB friction syndrome. Control of pain and inflammation may be necessary with ice and nonsteroidal anti-inflammatory drugs [49]. Management should include a period of relative rest, as well as modification of training errors, such as stride length, hills, cant of the training surface, and height of the cycle seat. A physiotherapy program emphasizing gluteal strengthening and flexibility is the mainstay of treatment. If symptoms are persistent, an injection of steroid into the associated bursa may help. Caution is advised when using this procedure in children. In rare refractory cases, where conservative management has failed, orthopedic consultation is helpful to assess the need for surgical intervention.

Sinding–Larsen–Johansson Disease

Sinding–Larsen–Johansson disease (SLJD) is a traction apophysitis of the inferior patellar pole, resulting in insidious onset of anterior knee pain localized to the inferior patellar pole. Pain is aggravated by running and jumping. The persistent traction of the quadriceps–patellar tendon unit on the immature inferior patellar pole leads to varying degrees of calcification and ossification of this apophysis. A classification system was proposed by Medlar and Lyne [50] (Table 12.3). SLJD can present concurrently with OSD and patellar tendonitis. The condition is common in growing athletes, particularly boys between the ages of 10 and 12 years. Occasionally, the pain may be located at the superior poles of the patella.

Table 12.3 Classification system of Sinding–Larsen–Johansson syndrome

Stage 1		Normal patella on roentgenograms
Stage 2		Irregular calcification at the inferior patellar pole
Stage 3		Progressive coalition of this calcification
Stage 4	A	Incorporation of the calcification within the patella
	B	Calcific mass remains separate from the main body of the patella

Source: Medlar and Lyne, 1978. Reprinted with permission of The Journal of Bone and Joint Surgery, Inc.

Clinical Examination

Examination of the knee will reveal point tenderness at the inferior patellar pole (or the superior patellar poles if these are involved). There may be pain with active resisted knee extension and passive knee flexion. The remainder of the knee examination is within normal limits. Knee x-rays, particularly a lateral film, may be normal, or they may show varying degrees of ossification and calcification of the inferior patellar pole (Fig. 12.13).

Management

The natural history of this condition is spontaneous resolution of symptoms. The resolution of symptoms can be expedited, however, by a few simple interventions. Moderation of the aggravating activity is essential. Ice and anti-inflammatories may help with reduction in pain and inflammation. Physiotherapy consisting of a series of strengthening and flexibility exercises can promote healing and help prevent recurrence of symptoms once normal activities have resumed.

Fig. 12.13 Plain film of SLJD. Lateral plain film showing fragmented ossification of the inferior patellar pole in SLJD

Osgood–Schlatter Disease

Osgood–Schlatter disease is a common cause of knee pain in the adolescent athlete involved in running or jumping sports. This injury manifests as pain and tenderness at the site of insertion of the patellar tendon into the tibial tubercle, usually occurring during a growth spurt. Symptoms are the result of minor avulsions at the junction of the patellar tendon and the tibial tubercle. These avulsions are secondary to the forces of the patellar tendon when it overcomes the strength of the growing bone at the tibial tubercle apophysis. Repeated attempts at bony repair result in a callous of varying sizes at the site of the tibial tubercle. Pain that is more prominent in the patellar tendon rather than the bony prominence would be consistent with patellar tendonitis (jumper's knee) rather than OSD. Aggravating and alleviating factors are similar to those of SLJD. Management of these two conditions is similar.

The condition was described in 1903 by both Osgood [51] and Schlatter [52]. Kujala confirmed that this condition is more common in athletes, finding an incidence of 21% in a group of adolescent athletes compared with 4.5% in an age-matched, non-athletic group [53]. Athletes are affected during their adolescent growth spurt, at 11–13 years of age for girls and 12–15 years of age for boys. Traditionally, OSD is more common in boys, but the increase in sport participation in girls has led to an increase in incidence of this disease in females [40]. The natural history of the condition is improvement with time [54]. However, some adults are left with minor symptoms, including the inability to kneel for prolonged periods. Complications of this condition are minimal and consist mainly of the non-union of a tibial tubercle fragment/ossicle resulting in persistent pain.

Clinical Examination

Physical examination often reveals a prominent tibial tubercle that is tender to palpation. This tenderness may extend proximally into the patellar tendon. There may also be mild edema in this area. There is pain with active resisted extension of the knee and with passive flexion of the knee as the quadriceps are stretched. X-rays are not necessary; however, if obtained, lateral x-rays of the knee may show increased fragmentation of the tibial tubercle or separation of these fragments (Fig. 12.14). There may also be soft tissue edema anterior to the tibial tubercle, thickening of the patellar tendon, and loss of the sharp inferior angle of the infrapatellar fat pad [53].

Management

Because of the self-limiting nature of the disease, the outcome is unusually good. Recovery may be expedited by a relative reduction in the frequency or duration of offending activities, such as running, jumping, squatting, and kneeling. Ice massage of the tibial tubercle, along with nonsteroidal anti-inflammatory drugs, is often helpful with reduction of pain and inflammation. A physiotherapy program emphasizing quadriceps and hamstring flexibility may be beneficial as well. Immobilization is generally not recommended in the management of OSD. One recent small trial has found benefit with injection of dextrose (12.5%) and lidocaine when compared to standard therapy alone in cases of

Fig. 12.14 Osgood–Schlatter disease. Note the fragmented ossification of the tibial tubercle and thickened soft tissue anterior to the tibial tubercle

refractory OSD [55]. Although the pain associated with OSD is often reduced with these treatments, the bony deformity of the tibial tubercle will persist to varying degrees in many patients. Occasionally, pain will persist despite compliance with the treatment program. In these patients, the presence of a non-united ossicle should be sought. Excision of a symptomatic ossicle will often result in prompt relief of symptoms [56].

Juvenile Osteochondritis Dissecans

Osteochondritis dissecans is a lesion of bone and articular cartilage of uncertain etiology that results in necrosis of subchondral bone with or without articular cartilage mantle involvement [57]. The etiology of this lesion remains uncertain. Possible etiologies have included trauma, ischemia, and genetics [58]. In less advanced lesions, the affected area remains continuous with its origin. In more severe cases, the damaged bone and cartilage may partially or completely separate from their origin, resulting in irregularity of the articular surface or even a loose body within the joint. The lesions typically present in active adolescents, more often in males than females (3:1 or 4:1). Linden reported less variability between the sexes, with an incidence of 19 per 100,000 in females and 29 per 100,000 in males [59].

Table 12.4 Classification system of osteochondritis dissecans

Stage 0	No symptoms
Stage 1	Intermittent pain and swelling related to activity
Stage 2	Persistent pain and swelling without mechanical symptoms
Stage 3	Mechanical symptoms other than locking
Stage 4	Frank locking of the knee

Data source: Litchman et al. [62]

It has been reported that juvenile osteochondritis dissecans (JOCD) (OCD in athletes with open physes) has more potential to heal with conservative management than the adult osteochondral lesion [58–60]. JOCD lesions are most commonly located in the lateral, non-weight-bearing portion of the medial femoral condyle (51–72%) but can also be located on the lateral femoral condyle (17–20%) and the articular surface of the patella (7–15%) [60, 61]. OCD is often unilateral, although it can be bilateral. Litchman [62] proposed a staging system based on clinical presentation (Table 12.4).

Adolescent athletes with JOCD often present with a chronic (several months) history of vague anterior knee pain aggravated by activity. They may complain of knee swelling after activity. Complaints of locking may be present if there is an intraarticular loose body. Hefti reported that one third of patients had little or no pain at presentation [60]. A history of trauma may be reported in 40–60% of cases [63].

Clinical Examination

The physical examination often reveals a limp secondary to pain or stiffness. Tenderness to palpation of the affected bony surface (femoral condyles, articular surface of patella) and a small effusion may be all that are present on the examination of the knee. X-rays of the knee, including AP, lateral, and tunnel (notch) views, will usually reveal the lesion (Fig. 12.15). The tunnel view allows for better visualization of the posterior two thirds of the femoral condyle, where many OCD lesions are found [64]. This area is poorly visualized on the standard AP film, and therefore an AP film interpreted as normal may be falsely reassuring (Fig. 12.16). JOCD lesions can often be seen on the lateral view but can be subtle and easily overlooked.

Traditionally, technetium bone scintigraphy has also been used in the evaluation of JOCD [65, 66]. With the improvements in MRI technique and availability, it has become the imaging modality of choice for assessing and managing JOCD.

MRI helps to determine the size of the lesion and whether the cartilage overlying the lesion is intact, which in turn determines stability of the lesion. The use of gadolinium contrast can help determine if blood flow to the lesion is adequate. Unstable lesions are those that have separated themselves from their base. Stable lesions and small lesions have better healing potential. Lesions with intact cartilage improved with conservative treatment, regardless of extensive subchondral bone changes evident on MRI [67]. O'Connor reviewed the interpretation of signal change at the site of JOCD lesions imaged by MRI and reported increased prediction of stability if the high signal line on the T2-weighted image did not breach the articular cartilage on the T1-weighted image [68]. MRI is also helpful in the identification of loose bodies that are often missed on plain films.

Fig. 12.15 Notch view of OCD. Note significant fragmentation of the advanced lesion on the medial aspect of the lateral femoral condyle. This lesion is obvious, and the articular surface is clearly disrupted

Fig. 12.16 OCD as seen on AP plain films. Note the subtle lucency on the lateral aspect of the medial femoral condyle. Many lesions can be even more subtle

Management

The primary goals in the management of JOCD include symptom relief, maintaining or restoring the integrity of the articular cartilage surface, and the prevention of the development of arthritis. Wall indicates that because 50–94% of stable JOCD lesions heal with conservative management, a 3–6-month trial of non-operative therapy should be initiated [58]. Hefti has shown that when these lesions are initially treated operatively, a worse outcome can be expected [60]. Several options for conservative treatment have been recommended with variable success rates. Most authors recommend a period of protected weight bearing with a removable knee immobilizer to allow for intermittent controlled knee range of motion [63]. Wall, however, prefers casting to decrease the likelihood of non-compliance [58]. Regardless of type of immobilization and protected weight bearing, this intervention is necessary for at least 8–12 weeks and sometimes up to 1 year, depending on the amount of healing evident on either plain films or MRI.

Once significant reossification has been documented, a gradual increase in weight bearing and return to sport is implemented. Physiotherapy is essential in regaining the strength lost from deconditioning and immobilization during the healing phase.

If healing is not documented after 6 months of conservative treatment, operative intervention may be necessary. There are several options for operative intervention, including arthroscopic drilling and fixation, abrasion chondroplasty and microfracture, allograft, osteochondral autograft transplantation, and autologous chondrocyte transplantation [63].

Plicae

Plicae are an uncommon cause of knee pain in the adolescent athlete. A plica is a fetal remnant of mesenchymal tissue, initially formed as the knee joint was dividing into its various compartments. It has been estimated that 20% of the adult population has asymptomatic persistent synovial plica [69, 70]. Pain is experienced in the anterior aspect of the knee when the plica becomes inflamed. This may result from a direct contact injury (hit to the knee in the area of the plica). The plica may also become inflamed as it bowstrings across the medial femoral condyle in knee flexion, causing painful snapping [71]. During childhood, this tissue glides uneventfully over the condyle. During the adolescent growth spurt, the imbalances in growth increase the tension of this band as it crosses over the condyle. With the increase in tension, there is an increase in friction, which may result in inflammation, fibrosis, and hypertrophy of the plica. This is amplified with repetitive running and jumping [40]. Although there can be up to four plica within the knee joint (infrapatellar, suprapatellar, medial patellar, and lateral patellar), it is the medial patellar plica that is most commonly implicated in the painful plica syndrome.

Clinical Examination

The physical examination may contain little in the way of positive findings. There may be pain to direct palpation of the plica (one finger breadth medial to the medial border of the patella). A popping may be palpated in the medial compartment as the knee ranges from 30 to 60° of flexion. Occasionally, the band itself is palpable. Classically, there is no effusion. This may be helpful in distinguishing between the pain from an inflamed plica and a torn meniscus. Imaging is not helpful.

Management

The management of an inflamed plica begins with identification of any training errors and modifying training accordingly. Relative rest will help decrease pain. Physiotherapy aids in the improvement of balance of strength and flexibility. Anti-inflammatories such as ice and ibuprofen are helpful in controlling both pain and inflammation [72]. Although Rovere and Adair found some benefit to steroid injection into the inflamed plica [73], this method of treatment is uncommonly used. If conservative therapy fails and other diagnoses have been ruled out, surgical resection of the plica may be necessary.

Congenital

Discoid Meniscus

The discoid meniscus is a congenital variation in the shape of the meniscus, most often the LM. The discoid meniscus does not have the C-shaped concavity found in the normal meniscus; rather, it is shaped like a disk, thicker centrally. Kelly and Green have summarized the proposed theories on the origin of the discoid meniscus, which culminate in the current theory of the discoid meniscus as a congenital anatomic variant [74]. The incidence of discoid meniscus has been noted to be up to 17%, depending on the population studied [74]. It can occur bilaterally in up to 20% of cases [75]. The discoid meniscus is most often characterized using the Watanabe classification system (Table 12.5) [76]. Types 1 and 2 tend to be asymptomatic and are discovered incidentally. Type 3 is thought to produce the "snapping knee" syndrome. Kocher et al. proposed a classification system based on the type of discoid (complete vs. incomplete), the presence of peripheral rim stability (stable or unstable), and the associated tear of the meniscus [24].

A symptomatic discoid meniscus may present with a history of painless palpable or audible snapping (the snapping knee syndrome). Symptoms are most likely to appear after the discoid meniscus has been injured. Once torn, symptoms on presentation include pain, locking, catching, and decreased range of motion.

Clinical Examination

Once symptomatic, the physical examination reveals an effusion, decreased range of motion with pain at extremes of range, and positive provocative testing with the McMurray and Apley tests. Plain films may show subtle indications of a discoid LM, including a widened lateral joint line (Fig. 12.17), calcification of the LM, squaring of the lateral femoral condyle, cupping of the lateral tibial plateau, hypoplasia of the tibial eminence, and elevation of the fibular head. Discoid menisci can be identified by MRI (Fig. 12.18). Although the sensitivity for detection is low, the positive predictive value is high [27].

Table 12.5 Classification system of discoid meniscus

Type 1	Complete discoid meniscus with intact posterior tibial attachment
Type 2	Incomplete discoid meniscus with intact posterior tibial attachment
Type 3	"Wrisberg ligament type" – complete or incomplete discoid meniscus lacking posterior tibial attachment

Data source: Watanabe et al. [76]

Fig. 12.17 Discoid meniscus. Note widening of the lateral joint space

Fig. 12.18 MRI of discoid LM. Note the disk shape of the LM compared with the concave shape of the MM

Management

Asymptomatic discoid menisci identified incidentally require no further treatment. The symptomatic discoid meniscus necessitates referral to a pediatric orthopedic surgeon.

Knee Injury Prevention

Although not all injuries can be prevented, a few guidelines may be helpful in preventing some injuries. It is helpful for athletes to maintain a general level of fitness year-round. Many sports will have an off-season, which the athlete can use to rest the muscles used repetitively during the competitive season. Participation in other sports during the off-season is also helpful in achieving global strength and fitness. No specific exercises have been shown to consistently reduce the incidence of any particular knee injury; however, athletes should be encouraged to continue a year-round general strength and conditioning program that is complimentary to their chosen sport.

Sport safety is essential in reducing the incidence of injuries to athletes. All recommended protective gear should be worn, and "courtside rules of etiquette" should be followed. Surfaces and sporting equipment should be kept well maintained and in accordance with safety regulations.

Return to Play Guidelines

Specific return to play guidelines are discussed above in the context of each injury. In general, athletes returning to sport should have regained a baseline level of conditioning that will allow them to begin to participate in practices and drills. The treating therapist should progress the athlete from general strengthening and conditioning to sport-specific rehabilitation. Once the athlete has shown proficiency with these interventions, graded return to play can be initiated and supervised by the treating therapist. At no point should participation increase pain or dysfunction. All recommended braces and sup-

Clinical Pearls

- Always compare the injured side with the uninjured side to gain an accurate appreciation for what is normal for each patient.
- The presence of a knee effusion in a child is always significant. Its presence often indicates intraarticular pathology and warrants investigation until a diagnosis is obtained.
- Quadriceps atrophy begins immediately after a significant knee injury and can be a subtle finding of a significant knee injury.
- In the absence of physical exam findings at the knee in a young athlete with knee pain, the hip must be examined and investigated as a source of pathology leading to pain referred to the knee.

- Multiple joint involvement, fevers, systemic symptoms, and night pain suggest non-mechanical causes of knee pain and should be investigated further.
- Often, an injured athlete will be able to continue participation/training in some aspect of their sport while rehabilitating an injury. When possible, this continued participation is important for the athlete's skill development and psychological well-being. When a physician is unfamiliar with a sport, the coach or therapist may be helpful in determining which areas of the sport may be appropriate to continue through rehabilitation of an injury.
- Although most injuries are not career ending, caregivers must remember that these athletes are children and with proper management and can have a lifetime of athletic participation ahead of them.

ports should be used until the treating therapist or physician has advised the athlete that their use may be discontinued.

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13 Lower Leg Injuries

Angela D. Smith

Lower leg pain rarely occurs from the usual activities of daily living of children and adolescents. Non-acute repetitive microtraumatic injuries are typically related to running and jumping associated with sports. Pain in the tibia or fibula not caused by acute trauma is most often associated with recurrent impact loading. Training errors and inappropriate equipment are often causative factors. In addition lower leg injuries caused by acute trauma that is *unrelated* to sport may impact the young athlete's ability to participate in desired activities.

The symptom of lower leg pain, particularly when unilateral, must prompt consideration of diagnoses such as benign or malignant neoplasm, acute or chronic infection, and metabolic bone disease. The diagnosis may not be apparent from the history and physical examination alone. If a problem such as neoplasm or infection is found, choosing one particular treatment method over another may allow a young athlete to successfully return to sport sooner.

A published algorithm for developing a differential diagnosis for lower leg pain in an adult athlete can generally guide the evaluation of child and adolescent athletes [1]. This chapter outlines lower leg injuries with specific attention to the young athlete, addressing methods for the most rapid, yet safe, return to activity. Few original studies in the literature specifically address the lower leg injuries of young athletes. Therefore, some of the concepts and much of the literature referenced in this chapter are derived from studies of adults, in addition to the clinical experience of the author and pediatric sports medicine colleagues.

Anatomy

The bones of the lower leg are the tibia and fibula, each covered by only a thin layer of skin and subcutaneous tissue in some areas (Fig. 13.1). Although almost all the muscles that control knee motion insert onto the proximal tibia and fibula, their muscle bellies are in the thigh. Most lower leg muscles control only ankle and foot motion, but the gastrocnemius muscle also flexes the knee. The greater total excursion of the gastrocnemius makes it the most likely lower leg muscle to be strained.

The anterior compartment contains the tibialis anterior, extensor hallucis longus, extensor digitorum longus, and peroneus tertius muscles. These muscles are primarily dorsiflexors. The deep peroneal nerve supplies these muscles and is the sensory nerve for the dorsal web space between the first and second toes. The lateral

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L. J. Micheli, L. Purcell (eds.), *The Adolescent Athlete*, Contemporary Pediatric and Adolescent Sports Medicine, https://doi.org/10.1007/978-3-319-56188-2_13

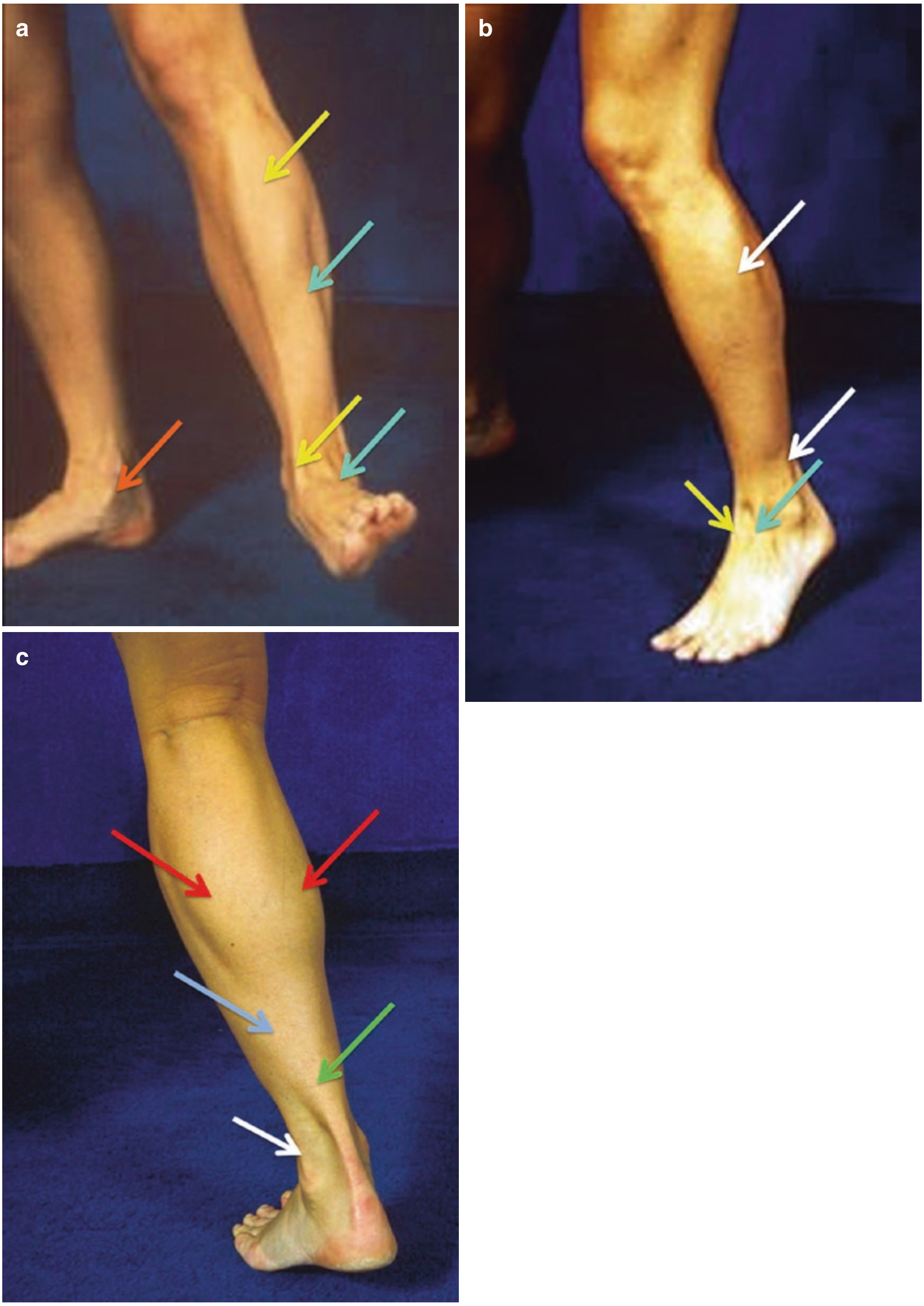

Fig. 13.1 Surface anatomy. (**a**–**c**) The anterior tibial muscle and tendon (yellow arrows) and the toe extensors (aquamarine arrows) dorsiflex the ankle. The peroneus longus (white arrows) courses down the lateral leg and foot and then deep across the plantar aspect of the foot to insert at the first metatarsal. It everts the foot and depresses the first metatarsal. The orange arrow indicates the right foot posterior tibial tendon that inserts into the prominent medial navicular bone. The two heads of the gastrocnemius (red arrow) are superficial to the soleus muscle (light blue arrow). The green arrow indicates roughly the center of the long musculotendinous junction of the triceps surae/Achilles tendon unit

compartment contains the peroneus longus and brevis muscles, the most important evertors of the foot. Also in the lateral compartment is the superficial peroneal nerve, which is sensory. The peroneal nerve divides into the deep and superficial peroneal nerves at the level of the fibular head where it is quite superficial, tented across the bone. Near the midpoint of the lower leg, the superficial peroneal nerve pierces the lateral fascia of the lateral compartment to continue to the lateral ankle subcutaneously before branching and supplying sensation to the lateral foot distally. The superficial posterior compartment muscles include the medial and lateral heads of the gastrocnemius, which originate on the femur, and the soleus, which originates in the lower leg. The small, thin plantaris muscle also resides in this compartment. The deep posterior compartment contains the tibialis posterior, flexor hallucis longus, and flexor digitorum longus muscles. There may be a variable "fifth" compartment, a subcompartment of the deep posterior compartment, related to variation of the fibular attachment of the flexor digitorum longus [2].

The popliteal artery bifurcates at or just below the popliteal fossa, into the anterior and posterior tibial arteries. The anterior tibial artery courses through the anterior compartment, palpable as the dorsalis pedis pulse. The posterior tibial artery courses through the deep posterior compartment, which is palpable adjacent to the medial malleolus. The large saphenous vein is superficial over the distal medial leg.

Clinical Evaluation

History

The differential diagnosis of lower leg problems is narrowed by determining the mechanism of onset, duration, location, and character of the pain. The timing of the pain, when it occurs in relation to different activities and whether it then resolves or recurs during the same activity, further indicates the most likely diagnosis (Table 13.1).

The cause of an injury may not be immediately obvious; it may not be solely mechanical. A young athlete who sustains repeated injuries may have an underlying systemic disorder, such as Ehlers–Danlos or osteogenesis imperfecta. Injuries may be related to a psychological disorder, such as depression or anorexia nervosa. A child may be on growth hormone or insulin. Performance-enhancing drugs may be involved. A young athlete who no longer finds a sport exciting may even need an excuse to bow out of a sport without losing esteem in the eyes of parents or friends. Those caring for children and adolescents need to be sensitive to subtle signs from the athlete and the parent, not simply care for the physical injury, blind to the psychosocial context. Red flags may include overbearing parents who answer all the questions that are addressed to the athlete, an athlete avoiding eye contact, unusual constellations of symptoms and physical findings, excessive leanness or obesity, or loss of

Table 13.1 Key history details in lower leg injuries

	Exertional compartment syndrome	Stress fracture	Posteromedial tibial stress syndrome	Tendon overuse injury
Pain location	Large area, muscle	Focal, bone	Longitudinal, along much of posteromedial border of tibia	Tendon, often musculotendinous junction
Pain character	"Dead," "numb," weak	Sharp, stabbing, boring, like toothache	Sharp or dull	Burning, stabbing, searing with radiation into muscle
Timing	Resolves within minutes after stopping activity but may remain "sore"	Worse as activity continues, improves with rest	Persists long after activity, may decrease in severity *during* lengthy activity	Pain with any use of the structure, persistently tender
Typical location	Anterior compartment, anterolateral leg; isolated lateral or posterior less common	Small, defined area of anterior tibial shaft, distal fibula	Central and distal posteromedial tibia	Tendon, musculotendinous junction, usually Achilles

regular menses for a young female athlete. A nutrition and menstrual history (when appropriate) might suggest relative energy deficiency for sport (RED-S) or specific nutrient deficiency such as vitamin D or calcium.

The history should also include questions about other injuries or illnesses. For example, the athlete who deconditions during the course of mononucleosis and then rapidly ramps up for track and field soon afterward, will often sustain lower leg injury. The history might include a combination of seemingly diverse medical problems such as concussion, foot sprain, and minor heel pain, but all will have contributed to the subsequent lower leg injury. For example, a 14-year-old track athlete required a rest period for concussion healing that was followed by training error (sudden and rapid return to sport, right away running 7 miles almost daily in addition to sprint workouts) and then sustained a mild foot sprain when the muscles fatigued. The foot sprain was minor and was not rehabilitated, and the combination of relatively tight calf muscles and relatively weak push-off caused the heel pain. The resultant alterations of gait, combined with the combination of training error, calf muscle tightness, and muscle weakness, led to tibia bone stress injury.

Physical Examination

The physical examination of the injured lower leg includes observation of the legs, both still and in motion. The young athlete may have video recordings of the sports activities related to the pain, and these can be evaluated for biomechanical errors or for the type of limp that occurs with activity. The functional evaluation often includes the athletic footwear as well, so athletes should be encouraged to bring this to the office visit.

Abnormal color of the entire lower leg may indicate actual or incipient reflex neurovascular dystrophy (also known as reflex sympathetic dystrophy or chronic regional pain syndrome). Muscles should typically be symmetric side to side, although sport-specific muscle asymmetry should be present when appropriate. They should also be proportional within the limb. Very slender lower legs and heavily muscled thighs may simply reflect normal heredity, but such proportions may also suggest a diagnosis of progressive peroneal muscular atrophy. Even the foot shape should have relative bilateral symmetry. The medial side of the feet can be more easily observed when the young athlete sits in the butterfly position, with the soles of the feet together. From the dorsal or plantar view, if the normal right forefoot appears filled out but the injured left foot looks relatively flattened, the intrinsic muscles are probably atrophied, for example. Some sports develop the limbs asymmetrically of course (e.g., soccer and figure skating for legs, tennis players for arms), and some children have lower extremity hemihypotrophy or hemihypertrophy. In these situations, typically the entire extremity—all muscle groups—differ symmetrically and proportionately from the opposite side. Length usually differs similarly but not always.

Walking and running gait should be observed, followed by jumping on two feet and jumping up from a full squatting position. Tiny steps on tiptoes or heels, with the knees fully extended, may readily show lack of muscular symmetry or subtle strength deficits of the intrinsic muscles of the feet. Successfully hopping repeatedly on one foot without any functional angular or rotational problem usually indicates satisfactory balance and coordination, as well as good strength of the lower extremity kinetic chain. The athlete who hops with knees medial to the second toes, with hip internal rotation, apparent knee valgus, and excessive hindfoot pronation, is not prepared to return safely to unrestricted jumping, cutting, and pivoting sports. These findings often indicate weakness of the hip external rotators and abductors, subtalar joint invertors, and, often, evertors and foot intrinsics.

Although these findings are considered by many to be concerning for relationship to injury, a 3-year prospective study of 230 high school runners (125 of whom developed shin pain) found no correlation between navicular drop and either tibial stress fracture or medial tibial stress syndrome, but there was wide variation both in this variable and in passive ankle dorsiflexion across the groups [3]. However, they evaluated passive ankle dorsiflexion with the subtalar joint in neutral position rather than in maximal inversion, which in our hands has been more highly reproducible with better interobserver reliability. Among the male adolescent runners, tight hamstrings were possibly a risk factor for tibial stress fracture, but the number of affected runners was too small to draw a conclusion. In that prospective study, no other predictive parameters of tibial injury were found.

Palpation of the lower leg includes the subcutaneous portions of the tibia and fibula, as well as the muscles and tendons. Irregularities of the subcutaneous tissue and skin may be apparent. Palpation also includes checking for pitting edema and unusual skin texture (e.g., which may suggest hypothyroidism), as well as noting skin temperature.

Range of motion of the foot and ankle joints may be limited by congenital or acquired causes. A cavus foot is usually somewhat rigid even when the young athlete is otherwise hypermobile. Passive correction of the hindfoot to a neutral position may cause the 1st metatarsal to be depressed, indicating stiffness and malalignment of the forefoot relative to the hindfoot. Limited subtalar joint inversion (especially with repeated passive cycling of the subtalar joint into inversion and eversion) suggests tarsal coalition, which is more readily apparent if the athlete has just completed a short jog in the hall. Ligament injury may cause excessive proximal or distal tibiofibular mobility.

Muscle strength is tested functionally with the maneuvers above, but manual resistance can also be useful. Peroneal muscle strength may be difficult to see with the functional testing above but is easily tested by resisted manual muscle testing.

Calf muscle flexibility is checked by passively dorsiflexing the athlete's ankle with the knee extended and the hindfoot held in varus. In this position, the young athlete's ankle should typically dorsiflex 10° above neutral.

Acute Injuries

Acute Fracture

Acute fracture of the tibial or fibular shaft may occur from an athlete's collision with another athlete or with an object, or simply from a bending or rotational force, such as cutting on a planted foot or catching a ski edge. Initial treatment for an athlete is no different from any other child and involves splinting the limb without circumferential material that might constrict the limb as it swells. Because the entire tibial shaft and the distal third of the fibula are subcutaneous, open fractures in this setting are not unusual. A moist, sterile dressing, if available, should be applied to the open area. Transport to an appropriate facility for imaging and treatment should not be delayed.

Tibia fractures may lead to acute traumatic compartment syndrome, and more than one of the lower leg compartments may be involved. Often, the earliest sign of compartment syndrome is pain in the lower leg when the involved muscle is passively stretched. By the time the patient experiences actual change of sensation, circulation, or motor function, there may already be permanent loss of muscle. Measurement of compartment pressure is indicated if there is clinical suspicion of compartment syndrome or if the patient is unable both to adequately feel pain and communicate a response to pain.

Among adolescents, particularly those nearing tibial growth plate closure, rigid internal fixation has long been considered for athletes with tibial fractures. This allows them to begin rehabilitation very early in the healing process, so they may be able to return to full activity weeks earlier than they would if treated with cast immobilization. In recent years, there has been a trend toward the use of flexible nails, internal plate fixation, or external fixation devices for long bone fractures even in younger children. These procedures may speed the return to sport for a child, but the difference relative to treatment by cast immobilization is probably small. In general, when treating young athletes, we recommend using functional bracing rather than rigid cast immobilization as soon as is reasonable during fracture healing. The role of bone growth stimulating substances and devices has not yet been adequately studied in children and adolescents but will likely play a role in the future.

Acute Exertional Compartment Syndrome Without Fracture

Livingston and colleagues have reported seven cases of acute exertional compartment syndrome without fracture that required compartment release, over a 17-year period at a tertiary referral children's hospital [4]. All were male, six in running sports and one rollerblading, one each being 15, 16, and 22 years old, and the remaining four were 17 years old. All but the 15-year-old had both anterior and lateral compartments affected. When measured, compartment pressures were very high, up to 150 mmHg. Diagnosis was considered delayed in the 15- and 16-year-old, and both sustained subsequent foot drop, but the others had no sequelae and resumed full sports. Those authors did not yet present data on AECS without fracture that did *not* require compartment release, however. Because the signs and symptoms may mimic typical post-exertion muscle soreness, diagnosis can be difficult. When the diagnosis is suspected, frequent reevaluation is needed, and the athlete may require hospital admission for this.

Muscle Strain/Peroneal Tendon Subluxation

Triceps Surae

Calf muscle strains occur rarely among children but somewhat more often among adolescent athletes. The athlete with an acute strain of the triceps surae often reports some preexisting, dull pain related to sport activity. A sudden contraction, usually an eccentric contraction, may result in tearing of the muscle. An area of swelling, often described by the patient as a "knot," may be accompanied by ecchymosis. The discoloration of the skin often doesn't appear for several days, however, until blood breakdown products dissect to the surface. Unilateral strain must be differentiated from deep venous thrombosis by Homan's test, Doppler ultrasound, and/or MRI, as passive stretch of the calf muscles may cause pain with either entity.

Treatment is generally rest until the pain and swelling have resolved. Use of a heel lift may decrease symptoms, but often, a removable boot is needed to allow easy and relatively painless ambulation. If the strain is severe, crutch ambulation may be required, but early weight bearing (partial weight bearing as tolerated) is encouraged to decrease disuse atrophy of the entire lower extremity.

Anterior Compartment Muscle Strain

A true plantarflexion injury can cause strain of the tibialis anterior with or without the long toe extensors. Pain, tenderness, and swelling often also occur at the anterior ankle retinaculum. Depending on injury severity, a boot may be required for comfortable ambulation. At times, a brace that includes a firm strap across the anterior ankle allows increased comfort while the anterior retinaculum heals.

Peroneals (with Ankle Sprain)

In an inversion injury such as a lateral ankle sprain, the peroneal muscles may contract in an effort to stop the inversion. This eccentric contraction can lead to peroneal muscle strain or peroneal tendon subluxation. A single injury may result in all three: significant anterolateral ankle sprain, anterior subluxation of the peroneal tendons, and peroneal muscle strain. Recovery in this situation is significantly prolonged compared with a simple, mild ankle sprain. Early recognition of this more complex injury can help the athlete prepare emotionally for the typically longer recovery time, as well as allow better planning for future training opportunities and competitive events.

In most cases, treatment is similar to that of the more typical isolated ankle sprain: initial cold therapy, elevation, and functional immobilization, with early range of motion and strengthening as tolerated. However, when there is significant peroneal injury, the athlete is more likely to require the use of an air stirrup brace that reaches proximally almost to the knee or even a removable walking boot. We prefer the removable boot to a rigid cast so that the athlete and those providing the medical care can monitor the progress more easily and more frequently and allow the most rapid progression through the rehabilitation process that is safely possible.

In contrast, the younger child (aged 6–9) who sustains an inversion injury most often has clinical findings consistent with avulsion of the fibular attachment of the anterior talofibular ligament (ATFL), with focal bony tenderness and swelling at the anterior aspect of the distal fibular epiphysis. A Toronto study (Boutis) was performed, using MRI to study the ankle injuries in their ER. Clinically, if the examiner palpates carefully and thoroughly, the distal fibular physis may or may not additionally seem involved, and the distal fibular metaphysis may also have tenderness and swelling, but the ATFL substance seems normal except immediately adjacent to the fibula. If these very young athletes have subsequent plain x-rays, an unfused ossicle consistent with previous avulsion injury may be seen (Fig. 13.2). Because these are cartilage fractures, the author recommends walking cast immobilization for 3–4 weeks. When a child reports a history of 2–3 months treatment with a boot, with persistent pain and focal findings that suggest this injury, we suggest cast immobilization for 2–4 weeks. Both treatments are followed by physical therapy to minimize recurrent inversion injury. Following this course, recurrent injury has been extremely rare.

Fig. 13.2 This 6-year-old dancer rolled her ankle on a trampoline. Examination found focal tenderness and greatest palpable swelling at the site of attachment of the ATFL to the distal fibula. About 9 months earlier she had initially injured this area, and her parents said she had no treatment but had not run symmetrically since that injury. The child herself felt less secure on that foot in dance. X-rays at the time of the second injury show a previous avulsion fracture of the distal fibula that was not appreciated at the time of the initial injury and presumably ossified subsequently. She reinjured the ankle clinically through the chondral/fibrous union, with greatest soft tissue swelling persisting at the level of the distal half of the epiphysis after cast immobilization for 1 month; she had minimal focal tenderness to palpation, and following physical therapy, she resumed full dance activity without subsequent difficulty

Achilles Tendon Rupture

Achilles tendon rupture, which is relatively common among adult athletes, is virtually unheard of among healthy children [5], although Achilles strain without rupture can occur from sudden loading. It is rare among adolescents but does occur, particularly in older adolescence. The author is not aware of any studies specifically comparing treatment options for Achilles tendon ruptures in children or adolescents.

Contusions

Bone Bruise

Shins are frequent sites of bumps and bruises. Because the tibia has only a thin layer of subcutaneous fat over it, blunt trauma may cause a significant bone contusion with subperiosteal bleeding. The resulting fusiform mass may appear frightening to the athlete and parents. The erythema and induration may even suggest subacute osteomyelitis, which typically occurs in a metaphyseal region a few days after blunt trauma that alters the local intraosseous circulation

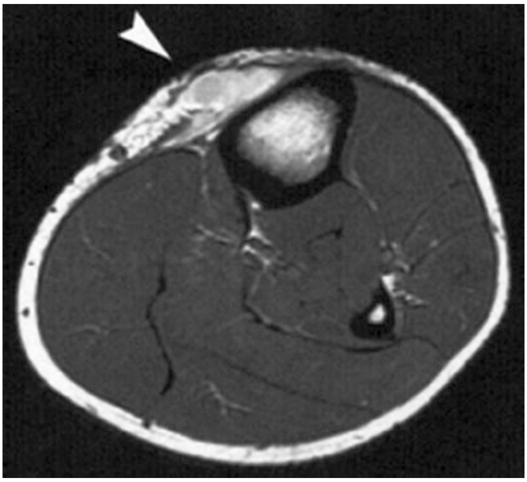

Fig. 13.3 A 15-year-old baseball player slid into home base, striking his proximal medial shin against the catcher's shin guard. The game was almost over, and 4 days later at the next scheduled game, he was able to play a full game as catcher himself. However, by the end of the game, he had significant pain, and it was so much worse the following day that he stopped all training. Ten days after the injury, he had exquisite tenderness of the entire tibia, with moderate induration of the deep soft tissues over the medial border of the tibia, surrounding a long, healing superficial abrasion. He had moderately tender enlarged lymph nodes in the left inguinal region, larger than on the right. He was afebrile. Laboratory studies and plain x-rays were unremarkable. An MRI scan showed a subcutaneous fluid collection consistent with resolving hematoma, with additional subcutaneous edema, most likely from a significant shearing injury similar to a ring avulsion or bicycle spoke injury

(Fig. 13.3). The subcutaneous or subperiosteal mass may persist for months before finally remodeling away. There may be associated focal fat necrosis that causes the appearance of a dent in the contour of the lower leg. This change in contour usually persists.

Saphenous Vein Hematoma/Occlusion

Blunt trauma to the saphenous vein, especially in its distal course over the distal third of the tibia, may also result in an area of tenderness and swelling, but it may be slightly mobile relative to the tibia, unlike the subperiosteal hematoma. The saphenous vein usually recanalizes at least partially within 1–2 weeks, but swelling and tenderness may persist many weeks longer.

Chronic Injuries

Many lower leg injuries result from training errors. A sudden increase in training time or intensity, adding hill running or intervals, and changing footgear or training surface are some of the most common etiologies for non-acute injuries to the lower legs. Changes in technique, such as increasing the running stride length or the approach to the gymnastics vault springboard, also change the forces applied to the lower leg in sport.

Athletes and coaches alike may not realize that return to activity after an injury or illness requires gradual, progressive reconditioning. Without a progressive approach in returning to a sport that includes running or jumping, lower leg injury is more likely to occur. Complete rehabilitation of any injury is important before safe return to unrestricted activity. This includes restoration of appropriate muscle symmetry, flexibility, quickness, and endurance.

More unusual etiologies of lower leg pain, such as neoplasm or infection, must be ruled out, particularly if symptoms are unilateral (Fig. 13.4). Metabolic bone disease may weaken the long bone structure, leading to stress fracture. Inadequate nutrition, especially inadequate energy intake, may disrupt the normal, daily bone healing that allows the bone to adapt to training stress rather than to fracture.

Chronic Exertional Compartment Syndrome

Chronic exertional compartment syndrome causes aching or cramping pain, or a sensation of severe heaviness, in one or more lower leg compartments. Between episodes, the athlete feels normal or has only mild discomfort. The anterior compartment is often involved. Some young athletes experience compartment syndrome symptoms in both the anterior and lateral compartments,

Fig. 13.4 The healing stress fracture through the large fibular nonossifying fibroma was symptomatic. The nonossifying fibroma in the tibia was not

but lateral compartment involvement among children and adolescents seems to occur less often than anterior compartment syndrome [6].

Symptoms are more often bilateral than unilateral, usually involving the same compartment in each leg. Pain begins soon after onset of the exacerbating activity. Onset of symptoms may not occur until a certain level of activity intensity is reached, such as running at a certain speed. A change in stride length may alter the running biomechanics sufficiently to increase or, rarely, to decrease symptoms. Athletes with recurrent anterior compartment syndrome complain of pain in the front of the shin, described as aching, burning, heavy, or tense. They may notice foot slapping as the muscle function decreases. A few athletes may appreciate numbness in the dorsal web space between the first and second toes, the sensory distribution of the deep peroneal nerve. Symptoms of superficial and/or deep posterior exertional compartment syndrome may initially be posterior or posteromedial leg pain. However, the young athlete may report numbness spreading across the plantar surface of the foot as the first symptom.

It is sometimes possible to reproduce anterior compartment syndrome symptoms in the office with repeated, resisted ankle dorsiflexion. While the examiner applies manual resistance, the athlete's ability to dorsiflex decreases within a minute or so, as the pain increases. The affected muscle compartment becomes taut and tender. First dorsal web space sensation may decrease. This can be a simple screening test for exertional compartment syndrome.

If definitive diagnosis is required, particularly if surgical compartment release is under consideration, formal compartmental pressure measurements should be performed. Insertion of a catheter into the compartment(s) allows repeated pressure measurements as the athlete performs the exacerbating activity and then rests. Multiple compartment pressures may be elevated although the athlete only appreciates pain in one compartment. Pressure measurements may be repeated 15 min later to monitor whether the pressure returns to normal range. Currently the Pedowitz criteria are used most frequently [7]. Surgeons who studied 23 adolescents suggested using the following intracompartmental pressure (ICP) criteria for consideration of fasciotomy: baseline ICP (at rest) >10 mmHg, >20 mmHg 1 min after stopping exercise, >20 mmHg 5 min later, and >15 min to achieve ICP normalization [8].

Fig. 13.5 The muscular build of a young woman afflicted with bilateral chronic exertional anterior compartment syndrome

Although several theories have been published, the etiology of chronic exertional compartment syndrome is not yet clear. Physicians who care for many young athletes with this condition have noted that it rarely occurs among athletes with gracile, slender builds. More commonly, these patients are mesomorphic, with well-developed, sturdy, and relatively bulky muscles (Fig. 13.5). Female adolescent athletes seem much more likely to develop exertional compartment syndrome than their male peers, a recent study of pediatric patients finding 88% females among those needing surgery [6]. Although typically a problem of runners and jumpers, lower leg exertional compartment syndrome may even occur in swimmers.

An interesting observation is that some very muscular girls, especially those playing running sports such as soccer, field hockey, and lacrosse, seem more prone than other groups to suffer from both anterior exertional compartment syndrome and midshaft anterior tibial stress fracture. Although more rare, posterior calf cramping and pain, even unrelated in time to sports activity, affect girls with this habitus more than others. All of these problems in this muscular group seem more difficult to treat successfully than other athletes. It is also interesting that exertional compartment syndrome is almost unheard of among prepubertal children. This author has evaluated only one, and her 10-year-old identical twin, who did the same competitive sports and appeared equally mesomorphic, had no lower leg problem.

Early investigators of this problem surmised the pain was related to muscle ischemia, as the enlarging muscle pushed against its enveloping fascia to the extent that venous drainage, and then arterial inflow, were diminished. However, several studies using radionuclide bone scans or magnetic resonance imaging have not found ischemia, although one study did note improved perfusion of the compartment after compartment release in adults tested with thallium SPECT imaging [9]. An ultrasound study of anterior tibial muscle "size" of adult chronic exertional compartment syndrome patients found that their muscle size increased 8% with an isometric exercise protocol, no different from the control group [10]. The patients developed pain but had no greater muscle volume increase, suggesting that the theory of excessively tight fascia surrounding the compartment may be flawed. The hypothesis that the pain is caused by ischemia has also been challenged by scintigraphic study [11] and magnetic resonance imaging [12] that show no perfusion difference. However, the magnetic resonance imaging (MRI) study did show that four of the five patients with both typical symptoms and elevated pressures took longer than those in the other groups for the blood flow to return to normal after exercise ceased [12].

Few studies have evaluated surgical compartment release among youth athletes. Adult surgical results have typically been good or excellent in 80–85% of patients with anterior CECS. A large study of 155 pediatric patients who had surgery over a 10-year period, almost all adolescents, found that 85% presented with bilateral symptoms, and only 48% had just the anterior or lateral compartment released [6]. Of these patients, 80% returned to sport, but 19% of legs for which outcome measures were available had repeat surgery for recurrent CECS at median 1.3 years following the initial release. For those who had only anterior or lateral compartment release, the odds of requiring reoperation were 3.4 times those of patients who initially had four-compartment release. An unexpected finding was that patients with lower compartment pressures had a higher incidence of reoperation. The authors found no relationship between symptom duration and reoperation.

In 2013 a preliminary retrospective case series of 16 adult runners with CECS (11 recreational, 5 military) treated with botulinum toxin injection found reduction of intramuscular pressure and relief of exertional pain in 15 of the runners at the final follow-up visit 3–9 months after injection. Strength decreased to 3.5/5.0 in 11 of the patients but was normal for all muscles at their last follow-up. Four years later, no further English-language long-term studies have been published, but interest in this treatment remains [13].

An unusual cause of lower leg pain that mimics exertional compartment syndrome is an accessory soleus muscle [14]. A painful muscular bulge distal to the normal soleus contour may be visible and palpable after activity such as running. Magnetic resonance imaging shows normal muscle. If the athlete cannot participate in activities because of the pain, surgical resection may be considered and typically leads to resolution of symptoms [14].

Plain x-rays are important to rule out other causes of lower leg pain. Routine MRI does not show findings specific for chronic compartment syndrome.

Non-operative treatment is generally unsuccessful unless the athlete decreases activity or changes sport. Stretching the antagonist muscle groups has been suggested but has not generally proved helpful. Altering footwear, using customized shoe inserts, or changing technique may provide relief. Surgical intervention, releasing all affected compartments, has approximately 80–85% success rate among adolescents, similar to the rate range typically seen in studies of adults [6].

Stress Fracture/Stress Reaction

Growing children and adolescents undergo remarkable changes in the tibia and fibula, especially if they participate in sports at an intense level. Each long bone must lengthen, widen, and nearly constantly remodel its shape. The growing bone adapts to the forces applied to it, even thickening with stress as its geometry alters. Bone generally adapts effectively to these loads. However, if too large a force is applied too frequently, new bone formation and remodeling cannot match the level of recurrent stress and microscopic injury, and stress reaction or stress fracture occurs. Rather than set a somewhat arbitrary definition of stress reaction or fracture along the injury continuum, studies increasingly use the term “bone stress injury” to describe focal pain related to recurrent bone loading.

A study of 11–17-year-old girls, part of a longitudinal health study carried out by written questionnaire, found that girls who participated in moderate to vigorous activity 16 or more hours per week were almost twice as likely to sustain stress fractures as girls who did less than 4 h per week of moderate to vigorous activity [15]. Of the 5461 girls, approximately 3% reported having sustained a stress fracture. Each hour per week of high impact activity increased the chances of stress fracture. These findings must be interpreted with caution, however. The girls’ mothers were questioned only once about whether the daughter had ever had a stress fracture, and stress fracture was not further defined. In addition to the validity issues related to a study based on recall, over 2% of the 11- and 12-year-old girls were reported as having had stress fractures. This finding suggests either a methodological flaw or that the mothers considered calcaneal apophysitis or other similar common injuries to be stress fractures. To this author’s knowledge, no other study has found such a high incidence of stress fractures among a similar group of preteen girls.

The young athlete may first experience soft tissue symptoms related to a new or increased activity. If appropriate action to decrease the loading is not taken, the soft tissues may fail, followed by bony failure, resulting in a stress fracture. For example, among figure skaters in a longitudinal injury study, we found several instances of posterior tibial tendonitis followed a week or two later by distal medial tibial stress reaction or stress fracture and others of peroneal tenderness soon followed by fibular fracture [16]. As a result of this finding, we began treating these skaters' tendon injuries earlier and more aggressively with rest and protection before development of a stress fracture, followed by altering the biomechanics of the boot/leg interface and their skating technique as appropriate.

The typical history of a young athlete with a lower leg bone stress injury is increasing, focal pain made worse with activity. In the early stages (stress reaction), the pain resolves within minutes after stopping the aggravating activity. In later stages, when a stress fracture is apparent by imaging techniques, aching or throbbing pain may still be present even the morning after the aggravating activity. However, lower leg stress fractures may be asymptomatic, found serendipitously (usually healed) on imaging studies done for symptoms at another site. There is often a logical reason for the stress fracture, such as significant training error as discussed earlier. Nutritional and menstrual history may include significant abnormalities.

Physical findings include focal tenderness and palpable deep swelling or callus. The location of the injury may be related to the sport equipment. For ballet dancers, fibular stress fractures occur at the level of transversely tied ribbons, and for skaters, this level is near the boot top. Although equipment has been implicated in these fibular stress fractures, they also tend to occur at this level in other running or jumping athletes who wear low-top shoes or are barefoot, so the cause remains unclear.

The best imaging modality can vary based on length of symptoms and potential treatment plans. For example, on plain x-ray, a stress fracture can be diagnosed if an actual fracture line is apparent or if periosteal new bone has formed (Figs. 13.6 and 13.7). These x-ray findings rarely appear sooner than 10–14 days after onset of symptoms. Radionuclide bone scan or MRI may show evidence of a stress fracture only a few days after the onset of symptoms. There is often inconsistency among radiologists in the diagnosis of stress fracture. Using bone scans, Jones and his colleagues considered four grades of stress injury, based on what percentage of the cross-sectional area of the bone showed increased uptake [17]. An MRI classification of stress fractures is also available [18]. One useful criterion for enhancing consistency is to define stress reaction as incomplete stress fracture, with fewer disrupted trabeculae across only a portion of the bone diameter. In contrast, a stress fracture either has a fracture line clearly visible on plain x-ray, MRI, or computed tomography (CT), or a bone scan shows significantly increased uptake through most or all of the cross section of a long bone. Recent information suggests that if plain x-rays are negative, the most sensitive and accurate study to diagnose a tibial stress fracture is an MRI [19, 20]. Technetium 99 scans for this diagnosis have been generally replaced by MRI scanning, due to concerns about radiation exposure from technetium 99 and the high sensitivity of MRI.

Unfortunately, none of these imaging modalities related to clinical severity or length of time to healing in a thorough study of (mainly) young adults over 18 years of age [19]. The authors completed a comparison of x-ray, nuclear bone scan, MRI, and CT for each individual with tibial stress injury and discussed the use of the various grading schemes. Surprisingly, they found that MRI signs of severity were *more* likely among those with *less* pain with daily activities. MRI did show a trend to correlation expected with time to healing, the greater severity relating to longer healing time, but not statistical significance. Further study of MRI, perhaps utilizing sequences developed in the future, may increase the ability of MRI to predict healing parameters. At this time the chapter author uses primarily plain x-rays to rule out other pathology and to visualize current or previous bone adaptation and stress

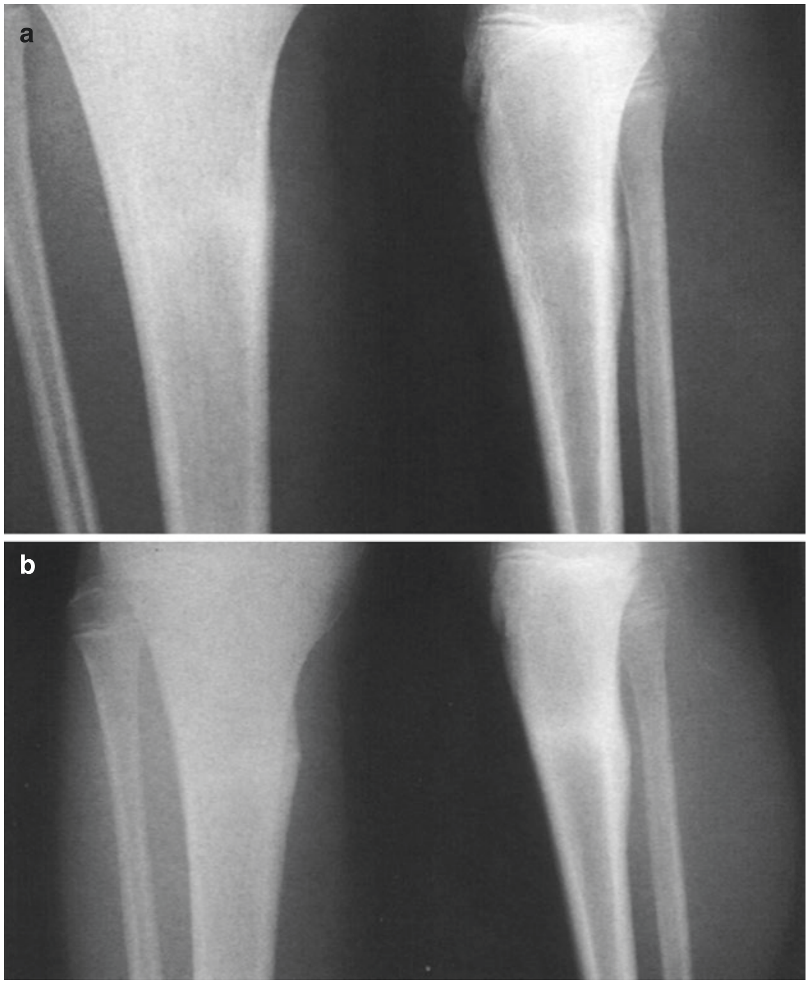

Fig. 13.6 (**a**) This 14-year-old soccer player increased his training time, practicing corner kicks repeatedly, kicking the ball with the medial foot. One month later, he had persistent pain in the upper medial shin. Anteroposterior and lateral plain films show periosteal new bone formation just distal to the metaphyseal–diaphyseal junction of the tibia. (**b**) One month later, he was asymptomatic, with mature healing callus on AP and lateral x-rays

injury. When needed for early diagnosis, or when positive MRI findings will alter the young athlete's treatment, MRI can play a useful role.

Non-operative treatment of lower leg stress fracture is usually successful. The athlete's first goal should be to become pain-free as rapidly as possible. If the athlete has reported the injury after only a few days of pain, the problem is likely stress reaction or early bone stress injury, and a few days of rest from the specific aggravating activities may be all that is needed to regain pain-free status. More prolonged symptoms typically require protected mobilization or full immobilization. Removable devices are used if possible to allow maintenance of range of motion and easy, frequent examination by the athlete and medical personnel, so that progressive rehabilitation may begin as early as possible. For most tibial stress fractures, a well-fitted removable walking boot is effective. For fibular stress fractures at or distal to the midshaft level (as almost all are), a long air stirrup brace that extends proximally, almost to the knee, is effective in treating the fracture while allowing normal ankle motion. This approach decreases muscle atrophy compared with a completely immobilizing device.

The second treatment phase includes strengthening and flexibility exercises, while ensuring good sports technique and appropriate equipment. The aim is to remove any etiologic component that was determined, to prevent recurrence if possible. The athlete must remain pain-free during both the therapeutic exercise program and the progressive resumption of sport activity.

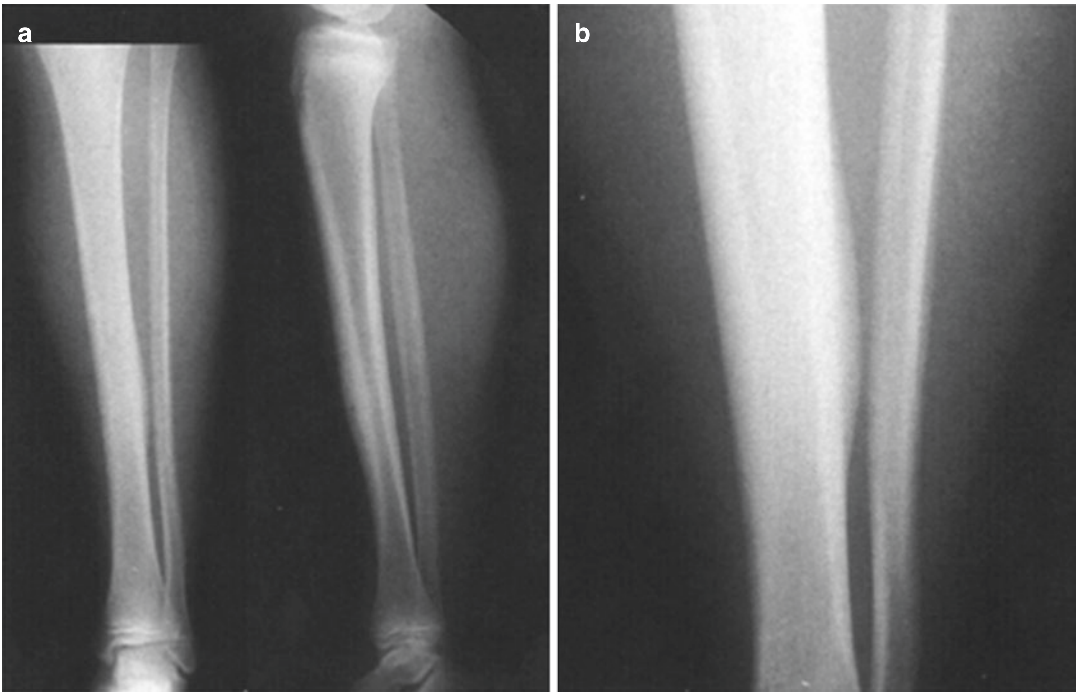

Fig. 13.7 (**a**) AP and lateral x-rays of a healed tibial diaphyseal stress fracture, showing markedly thickened cortex. (**b**) Magnified view of the AP x-ray

Some young athletes follow a frustrating course of very slow healing, with persistent pain and tenderness after more than 6 weeks, including periods of non-weight bearing with crutches [21]. Nutritional status should be evaluated by history and possibly laboratory studies for athletes with bone stress injury. More comprehensive evaluation including referral to a nutritionist is needed for those who are healing very slowly, who may have relative energy-deficit disorder. Smoking status of both the athlete and contacts should be determined and appropriate counseling given if smoke exposure is identified. Vitamin D supplementation remains somewhat controversial but should be considered.

The use of adjunct bone stimulation, either electrical stimulation or low-dose pulsed ultrasound, may occasionally be considered when even a slight decrease in healing time is critical to the athlete. Given the variability of lower leg stress fractures, carefully controlled studies of bone stimulator efficacy in treating them are unlikely in the near future. Because adolescent athletes' stress fractures generally heal rapidly, and little is known about the effectiveness of bone stimulation among growing children, the expense of stimulators is generally not warranted.

One exception is the established "black line" stress fracture of the anterior tibia. Even prolonged cast immobilization may not lead to complete healing. Tibial reaming with internal fixation has been shown to be effective, typically allowing the athlete to return to running and jumping in 2 months or less [22]. Before embarking on surgical treatment, electrical stimulation or pulsed ultrasound treatment may be considered.

Posteromedial Tibial Stress Syndrome

Activity-related pain and tenderness along much of the posteromedial border of the tibia is known by several names, including "shin splints" and periostitis. Given the anatomic location of the physical findings and the diffusely increased uptake seen on radionuclide bone scan, posteromedial tibial stress syndrome is a reasonable, descriptive name for this entity. In addition to the findings along the bone, there may be associated tenderness and swelling of the posterior tibial tendon and possibly even a painful accessory navicular. The differential diagnosis includes the much less common deep posterior compartment syndrome. Both may coexist.

Development of this syndrome most often seems related to excessive hindfoot pronation. Decreasing the pronation by improving calf flexibility, strengthening the foot and ankle muscles, and changing shoes or their insole configuration (with or without orthotics) often markedly improve the posteromedial symptoms.

Plain x-ray is recommended to check for stress fracture, neoplasm, and infection. MRI may further rule out more concerning diagnoses. Radionuclide scans, often done in the past, typically showed moderately increased uptake localized to the posteromedial border of a long portion of the distal and often even the central tibia (Fig. 13.8).

The first step of treatment is careful exploration of the history of the injury to attempt to learn what changed (training error, footwear change, technique change, etc.). These factors are addressed before recommending additional changes. Further treatment recommendations include correcting abnormal gait mechanics, if present. Inadequate calf muscle flexibility causing excessive hindfoot valgus in gait is often related to rapid growth in adolescence. It can usually be reversed rapidly with calf stretching for a few minutes daily. Athletes who perform barefoot may need to strengthen the intrinsic muscles of their feet to stop the arch collapse of a flexible flat foot. Athletes who perform in shoes often return to activity more quickly simply by choosing more appropriate athletic shoes for their foot type or adding over-the-counter or custom arch supports. The entire lower extremity kinetic chain should be addressed, correcting poor mechanics of coupled motions, including internal hip rotation, apparent knee valgus, and subtalar joint eversion.

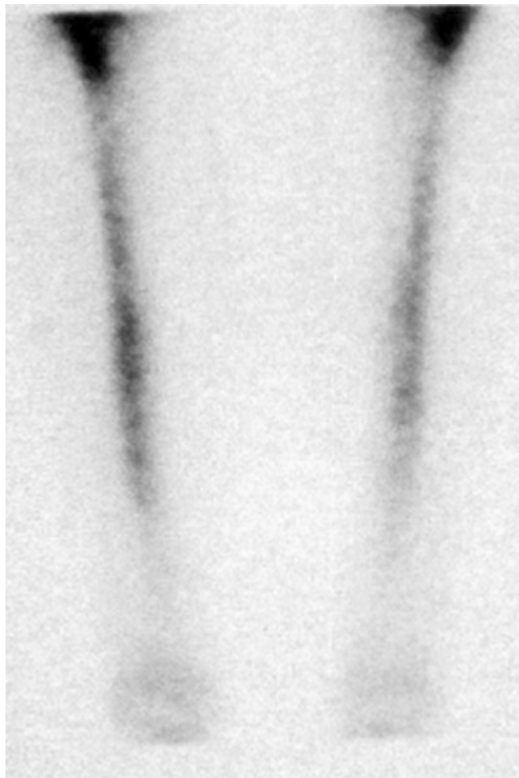

Fig. 13.8 Diffusely increased uptake of Tc99 along nearly the entire medial border of the tibia is consistent with posteromedial tibial stress syndrome

Tendon Injury

There are not histologic studies of children and young adolescents that indicate whether tendon injuries are more typically tendinitis or tendinosis. The physical findings of tendon tenderness, bogginess, and peritendinous swelling often respond to treatment within days, suggesting the pathology is inflammation rather than significant structural change. The Achilles is involved much more frequently than the other lower leg tendons in this age group. Symptoms are often bilateral, so unilateral symptoms may prompt a more complete diagnostic work-up. Plain x-rays of the tibia/fibula, ankle, and/or foot as indicated by symptoms and physical findings are appropriate to rule out underlying bone abnormality. Non-traumatic tendon injuries of children and adolescents are generally short-lived, and further imaging such as ultrasound or MRI is rarely indicated.

Achilles

Among children and adolescents, Achilles tendon symptoms are often associated with either excessively tight or hypermobile calf muscles and heel cords. Passive ankle dorsiflexion with the knee extended and the hindfoot held in varus is usually less than 10° in these cases. Paradoxically, some athletes, particularly gymnasts and dancers, have excessive ankle dorsiflexion (greater than 20°). The athlete's foot configuration is often cavus, suggesting that poor shock absorption plays a role. Symptoms are related to sudden impact or force such as jumping and landing. Careful observation of the young jumping athlete with Achilles pain may show excessively abrupt and explosive plantarflexion isolated to the ankle, rather than jumping by working through the feet, then the ankles, then the knees, and on up through the kinetic chain. Similarly, landings may be poorly cushioned related to poor biomechanics.

Diagnostic findings include focal tenderness and swelling. The tenderness often tracks along the broad musculotendinous junction, well into the calf.

Initial treatment is a heel lift to decrease tension on the tendon. Girls often find it easy to wear 1-inch heels, even in the house. Some young athletes feel relief with a counterforce brace or strap. Patients with severe or prolonged symptoms may need a walking boot, wearing it full time initially and weaning out of it as symptoms improve. Unless the injury is of short duration, caused by obvious training error or direct tendon compression by equipment, more comprehensive treatment is usually needed, including correcting flexibility deficits, jumping and landing biomechanics, and foot intrinsic muscle strength.

Peroneal

Non-acute peroneal tendon injury may be related to a previous acute injury such as peroneal strain or ankle sprain that was not fully rehabilitated. It may result from direct pressure from sport equipment. Less frequently, a young athlete with a cavus foot configuration and relatively inflexible calf muscles may chronically walk, run, and jump with hindfoot varus and develop recurrent microtraumatic injury of the peroneal tendons.

The diagnosis of peroneal tendon injury is made by physical findings of focal tenderness and swelling and often pain with resisted eversion of the foot. The treatment includes removing any obvious causes of the injury. Therapeutic exercises include evertor strengthening (after peroneal subluxation is ruled out or has healed) and calf stretching. Occasionally, bracing is useful to decrease subtalar joint inversion. It is important to correct any faulty landing biomechanics that persist after strength is normalized.

Flexor Hallucis Longus

Flexor hallucis longus tendon injury of adolescents occurs mainly among ballet dancers and Irish dancers. Rarely, athletes in running sports may develop the problem. Injury may be related to an atypically long muscle belly that is pulled into the flexor retinaculum. The diagnosis is made by finding focal pain and swelling along the course of the musculotendinous junction and the tendon. There is typically pain with resisted active great toe plantarflexion, tested with the ankle both in neutral and in full plantarflexion.

Initial treatment, particularly for the young dancer, consists of correcting any faulty technique and strengthening the foot's intrinsic muscles. An in-shoe rigid or semirigid splint can decrease dorsiflexion and provide some relief, particularly for runners. Persistent symptoms in adolescents generally respond to immobilization in a walking boot. For very persistent pain and swelling, steroid injection or surgical release of the tendon sheath may be recommended [23, 24].

Ankle and Toe Dorsiflexors at the Distal Tibia

Painful swelling of the ankle and toe dorsiflexor tendons is usually caused by pressure from sports equipment, such as skating or snowboard boots. Symptoms may be initiated by a contusion or a plantarflexion injury. Chronic tenosynovitis in this region may cause a surprising amount of swelling with fluctuance that must be differentiated from an abscess (Fig. 13.9). Recommended treatment is to operate on the equipment, not the athlete where possible.

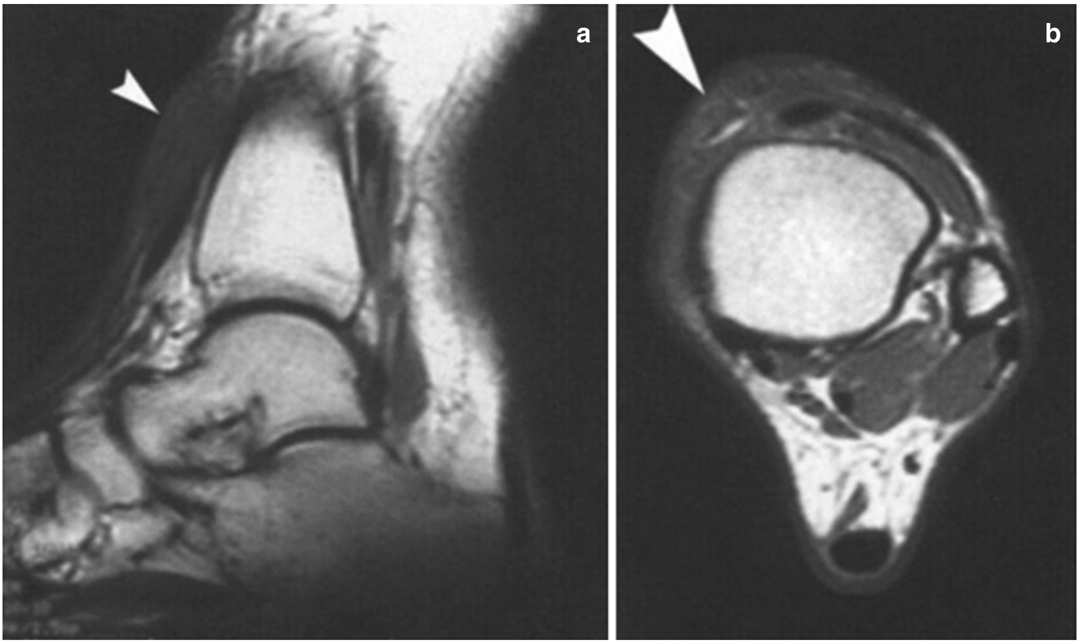

Fig. 13.9 (**a**) A young figure skater developed painful swelling of the anterior tibial tendon sheathe, infected with staphylococcus. (**b**) The axial MRI view shows abnormal signal of the tendon itself, surrounded by excessive fluid and adjacent synovial and subcutaneous edema

Other Causes of Lower Leg Pain

Osteoid Osteoma

Osteoid osteomas are benign tumors that have a predilection for the midshaft tibia region. The hallmark thickening of the surrounding cortex can mimic normal stress adaptation or a stress fracture. Possible tip-offs of osteoid osteoma include night pain that may awaken the athlete and pain relief by nonsteroidal anti-inflammatory drugs or aspirin.

Ewing's Sarcoma

The lower leg is not an unusual location for this malignant neoplasm. The history may mimic that of a typical stress fracture. Tip-offs include unilateral symptoms, aching that is incompletely relieved with rest, and circumferential swelling that seems to involve bone and deep soft tissue on palpation. Plain x-rays early in the course of the disease may show only slight periosteal new bone formation that may also mimic stress fracture. The onionskin pattern of periosteal new bone is a classic x-ray finding of Ewing's sarcoma of a long bone and should not be confused with a stress fracture.

Brodie's Abscess

The history of lower leg pain can be similar for slowly developing stress fracture, malignant or benign neoplasm, and the subacute bone infection known as Brodie's abscess. Thickened subcutaneous tissue that appears somewhat discolored, with brawny edema, may suggest Brodie's abscess.

Osteogenesis Imperfecta or Other Metabolic Bone Disease

Bilateral, multilevel, or recurrent stress fractures should raise the suspicion of osteogenesis imperfecta, malnutrition (as in the female athlete triad), or other metabolic bone disease. Possible tip-offs of osteogenesis imperfecta include positive family history, blue sclera, and a parent with poor dentition or a hearing aid.

Reflex Neurovascular Dystrophy

Even prepubertal children may present with lower leg pain that is out of proportion to the history and the objective physical findings. They report pain that became much more severe days to weeks after a relatively minor injury, such as a contusion or twisted ankle. Even the touch of socks or bedclothes may cause severe pain and dysesthesia. The gait ranges from antalgic to bizarre, not typical of any of the usual traumatic injuries seen in this age group.

Early in the course of this disorder, the skin of the entire lower leg and foot can appear reddish-purple, even changing color during the course of the examination. Later, significant muscle atrophy may be accompanied by color and temperature change and clammy skin. As soon as atypical skin color is noted, especially if tenderness is multifocal and does not seem to "fit" with likely mechanisms of injury, regular therapeutic exercise monitored closely by a knowledgeable physical therapist should be initiated, and the child should be checked more frequently than for the usual injury. Temporary protection with a removable walking boot and crutches may be necessary but should be minimized as much as possible. Recognizing that pain is out of proportion to the physical findings in this disorder, it's preferable to rely on objective findings of swelling and x-ray findings.

The author's approach is to teach the patient desensitization activities as soon as RND or amplified musculoskeletal pain syndrome (AMPS) is even suspected. We have not found success with "medicalizing" the care. We do not recommend use of any pain medication initially, and all desensitization is performed by the patient alone, not by a parent or physical therapist. We use a three-stage self-massage technique for each session. First the young athlete rapidly and lightly rubs the painful area just superficially, similar in technique to transverse friction massage, until the area feels warmed. The second stage is for the athlete to apply moderate pressure to the area, just enough to move the skin, usually in a circular manner. The third stage is to firmly massage the area. The athlete moves through the stages sequentially, doing each for roughly 1 min before moving to the next, and then performs range of motion and strengthening exercises, emphasizing functional activities such a standing and walking on tiptoes and heels. The sequence is completed several times daily. Immobilization should be avoided if there is no clear evidence of fracture that requires it. If symptoms do not respond quickly, a pain management team, including psychological counseling, may be necessary. However, using the above technique, the author has found formal pain management to be needed very rarely. If the patient presents with long-established RND/AMPS, with severe discoloration, dysesthesias, and atrophy, formal pain management programs are often needed, however.

Management of Difficult Lower Leg Injuries

A multidisciplinary team approach is preferred when the diagnosis is difficult or unclear or when psychosocial issues seem predominant or significant. The team may consist of the young athlete's primary physician, orthopedist and/or physiatrist, rheumatologist, physical therapist, certified athletic trainer, pain management specialist, psychologist, psychiatrist, nurse, and nutritionist, depending on the patient's needs. All should interact with both the athlete and the family. The coach is a critical component. In general, even if the athlete and family have given the health-care team written permission to speak directly with the coach, it's good to have a parent and the young athlete also involved in those discussions. The management of lower leg injuries is presented in Table 13.2, and the physical therapy prescription for lower leg injury is presented in Table 13.3.

Table 13.2 Management of lower leg injuries

1. Determine why the injury happened. If symptoms are only unilateral, determine why
2. Eliminate or change causative factors
3. Decrease inflammation and pain; become pain-free as soon as possible, and then gradually increase activity while remaining pain-free
4. Immobilize, use crutches as needed; rapidly decrease immobilization as healing allows
5. Begin some sports participation with specific restrictions
6. Rehabilitate completely

Table 13.3 Physical therapy prescription for lower leg injury

A. Typically includes
1. Active rest: do all parts of the sport and conditioning that don't aggravate the injury
2. Correct lower extremity flexibility deficits
3. Restore strength to normal
4. Restore/improve proprioception and balance
5. Modalities (cold, heat only), taping, bracing, orthoses if indicated
6. Return the athlete to usual activities gradually and progressively, as appropriate
B. Pressure disorders (tendon injury, stress reaction of bone)
1. Pad or relieve tender area
2. Alter equipment
3. Ice massage, partial rest
C. Adjunct non-operative treatments
1. Ice or heat for symptomatic treatment if the athlete feels better with either
2. Compressive bandage for swelling
3. Nonsteroidal anti-inflammatory drugs rarely
4. Brace as discussed in the text
5. Corticosteroid injection rarely indicated in this population
6. Orthotic shoe inserts for angular or severe rotational malalignment or abnormal foot biomechanics
7. Improve footwear shock absorption
8. Operate on the problematic equipment, not the athlete

Prevention

Preventing lower leg injuries related to recurrent microtrauma involves the same principles as treating those injuries. Injury prevention principles include careful preparation of the young athlete to develop sufficient strength, flexibility, and endurance to meet the requirements of the sport. The athlete should gradually and progressively advance the time spent doing repetitive sport maneuvers, learning new skills at a safe rate that allows not only sufficient motor learning but also tissue adaptation.

Return to Play Guidelines

Young athletes would like a crystal ball prognosis, with specific healing times for each injury. Although such predictions can be rather accurate with most typical, acute fractures, sports injuries resulting from microtrauma are much more varied. The athletes usually understand functional goals, however.

For most injuries, the first goal is to become pain-free. With almost all lower leg injuries, as soon as the athlete is pain-free, progressively increasing rehabilitation activity may begin.

After any immobilizing devices have been discontinued, the athlete may require a protective brace, pad, or other device. The author allows participation in conditioning or sports activity as long as the athlete either remains pain-free (depending on the diagnosis and the recovery phase) or is in the "happy face" zone of the Wong–Baker FACES scale (0–3/10). We have used this method for more than 10 years and during that time have not recognized a single injury that we think should have been preventable following injuries that we were treating. Using our previous instructions before we adopted the FACES scale for this purpose, recurrent or new/related injuries were rare but did occur.

Clinical Pearls

- Lower leg injuries resulting from macrotrauma and from repeated microtrauma occur even in child athletes.
- The symptom of lower leg pain, particularly when unilateral, must prompt consideration of diagnoses such as benign or malignant neoplasm, acute or chronic infection, and metabolic bone disease.
- For young athletes, immobilization should be minimized when safely possible.
- When possible, the cause of an overuse injury should be determined and eliminated.
- Treatment includes full rehabilitation to normal or near normal strength, flexibility, balance, coordination, quickness, and endurance. "Normal" for a dedicated young athlete means equivalent to the uninjured side or at the level required for the sport.

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14 Foot and Ankle Injuries

John P. Batson and Mark D. Locke

Foot and ankle injuries are common in the adolescent age group, particularly in running and jumping sports such as basketball, soccer, and volleyball. Although many injuries are diagnosed as sprains, skeletally immature athletes may sustain physeal injuries and growth-related injuries. In addition, developmental variants may "declare" themselves in the adolescent years due to the added stress of sports and fitness participation. To properly diagnose and manage ankle and foot conditions in growing athletes, physicians should be familiar with ankle and foot anatomy, the changes that occur with growth, and the injury patterns associated with the various stages of growth.

Anatomy

The ankle is an amazingly functional and durable joint (Figs. 14.1, 14.2, 14.3, 14.4, 14.5, and 14.6). The bony anatomy is comprised of the tibia, talus, and fibula. These three bones articulate at the ankle joint and are stabilized by a number of ligaments and an interosseous syndesmosis. The tibia and fibula form a boxlike mortise in which the talus rests (Fig. 14.5a, b). The tibia is the dominant weight-bearing bone in the lower leg. The medial malleolus is an extension of the tibia and provides medial bony support for the ankle mortise. The talus is wider anteriorly, providing more inherent bony stability with the ankle in dorsiflexion as opposed to plantar flexion [1]. Movement at the ankle joint is primarily plantar flexion and dorsiflexion [2].

The deltoid ligament makes up the medial ankle ligamentous support (Fig. 14.2). It consists of a deep layer, which runs from the medial malleolus to the talus, and a superficial layer, which originates on the medial malleolus and attaches to the medial aspect of the calcaneus. Anterior fibers attach to the talus and navicular and posterior fibers attach to the talus. The lateral ligament complex is comprised of the anterior talofibular ligament (ATFL), calcaneofibular ligament (CFL), and posterior talofibular ligament (PTFL) (Fig. 14.3). The ATFL originates at the anterior aspect of the lateral malleolus and runs nearly parallel to the axis of the foot. It attaches to the talus anteriorly and is the primary ligamentous restraint to inversion stress at the ankle [3]. It becomes taut with the ankle in slight plantar flexion. The ATFL is the most commonly injured ligament in the body [4]. The CFL is stronger

This chapter is dedicated to the memory of Angus M. McBryde, MD. A mentor to many in the field of sports medicine. Enjoy your next run Angus. "And the beat goes on…"

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L. J. Micheli, L. Purcell (eds.), *The Adolescent Athlete*, Contemporary Pediatric and Adolescent Sports Medicine, https://doi.org/10.1007/978-3-319-56188-2_14

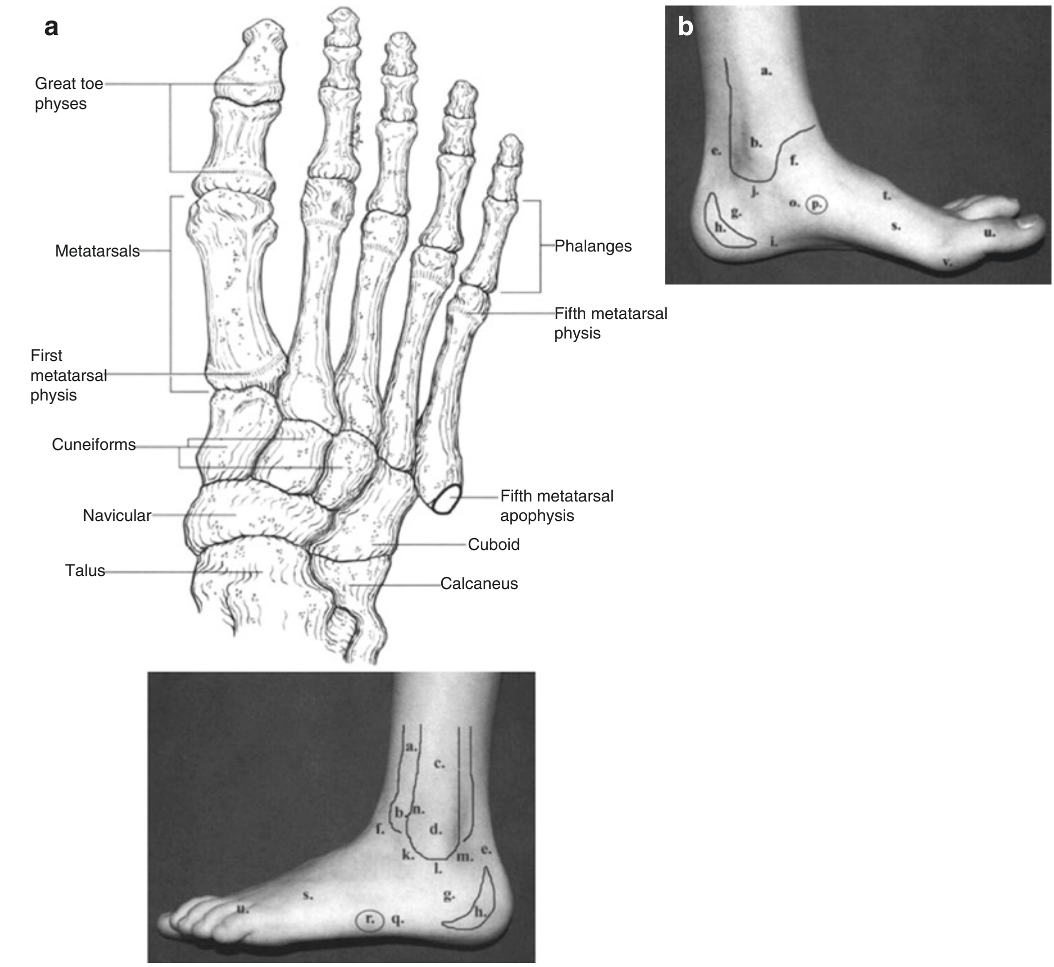

Fig. 14.1 (**a**, **b**) External foot and ankle anatomy. a, tibia; b, tibia physis; c, fibula; d, fibula physis; e, Achilles tendon; f, talus; g, calcaneus; h, calcaneal apophysis; i, plantar fascia; j, deltoid ligament; k, ATFL; l, CFL; m, PTFL; n, anterior tibiofibular ligament; o, posterior tibialis tendon; p, medial navicular; q, peroneal tendon; r, 5th metatarsal apophysis; s, metatarsals; t, Lisfranc ligament; u, phalanges; v, sesamoids

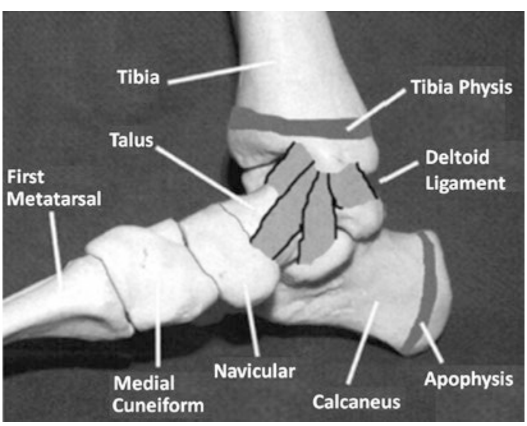

Fig. 14.2 Medial foot and ankle bony anatomy

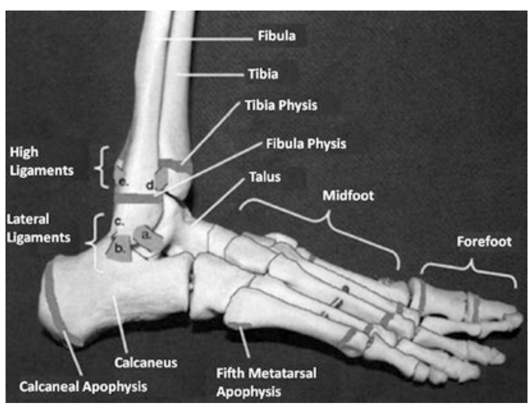

Fig. 14.3 Lateral foot and ankle bony anatomy. a, ATFL; b, CFL; c, PTFL; d, anterior tibiofibular ligament; e, posterior tibiofibular ligament

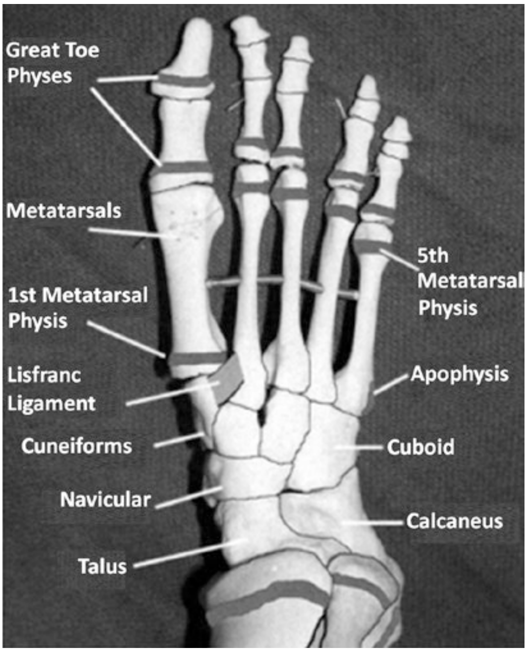

Fig. 14.4 Dorsal foot and ankle anatomy

than the ATFL [4] and spans the tip of the lateral malleolus to the lateral surface of the calcaneus. The PTFL originates on the posterior tip of the lateral malleolus and attaches to the posterior talus. The high ligaments consist of the anterior inferior tibiofibular ligament, posterior inferior tibiofibular ligament, and interosseous syndesmosis.

The bones of the foot are divided into those of the hindfoot, midfoot, and forefoot (Figs. 14.3 and 14.6a–c). The talus and calcaneus make up the bones of the hindfoot (Fig. 14.4). The calcaneus is the largest and strongest bone in the foot [5, 6]. It serves as the attachment for the Achilles tendon and as the origin of the plantar fascia. The talus and calcaneus have three articulations. This subtalar or talocalcaneal joint permits inversion and eversion of the foot [5, 7]. The bones of the midfoot include the cuboid, navicular, and three cuneiforms. The navicular is on the medial aspect of the foot and serves as the attachment for the posterior tibialis tendon. The forefoot is comprised of the metatarsals and their corresponding five phalanges. The great toe has a proximal and distal phalanx. The other four toes have proximal, middle, and distal phalanges. The sesamoids are two pea-sized bones in the substance of the flexor hallucis brevis tendons. They are positioned on the plantar aspect of the first metatarsophalangeal (MTP) joint and function to increase the mechanical advantage of the flexor tendons, as well as to disperse forces with gait and stance [5, 8].

Ligaments of note in the foot include the spring ligament and Lisfranc ligament (Fig. 14.4). The spring, or calcaneonavicular, ligament has an important role in the stabilization of the medial arch of the foot [5, 6]. This ligament prevents talar head sag and medial migration commonly seen with flat foot deformity. The Lisfranc joint includes the five MTP joints and divides the foot into midfoot and forefoot. The Lisfranc, or tarsometatarsal (TMT) ligament, originates on the lateral aspect of the medial cuneiform and inserts on the medial aspect of the second metatarsal base dorsally and plantarly. This ligament is the main stabilizer of the Lisfranc complex.

Muscles of the foot and ankle can be divided into three compartments: the anterior, lateral, and posterior [6]. The interosseous membrane and anterior crest of the tibia form the boundaries between these compartments [1, 5]. The extensor hallucis longus, extensor digitorum longus, and anterior tibialis make up the anterior compartment and primarily dorsiflex the ankle. The anterior tibialis attaches to the first cuneiform and metatarsal and inverts the foot. The lateral compartment is made up of the peroneus longus and brevis. The peroneal brevis attaches to the base of the 5th metatarsal. The longus crosses the sole of the foot to attach on the first cuneiform and base of the first metatarsal. The peroneals evert the foot. The posterior compartment has superficial and deep groups. The triceps surae is the superficial group and includes the gastrocnemius, soleus, and plantaris [9]. The deep compartment includes the flexor hallucis longus, flexor digitorum longus, and tibialis posterior muscles. These muscles function to plantar flex the ankle, flex the toes, and invert the foot. There are many intrinsic muscles of the foot analogous to the intrinsic muscles of the hand. The plantar fascia runs from the inferior aspect of the calcaneus to the forefoot. It has a role in support of the longitudinal arch of the foot [5].

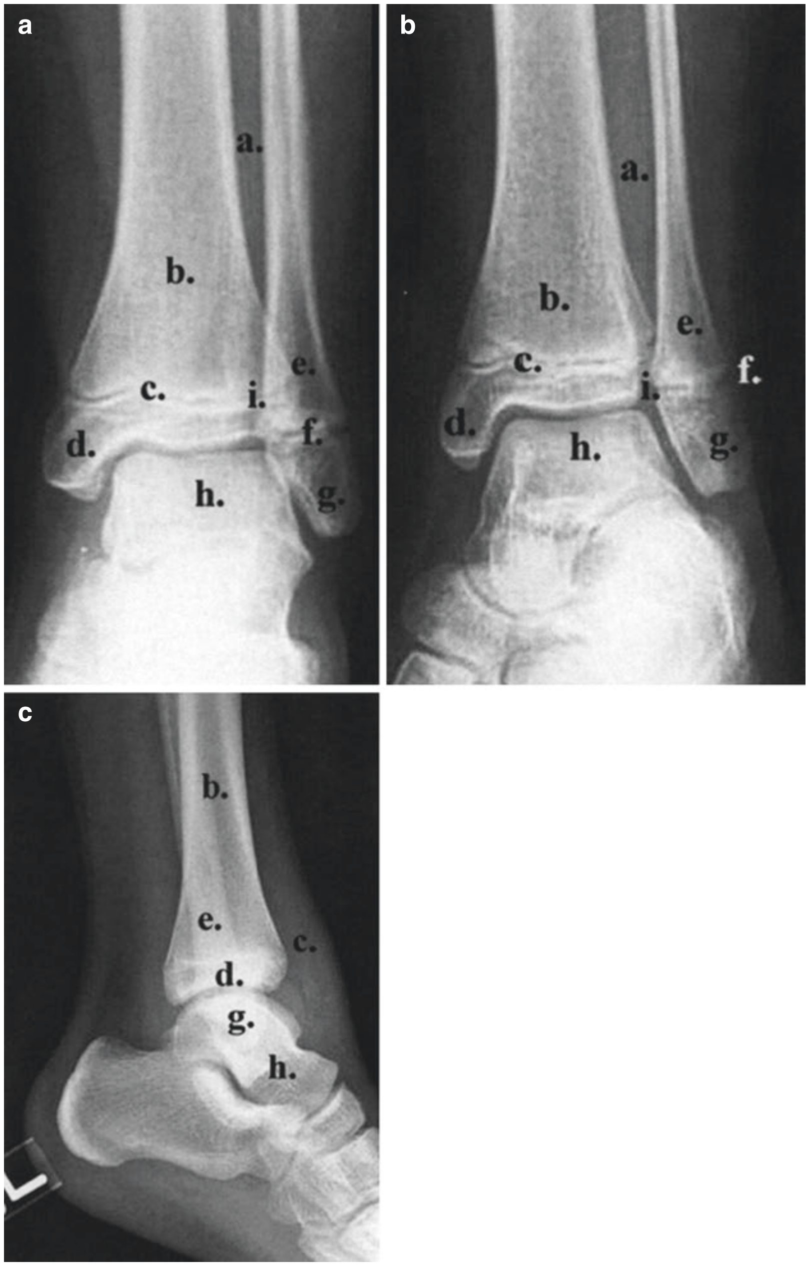

Fig. 14.5 (**a**–**c**) Anteroposterior, mortise, and lateral radiographs of the ankle. a, syndesmosis; b, tibia; c, tibia physis; d, medial malleolus; e, fibula; f, fibula physis; g, lateral malleolus; h, talus; i, tibiofibular clear space

Innervation of the lower leg, foot, and ankle is primarily supplied by the sciatic nerve [1, 5]. The common peroneal nerve innervates the dorsiflexors of the foot and ankle. The tibial nerve innervates the muscles of the posterior compartment of the leg and all of the intrinsic foot muscles except the extensor digitorum brevis [1]. The superficial peroneal nerve innervates the peroneal muscles. The deep peroneal nerve innervates the muscles of the anterior compartment of the leg. Blood supply to the foot and ankle is derived from the popliteal artery's three branches [1, 5]. Venous drainage is primarily with the great saphenous vein. The majority of lymphatic flow follows the great saphenous vein to the inguinal nodes.

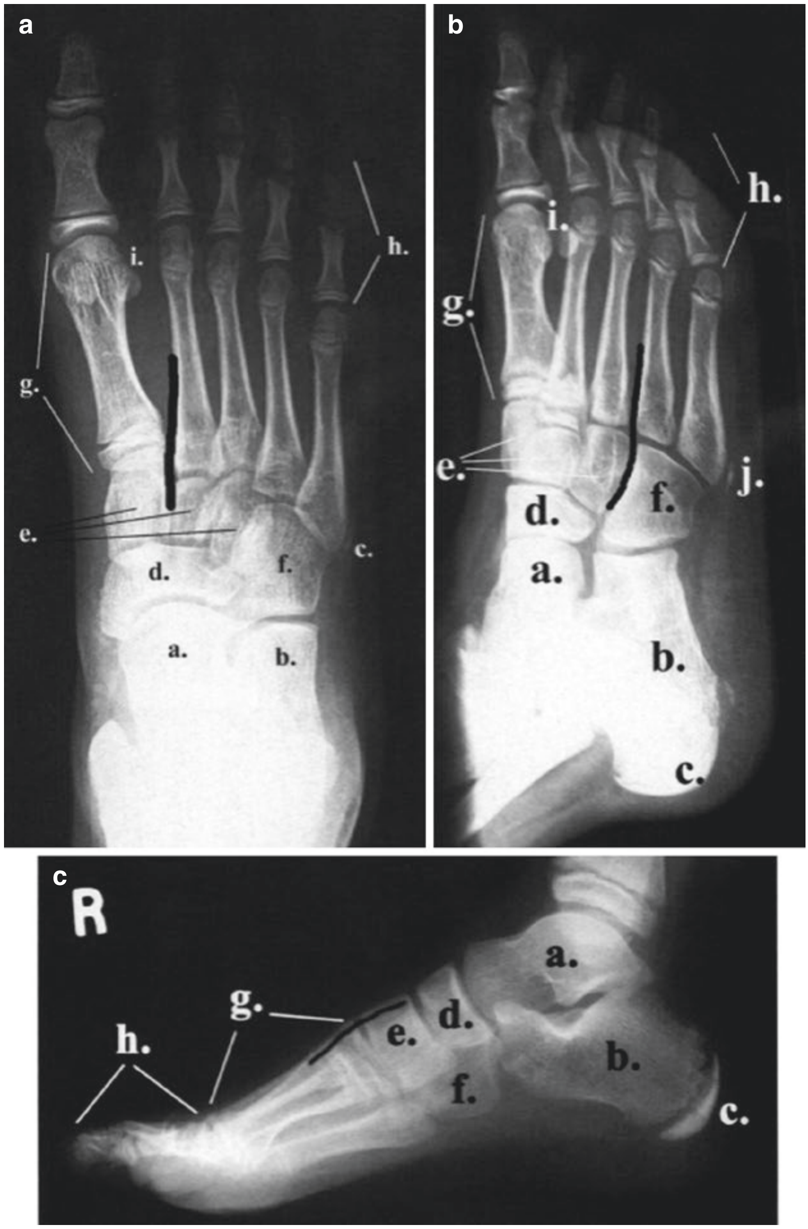

Fig. 14.6 (a–c) Anteroposterior, oblique, and lateral radiographs of the foot. a, talus; b, calcaneus; c, calcaneal physis; d, navicular; e, cuneiforms; f, cuboid; g, metatarsals; h, phalanges; i, sesamoids; j, 5th metatarsal apophysis. The normal relationship of the Lisfranc complex and mid foot is drawn in thick black line

Clinical Evaluation

History

For acute injuries, the athlete should describe as best possible the mechanism of injury. Important information includes when the injury occurred, where it occurred, and if the athlete was able to ambulate off the field or court with or without assistance. Immediate swelling or bruising can be associated with both significant fractures and sprains. Athletes may remember hearing or feeling a "pop" or "snap" at the time of injury. A pain scale (i.e., 1–10, a pain of 1 being mild and 10 being extreme) can be utilized to describe the severity. Determining which phase of the gait cycle or what specific action causes pain is helpful information. The examiner should ask if the athlete has had any prior injury to this or the opposite foot or ankle. These days, it is not uncommon to have the athlete, parent, or coach show the injury to the examiner on a recorded video, which can be very informative.

Chronic or overuse injuries require more questioning. A history of prior sprains or frequent injuries may be present. Residual weakness or proprioceptive deficiency can be a potential cause of reinjury. Mechanical symptoms (snapping, clicking, or locking) or the presence of intermittent swelling can indicate conditions, such as osteochondral lesions and loose fragments in the ankle joint. Painful "snapping" or "popping" can be present with peroneal tendon subluxation. Has the athlete received any physical therapy or orthosis? Young athletes can present with conditions such as inflammatory arthritis, tumors, or infections. It is therefore important to ask about the presence of fevers, chills, weight loss, nighttime pain, rashes, as well as localized warmth or redness. Has the athlete been going through a recent growth spurt? Often during this timeframe, the athlete may be prone to overuse injuries related in part to muscular tightness. Family history, such as juvenile idiopathic arthritis, tarsal coalition, or multi-joint laxity, is important as well.

"Athlete" sensitive questions must be asked: What is his or her sport or position? What are the demands necessary to participate? Where is the athlete in terms of the season (beginning, middle, end)? Has there been a change in the athlete's training schedule in terms of intensity, duration, or lack of adequate rest and recovery? Is the athlete specializing in one sport and on multiple teams or simply involved in recreational activities? Which motions or movements (i.e., running, jumping, landing, or cutting) cause problems? Nutritional habits, such as hydration, overall calorie intake, and the intake of specific micronutrients (calcium, vitamin D, and other antioxidants), should be elicited, as they may play a role in the injury and the subsequent healing. Is there access to a certified athletic trainer? Is the child or adolescent an "elite" or "high-demand" athlete? These young athletes and their parents will expect convenient access to care, expedient diagnosis, and rapid return to sports.

Physical Exam

The physical exam begins with a general overview of the patient in terms of development and body habitus. Body mass index, body composition, ligamentous laxity, and lower extremity alignment should be noted. Gait should also be assessed. An antalgic or "painful" gait is a gait in which the stance phase is shortened on the affected extremity. The athlete may walk "flat footed" to avoid motion at the ankle. Conversely, an ankle effusion is painful with dorsiflexion and can result in a forefoot gait. Furthermore, the athlete may "de-weight" the area of pain (i.e., in the case of a toe fracture, walking on the heel). In the more chronic setting, shoe wear may be assessed for abnormal wear patterns.

The foot and ankle is observed for obvious deformity, swelling, redness, or bruising. Ankle effusions are best visualized at the anterolateral aspect of the ankle. The normal hindfoot is in slight valgus when weight bearing and moves into varus with toe rise. When observing the foot from the posterior aspect, it is normal to see the 4th or 5th toe on the lateral side. Forefoot abduction can be appreciated by the "too many toes" (more than two toes present) sign.

In the non-acute setting, the athlete can attempt to walk on the toes, heels, and the lateral border of the foot. Passive and active range of motion at the ankle is approximately 10–15 degrees of dorsiflexion and 40° of plantar flexion. A subtle clue to an ankle effusion is limitation or pain with passive range of motion. Subtalar motion is assessed by observing the heel move to varus with toe raise and the ability to walk on the lateral border of the foot. Subtalar motion can also be assessed by "rocking" the mid- and forefoot in and out. Range of motion at the first MTP joint should be tested and compared to the opposite foot.

Immediately after an acute injury, swelling may be localized over the injured structures. With time and in the absence of ice, elevation, and compression, the swelling is often diffuse and landmarks obscured. The entire length of the tibia and fibula, the medial and lateral malleoli, and, in athletes with an immature skeleton, the tibial and fibular physes should be palpated. Laterally, the ATFL, CFL, and PTFL and, medially, the deltoid ligament are palpated. The anterior tibial–fibular ligament is assessed. Posteriorly, the gastrocnemius/soleus and Achilles complex are palpated. Snapping may be palpable over the lateral malleoli with peroneal subluxation when the foot is brought into dorsiflexion.

The crescent moon-shaped calcaneal physis is palpated at the superior Achilles attachment, inferiorly at the plantar fascia attachment, and centrally. The navicular bone is a helpful medial landmark. Each metatarsal should be isolated and palpated in their entirety. In the case of isolated foot trauma, particular attention should be paid to tenderness over the metatarsal growth centers. Styloid, metaphyseal–diaphyseal junction, and diaphyseal tenderness should be sought. Lastly, the MTP joints and each toe should be palpated.

Specialized tests include the anterior drawer test (Fig. 14.7), which isolates injuries to the ATFL. It is performed by placing the ankle in slight plantar flexion. The tibia is stabilized with one hand and the other hand grasps the calcaneus. The calcaneus is pulled anteriorly. Excursion is assessed and compared to the opposite ankle. It is normal to have a small amount of forward excursion of the talus in the mortise (0–5 mm). The endpoint should be graded as soft or solid. A marked difference from side to side, soft endpoint, or pain with the maneuver can all indicate injury to the ATFL. The talar tilt test assesses the stability of the CFL and is performed by inverting the calcaneus with the ankle in neutral position (Fig. 14.8). The test should be performed on the opposite ankle for comparison. A difference between the two can indicate an injury to the CFL. Various tests have been described for diagnosing "high" ankle sprains (injuries to the anterior tibiofibular ligament). The external rotation test is performed by stabilizing the lower leg in neutral with one hand and abducting the foot with the other hand (Fig. 14.9). The squeeze test is performed by squeezing the proximal tibia and fibula together (Fig. 14.10). Both tests are designed to stress the anterior tibiofibular ligament by widening the ankle mortise and are positive if the athlete experiences pain. The integrity of the Achilles tendon is assessed with the Thompson's test (Fig. 14.11). In a prone or seated position, the calf is squeezed to mimic a muscle contraction. A negative test, in which the ankle passively moves into plantar flexion, is normal. A positive test occurs when the ankle does not move, indicating a non-functional Achilles tendon.

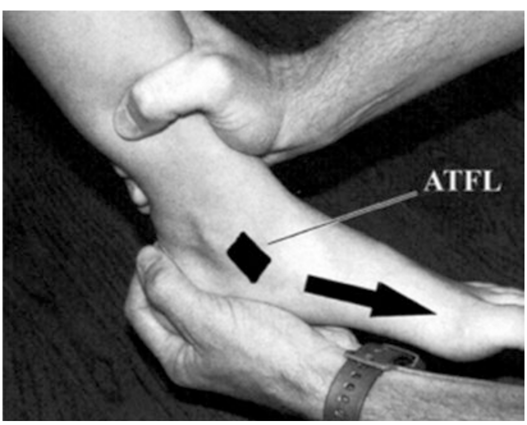

Fig. 14.7 The anterior drawer test

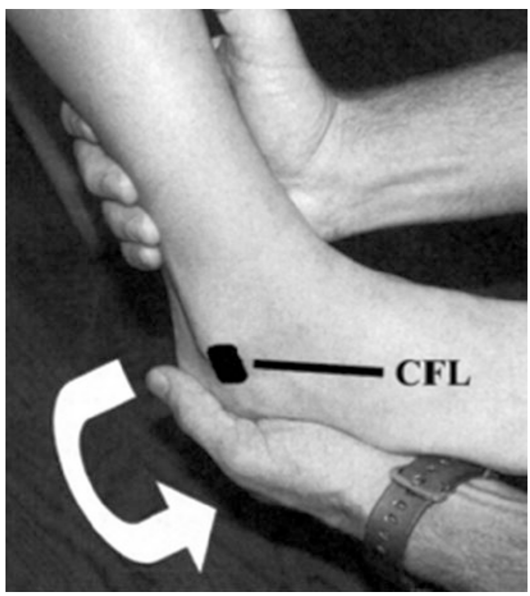

Fig. 14.8 The calcaneal tilt test

Fig. 14.9 The external rotation test

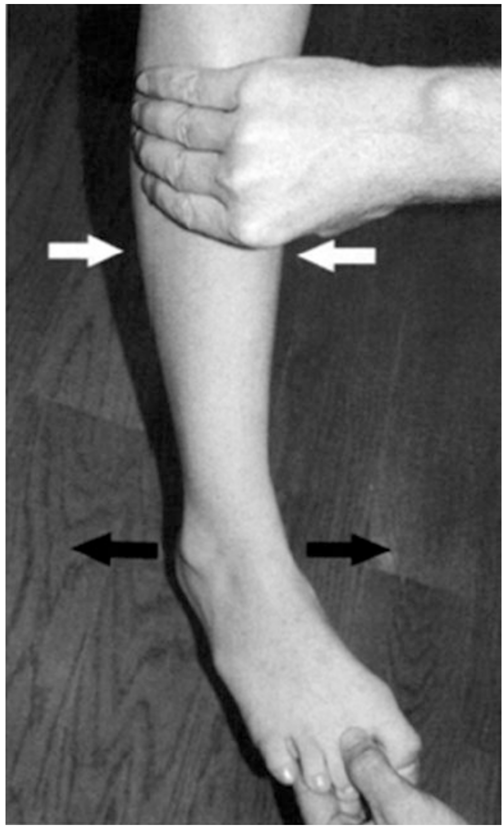

Fig. 14.10 The squeeze test

A complete exam of the foot and ankle includes a neurovascular and skin assessment. Abnormal tone involves tight hamstring or calf musculature. Pathologic tightness should be differentiated from the normal tight musculature accompanying young athletes during periods of growth. Ankle clonus can indicate an upper motor neuron abnormality. Deep tendon reflex asymmetry, differences in sensation to light touch, and strength differences should be recorded. Strength testing of the foot and ankle includes plantar flexion and dorsiflexion, as well as inversion and eversion against resistance. The vascular exam is important in the acute injury setting. Abrasions and lacerations may be present and necessitate care. Erythema may be present with injuries, infectious processes, and inflammatory conditions. Various rashes may be present with systemic conditions (i.e., psoriatic arthritis or juvenile idiopathic arthritis).

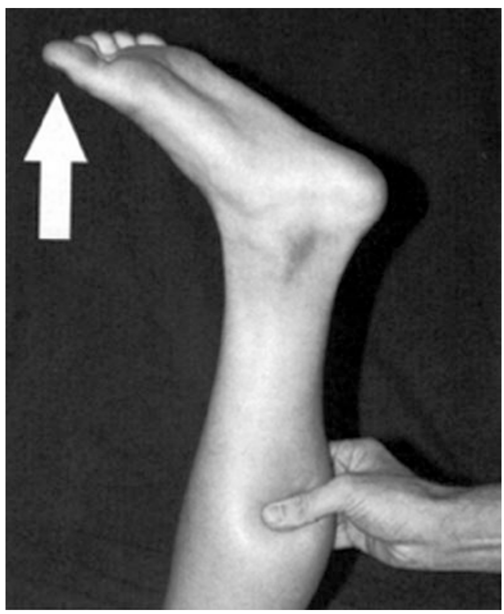

Fig. 14.11 Thompson's test

Acute Injuries

Ankle Fractures

Fractures of the ankle are very common in adolescent athletes [10–14]. Ankle fractures are the second leading fracture type in childhood [15]. The physes are relatively weaker than adjacent ligaments. A good rule of thumb for members of the sports medicine team and primary care physicians is "rule out a fracture" before thinking "sprain" in athletes under 12–14 year of age.

The Salter–Harris classification is the most commonly recognized and utilized classification system for fractures involving the physis [14, 16]. Type 1 injuries involve stress to the physis with or without radiographic evidence of widening. Type II injuries involve stress to the physis and a fracture exiting the metaphyseal region of the bone. In type III injuries, the fracture involves the growth center and the epiphyseal region of the bone. Type IV fractures involve both the metaphyseal region and the epiphysis. Type V injuries are crush injuries and are often only appreciated after growth arrest or deformity. The Salter–Harris classification is not only a way to describe the fracture but also provides prognostic value. Non-displaced type I and II fractures typically do very well and rarely result in any growth disturbance or long-term problems. Type III and IV injuries involve the growth center and the articular surface. These injuries necessitate anatomic reduction and carry a high risk of growth disturbance [10, 14].

Type I injuries to the distal fibula (Fig. 14.12) are very common and typically occur in the same fashion as lateral ankle sprains (plantar flexion, inversion). These are essentially a clinical diagnosis with point tenderness over the distal fibular physis. A critical point to emphasize is the X-ray may or may not show any widening of the physis laterally. Type I and II Salter–Harris injuries to the distal fibula are typically treated with a short-leg cast, walking boot orthosis, or stirrup-type splint for 2–3 weeks. Weight bearing is allowed as tolerated. After this period of relative immobilization, the athlete is given a more functional ankle support orthosis that allows shoe wear, physical therapy, and eventual return to sport. Type I injuries to the distal tibia are less common. Treatment is like non-displaced lateral physis injuries. Because of the importance, the tibia plays in growth and weight bearing, Salter–Harris type II injuries (Fig. 14.13) necessitate anatomic reduction and may require referral. More significant physeal injuries (Fig. 14.14, A and B, and Fig. 14.15) or ankle fractures in older adolescents should be immobilized and referred to an orthopedic surgeon. Physeal growth disturbances are less common with low-energy injuries. In cases of more significant trauma, this should be discussed as a possibility with the athlete's care team early in the treatment process. Periodic follow-up with limited X-rays may be indicated.

Fig. 14.12 Salter–Harris type I fracture of the distal fibula with associated soft tissue swelling

Ankle Sprains

Ankle sprains are the most common injury related to sports and recreation [3]. Roughly 25,000 ankle sprains occur each day in the United States

Fig. 14.13 Salter–Harris type II fracture of the distal tibia

Fig. 14.15 Salter–Harris type IV fracture of the distal tibia with displacement

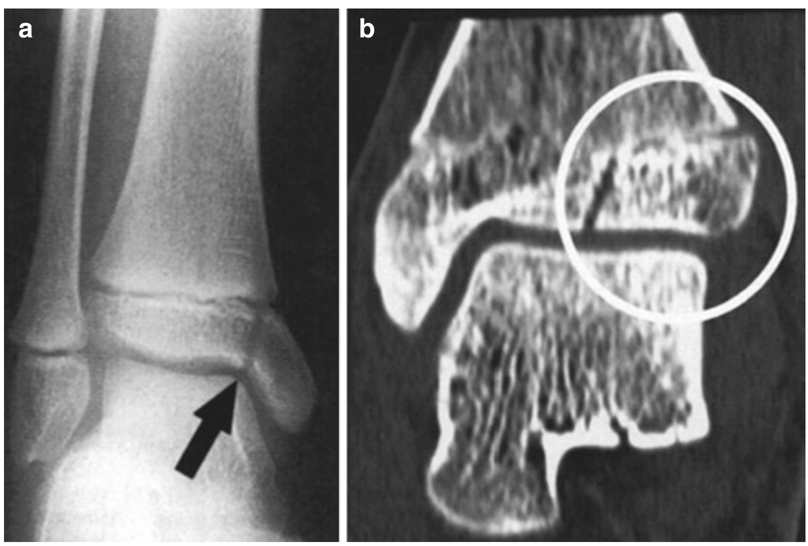

Fig. 14.14 (**a**) Salter–Harris type III fracture of the distal tibia. (**b**) CT demonstrating a Salter–Harris type III fracture of the distal tibia

[17]. Sports in which ankle sprains are common include basketball, football, lacrosse, soccer, and volleyball. Injury rates in sports such as football are higher in college-level versus high school- and youth-level athletes (1.19, 0.73, and 0.59 sprains per 1000 athlete exposures, respectively) [18]. The typical injury occurs with the ankle in slight plantar flexion and a forceful inversion stress occurs. Thus, injures to the lateral ligament complex (ATFL, CFL, and PTFL) is most common [3, 19]. A "pop" may occur with the injury. The athlete may or may not be able to ambulate after the injury. Swelling and bruising develop with time and often dissect distally into the foot. The ATFL is the most common ligament involved, followed by the CFL and the PTFL [3, 4]. The examiner should ensure no injury has occurred to the medial structures, the anterior tibiofibular ligament, the tibiofibular syndesmosis, or the proximal fibula. Fifth metatarsal styloid fractures frequently accompany lateral ankle sprains. Stability testing (anterior drawer and calcaneal tilt tests) may not helpful in the acute setting because of pain and guarding.

Various grading scales have been described for ankle sprains. Injury to the ATFL is a grade 1 sprain, injury to the ATFL and CFL a grade 2 sprain, and injury to the ATFL, CFL, and PTFL a grade 3 sprain. A more predictive grading scale is based on the presence of pain and instability, where a grade 1 sprain is associated with pain and no instability, grade 2 with pain and slight instability, and grade 3 injury with both pain and instability. MRI or ultrasound findings may also allow grading based on the presence of edema or tears in the individual ligaments. The Ottawa ankle rules (Table 14.1) were developed to help determine when radiographs of the foot or ankle are needed. Studies have shown them to have a near 100% sensitivity for detecting significant ankle and midfoot fractures [20, 21]. Although originally described for patients over the age of 18 years, these rules can be applied to young individuals as well [22]. To further reduce cost and unnecessary radiation exposure, a new possible guideline has been suggested, which is termed the "low-risk ankle rule" [23, 24]. This suggested guideline states that if a child's pain and swelling is isolated to the distal fibula and/or adjacent lateral ligaments distal to the tibial anterior joint line, then ankle plain films are likely not needed to rule out a significant injury. When implemented in the emergency department setting, this rule was shown to reduce the rate of ankle radiographs without significant complications [23]. Implementation of this rule may be difficult with elite athletes and/or demanding athlete care teams, but physician experience and new tools such as point-of-care ultrasound [25, 26] may assist with this guideline.

Table 14.1 The Ottawa foot and ankle rules

X-rays of the foot and/or ankle are required in the presence of:
• Any pain in the midfoot (from the lateral malleolus to the middle portion of the malleolus)
• Any of the following:
Tenderness or pain at the base of the fifth metatarsal
Tenderness or pain at the navicular bone
An inability to bear weight immediately after the injury or to take four steps in the clinical setting

In the acute setting, the ankle needs compression and splinting in the neutral position. This can be accomplished with a stirrup-type or posterior mold splint. At times, the athlete may be best managed in a well-molded and padded short-leg walking cast to allow ambulation without crutches. If a cast or splint is used, it is important to allow for some swelling to avoid compartment syndrome. A walking boot orthotic may accomplish similar pain control and allow early physical therapy. Compression can help to reduce swelling. A horseshoe-shaped soft felt pad can be placed around the lateral malleolus under taping or elastic stocking. Ice therapy helps with pain control and inflammation. Swelling requires elevation of the foot and ankle above the heart. Basic functional treatment with gentle range of motion, calf stretches, and isometric exercises can begin in the subacute setting [27]. Most athletes with ankle sprains can return to sports in a protective orthosis 1–2 weeks after the injury. Recurrent injuries tend to progress more rapidly than initial injuries. The best evidence recommends aggressive physical therapy for all ankle sprains regardless of the grade, as surgery can always be performed if the athlete has problems with chronic pain or instability [3, 19, 28]. Supervised physical therapy potentially adds a large expense and may not be more effective than a home-directed therapy plan [29, 30]. A home-directed treatment plan may not be as effective in younger patients where compliance can be an issue or elite athletes where speed of recovery is important. Grade of injury would be an important consideration here as well with more significant injuries likely better treated in a formal therapy program.

Two sprains deserve special mention. An injury to the deltoid ligament is not as common and usually results from eversion/external rotation/abduction stress to the ankle [3, 19]. At the collegiate level, deltoid ligament injuries have been reported with an injury rate of 0.79/10,000 athlete exposures, and the highest rates were seen in women's gymnastics and men's and women's soccer and football. Half were due to player contact [31]. The deltoid ligament is stronger than the lateral ligaments. In addition, the ankle mortise is inherently more stable from a bony standpoint to resist eversion. Thus, a medial ankle injury generally indicates more significant trauma has occurred. The structures on the lateral aspect of the ankle may be injured and associated fractures may occur [3, 19]. Also, the force may extend to the syndesmosis and transmit out the proximal fibula, the so-called Maisonneuve fracture. The second injury, termed a "high" sprain, has been given more attention in recent years [32, 33]. This is an injury to the anterior tibiofibular ligament and proximal syndesmosis and can occur if the ankle is forced into dorsiflexion and external rotation. Syndesmosis injuries have been shown to have an incidence of 0.96% of pediatric and adolescent ankle trauma [34]. These injuries are more common in sports injuries verses other related ankle trauma. The squeeze test and external rotation test assess injury to the ligament and adjacent syndesmosis. With a suspected deltoid or high sprain, radiographs of the ankle should be obtained. Attention is given to the tibiofibular clear space, medial clear space, and fibular overlap (Fig. 14.16) [19, 28, 35, 36]. Comparison films to the uninjured ankle and weight-bearing films may demonstrate subtle disruption of the mortise. MRI is a sensitive tool to confirm injury to the high ligaments and associated structures [33]. Dynamic ultrasound and weight-bearing CT scans have recently been reported as possible modalities of choice for the evaluation of syndesmosis injuries [37]. Suspected deltoid ligament injuries, syndesmosis injuries, or high ankle sprains should be referred to a sports medicine specialist. A critical distinction with syndesmosis trauma is the distinction of stable versus unstable injuries [37]. With either injury, it is important to emphasize to the athlete a more significant sprain has occurred, and it may require more initial immobilization as well as longer rehabilitation. Athletes with disruption of the mortise or certain associated fractures often require open reduction with internal fixation. Surgical intervention for syndesmosis injuries is more commonly required in older patients (closed physes), patients with associated fractures and patients with a medial clear space greater than 5 mm [34]. Significant injuries and injuries not managed properly carry the risk of ankle instability, chronic dysfunction, and premature arthritis.

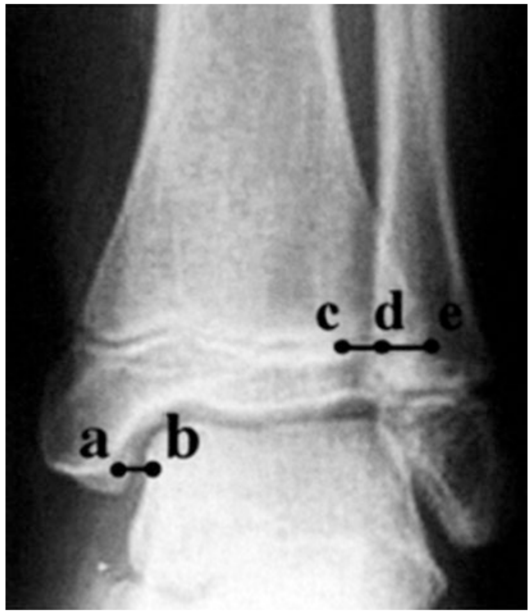

Fig. 14.16 Normal mortise relationship. a–b, medial clear space; c–d, tibiofibular clear space; d–e, fibular overlap

Metatarsal Fractures

Metatarsal fractures are common injuries in the young foot. Potential mechanisms of injuries include falls from heights, axial load or twist injuries to the foot, or when objects such as dumbbells or shot puts are dropped on the foot. In most cases, the athlete can pinpoint the exact location of pain. Radiograph evaluation includes an AP, lateral, and oblique view of the foot. Uncomplicated injuries are treated in a wooden shoe or walking boot orthosis. An important concept is that lateral or medial displacement of the fracture is generally well tolerated and heals without consequence. Apex plantar or dorsal angulation, particularly in the metatarsal neck or heads, on the other hand, can cause future problems with shoe wear and minimal displacement or angulation is accepted. A short-leg cast with toe extension plate may be necessary for pain control in the first 1–2 weeks. Weight bearing is allowed as tolerated. The fracture is generally treated a total of 4–6 weeks. Some activities may be tolerated in a shoe with the addition of a stiff last orthosis toward the terminal healing phase.

The fifth metatarsal bears special consideration. Mid-diaphyseal, neck, or head fractures are treated in a similar fashion as the aforementioned metatarsal fractures. Proximal fractures can be divided into those occurring in zones 1, 2, or 3 [38]. Zone 1 includes the 5th metatarsal tuberosity. Zone 2 involves the proximal metaphyseal–diaphyseal junction (without extension distal to the 4th and 5th intermetatarsal articulation). Zone 3 enters the diaphyseal portion of the 5th metatarsal. Styloid avulsion fractures (zone 1) often occur with inversion injuries to the ankle. A forceful pull from the peroneal brevis tendon and/or the lateral band of the plantar aponeurosis, which attaches to the proximal fifth metatarsal, is thought to cause the injury [14, 39]. This fracture line in most cases runs perpendicular or oblique to the shaft of the bone (Figs. 14.17 and 14.18). This fracture should not be confused with the normal proximal apophysis in younger athletes, which runs parallel to the metatarsal shaft (Fig. 14.19). This growth center can be tender after an acute injury or with overuse. Styloid avulsion fractures are best demonstrated on the oblique or anteroposterior projection of the foot. These injuries are typically treated for 4–6 weeks in an orthopedic shoe, walking boot, or short-leg cast, and weight bearing is allowed. Occasionally, these fractures may go on to non-union, but in most cases, the athlete is symptom-free and no long-term consequences are seen [40]. Surgery

Fig. 14.17 Fifth metatarsal styloid avulsion

Fig. 14.18 Normal 5th metatarsal apophysis

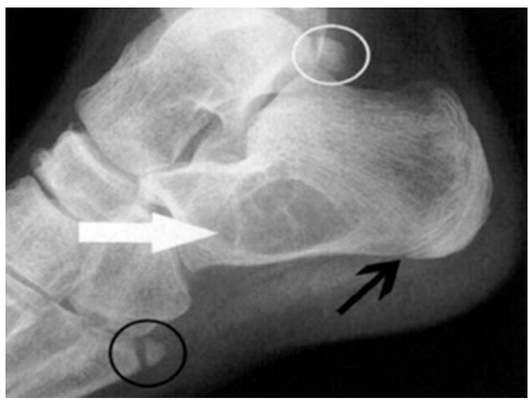

Fig. 14.19 Lateral radiograph of the foot demonstrating the normal calcaneal apophysis (black thin arrow), unicameral bone cyst (white block arrow), an os trigonum (white circle), and a fifth metatarsal avulsion (black circle)

Fig. 14.20 Acute Jones fracture

may be indicated for significant displacement or persistent pain with non-union [41]. Fractures that occur at the metaphyseal–diaphyseal junction (zones 2 and 3, typically within 1.5 cm of the tuberosity) are more significant injuries (Fig. 14.20). The blood supply to this area of the bone is reduced [40]. These injuries (the so-called Jones fracture) often occur with an inversion and axial load stress to the foot. Tenderness is localized distal to the styloid. The standard foot series of radiographs will confirm the fracture. These fractures require immobilization and non-weight bearing, often for 6–10 weeks, followed by weaning to a walking boot, provided some evidence of callous formation is present. This fracture may require a total of 12 weeks before advancing rehabilitation and return to sports participation. Even with compliant patients, healing may be protracted and may not occur at all. Patients committed to non-operative management may benefit from a bone stimulator to promote healing. Surgery is less often indicated in pediatric patients (under the age of 18 years). In pediatric patients, fractures between 20 and 40 mm from the proximal tip of the 5th metatarsal have been shown to require surgery more often than those less than 20 mm [42]. For older patients, recent literature favors the option of intramedullary screw placement at the time of diagnosis, with faster and more consistent healing, faster return to sport, and a lower incidence of reinjury [40, 41, 43–45]. Refracture is a potential complication, even after intramedullary screw placement [46].

Toe Fractures

Toe fractures can occur when young athletes drop heavy items on the foot or when athletes accidentally kick a hard object. These injuries present with localized pain, swelling, and erythema. The radiograph is usually diagnostic, though in the young athlete each phalanx has a growth center, and subtle injuries may be difficult to visualize. Fortunately, most toe fractures and sprains heal without problems with simple immobilization with buddy taping and a stiff last orthopedic shoe. The great toe is important for the gait cycle and balance. It therefore does require anatomic reduction, and a walking boot or short-leg cast with toe extension is recommended. Fractures of the distal phalanx associated with nail bed injuries are considered open fractures. Consideration is given to prophylactic antibiotics, and close observation is required for signs of osteomyelitis [14].

Midfoot Sprains and Turf Toe

Midfoot sprains are uncommon in young athletes. These injuries involve the TMT joint and are known as “Lisfranc sprains.” Potential mechanisms include an axial load placed on the heel of a plantar-flexed foot or forceful plantar flexion with a fixed forefoot or forced abduction of the forefoot with a fixed hindfoot [10, 47]. The force is transmitted through the TMT joint. Such injuries have been described in football linemen, equestrian riders, and windsurfers [48, 49]. Tenderness is localized over the dorsum of the foot at the TMT joint. Abduction and pronation of the forefoot stress the complex and cause localized pain. Asking the individual to perform a toe raise is painful [19]. Weight-bearing radiographs of the foot may be needed [50]. The normal relationship of the TMT complex is shown in Fig. 14.6a–c. On the AP projection of the foot, a line drawn along the medial aspect of the second metatarsal should follow the lateral border of the medial cuneiform. On the oblique view of the foot, a line drawn down the medial border of the fourth metatarsal should line up with the medial border of the cuboid. The lateral radiograph also can demonstrate disruption of the Lisfranc ligament by showing a step-off between the metatarsal base and cuneiforms. Normal adult measurements between the metatarsals number 1 and 2 and the measurement of the second metatarsal and the medial cuneiform approach that of adults by age 6 years [51]. A fracture of the proximal 2nd metatarsal should be evaluated closely for an associated Lisfranc sprain [40, 52]. For cases in which radiographs fail to demonstrate a suspected injury, CT scan, bone scan, and MRI can play a diagnostic role [40, 43, 48–50, 52]. Midfoot sprains should be referred to a sports medicine specialist. Injuries without instability are typically treated in a short-leg cast or walking boot, with weight bearing as tolerated, for 4–6 weeks [50]. Athletes with as little as 2 mm of diastasis or signs of instability require internal fixation [47, 49, 52]. Late widening and instability may occur; thus, symptoms and radiographs should be followed after the initial evaluation. Athletes requiring surgical intervention tend to do well and are able to return to pre-injury levels when the diagnosis was not delayed [50].

Sprains of the first MTP joint are known as turf toe injuries. Usually, hyperdorsiflexion occurs with an injury to the conjoint plantar structures [49, 53]. These injuries are common in football, soccer, wrestling, and dance. Artificial turf and flexible shoes have been implicated as risk factors [35]. Improvements in shoe wear and artificial turf have led to less incidence of turf toe injuries [54, 55]. Injury rates of 0.062 per 1000 athlete exposures have been described in NCAA football players [54]. The athlete typically presents with pain localized to the first MTP joint. The pain is worse on the plantar aspect of the joint and exacerbated by dorsiflexion of the joint. Radiographs may demonstrate a fracture or separation of the sesamoids. MRI may be helpful for further clarification of the injury. Typically, conservative treatment involves immobilization of the MTP joint with a walking boot, orthopedic shoe, or stiff last insert. Physical therapy can reduce swelling, improve range of motion, and redevelop strength in the subacute healing phase. Restrictive taping can help limit dorsiflexion of the joint and facilitate return to sport. The injury is often frustrating because of the extended healing time and inability to participate in sports at an elite level. Complete ligament tears may require surgical intervention.

Overuse Injuries and Chronic Pain

The Unstable Ankle

It is common to encounter the athlete with repeated ankle "sprains" or repeated episodes of their ankle "giving out." Chronic ankle instability has been shown to affect over 20% of high school and division 1 athletes with women more common than men [56]. Associated injuries have been found in up to 64–77% of unstable ankles [3, 53, 57]. Thus, every effort should be made by the examiner to diagnose any predisposing or associated conditions, such as tarsal coalition, peroneal tendon subluxation, peroneal tendonitis, impingement lesions, ankle synovitis, osteochondral pathology, as well as strength or proprioceptive deficits. Certain anatomic variants (i.e., cavus foot or hindfoot varus) have also been associated with unstable ankles [58]. Joint laxity may be a result of previous injuries to the lateral ligament complex but also can accompany medical conditions such as Down syndrome, Ehler–Danlos syndrome, and Marfan's syndrome. Associations with chronic ankle instability in young adults include elevated BMI and tall stature [59]. A flexible flat foot should not contribute to ankle instability unless accompanied by peroneal weakness or tendinopathy.

Table 14.2 Functional return to sport protocol

1. Toe raises, both legs together: 1–3 sets, 15 repetitions
2. Toe raises, injured leg alone: 1–3 sets, 15 times each
3. Balance on the injured leg: 1–3 sets, 30 seconds in duration
4. Walk at fast pace: 1–3 times, 50 yards each
5. Jumping on both legs: 1–3 sets, 10 times each
6. Jumping on the injured leg: 1–3 sets, 10 times each
7. Easy pace straight line jog: 1–3 times, 50 yards
8. Sprint (half speed, quarter speed, and full speed): 1–3 times each, 50 yards each
9. Jog straight and gradual curves: 2–3 laps around field, court, or track
Cross-country track and running can gradually advance to desired distance at this point. More demanding sports (i.e., football, soccer, base and softball, tennis) need to advance sport-specific drills such as:
1. Run figure 8's (half speed, quarter speed, and full speed): 1–3 times each
2. Crossovers – 40 yards: 1–3 times to the right and left
3. Backward running (back peddling): 1–3 times, 40 yards each
4. Cutting (half speed, quarter speed, and full speed): 1–3 times
5. Sport-specific drills
6. Return to sport

Source: Reprinted from Kaft DE. Low back pain in the adolescent athlete. Pediatr Clin North Amer 2002:49(3):643–653. With permission from Elsevier

Anteroposterior, lateral, and mortise views of the ankle are warranted in the case of chronic pain or instability. Radiographs may reveal findings such as syndesmosis hypertrophic ossification, an osteochondral lesion, or intra-articular fragments. MRI can be helpful not only to visualize the ligaments involved but also to rule out many associated conditions, such as tendinopathy, tendon tears, and osteochondral lesions. Any problems with the young athlete's foot should be evaluated accordingly. Stress radiographs, MRI, and dynamic ultrasound can help to show ligament instability and chronic abnormal tendon findings [60].

The unstable ankle requires referral to a sport medicine specialist. Conservative treatment of the unstable ankle includes physiotherapy to reduce edema, control range of motion, strengthen weak muscles, and improve proprioceptive deficits. Taping or bracing often allows monitored return to sports. The athlete with a weak and unstable ankle must obtain adequate strength and pass a functional return to sport protocol (Tables 14.2). Activities such as stationary biking or swimming can allow the athlete to stay physically active, while not stressing the ankle. Surgical indications include continued pain and recurrent instability despite dedicated physical therapy. Repair with a modified Brostrom technique has shown good results in patients under the age of 18 years [61].

Osteochondritis Dissecans of the Talus

Osteochondritis dissecans (OCD) is a condition in which the articular cartilage and underlying subchondral bone is abnormal. The mean age of young athletes with an OCD lesion is 13–14 years [14]. A more recent study showed the majority of lesions occurring in patients 12–19 years of age with an overall incidence of 6.8/100,000. Lesions occur more commonly in female patients [62, 63]. These lesions most commonly involve the medial aspect of the talus (Fig. 14.21) [14, 19, 62, 63]. Lateral lesions are most often the result of an acute traumatic event [13, 35, 64]. Repetitive

Fig. 14.21 MRI demonstrating a medial talar osteochondral lesion

stress and vascular insults to the affected area are thought to be other potential causes. Chronic pain and intermittent swelling can occur with OCD lesions. Unstable lesions can separate from the body of the talus. Detached bony or cartilaginous fragments may cause mechanical symptoms, such as locking, clicking, and catching.

The Berndt and Harty classification has been used to characterize OCD lesions and is based on the radiographic appearance [64–66]. Their classification scheme describes stage I lesions as a small area of compression, stage II lesions as a separate fragment, stage III lesions as a detached but hinged fragment, and stage IV lesions as completely detached fragments. MRI is a very sensitive and specific tool to detect OCD lesions, and it is commonly performed in suggestive cases with normal or inconclusive radiographs. In addition, MRI can help to better define the lesion's size, location, and signs of instability such as a fluid interface between the lesion and healthy talus. Ankle arthroscopy can visualize, palpate, and grade the osteochondral defect [64, 65]. Grading scales based on MRI and arthroscopy findings have been proposed [67].

OCD lesions require referral to a sports medicine specialist. Skeletal immaturity is taken into consideration. Non-surgical management is recommended for most skeletally immature athletes unless the fragment is detached [14, 68, 69]. Rest and immobilization is also recommended for most stage I and II lesions and medial grade III lesions [64, 65]. This includes an initial period (4–6 weeks) of non-weight bearing. Radiographs are repeated, and if the lesion continues to look stable and some evidence of healing is taking place, the athlete is progressively advanced to protected weight bearing, as tolerated. Lateral grade III or grade IV lesions generally require operative management [64, 65]. Any free fragments are debrided. Drilling, microfracture, or curettage promote vascularization and healing [70]. Internal fixation is considered with acute injuries and relatively large, unstable fragments [64, 65]. Lateral lesions generally have a better prognosis [35]. Reoperation rates for OCD lesions have been shown to be high (27%) [63]. Females and patients with higher body mass index trended toward worse functional outcomes [63].

Tendonitis and Tendinopathy

Tendonitis produces pain to palpation and with active use or resisted movement of the muscle–tendon complex. These conditions in the foot and ankle are primarily overuse injuries. Tendinopathy indicates a more chronic problem affecting the tendon.

Achilles tendonitis is common. It is frequent in sports, such as cross-country running, track, basketball, soccer, and dance, especially in older adolescent elite athletes. Typically, the athlete has pain with activities such as toe raise, running, and jumping. The athlete usually presents with localized tenderness in the Achilles tendon. Resisted ankle plantar flexion and repeated single-leg toe raises may cause pain. The calf complex and hamstrings may have associated poor flexibility. Radiographs are not necessary. Point-of-care ultrasound evaluation can show tendon abnormalities, including increased neovascularity, calcification, and defects. Treatment involves stretching, cryotherapy, and an anti-inflammatory medication. Heavy slow resistance training and eccentric training have both shown benefits in chronic cases [71]. Gel heel cups or a lift may reduce tendon stress. Steroid injections should be avoided because of the risk of tendon weakening and rupture. Older athletes are more prone to tears and tendinopathy, which often require longer and more intensive therapy. Newer treatment options including prolotherapy and platelet-rich plasma injections have been tried in recent years for athletes with chronic complaints. Thus far, their effectiveness in clinical trials is not consistent. Recent studies have shown ultrasound can identify tendon abnormalities (i.e., hypoechoic regions) in asymptomatic athletes that are predictive of future dysfunction and pain [72, 73]. Targeting these athletes with preventive exercises and training modifications could prevent lost time in sport.

Posterior tibialis tendonitis causes localized pain in the medial ankle or foot. There may be a recent history of an ankle sprain. The injury is common in any sport involving running, jumping, and repeated ankle plantar flexion. On physical exam, the athlete may have some localized swelling. Ankle range of motion is usually full. Tenderness is present in varying amounts from the navicular attachment to the medial malleolus, and it is proximal along the posterior medial distal tibia. Resisted ankle plantar flexion and inversion cause pain and may show weakness. A flat foot and/or an accessory navicular may be present. Radiographs are necessary if anatomic or structural abnormalities are present. Point-of-care ultrasound can play a role as with Achilles tendon evaluation. Treatment involves immobilization with an ankle support, walking boot, or short-leg cast. The athlete should wean to shoes with a supportive arch. An over-the-counter or custom foot orthotic can be helpful if supportive shoes are not adequate. Basic ankle therapy with an emphasis on calf stretches and strengthening the posterior tibialis should be initiated. Cryotherapy and anti-inflammatory medications help as well in the acute phase. Chronic problems warrant referral for surgical considerations.

Peroneal tendonitis often follows a history of inversion-type sprains. A "popping" sensation may be described if the tendon is subluxing. Peroneal tendon subluxation may initiate after a forceful episode of extreme ankle dorsiflexion. This may also occur without trauma if the fibular groove is shallow. Resisted eversion of the foot and ankle cause pain, as does passive plantar flexion and inversion. Weakness may be present. Subluxation may be reproducible on physical exam by palpating the lateral malleolus and having the patient repeatedly plantarflex and dorsiflex the ankle. Radiographs of the foot and ankle should be obtained in cases of associated trauma or chronic pain. Ultrasound can demonstrate synovial thickening and fluid in the tendon sheath in cases of tendonitis [74] and may even show the tendon subluxing with dynamic testing. A lateral malleolus "rim" fracture is commonly seen in cases of acute peroneal subluxation [35]. Treatment initially involves an ankle support. Therapy is directed at calf stretches and eversion strength. Proprioceptive work, eccentrics, cryotherapy, and other modalities are utilized. Persistent symptoms require surgical referral. Surgical options include tendinopathy resection with tubulization, split tendon repair/resection, or stabilization for instability.

Stress Fractures

Stress fractures (also known as "fatigue" fractures) occur when the stresses placed on the bone outweigh its ability to repair and remodel. Running-oriented sports cause the majority of stress fractures. These fractures occur in male and female athletes in equal numbers [75]. The tibia, fibula, tarsals, and metatarsals are among the bones most often affected. Information regarding the athlete's training schedule should be obtained. Female athletes with a stress fracture should be questioned about nutrition (adequate calories, calcium, and vitamin D) and their menstrual history. Athletes with recurrent stress fractures should be evaluated for conditions such as hyperthyroid and osteopenia. Biomechanical lower extremity alignment, leg length discrepancy, and other intrinsic risk factors, such as foot shape, have been associated with stress fractures [75, 76]. The pain with stress fractures is worse with physical activity and may occur at night. Radiographs may or may not demonstrate the fracture during the initial 3 weeks. Bone scans can show early stress fractures. Most experts recommend MRI rather than bone scan to confirm the diagnosis because of its availability and specificity [75, 77] as well as lack of radiation exposure. Grading scales based on MRI findings have been proposed. The mainstay of treatment of stress fractures involves relative rest. Low-risk stress fractures (i.e., second metatarsal) rarely cause permanent problems. High-risk stress fractures (i.e., fifth metatarsal, navicular, and sesamoids) often require non-weight-bearing treatment, and even then, they may not heal sufficiently [17, 78]. In some centers, the use of transcutaneous bone stimulators has increased the rate and incidence of healing in difficult stress fractures, but research is needed in this area (unpublished results). Factors which may inhibit healing, such as continued training, tobacco, poor nutrition, and nonsteroidal anti-inflammatory medications, should be discussed [79].

The second metatarsal is unique in its anatomic relationship and positioning with the tarsal bones. Motion is limited, which makes this bone prone to stress [9]. Though less common, stress

Fig. 14.22 Fourth metatarsal stress fracture (healed)

fractures can also occur at the 3rd and 4th metatarsal (Fig. 14.22). These fractures have been described in military recruits and sports involving running and repetitive jumping. The patient is usually point tender over the fracture. Standard radiographs of the foot may offer confirmation; however, CT or MRI may be necessary for diagnosis, particularly early on. Treatment consists of relative rest from the offending sport or activity. Activities that stimulate, but do not cause pain, are allowed. Patients may require a short-leg cast, walking boot, or crutches. These fractures are "low risk" for potential non-union and usually heal without permanent problems [9]. The treatment time is approximately 6 weeks before gradual return to sports is allowed. A semirigid orthosis with metatarsal pad may be a good transition from a walking boot orthosis. Transfer lesions with stress fracture progression across the foot must be avoided.

Stress fractures of the 5th metatarsal deserve special mention. These injuries typically occur at the metaphyseal–diaphyseal junction (zones 2 and proximal 3). In European professional footballers, 5th metatarsal fracture incidence has been shown to be 0.04 injuries/1000 h of exposure with over half being stress fractures [80]. Some associations found with this injury include low levels of vitamin D (25-OHD) [81], reduced toe grip strength, and injury in the non-dominant leg [82]. It is well known, in contrast to other metatarsal stress fractures, that these injuries are prone to delayed healing, non-union, reinjury, and chronic pain [78]. These fractures are common in jumping-oriented sports, such as basketball, gymnastics, and dance. Athletes may present with the acute onset of an injury but often recall intermittent and increasing pain present for weeks prior. Tenderness is localized to the lateral border of the foot. Standard radiographs of the foot usually confirm the diagnosis. Treatment for these "high-risk" stress fractures is controversial. A trial of conservative treatment is reasonable, especially in younger athletes free of other risk factors for poor healing. Like acute Jones fractures to this region, most experts recommend a period of 4–6 weeks in a non-weight-bearing short-leg cast. This course can be continued if evidence of healing is present on follow-up radiographs. The athlete is transitioned to a weight-bearing cast for another 2–4 weeks. If clinical and radiographic evidence of healing continues, the athlete is then placed in a walking boot, and physical therapy is initiated. Return to sports is gradually permitted at 10–12 weeks. On the other hand, if after 6–8 weeks of non-weight bearing the fracture displays no evidence of radiographic healing, intramedullary screw placement may be warranted. A limited CT of the bone may help to reveal the potential for healing. If sclerotic margins are present, the potential for non-operative healing is low, and surgery should be considered [75, 78]. Intramedullary screw placement with or without bone grafting is recommended. Elite-level athletes may elect for surgical fixation at the time of the diagnosis because of the potential lengthy healing time. Studies have shown low complication rates in athletes undergoing intramedullary screw fixation with bone autograft and a mean return to sport at 12 weeks [83]. Recurrent fractures after surgery are associated with elevated BMI and a "protruding 5th metatarsal head" [84].

Navicular stress fractures are another "high-risk" fatigue fracture prone to delayed healing and non-union. As with proximal fifth metatarsal stress fractures, these injuries are common in sports such as basketball and dance. The athlete presents with increasing pain on the dorsum or medial aspect of the foot. Tenderness is usually localized to the navicular "N" spot or medial aspect of the bone [75, 78]. MRI or CT may be needed to visualize and characterize the injury. The Saxena classification protocol can give some guidance to treatment [85, 86]. The younger athlete is usually placed in a non-weight-bearing cast for 4–6 weeks. If radiographic healing is present, the athlete is advanced to a walking boot and begins physical therapy directed at calf flexibility and strength about the ankle. For those cases not responding to non-operative treatment, screw fixation with or without bone grafting is considered [78]. Elite athletes may opt for surgical management at the time of diagnosis.

Fig. 14.23 Normal calcaneal apophysis with attachment site of the Achilles tendon (white arrow) and origin of plantar fascia (black arrow) labeled

Apophysitis

Apophysitis, or inflammation of the tendon attachment, can occur for a number of reasons. During periods of rapid growth, the physis is under stress, as there is a mismatch between the fast-growing bone and the increasingly taut musculo-tendon complex. It may be present with conditions such as juvenile idiopathic arthritis. These conditions are more common in boys and primarily a problem of the lower extremity. Athletes between the ages 8–12 years are commonly affected.

Calcaneal apophysitis is known as Sever's disease. The calcaneal apophysis resembles a crescent moon wedged between the Achilles tendon and the plantar fascia. Young athletes often complain of pain in the heel or foot. The condition may be bilateral. The physical exam reveals tenderness at the superior and/or inferior pole of the posterior calcaneus. Other associated physical exam findings, such as elevated BMI, tight muscle–tendon complexes, and flat feet, should be noted. Occasionally, the tenderness may extend into the Achilles tendon. Radiographs are not necessary but typically reveal the sclerotic and fragmented apophysis (Figs. 14.18 and 14.23). Treatment includes rest from the activity that causes pain. Cryotherapy is helpful after physical activity. Stretching the hamstrings, calves, and foot should be done 3–4 times a day until adequate flexibility is obtained. Subsequently, the stretching should be performed at least once per day, ideally before and after physical activity. Heel cups or lifts shorten the distance from the calf to the heel, thus reducing traction stress. Shoes should be supportive in the arch and fitted appropriately. Excess body weight only adds more stress to the foot and should be avoided. Patients with continued pain warrant referral and radiographic evaluation to rule out bone cysts (Fig. 14.18), tumors, and fractures. In a recent study utilizing MRI, Ogden et al. showed persistent cases resembled more of a metaphyseal stress fracture in the immature calcaneus rather than inflammation of the apophysis [87]. These refractory cases required a casting protocol.

The proximal fifth metatarsal has an apophysis at the attachment of the peroneal brevis tendon. Inflammation of this apophysis is termed Iselin's disease. The patient is point tender at the base of the fifth metatarsal and resisted eversion is painful. The apophysis is best visualized on the AP or oblique view of the foot (Fig. 14.19). An important distinction is the apophysis runs parallel to the shaft of the diaphysis. In contrast, fractures tend to track perpendicular or oblique to the shaft of the fifth metatarsal. Treatment involves relative rest. Immobilization may be necessary with an ankle support orthosis, walking boot, or short-leg cast. Ice therapy and anti-inflammatory medications also may be of benefit. Therapy is directed at calf and plantar fascia flexibility and strengthening of the peroneals. Narrow shoe wear should be avoided. The condition responds to conservative treatment and rarely results in long-term pain or problems.

Anterior and Posterior Impingement

Anterior impingement refers to entrapment of anterior ankle joint structures with repetitive dorsiflexion. The condition occurs commonly in young elite-level gymnasts and cheerleaders participating in repetitive high-velocity tumbling. Landing "short" with tumbling and dismounts forces the ankle into maximal dorsiflexion. It has been reported in young dancers, football players, and soccer participants [70, 88]. Soft tissue structures including the ankle synovium and/or capsule may become impinged and cause pain. This is usually medial or lateral and in the sulcus. Calcific deposits, spurring, and cartilage injury accrue on the tibia and talus and often precede the clinical impingement. The athlete presents with anterior ankle pain. Passive dorsiflexion reproduces the pain, and tenderness is localized. Weakness around the ankle may be appreciated, and heel cord tightness and ankle instability have been associated with the condition [70, 88]. A lateral projection of the ankle in maximal dorsiflexion may allow visualization of anterior talotibial bony impingement. Bony osteophytes may be present. MRI can further visualize the inflamed structures as well as associated intra-articular loose bodies and lesions [89, 90]. Treatment of the condition initially begins with avoiding the activities that exacerbate the pain, cryotherapy, and anti-inflammatory medications. Gentle stretching of the heel cord and strengthening the ankle, especially plantar flexion, is recommended. A heel lift may be of benefit. Continued pain requires referral for consideration of arthroscopic debridement of the anterior soft tissue structures and any bony spurs.

Posterior ankle impingement refers to inflammation of the posterior ankle structures (bony and/or soft tissue) related to repetitive ankle plantar flexion. This is a common pain syndrome reported in young gymnasts, ballet dancers, ice skaters, and karate participants. Pain is localized to the posterior ankle. Passive and active ankle plantar flexion is painful, especially with inversion. Plain films often show bony abnormalities if the posterior talus [90]. A lateral radiograph of the ankle in extreme plantar flexion may demonstrate bony impingement. An os trigonum (Fig. 14.18) may be present. MRI demonstrates the posterior soft tissue involvement or bony edema. Often the flexor hallucis longus is involved [90]. Treatment involves relative rest, ice, anti-inflammatory medications, and basic ankle therapy. An ankle support orthotic may assist by limiting plantar flexion. Chronic symptoms unresponsive to non-operative measures undergo ankle arthroscopy for bony resection and soft tissue debridement.

Sesamoiditis

Acute fractures of the sesamoids often have a preceding history of direct or indirect trauma. The sesamoids may also be subject to repetitive stress. Athletes present with the gradual onset of activity-related pain localized to the plantar surface of the 1st MTP joint. The examiner should localize the pain to the tibial or fibular sesamoid. Range of motion at the MTP is limited. Forefoot valgus, rigid pes cavus, and multipartite sesamoids

Fig. 14.24 Normal bipartite tibial sesamoids

have been associated with sesamoiditis. Radiographs of the sesamoids include a lateral, axial sesamoid, and medial oblique view. Radiographic interpretation can be challenging because up to 25% of the population has bipartite sesamoids. This finding is frequently bilateral and is more common in the tibial sesamoid (Fig. 14.24). Bipartite fragments typically have smooth sclerotic margins. Irregular fragment margins may be visible with either acute fractures or stress fractures. Treatment of sesamoiditis involves relative rest and immobilization if necessary. A J-shaped pad may help to de-weight the painful sesamoid. A stiff last can help by limiting motion at the MTP. The diagnosis of a sesamoid stress fracture should be considered in patients with continued pain. Bone scan or MRI may assist with this diagnosis. For patients with refractory symptoms, excision, partial excision, or bone grafting is performed, depending on the findings at surgery.

Reflex Sympathetic Dystrophy

Complex regional pain syndrome (CRPS), or reflex sympathetic dystrophy (RSD), is a medical condition involving chronic musculoskeletal pain, often with accompanying autonomic dysfunction. It is more common in females and most cases involve the lower extremity, including the legs, ankles, or feet [10]. It typically follows a minor injury such as an ankle sprain or overuse syndrome. The pain is clearly out of proportion to the injury and is often difficult to localize. The child or adolescent appears tender "everywhere" around the affected extremity. The individual may complain of "burning," "stinging," or "tingling." The skin may show color changes, temperature differences, or abnormal sensation compared with the opposite side. Muscle atrophy is often present with chronic lack of use. The injury responds poorly to typical treatment modalities. Social issues or psychological stressors may be present. The evaluation must be exhaustive to rule out significant underlying pathology or injury. A basic laboratory evaluation helps to exclude an inflammatory or infectious process. Treatment includes aggressive physical therapy, cognitive behavior therapy, and, occasionally, medications such as antidepressants. Immobilization and inactivity make the condition worse. Anti-inflammatory medications may be used initially as one would prescribe for the initial injury. The child is encouraged to participate fully in expected school activities. Children typically recover from the condition, but recurrence may occur.

Developmental and Related Conditions

Osteochondroses

Osteochondrosis disorders are unique to the maturing skeleton. These conditions are thought to be caused by repetitive stress and disruption to the vascular supply of the bone [91].

Kohler's disease of the tarsal navicular is more common in males and affects children between 4 and 6 years of age [68, 91]. The child presents with

Fig. 14.25 Kohler's disease of the navicular

Fig. 14.26 Freiberg's infarction of the 2nd metatarsal head

the insidious onset of midfoot pain. Tenderness is localized to the medial aspect of the foot and most pronounced over the navicular bone. Gait is often antalgic and toe raises are painful. Basic radiographs demonstrate the sclerotic, narrowed, and sometimes fragmented navicular bone (Fig. 14.25) [19, 68]. Treatment involves a 4–12-week period of immobilization in either a walking boot or short-leg cast. Weight bearing is allowed. The condition is self-limiting, and the goal of treatment is symptom resolution [88, 91]. Radiographic healing can take 6–12 months or longer.

Freiberg's infarction most commonly involves the second metatarsal head. Typically, the condition affects adolescent females in the second decade of life [19, 35, 68, 91] and is more common in athletic individuals [92]. Tenderness is localized over the metatarsal head involved. Swelling is present, and range of motion at the MTP joint limited. Early in the condition, the radiographic findings may be subtle and only show some flattening of the metatarsal head (Fig. 14.26) or slight sclerosis in the bone. Later, there is further sclerosis, fragmentation, and narrowing of the MTP joint. Prompt diagnosis is important to try to preserve the structure of the metatarsal head and the MTP joint function [68]. Initial treatment involves a walking boot or short-leg cast with a toe plate to reduce pain. Weight bearing is allowed, but activities must stay below the level of discomfort. Patients are transitioned to a stiff last orthosis to limit motion of the metatarsal head. Surgery is reserved for those with persistent symptoms or presenting late in the disease course [35, 68, 88].

Flat Feet

Flat feet (pes planus) are common in young athletes. The arch of the foot is primarily formed and stabilized by the bones and ligaments [68, 91].

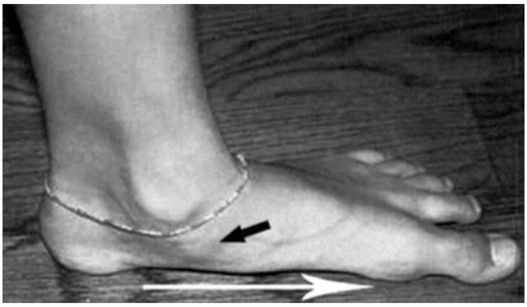

Fig. 14.27 Moderate relaxed flat foot deformity with no arch (white arrow) and talar head sag (black arrow)

A "flat" foot refers to a loss of the normal longitudinal arch of the foot (Fig. 14.27). The condition is universal in children under the age of 3 years and relates to ligamentous laxity through the foot and interposition of fat in the arch [68, 91]. Children can "develop" an arch up through the first decade of life with most present by the age of 6 years [93–95]. The condition is more common in individuals with ligamentous laxity. Expensive shoes and orthotics will not influence the development of an arch [91, 93]. Flat feet have been associated with conditions such as medial tibial stress syndrome, lower leg stress fractures, and knee pain. Associations also include ligamentous laxity, elevated BMI, and male gender [95]. The critical aspect of the examination is to determine if the foot is flexible or rigid. A flexible flat foot forms an arch when non-weight bearing and when completing a toe raise (Fig. 14.28). Gross inspection of the patient weight bearing can determine the severity of the flat foot. A valgus deformity of the hindfoot in combination with a flat foot is termed a "planovalgus" foot. With toe raise, the hindfoot should move into neutral or varus (Fig. 14.28). The medial border of the foot is observed for the degree of talar head sag (Fig. 14.27). As the medial border of the foot becomes more prominent with severe deformities, the lateral border of the foot will appear more concave in contour. Subtalar and midfoot motion should be assessed to rule out a tarsal coalition. Standard radiographs are obtained in patients with painful or rigid flat feet. Weight-bearing films demonstrate the true functional and anatomic relationship. In younger athletes with a flexible but painful flat foot, conservative treatments include relative rest, supportive shoe wear/orthotics, and physical therapy. Persistent cases in the later adolescent years should be referred to a specialist for evaluation and possible surgical intervention. Good results have been seen, including return to sports, in patients undergoing surgical correction [95].

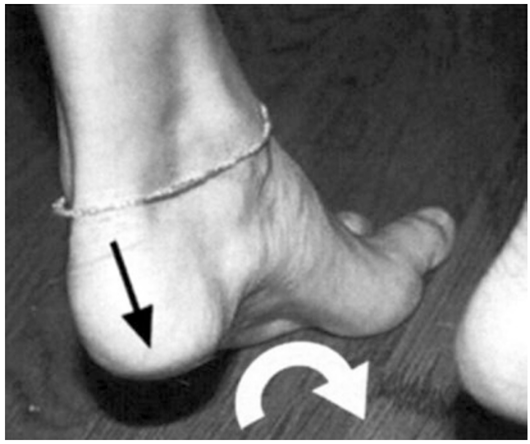

Fig. 14.28 Normal foot motion with toe raise-hindfoot varus (black arrow) and arch formation (white arrow)

Tarsal Coalition

Tarsal coalition is a condition in which two or more of the tarsal bones develop together or fail to separate. This connection can be cartilage, fibrous tissue, or bone. The condition is bilateral in approximately 50% of patients [19, 68, 91]. Most coalitions involve the calcaneus and the navicular (calcaneonavicular) and the talus and calcaneus (talocalcaneal) [12, 13, 91]. The etiology of the coalition is unknown. A failed differentiation of mesenchymal tissue has been proposed [91, 96]. The coalition limits the normal subtalar motion. Pain often develops in the second decade of life, corresponding with sport-related demands, increased body weight, and the period when the coalition typically ossifies [68, 96]. Participation in sports involving running, jumping, and cutting place a tremendous stress on the subtalar complex. Tarsal coalition should be considered with recurrent ankle sprains or foot/ankle pain seen with flat feet; it is often associated with rigid or

Fig. 14.29 Oblique projection of the foot demonstrating a calcaneonavicular bar

Fig. 14.30 Lateral projection of the foot demonstrating a calcaneonavicular bar (the anteater sign)

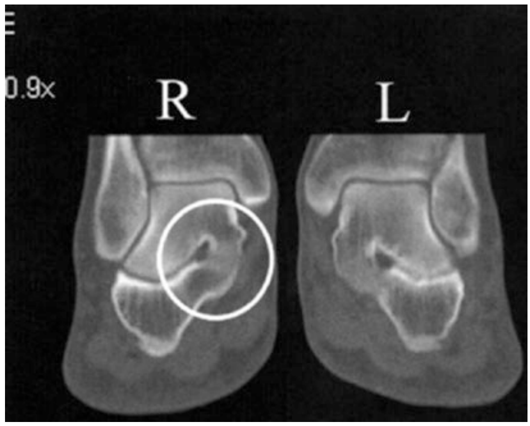

Fig. 14.31 CT of the foot demonstrating a bilateral talocalcaneal bar (right circled)

stiff flat feet. Thus, motion in the hindfoot and subtalar joint is limited. The arch will not be present with toe raise, and the athlete is unable to walk on the lateral border of the foot. Pain is typically non-specific and diffuse through the hind and midfoot. Peroneal and calf muscle tightness may be present. In cases of talocalcaneal coalition, a "fullness" below the level of the medial malleolus may be present—the double medial malleolus sign [97]. Standard three-view radiographs demonstrate the calcaneonavicular coalition best on the oblique projection (Fig. 14.29). The lateral view may demonstrate the elongation of the talar head, the so-called "anteater" sign (Fig. 14.30) [91]. The talocalcaneal coalition is more difficult to appreciate on standard radiographs, except for early degenerative changes throughout the foot related to the abnormal biomechanics. When radiographs fail to demonstrate the coalition, further investigation is warranted. Both CT and MRI have advantages [19, 68, 91]. CT can best detect bony coalitions, particularly talocalcaneal bridges (Fig. 14.31). MRI is superior in detecting fibrous or cartilaginous connections.

Non-operative measures should be attempted to reduce pain and allow sports participation. Immobilization in a short-leg cast or walking boot can be utilized to reduce pain. Physical therapy can address associated muscle tightness or weakness. A custom foot orthosis and ankle support orthotic can be used to support the ankle and subtalar complex. Referral is warranted for athletes with continued symptoms. Surgery typically involves bar resection and fat or other soft tissue interposition [68].

Accessory Bones of the Foot

Young athletes with a symptomatic accessory navicular bone present with pain along the medial aspect of the foot. Pain is often gradual in onset with no known preceding trauma. Weight gain, arch collapse, sports participation, injuries, or narrow shoe wear may all aggravate the condition. Accessory navicular bones are frequently bilateral, which can help if there is trauma and question of a fracture. A tender prominence is noted in the proximal medial arch. Swelling and redness may be present. Resisted inversion and a single-leg toe raise are often painful because of posterior tibialis inflammation. Radiographs are diagnostic, and the accessory bone is best appreciated on the AP or oblique view (Fig. 14.32). Non-operative treatment includes relative rest, ice, and anti-inflammatory medications. Shoe wear or orthotics with a supportive medial wedge may help. Restrictive or tight shoes are discouraged. A brief period of immobilization in a cast or walking boot may be required to settle down the pain and inflammation. Adults with the condition rarely have symptoms [91]. Surgery is reserved for patients with continued symptoms. Removal of the accessory bone and, in some cases, advancement of the posterior tibialis tendon to the remaining navicular bone are the standard surgical management [91].

Fig. 14.32 Accessory navicular bone

The os trigonum is the most common accessory bone in the foot. This ossicle forms at the posterior aspect of the talus and ossifies early in the second decade of life. These bones can become symptomatic in athletes who participate in sports involving repetitive ankle plantar flexion or inversion (i.e., ballet, gymnastics, dance, and soccer). The pain often is a result of overuse-related mechanical posterior ankle impingement. This impingement can be bony or soft tissue related. The diagnosis is difficult because many structures can cause pain in the posterior ankle (i.e., peroneal tendons, flexor hallucis longus, Achilles tendon, retrocalcaneal bursa, etc.) and because the unfused os trigonum can be seen in up to 10% of the general population. The athlete presents with posterior ankle pain that is worse with maximal ankle plantar flexion. Direct or medial/lateral compression tenderness may be elicited. Drawer testing may show instability creating the specific symptoms. The lateral radiograph will demonstrate the bony ossicle posterior to the talus (Fig. 14.18). A lateral view with the ankle in maximal plantar flexion may demonstrate impingement. Treatment involves avoidance of pain-producing positions, cryotherapy, and an anti-inflammatory. Immobilization may be necessary initially in a walking boot or ankle-stabilizing orthotic. The athlete may not be able to return to optimal participation without surgical resection of the bony fragment.

Adolescent Bunion

Adolescent bunion (also known as juvenile hallux valgus) primarily affects adolescent females. The term "adolescent" bunion infers the growth centers of the foot are still open [91]. In some cases, there is a familial pattern to the disorder. The adolescent may present, because of pain, difficulty with shoe wear or simply cosmetic concerns. Young athletes with

Fig. 14.33 Adolescent bunion deformity. The IMT angle (a) and metatarsophalangeal angle (b) are labeled

a problematic bunion are often involved in sports that require narrow and firm shoe wear or repetitive foot movements, such as soccer, cheerleading, and dance. For young ballet dancers going on point, hallux valgus may be particularly bothersome. The deformity varies in severity. Soft tissue and bursa inflammation develop over the medial prominence. MTP motion is usually full, but rotation causes "pinch" calluses and an abnormal arc of motion. Radiographic evaluation involves weight-bearing AP and lateral projections (Fig. 14.33). The intermetatarsal (IMT) angle and MTP angle are calculated [91]. The IMT angle is normally less than 10° and MTP angle less than 15°. Subluxation of the proximal phalanx on the 1st metatarsal head is a worrisome sign for further progression [91].

Treatment of the condition depends on the severity of the deformity and the age of the child. Milder cases respond to proper shoe wear with medial support and a wide toe box. A stiffer last insert or shoe can help limit motion and pain at the joint. Surgery is reserved for intractable pain, increased deformity, or pain interfering with lifestyle activities in skeletally mature individuals [13]. There is an increased recurrence rate compared to adults.

Prevention of Foot and Ankle Injuries

Prevention of foot and ankle injuries can be divided into external influences and internal influences. External influences include:

1. A quality pre-participation exam
2. Having individuals "walk the field" before practices or games to note uneven playing surfaces or debris on playing fields
3. Proper protection and shoe wear (i.e., shin guards)
4. Replacing old equipment (i.e., running shoes every 300–500 miles)
5. Athletic taping and supportive brace wear
6. Avoiding dangerous recreation equipment (i.e., trampolines)

Of note, most studies have failed to demonstrate a protective benefit of ankle taping or bracing unless a prior injury has occurred [98]. Also, high-top shoes versus low-top shoes have not been found to reduce ankle injuries [35]. Intervention strategies to decrease ankle injuries have been reported in the literature with some success [3, 99–103]. These programs have focused on various braces or taping, as well as tasks such as a structured warm-up, balance training, and practicing cutting, jumping, and landing to improve strength, flexibility, and neuromuscular control.

Internal influences include items such as:

1. Overall fitness level and body weight. Elevated BMI (presumed elevated fat mass) has been linked to prolonged ankle morbidity after an injury and musculoskeletal surgical complications [104, 105].
2. Proper nutrition and healthy lifestyle behaviors.

The challenge with preventive strategies is standardizing these efforts and proving their effectiveness. Education plays a huge role in injury prevention. Young athletes, parents, and coaches should learn topics such as basic injury care and when it is important to seek medical attention. Parents and coaches should understand that if the athlete cannot complete the return to sport tasks, they may worsen the injury if allowed to participate.

Return to Play

Return to sports participation after an injury can be complicated. With acute injuries, the treating physician should be comfortable that the injury has healed sufficiently to begin weight bearing. Certain activities, such as batting or shooting baskets, may even be possible while in a walking boot or cast. When the athlete is ready, a removable splint or foot orthosis will allow physical therapy to improve range of motion and strength and reduce edema. With certain injuries, the athlete will need to work on proprioception as well. When the athlete is walking comfortably with routines of daily living, a prescribed functional return to sport protocol can commence. This is best detailed under the direct supervision of a certified athletic trainer, physical therapist, or physician. The athlete should not feel any "sharp" pain while advancing to more difficult tasks. A prototype progression is shown in Table 14.2. Typically, the athlete should advance as tolerated every 1–2 encounters. The athlete can perform non-sport-specific aerobic activity, such as swimming or stationary biking, before completing the functional task. This will increase blood flow to the extremity and help with cardiovascular endurance when the athlete is ready to return to sport. Directed physical therapy can be continued each day after completing the functional task. Mild discomfort is acceptable. If the symptoms resolve with ice and a night's rest, advancement can continue. If pain is increasing, the athlete should move back to the previous task and allow another 2–3 days before trying to advance again. It is common to have some mild soreness and swelling until the athlete is able to truly take a break from the particular activity. It is also common practice to utilize an ankle-stabilizing orthosis, athletic taping, or foot orthotic, depending on the specific problem for the duration of that particular athletic season to hopefully prevent reinjury. It may be possible for the athlete to advance to a less demanding player position sooner than his or her typical athletic position.

Clinical Pearls

- Remember that fractures to the growth center are more common than ankle "sprains" in young athletes, even with "normal"-appearing radiographs.
- With any ankle injury, it is important not to overlook bony tenderness at the base of the fifth metatarsal and the proximal fibula, as associated fractures can be present.
- Ossification centers can be present on the medial malleolus (Fig. 14.34) and lateral malleolus and should not be confused with fractures.

- The proximal great toe physis may be bipartite, resembling a Salter–Harris type 3 fracture (Fig. 14.35). Clinical correlation is required.
- Nail bed injuries associated with underlying distal phalanx fractures are considered open fractures requiring prophylactic antibiotics and close observation for osteomyelitis.
- The apophysis of the fifth metatarsal runs parallel to the shaft of the bone. Fractures are often oblique or perpendicular to the shaft.
- Flexible, flat feet that are non-painful require no evaluation or treatment.
- Consider tarsal coalition in the young athlete with recurrent ankle "sprains."
- Consider conditions such as juvenile idiopathic arthritis in the young athlete with an ankle effusion or recurrent midfoot pain.
- The 1st metatarsal physis is proximal. All others are distal (Fig. 14.4).
- Deltoid ligament sprains are usually associated with a significant ankle injury and rarely occur in isolation. The examiner should look closely for associated fractures and instability.
- Heterotopic ossification may be present in the syndesmosis after a "high" ankle sprain (Fig. 14.36).
- MRI, rather than bone scan, is utilized with localized tenderness in the evaluation of stress fractures.
- Care should be taken when splinting or casting the foot and ankle, especially in the first 1–2 days after the injury. Compartment syndrome is a potential complication of the injury or the cast/splint.
- Recent studies have documented potential cardiovascular side effects with NSAID usage. Some studies indicate NSAIDS may also impair bone and tissue healing. For these reasons, NSAID usage should be limited to times when acute inflammation and pain control is necessary, ideally at the lowest dose possible and for the shortest duration possible [106–111].

Fig. 14.34 Medial malleolus ossification center

Fig. 14.35 Bipartite proximal great toe physis

Fig. 14.36 Heterotopic ossification in the syndesmosis seen after a "high" sprain

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IOC Consensus Statement on Training the Elite Child Athlete

IOC Consensus Statement on Training the Elite Child Athlete

Protecting the health of the athlete is the primary goal of the International Olympic Committee's (IOC) Medical Commission. One of its main objectives is the promotion of safe practices in the training of the elite child athlete. The elite child athlete is one who has superior athletic talent undergoes specialised training, receives expert coaching and is exposed to early competition. Sport provides a positive environment that may enhance the physical growth and psychological development of children. This unique athlete population has distinct social, emotional and physical needs which vary depending on the athlete's particular stage of maturation. The elite child athlete requires appropriate training, coaching and competition that ensure a safe and healthy athletic career and promote future well-being. This document reviews the scientific basis of sports training in the child, the special challenges and unique features of training elite children and provides recommendations to parents, coaches, health care providers, sports governing bodies and significant other parties.

Scientific Basis of Training the Elite Child Athlete

Aerobic and anaerobic fitness and muscle strength increase with age, growth and maturation. Improvement in these variables is asynchronous. Children experience more marked improvements in anaerobic and strength performance than in aerobic performance during pubescence. Boys' aerobic and anaerobic fitness and muscle strength are higher than those of girls in late pre-pubescence, and the gender difference becomes more pronounced with advancing maturity. Evidence shows that muscle strength and aerobic and anaerobic fitness can be further enhanced with appropriately prescribed training. Regardless of the level of maturity, the relative responses of boys and girls are similar after adjusting for initial fitness.

An effective and safe strength training programme incorporates exercises for the major muscle groups with a balance between agonists and antagonists. The prescription includes a minimum of two to three sessions per week with three sets, at an intensity of between 50% and 85% of the one maximal repetition (1RM).

An optimal aerobic training programme incorporates continuous and interval exercises involv-

L. J. Micheli, L. Purcell (eds.), *The Adolescent Athlete*, Contemporary Pediatric and Adolescent Sports Medicine, https://doi.org/10.1007/978-3-319-56188-2

ing large muscle groups. The prescription recommends three to four, 40–60 min sessions per week at an intensity of 85–90% of maximum heart rate (HRM).

An appropriate anaerobic training programme incorporates high intensity interval training of short duration. The prescription includes exercise at an intensity above 90% HRM and of less than 30 s duration to take into account children's relatively faster recovery following high intensity exercise.

A comprehensive psychological programme includes the training of psychological skills such as motivation, self-confidence, emotional control and concentration. The prescription applies strategies in goal-setting, emotional, cognitive and behavioural control fostering a positive self-concept in a healthy motivational climate.

Nutrition provided by a balanced, varied and sustainable diet makes a positive difference in an elite young athlete's ability to train and compete, and will contribute to optimal lifetime health. Adequate hydration is essential. Nutrition requirements vary as a function of age, gender, pubertal status, event, training regime, and the time of the competitive season. The nutrition prescription includes adequate hydration and individualises total energy, macro- and micro-nutrient needs and balance.

With advancing levels of maturity and competitiveness, physiological and psychological training and nutrition should be sport-specific with reference to competitive cycles. Confidential, periodic and sensitive evaluation of training and nutritional status should include anthropometric measures, sport-specific analyses and clinical assessment.

Special Issues in the Elite Child Athlete

Physical activity, of which sport is an important component, is essential for healthy growth and development.

The disparity in the rate of growth between bone and soft tissue places the child athlete at an enhanced risk of overuse injuries particularly at the apophyses, the articular cartilage and the physes (growth plates). Prolonged, focal pain may signal damage and must always be evaluated in a child.

Overtraining or "burnout" is the result of excessive training loads, psychological stress, poor periodisation or inadequate recovery. It may occur in the elite child athlete when the limits of optimal adaptation and performance are exceeded. Clearly, excessive pain should not be a component of the training regimen.

In girls, the pressure to meet unrealistic weight goals often leads to the spectrum of disordered eating, including anorexia and/or bulimia nervosa. These disorders may affect the growth process, influence hormonal function, cause amenorrhoea, low bone mineral density and other serious illnesses which can be life-threatening.

There are differences in maturation in pubertal children of the same chronological age that may have unhealthy consequences in sport due to mismatching.

Elite child athletes deserve to train and compete in a suitable environment supported by a variety of age-appropriate technical and tactical training methods, rules, equipment, facilities and competitive formats.

Elite child athletes deserve to train and compete in a pleasurable environment, free from drug misuse and negative adult influences, including harassment and inappropriate pressure from parents, peers, health care providers, coaches, media, agents and significant other parties.

Recommendations for Training the Elite Child Athlete

The recommendations are that

- More scientific research be done to better identify the parameters of training the elite child athlete, which must be communicated effectively to the coach, athlete, parents, sport governing bodies and the scientific community

- The International Federations and National Sports Governing Bodies should:
  – Develop illness and injury surveillance programmes
  – Monitor the volume and intensity of training and competition regimens
  – Ensure the quality of coaching and adult leadership
  – Comply with the World Anti-Doping Code
- Parents/guardians develop a strong support system to ensure a balanced lifestyle including proper nutrition, adequate sleep, academic development, psychological well-being and opportunities for socialisation
- Coaches, parents, sports administrators, the media and other significant parties should limit the amount of training and competitive stress on the elite child athlete.

The entire sports process for the elite child athlete should be pleasurable and fulfilling.

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Electronic Supplementary Material

Appendix B: International Olympic Committee consensus statement on youth athletic development

Appendix C: Position statement on youth resistance training: the 2014 International Consensus

Appendix D: The IOC consensus statement: beyond the Female Athlete Triad—Relative Energy Deficiency in Sport (RED-S

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