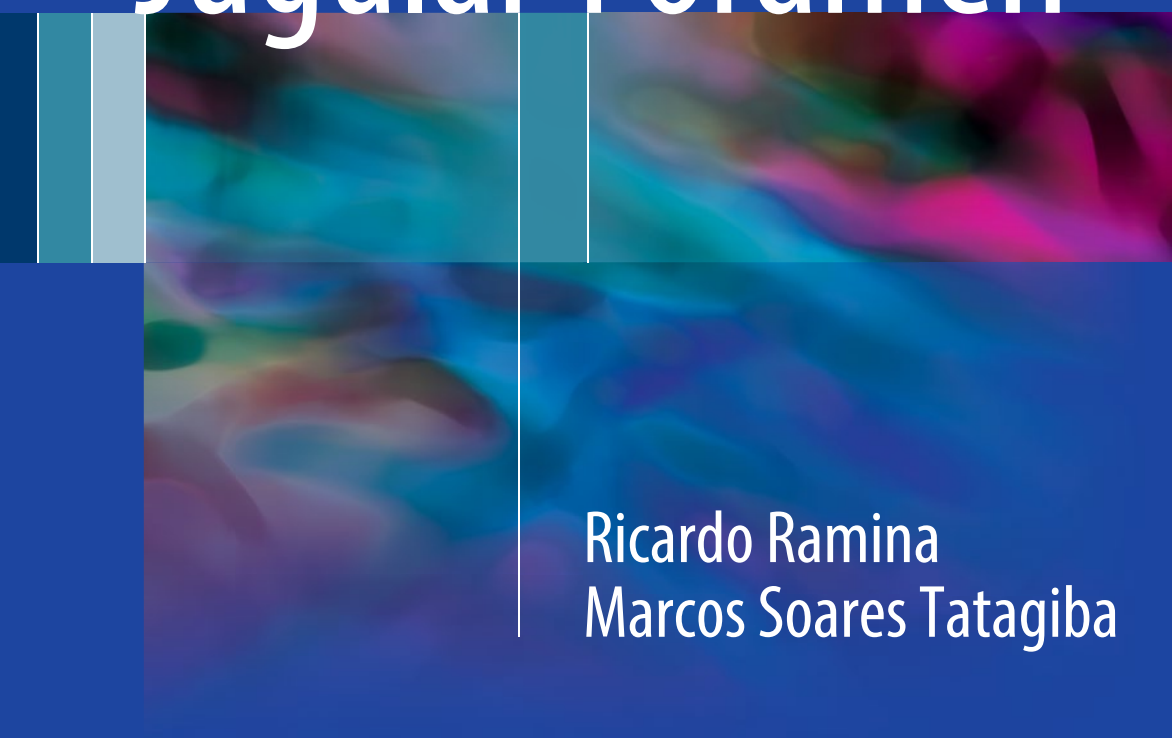
Tumors of the Jugular Foramen



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This book is dedicated to our patients.
Every patient teaches us something.
Something that we are ought to use
to help new patients.

Foreword

The jugular foramen is a special anatomical area of the skull base. It contains the jugular bulb and the vein and the lower cranial nerves 9, 10, and 11. In addition, the cranial nerves 12, and 7, the petrous internal carotid artery, the spino-medullary area, and the cerebrospinal fluid containing intradural space lie close to it. The bony and cartilaginous structures of the craniocervical junction also lie in the vicinity.

Because of the importance of the jugular vein (particularly when it is dominant), the lower cranial nerves, and the critical structures which are nearby, surgery of lesions involving the jugular foramen is complicated, and fraught with morbidity, which may lead to major disability or death. Due to this reason, lesions of this area should be treated in specialized centers and by experienced surgical—endovascular—intensive care teams. Such lesions include neoplasms such as paraganglioma, meningioma, chordoma, chondrosarcoma, schwannoma, and metastatic malignancies; dural arteriovenous fistulas; spontaneous thrombosis and stenosis of the jugular bulb; and traumatic lesions.

Professor Ricardo Ramina and his colleagues from Brazil have developed a special expertise in the treatment of lesions of this area, as reflected by their experience in surgically treating 163 patients. They have achieved international prominence for this surgery and are recognized all over the world for their innovations and expertise. This extensive experience has been translated by them into this monograph, which is focused on the tumors of the jugular foramen.

This book is divided into 13 chapters. These chapters address topics such as historical aspects; epidemiology, genetics, and pattern of spread; surgical anatomy; radiology; evidence-based treatment; preoperative embolization; surgical treatment and postoperative management; clinical examples and videos of individual cases; radiotherapy; pathology; chemotherapy; and surgical results and rehabilitation.

Each chapter is very well written, easy to read, and has an abstract which outlines the points contained in the chapter. The figures, illustrations, and videos are excellent and add greatly to the quality of this book.

It would be very difficult for any one team to accumulate such an extensive experience and expertise in the management of jugular foramen tumors. All young surgeons and surgical teams who are involved in the care of these tumors must read this book. Even surgeons with experience in this area will gain a lot from reading this book.

I congratulate Professor Ramina and his team for producing this excellent book. I am sure that they have labored for countless hours in writing this book, not to mention the experience and expertise accumulated in treating these lesions.

Seattle, WA, USA

Laligam N. Sekhar , MD, FACS, FAANS
William Joseph Leedom and Bennett Bigelow
and Leedom Professor,
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University of Washington

Foreword

It is with great pleasure that I write this preface for the book *Tumors of Jugular Foramen*. It brings me not only joy but also pride that the authors of this book are two of my best pupils who have both reached highest degrees of expertise in the management of skull base surgery in the school where I developed a new surgical philosophy together with my late friend Wolfgang Draf in the 1960s and 1970s.

Among all skull base approaches, the surgery of the jugular foramen triggered a special interest in me due to the high rate of morbidity and, in some cases, mortality. Solving the problems of existing surgical approaches to the jugular foramen was a great challenge, especially at a time when there were no sufficient diagnostic tools, no CT or MRI was available, and no embolization techniques were developed. I recall operating a giant vascular jugular foramen tumor with extreme intra- and extracranial extensions with no option of preoperative embolization. We achieved total removal with good postoperative results in a surgery that lasted 24 h!

Through the years, we have achieved more precise diagnoses with the help of CT and MRT and selective angiography. I am thankful to Anton Valavanis who developed a very sophisticated and safe embolization technique for the reduction of blood supply to the tumors such as large glomus jugulars with enormous vascularization. The intraoperative monitoring introduced for cranial nerves has become a routine procedure in every case.

The continuous cadaver study of anatomy has taught us many possible anatomical variations, and simultaneously we have had a learning curve for the surgical anatomy of different types of pathologies. We have not only extended our abilities in radical tumor excision but have also managed to avoid possible morbidities particularly through different biological behavior of tumors.

There is no doubt that the jugular foramen region is still a challenging region of the skull base from a surgical point of view. All those neurosurgeons and ENT surgeons wanting to deal with the surgical treatment of all pathological entities of the jugular foramen need to learn the exact surgical anatomy, natural history of different tumors, and all possible morbidities.

I am thankful to Ricado Ramina and Marcos Soares Tatagiba for their efforts in gathering and collecting all existing knowledge about the historical aspect of surgical development, epidemiology, genetic and natural history, clinical symptoms, different classifications, surgical anatomy, indication of conservative and surgical treatments including radio- and chemotherapy, preoperative embolization, and postoperative management. A special chapter is dedicated to surgical results and rehabilitation. With clinical illustrations of various cases and video demonstrations, this book facilitates the understanding of the very complex surgical approaches and the details of the challenging steps of the surgery.

My personal advice to current and future generations of skull base surgeons is

SURGICAL RESULTS SHOULD BE BETTER THAN NATURAL HISTORY OF THE PATHOLOGY.

I would like to congratulate Ricardo Ramina and Marcos Soares Tatagiba for their achievement, publishing such a valuable document for coming generations. This book is another contribution to the further development of skull base surgery.

Hannover, Germany
July 2016

Madjid Samii, MD, PhD
President of the International Neurosciences
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Preface

Jugular foramen tumors, once considered to be one of the most difficult skull base lesions to be resected, are now becoming manageable with reasonable morbidity and mortality rates. These lesions are deeply located and involve highly complex neurovascular structures. A plethora of pathological conditions are encountered in this region. The recent achievements in neuroradiology, molecular biology, and genetics have contributed to a better understanding of the natural history and biological behavior of these tumors. The innovations in computed tomography, magnetic resonance imaging, and digital subtraction angiography have increased our ability to diagnose and delineate the extension of the disease. The well-coordinated multidisciplinary surgical approach to these challenging tumors, added to the parallel advances in the fields of interventional neuroradiology, neuroanesthesiology, neuroelectrophysiology, and neurointensive care, has revolutionized the management of these lesions. In spite of all these achievements, surgical removal of jugular foramen tumors remains a challenge for neurosurgeons and ENT surgeons. Therefore, multimodal treatment that includes radiotherapy or radiosurgery, as well as chemotherapy in selected cases, will complete the armamentarium to manage these complex lesions.

This book attempts to address the issues of historical aspects, epidemiology, surgical anatomy, diagnosis, surgical techniques, and postoperative management of these tumors. The results of a series of surgically treated patients and clinical examples as well as videos of the surgical technique are presented.

We would like to acknowledge the masters in skull base surgery who have had a personal influence on our career: Dr. Madjid Samii, neurosurgeon, and Dr. Wolfgang Draf, ENT surgeon, whose teaching, encouragement, and thoughts stimulated us to manage the most challenging lesions at skull base.

Curitiba, Brazil — Ricardo Ramina, MD, PhD
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Success is no accident. It is hard work, perseverance, learning, studying, sacrifice and most of all, love what you are doing or learning to do. Pelé—Brazilian most successful soccer player, three-time World Cup Champion, considered by many to be the greatest soccer player of all time.

Acknowledgments

First and foremost, I wish to express my grateful thanks to all contributors who made possible this book become a reality, especially the staff of the Neurological Institute of Curitiba (INC), Brazil: Dr. Mauricio Coelho Neto for participating in a large number of surgeries and performing intraoperative neurophysiological monitoring; Dr. Lucas Aurich and Dr. Tiago Scopel for helping with the anatomical dissections; Dr. Erasmo Barros da Silva Jr. for the drawings; Dr. Teresa Cristina Santos Cavalcanti, pathologist for the histological images; and Mrs. Marli Ataka Uchida, scientific secretary, for reviewing the texts.

I would like to express my deepest appreciation to Dr. Yvens Barbosa Fernandes and Dr. Jorge R. Paschoal from the State University of Campinas, UNICAMP, for performing with me many jugular foramen surgeries.

I wish to express my sincere thanks to Prof. Dr. med. Bernhard Hirt, Director of the Clinical Institute for Clinical Anatomy of the Eberhard Karls University, for organizing all logistic facilities for the anatomical dissections in Tübingen, Germany.

It is a genuine pleasure to express my deep sense of thanks and gratitude to Prof. Dr. João Jarney Maniglia for his dedication, inspirations, and sharing with me his ENT surgical expertise, during the several hours we have spent operating the most complicated jugular foramen tumors.

To Roberta Braga, thank you for encouraging me with this project and still loving me even when I could not dedicate any time to you while researching and writing this book.

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Contents

Chapter 1
Introduction

The jugular foramen is deeply located at the cranial base, contains important neurovascular structures, and is in close relation to vital structures of the brain and neck. Tumors that develop in or around the jugular foramen (JF) are rare, mostly benign, deeply located, involve or embed vessels and cranial nerves, and very often highly vascularized. These characteristics pose significant difficulties in diagnosis, management, and rehabilitation. In the past, these lesions were considered inoperable and the lack of adequate diagnosis, surgical strategies, and postoperative care made prognosis of patients with benign jugular foramen tumors very poor. In spite of all diagnostic and surgical developments in the last decades, radical removal of large jugular foramen lesions with preserving the involved neurovascular structures remains a challenge. A wide variety of tumors can affect the JF, the most common are: paragangliomas, schwannomas, meningiomas, chordomas, chondrosarcomas, metastases, and primary bone tumors [1]. Bone tumors are uncommon and include a large number of neoplasias as giant cell tumors, aneurismatic bone cysts, plasmocytomas, osteoblastomas, and others. Some of these tumors like giant cell tumors and plasmocytomas of the jugular foramen may present with pulsatile tinnitus, hearing loss, and on otoscopy a hypervascular mass can be observed behind the tympanic membrane. The most frequent tumor arising in the JF region is paraganglioma. They have been called chemodectomas, nonchromaffin tumors, and glomus tumors. These tumors develop from neural crest tissue (paraganglia) and may arise sporadically. They can be familial with autosomal dominant inheritance and incomplete penetrance and as part of a genetic syndrome [2]. Familial cases of paragangliomas present higher incidence of multicentricity [3]. Paraganglia or glomus bodies are small masses developed from the neural crest. Guild [4], in 1941, was the first to describe carotid body-like structures in the temporal bone called them "glomus jugulare body." In the jugular bulb they are found in the adventitia of the jugular bulb beneath the floor of the middle ear, in the bony walls of the tympanic canals associated with the auricular branch of the vagus nerve (Arnold nerve) or the tympanic branch of the glossopharyngeal nerve (Jacobson nerve). In the head and neck region they can be found close to the mucosal lining of the middle ear

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in the ciliary ganglion, the ganglion nodosum of the vagus nerve, and in the walls of large arteries [5]. Paragangliomas rarely release catecholamines [6]. Hypertension, headache, arrhythmias, nausea, and palpitations may occur when the tumor secretes catecholamine; these symptoms must be preoperatively recognized to avoid morbidity or even mortality. Perioperatively, these patients should be treated with alpha adrenergic blockade to normalize blood pressure and eliminate episodic hypertension. Alpha adrenergic antagonists like phenoxybenzamine, and more selective α1 antagonists like prazosin, are used one to two weeks prior to surgery. Beta blockade is rarely used. Beta blockade before establishment of α blockade may result in myocardial infarction, organ ischemia, and death from unopposed α agonism [6].

Paragangliomas are more frequent in the jugular foramen region (glomus jugulare), the middle ear (glomus tympanicum), and along the course of the vagus nerve (glomus vagale). Rosenwasser [7, 8], in April 1942, operated on a patient with a bleeding mass in the middle ear and the ear canal. Histologically this tumor was identical with the benign carotid body tumors. In 1945, he published the first description of a middle ear paraganglioma and associated these tumors with the glomus jugulare bodies [7]. Alford and Guilford [9] classified these lesions as glomus tympanicum and glomus jugulare tumors.

Schwannomas are the second more frequent neoplasia in the jugular foramen. They are usually benign, noninfiltrative lesions [1, 10, 11]. Primary meningiomas of the jugular foramen are rare and only small series have been reported in the literature. These tumors arise from arachnoid cells in the jugular bulb and may infiltrate surrounding bone and nerve tissues [12]. In our series of jugular foramen lesions 13 patients had meningiomas [13]. Four patients presented malignant or aggressive tumors (3 anaplastic and 1 papillary). One patient developed a radiation-induced malignant tumor after subtotal resection followed by radiotherapy for a benign meningioma in other institution. Chordomas and chondrosarcomas may also originate in the jugular foramen.

Metastatic lesions cause more commonly “classic jugular foramen syndromes” (Vernet and Collet-Sicard syndrome) than paragangliomas or schwannomas [14]. Metastatic adenocarcinomas, melanomas, and renal cell carcinomas may radiologically resemble glomus tumors.

Management of each patient with a jugular foramen tumor requires careful and individual consideration. These tumors, once considered to be one of the most difficult skull base tumors to remove, are now managed with reasonable morbidity and mortality rates. The goal of treatment is radical removal with preservation of cranial nerves and vessels. Surgical difficulties are related to the deep location of these lesions, hypervascularization, involvement of cranial nerves (VII, VIII, IX, X, and XI) and vessels like the internal carotid artery and the vertebral artery (VA) and its branches, and the extensive surgical defect due to bone removal from the cranial base and involved dura mater causing CSF leak. Surgical morbidity and mortality are usually associated with damage to the lower cranial nerves.

The multidisciplinary management of jugular foramen tumors by neurosurgeons, ENT-surgeons, and interventional neuroradiologist permits a better understanding of diagnosis, preoperative evaluation, and treatment of these patients.

Radiation therapy as primary treatment, either by gamma knife, stereotactic techniques, or external beam, is recommended by some authors [15–19], but the beneficial effects of radiation therapy remain uncertain [19, 20]. Patients for whom radiotherapy failed to control their disease will present a decade or more after initial treatment with extremely advanced tumors or with excruciating pain caused by osteoradionecrosis of the cranial base. Radiation-induced neoplasm has been described after radiotherapy for benign glomus jugulare tumors [21].

In our opinion, radiotherapy or radiosurgery for benign jugular foramen tumors should be performed only for small tumor remnants that grow in postoperative MRI controls. In elderly patients with poor clinical condition, clinical observation or irradiation therapy may be the treatment of choice.

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Chapter 2
Historical Aspects

The treatment of jugular foramen tumors has always been a challenge to skull base surgeons. These lesions are relatively rare, located near cranial nerves and important neurovascular structures and are very often highly vascularized. These tumors may involve adjacent structures, such as the jugular bulb, carotid artery, the middle ear, petrous apex, clivus, infratemporal fossa, and posterior fossa. Along the years, several studies were conducted including advances in neuroimaging, techniques of endovascular embolization, neuromonitorization, and surgical techniques to achieve safe resection of these tumors with lower rates of morbidity and mortality, which were quite expressive in the past.

Such improvements, once reached, provided a better outcome. Initially it was restricted to the preservation of patient's life, and further it was changed to a better control of bleeding, preservation of cranial nerves function, reduction of the number of surgical approaches needed for a complete resection of the tumor, and better postoperative cosmetic results.

First Descriptions

Valentin (1840) [1] described a small structure resembling a ganglion, in the initial part of the tympanic nerve, suggesting calling it as "Gangliolum Tympanicum" or intumescentia gangliosa.

Krause (1878) [2] demonstrated that this structure was not a ganglion, but a vascular tissue resembling the carotid body and called it "die Glandula tympanica" [3]. It was located between the perineurium and the periosteum in the initial part of the upper tympanic canal. This structure resembled the "carotid gland" (Glomus caroticum), which led Krause to propose the name of "tympanic gland," as reported by Von Lushka (1862) [4].

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Zettergren and Lindstrom (1951) described the findings of Krause in their study as [5]:

> On opening up the canaliculus tympanicum of a human petrous bone, it will be observed that there is a fusiform swelling of the tympanic nerve where it has entered the canal after leaving the petrous ganglion. This swelling is about 4 mm long with a thickness not exceeding 1 mm. When the veins are well filled with blood, its reddish colour makes it resemble a small ganglion (the glangliolum tympanicum); when empty of blood it will have a whitish colour and look like a thickening of the periosteum. – Actually, it is neither the one nor the other. – The substance in question is highly vascularized consisting of a basic framework of connective tissue with elastic fibres. It contains a network of arteries, veins and capillaries. The arteries are branches of the 0.12 mm thick ramulus tympanicus of the ascending pharyngeal artery, which accompanies the tympanic nerve. This highly vascular tissue is characterized by triangular pyramidal or star-shaped perithelial cells of a diameter of 0.007-0.015 mm, varying in number. The nuclei of these cells are about 0.004 mm. Occasionally, such cells may be clustered round winding vessels in tubular formations suggesting the structure of the carotid body. Like the latter and the pineal body, the gland-like organ represents a relic of the history of evolution. To distinguish the tympanic gland formation from the so-called lymph node of the cavum tympani, it may be termed the glandula tympanica branchialis.

These studies have been widely referenced and followed in old handbooks. But, in 1932, the descriptive study of Watzka [6], using four human fetuses, two neonates, two adult guinea pigs, and a 57-year-old woman, categorically denied the existence of these structures. Therefore, the references work of Valentin and Krause disappeared almost completely from the literature.

First Definitions

In 1941, during the American Association of Anatomists meeting in Chicago, Guild SR [7, 8] (Fig. 2.1) had rediscovered the nonchromaffin paraganglioma of the jugular bulb and described the glomus tissue as an ovoid body flattened in the adventitia

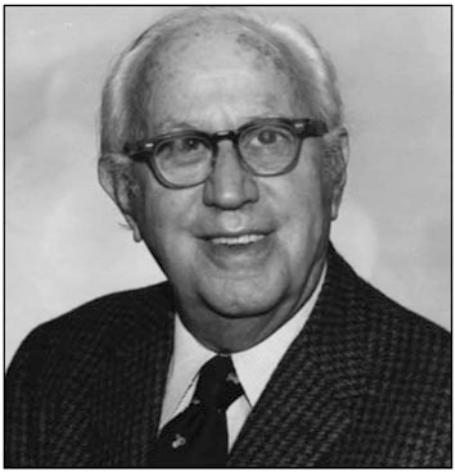

Fig. 2.1 Stacy Rufus Guild, PhD (1890–1966) (from Bordley JE. Ann Otol Rhinol Laryngol 1966)

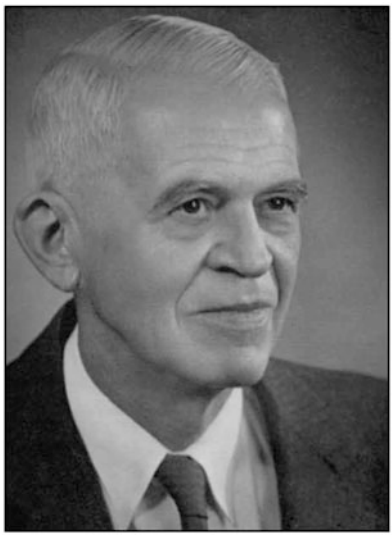

Fig. 2.2 Harry Rosenwasser, MD (1902–1987) (from the John Q. Adams Center for the History of Otolaryngology American Academy of Otolaryngology and Head and Neck Surgery)

of the dome of the jugular bulb, and called these bodies of glomus jugulare. This paraganglionic structure was comprised of capillaries or pre-capillaries interspersed with a number of epithelial cells found along the jugular bulb. In a process of sectioning human temporal bones, Guild reported 50 % of this tissue in the jugular bulb. Approximately 25 % was found over the course of the tympanic branch of the glossopharyngeal nerve (Jacobson's nerve) and 25 % was found throughout the auricular branch of the vagus nerve (Arnold's nerve). This aspect explains the existence of "glomus tumors" that occurred both in middle ear (glomus tympanicus tumors) and in the region of the jugular bulb (glomus jugular tumors).

Rosenwasser H (1952) (Fig. 2.2) [9] described the removal of a tumor with severe bleeding from the middle ear, which protruded to the external ear. The histological analysis of tumor proved to be a lesion similar to those found in benign tumors of carotid bodies. In 1945, he published the first description of a paraganglioma of the middle ear and associated these tumors with the glomus jugulare bodies.

Rosenwasser (1952) [10] was the first to suggest a possible relationship between the glomus jugulare and tumors of carotid bodies in the temporal bone. The designation "glomus jugulare tumors" was firstly mentioned by Lattes and Waltner (1949) [11].

The treatment of the jugular foramen tumors has evolved over the years. The inaccessibility of the jugular foramen due to its deep location, and the proximity of cranial nerves and vital vascular structures turn tumors arising in this region extremely challenging, and surgery was often associated with a poor outcome.

Surgery in the 1930s was primarily conducted through a suboccipital approach with removal of bone around the jugular foramen to avoid excessive bleeding [12]. Subtotal resection followed by radiation therapy was generally performed [13, 14]. In the postoperative period the majority of patients had paralysis of lower cranial nerves.

The mobilization of the facial nerve in order to offer a better access to the jugular foramen was first described by Capps (1952) [15] combined with proximal and distal control of sigmoid sinus and jugular vein. However, the attempts to remove the jugular bulb ended with excessive bleeding and poor results.

Chemoreceptor Function

De Castro (1926) [16] was the first to suggest that the carotid body had a chemoreceptor function. Later works of Heymans and Bouckaert (1939) [17], Schmidt and Comroe (1940) [18], and Dripps and Comroe (1944) [19] verified and confirmed the suggestion of de Castro, not only regarding to the chemoreceptor function of carotid paraganglioma, but also certified the existence of this function in paraganglion aorticum. These structures are sensitive to changes in pH and in oxygen and carbon dioxide tensions in circulating blood. Under certain conditions they may be of greater importance in the regulation of breathing. It is also interesting to note that Christie, in 1933 [20], showed that the carotid paraganglioma does not contain epinephrine.

Diagnostic and Treatment Refinement

In the 1960s and 1970s, the advent of a better surgical technology has resulted into most accurate diagnosis and better surgical results. These innovations included the surgical microscope, techniques of tumor dissection with microsurgery, bipolar electric cautery, safer neuroanesthesia, arteriography and embolization [21, 22], retrograde venography of the jugular vein [23], computed tomography (CT) [24], and magnetic resonance imaging [25].

Classifications

Surgical removal of glomus tympanicum tumors, with hearing preservation, was first proposed by House and Glasscock [26]. In 1969, McCabe and Fletcher [27] proposed that the size and extent of the tumor would be the determining factors for the choice of a more appropriate surgical approach. Soon after, new classification schemes have been proposed by Fisch [28] and by Jackson et al. [29] based on the size of the tumor, intracranial extension, and surgical viability.

Various classifications for paragangliomas were proposed. The most used were those described by Jackson and Glasscock (1982) [29] and by Fisch (1978) [28]. The Fisch classification was changed in 1981 to include tumors with intracranial extensions.

Ramina et al. (1988) [30] have formulated the Classification of Curitiba with the advantage, over the other classifications, of anticipating surgical difficulties that would be encountered, in addition to being easy to remember, based on the location and extent of the lesion, according to the authors conception.

Evolution of Surgical Technique

During the 1950s, several authors made efforts to treat glomus jugulare tumors, ending in disappointing results in the majority of cases [13, 31]. The complex anatomy of the region of the jugular bulb and the risk of hemorrhage during tumor dissection, in combination with the lack of studies of high definition images to elucidate tumor margins, were significant limitations at that time. In 1951, Weille and Lane [12] suggested the removal of the bone which surrounds the tumor to reduce intraoperative bleeding. Their approach did not take into account that the removal of the jugular bulb was an important risk of hemorrhage from the inferior petrosal sinus.

In the same year, Semmes [32] operated on a patient with a glomus jugulare tumor through the suboccipital approach and reported this case in 1953. Even resecting all the tumor of the posterior fossa, no attempt was made to remove the lesion extension in the mastoid or in middle ear. A year later, in a series of five cases of glomus jugulare tumor reported by Capps [15] one of these patients (the first one) was subjected to an extensive surgical resection. It consisted on the mobilization of the facial nerve (this maneuver had not been described previously), gaining proximal and distal control of the sigmoid sinus and jugular vein, followed by an unsuccessful attempt to remove the jugular bulb. The postoperative complications observed with this patient made Capps to treat the other four patients with radiation therapy alone.

Albernaz and Bucy (1953) [31] reported on the case of a patient with compression of the jugular foramen and hearing loss. The case drew attention to the non-visualization of the tumor at the opening of the dura mater, with abnormalities in the lower cranial nerves and after the local manipulation the patient suffered a cardiac arrest during closure. Only the autopsy revealed a glomus jugulare tumor of 1.0 x 2.0 cm.

Shapiro and Neues (1964) [33] reported their experience with a patient showing recurrent glomus jugulare tumor. They performed a complete resection of the tumor, with the removal of the jugular bulb and translocation of the facial nerve. Unlike previous reports, there was minimal loss of blood with good neurological outcome. Gejrot [23] described a similar procedure performed in 1965 in a series of four patients.

These reports were from established baselines to contemporary surgical techniques. They showed that the extirpation of the tumor, along with the preservation of neuronal function, could be possible. Gejrot [23] gave a fundamental contribution which persists until now as a crucial component of modern surgical treatment of glomus jugulare tumor, stressing the importance of maintenance of the sigmoid sinus medial wall at the jugular bulb, in an effort to protect the cranial nerves running under this wall.

The techniques of preservation of hearing were introduced, mainly by House and Farrior, at the end of the 1960s. House [34] described the removal of the glomus jugulare tumor preserving the bone portion of the auditory canal. This approach does not perform translocation of the facial nerve, exposes the facial recess and the hypotympanum for resection of the tumor. The technique described by Farrior [35], modifying the technique of Shambaugh [36], was very effective for small glomus tumors with medial extension, but was not effective in tumors involving the anterior surfaces and the internal carotid artery.

In the 1970s multidisciplinary approaches of skull base have emerged [29], combining approaches of the lateral skull base with suboccipital craniectomy and mastoidectomy. In 1971, Kempe et al. [37] published a report using suboccipital craniectomy with standard mastoidectomy to remove a tumor that involved both the temporal bone and the posterior fossa. Hilding and Greenberg [38] reported a similar case in the same year including the exposure of the internal carotid artery through the glenoid fossa. Glasscock et al. [39] published their approach using a combination of Shapiro's technique with a wide exposure of the cranial base and the technique of House using the extended facial recess. Gardner et al. [40] detailed a surgical technique in which the combined approach of the lateral base of the skull was used by a multidisciplinary team. Their approach consisted of the following three phases: (1) exposure of the base of the skull through the neck; (2) removal of the bone within the temporal bone and jugular fossa; and (3) removal of the tumor, followed by the reconstruction of the wound.

In 1977, Fisch [28] introduced the infratemporal approach to obtain access to the Internal Carotid Artery in the temporal bone, which was one of the main limitations of previous approaches, bringing more safety in the treatment of larger glomus tumors by controlling the carotid artery. Al-Mefty et al. (1987) [41] described a lateral infratemporal approach combined with a posterior fossa craniectomy to the removal of giant glomus tumors with large intracranial component. This approach allowed to access tumors thought to be inoperable avoiding the need for multiple surgical stages. Al-Mefty and Teixeira (2002) [42] reported the experience treating glomus jugulare tumors and classified them as tumors of complex type that meet one or more of the following criteria: giant size, multiple paragangliomas, malignancy, evidence of secretion of catecholamines, association with other injuries, previous treatment with adverse outcome, radiotherapy, or the adverse effects of embolization. Other modifications to access the jugular foramen using approaches to the skull base were subsequently defended by Bordi et al. [43], Patel et al. [44], and Liu et al. [45].

The Contribution of Tumor Embolization

Despite the improvements in surgical exposure, extreme vascularization of the tumor was still a major challenge during the surgery. The advent of superselective arterial embolization of the jugular foramen tumors published by Hilal et al. (1975) [46]

significantly reduced the tumor vascularization, making surgery safer despite of intraoperative massive bleeding. Murphy and Brackmann (1989) [47] based on the use of preoperative embolization reported a series of 35 patients. They concluded that there was a significant reduction in blood loss and intraoperative time. In addition, the embolization has led to a higher rate of total tumor resection. However, a reduced risk of injury to the cranial nerves was not reached. The morbidity associated with the embolization procedure, the current state of endovascular technology, and experience in interventional radiology have significantly reduced the incidence of stroke and injuries of cranial nerves more seen in the first years of their usage.

The technique for reconstruction of the skull base published by Ramina et al. [48] with rotation of the temporal muscle besides an excellent aesthetic result, also presented a considerable reduction of meningitis and postoperative CSF fistula, avoiding the need for the use of lumbar drain and consequently a shorter hospital stays. The technique was published in 2005 in spite of being used by the authors since 1987.

Radiotherapy and Radiosurgery

The first reports were made in 1973 by Spector et al. [49], who showed that the radiation therapy had relatively little effect on the tumor cells, with the more drastic changes consisting of a marked increase in the connective tissue of the fibrous stroma.

Several other authors have reported that the main effect of radiation therapy is a vascular injury secondary to irradiation [50, 51]. In addition, it has been shown in these studies that the catecholamine secretion is not affected by the radiation application [52].

However, in other studies with preferential radiotherapy an excellent control of the tumor was reached only in rare cases of progression of tumor [3, 53–55].

Two important considerations and worthy of note must be made on the findings of these studies. First, an overwhelming number of patients were followed up for less than five years, and is a well-known fact that recurrent tumors may arise until 25 years after the initial treatment [56]. The second point is that the majority of patients treated with radiation did not present any change in the size of your tumor. Regardless of the limitations of radiation therapy, surgical treatment involves the risks related to the anesthesia and carries the potential risk of injury of cranial nerves. Fractionated irradiation may reduce the risks of actinic complications.

Other irradiation treatment modality that has been currently used is radiosurgery (gamma knife, LINAC and Cyberknife) gamma knife. Foote et al. (1997) [57] published the first report as a preliminary study evaluating the immediate, acute, and chronic toxicity, and the effectiveness of stereotactic radiosurgery in patients with unresectable or partially resected glomus tumors. No acute or chronic toxicity was demonstrated, and eight of nine tumors remained stable in size with mean follow-up of 20 months. Two years later, Eustacchio et al. [58] showed in a series of 10 patients that 40 % of patients presented a reduction of the lesion and the rest remained

unchanged at 36 months of follow-up. In a series published by Jordan et al. [59], in 2000, eight patients had no indication for the surgery and were treated with stereotactic radiosurgery. None of them had an increase of the lesion in 27 months of follow-up and one patient had untreatable vertigo requiring hospitalization. Several other studies have been repeating the same results, i.e., controlling the growth and a minority, with regress of the lesion.

The historical developments in the treatment of the jugular foramen tumors can show us that surgery is the first choice of treatment. The treatment with radiotherapy or radiosurgery remains controversial. So far, there is no conclusive data establishing radiation as the ideal primary treatment for all the jugular foramen tumors. We conclude that radiotherpy can have a significant benefit if the patient is unfit for surgery due to advanced age, clinical condition or has significant risk of injury of cranial nerves. Inoperable or partially resectable lesions may be candidates for treatment with radiosurgery.

The knowledge of the historical evolution of anatomical concepts, diagnosis and management is fundamental to understand the current treatment possibilities of these challenging lesions.

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Chapter 3
Epidemiology and Genetics and Pattern of Spread

Epidemiology and Genetics

Pheochromocytomas are the majority of paragangliomas tumors, and according to the World Health Organization these tumors are classified as neuroendocrine tumors. Ninety percent of all pheochromocytomas are adjacent to the adrenal gland and only 0.3 % of all paragangliomas are located in the head and neck. They can also be found in other areas of the body as the aortic arch, larynx, nasal cavity, and orbit. Sixty percent of the paragangliomas in the head and neck are carotid body tumors. It is the most common tumor of the middle ear and the second most common temporal bone tumor [1]. Jugulotympanic paragangliomas are the most frequent jugular foramen tumor with an estimated annual incidence of 1 case per 1.3 million people. They originate from the auricular branch of vagal nerve (Arnold's nerve) or from the tympanic branch of glossopharyngeal nerve (Jacobson's nerve). Paragangliomas of the vagal nerve are rare, and tumors restricted to the middle ear are called glomus tympanicum, occurring most frequently in middle aged adults, with a female to male ratio of 4:1. A small number of cases produce significant levels of catecholamines (dopamine, norepinephrine, and 5-hidroxytriptamin) resembling a pheochromocytoma [2–5].These tumors require special pre-intra and postoperative management. Alfa-blockers are usually used to avoid intraoperative hemodynamic shock.

When there is a familial inheritance they may be multicentric in almost 80 % of the cases. Transmission of paragangliomas is by an autosomal dominant gene [6]. In recent years, researchers have isolated a group of defective genes known as PGL 1, 2, and 3 (also termed the SDH gene), which arise from a familial gene mutation found at the 11q23 locus with an autosomal dominant inheritance pattern. Predisposition genetic syndromes are recognized such as MEN Type IIA and B, von Hippel–Lindau (VHL) disease, and neurofibromatosis type 1 [7, 8]. Four different paraganglioma syndromes (PGLs 1–4) have been described: PGL 1—associated with mutations of the succinate dehydrogenase (SDH) subunit D (SDHD) gene;

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PGL 2—gene susceptibility is unknown, PGL 3—associated with SDHC gene mutations, and PGL 4—SDHB gene mutations [9]. Malignant paragangliomas have been observed with SDHC and SDHD gene mutations, more common in SDHB mutation carriers [10, 11]. Patients with genetic syndromes have lifelong predisposition to develop paragangliomas. Genetic counseling and diagnostic testing should be offered to young patients with diagnosis of paraganglioma.

The majority of paragangliomas are benign, slow growing with mild symptoms. Malignancy is rare and most frequent with carotid body tumors. Approximately 10 % of head and neck paragangliomas and pheochromocytomas are malignant [12]. Usually they are locally invasive but may metastasize to cervical lymph nodes, mediastinum, lungs, and bones.

Jugular foramen schwannomas constitute approximately 2.9–4 % of all intracranial schwannomas [13]. They represent 10–30 % of all tumors observed around the jugular foramen [14, 15]. These tumors commonly occur between third and sixth decades of life. There is a marginal female preponderance with no tumor predilection for the left or right side [16, 17], they grow slowly and it is difficult to identify the nerve that originates the tumor. The most frequent are the vagus and glossopharyngeal nerves. In a review of the literature Bakar found 199 patients in 19 articles published between 1984 and 2007. The nerve of origin was identified in 87 cases [18]. In 47 patients the glossopharyngeal nerve was the nerve of origin of the tumor, the vagal nerve in 26 cases, and the accessory nerve in 11 patients. They may also originate from the hypoglossal nerve and from the sympathetic cervical chain. Jugular foramen schwannomas may be purely intracranial, intra-extracranial (hourglass), or purely extracranial. In the majority of the cases are benign tumors that may be predominantly cystic, solid, or both. These lesions are poorly vascularized, present slow growth causing mild symptoms at the beginning. Jugular foramen schwannomas, as other schwannomas, may be associated with genetic syndromes as neurofibromatosis and schwannomatosis. NF2 is a well-known autosomal dominant disease characterized by bilateral vestibular schwannomas. Three types of NF2 according to clinical presentation and severity are described: Wishart type occurs in childhood or late adolescence and consists of bilateral vestibular schwannomas associated with spinal tumors; Gardner type less severe, patients present bilateral vestibular schwannomas and meningiomas; and mosaic NF2 when a postzygotic mutation occurs and only a portion of the cells carry this mutation. In cases of NF2 half of patients do not have a familial history of the disease.

Several pathogenic mechanisms may explain the molecular biology of vestibular schwannomas: chromosome 22 loss (total loss varies among studies), deregulation of genes, immunogenic factors, NF2 gene mutation, NF2 gene mitotic recombination, DNA methylation, and growth factors [19–25]. Schwannomatosis is characterized by multiple schwannomas but no vestibular schwannomas. The tumor suppressor gene INI1/SMARCB1 on chromosome 22 is a schwannomatosis-predisposing gene. The SMARCB1 gene is mutated in schwannomatosis patients [26].

Primary meningiomas of the jugular foramen are extremely rare [27]. A higher incidence of these tumors was associated with neurofibromatosis. In a review of the literature, Bakar (2008) found 96 patients treated for primary jugular foramen

meningiomas between 1992 and 2007 [18]. The mean age of the patients was 39.4 years with a male/female ratio of 0.4. Most tumors were benign but in our series a high incidence of malignant or aggressive tumors was found [27]. The genetic basis of meningioma development and transformation is not fully understood. In a recent article Pham MH et al. [28] reported that the mutation of the tumor suppressor gene NF2 on chromosome 22q12 is a critical initiating event in the formation of approximately half of all meningiomas. Other genes and pathways involved in meningioma formation and progression are: low levels of TIMP1 and TIMP3 tumor suppressors (associated with invasive behavior), NDRG2 (recurrent meningiomas); loss of chromosome 9p and its CDKN2A, CDKN2B, and p14ARF tumor suppressors (rapid growth and progression), C-sis, c-myc, c-fos, Ha-ras, c-mos, TP73, bcl-2, and STAT3 (high incidence in meningiomas) [28].

Chordomas are rare malignant midline tumors arising from persistent rests of notochordal remnants with an incidence of 0.08 per 100,000. Almost one-third of chordomas have eccentrically positioned extensions [29]. The male/female ratio is 2:1 with a mean age of 46 years [30]. They may occur anywhere from the skull base to the coccyx and constitute 0.2 % of all tumors of the central nervous system. Chordomas are slowly growing, local aggressive, and in almost 80 % of the cases are located in the posterior fossa. Very rarely their origin is in the jugular foramen but jugular foramen chordomas with extracranial extension into the carotid and neck have been described in the literature [31, 32]. They present more commonly during the fourth and fifth decades and in childhood are more frequent found at the skull base. These malignant tumors constitute between 1 % and 8 % of primary malignant bone tumors [33]. Chordoma expresses the transcription factor T, and changes in the T gene have been associated with chordoma. The T gene is involved in the process of making a protein called brachyury which has roles during embryonic development. The brachyury protein is related to the development of the notochord, precursor of the spinal column. Notochord rests may remain in the base of the skull or in the spine causing the development of a chordoma.

Scientists at University College London, Royal National Orthopedic Hospital , and the Sanger Institute reported that over 95 % of caucasian chordoma patients present a variation in the DNA sequence at a particular site on T gene. People with that variation of the T gene are five times more likely to develop chordoma than the general population [34]. Familial chordoma are extremely rare and different chromosomal loci have been identified including 7q33 and isochromosome 1q [35].

Chondrosarcomas are rare malignant tumors that produce cartilage matrix, with estimated incidence of 1 in 200,000 per year [36]. Primary intracranial chondrosarcomas correspond to 0.16 % of all intracranial tumors and 6 % of all skull base lesions [37], and may develop at any age with an average of 37 years [38]. They are exceptionally rare in the Jugular foramen [39]. Derivation from undifferentiated cells from cartilaginous synchondroses has been reported by some authors as the origin of chondrosarcomas [40]. However it is not well known when occurring at this location. Dural invasion occurs in 30 % of cases [37], and distant metastases in 10 % [41].

Described chondrosarcomas subtypes are: conventional (grades I to III), myxoid, clear cell, dedifferentiated, and mesenchymal [42]. Sixty-two percent of the skull

base chondrosarcomas are conventional and the overall survival rates are 90 %, 81 %, and 43 %, respectively, for grades I, II, and III [37, 38]. Mesenchymal chondrosarcomas originate from primitive multipotential mesenchymal cells, manifest usually at a younger age (below 30 years), being more common in females, and constituting 30 % of skull base chondrosarcomas [41, 43]. Dural and cerebral invasion, recurrences, and systemic metastases are not infrequent [37].

Differential diagnosis between chordomas and chondrosarcomas is sometimes difficult since the clinical, radiological, and even histological findings may overlap. Distinction between these two tumors is important due to different treatment strategies and prognosis. In a recent study Kanamori et al. [44] analyzed 7 SBCS specimens for chromosomal copy number alterations (CNAs) using comparative genomic hybridization and examined IDH1 and IDH2 mutations and brachyury expression. They detected CNAs in 6 of the 7 cases with chromosomal gains of 8q21.1, 19, 2q22-q32, 5qcen-q14, 8q21-q22, and 15qcen-q14. Mutation of IDH1 was found in 5 of 7 cases. There were no IDH2 mutations, and immunohistochemical staining for brachyury was negative in all cases. They concluded that these molecular findings are consistent and differentiate chondrosarcomas from skull base chordomas.

Endolymphatic sac tumor (ELST) is a rare, histologically benign but locally invasive and destructive, highly aggressive neuroectodermal neoplasm [45]. They originate in the posteromedial petrous portion of the temporal bone from the endolymphatic sac. ELSTs can arise sporadically or in association with VHL disease. In a literature review Diaz RC et al. found at the time of presentation patients with ages ranging from 17 to 75 years, female/male ratio of 2:1, and 24 % of the cases were associated with VHL syndrome [45, 46]. Histologically proliferation of cuboidal cells forming a papillotubular pattern is observed with occasional colloid-filled cysts. ELSTs usually stain positive for cytokeratin, vimentin, and epithelial membrane antigen [47]. Differential diagnosis includes paragangliomas, metastatic carcinomas, and other intrinsic temporal bone tumors.

Pattern of Spread

Comprehension of the invasion routes of Jugular foramen paragangliomas will help the surgeons to plan the surgical approach and predict the difficulties. These tumors tend to spread around the venous sinuses related to the jugular bulb (inferior petrosal sinus, internal jugular vein, and sigmoid sinus) [48]. From the jugular bulb the tumor can extend to the protympanum, hypotympanum, mesotympanum, and intradural cavity [49, 50] (Fig. 3.1). From the protympanum the tumor may involve the Eustachian tube and the carotid canal extending to the middle cranial fossa and nasopharynx (Fig. 3.2). The antrum, epitympanum, facial nerve canal, mastoid cells, and external auditory canal through the tympanic membrane may be invaded from the mesotympanum. Medially may erode the cochlea and the internal auditory canal. Into the posterior fossa these tumors may spread directly through the dura or along the cranial nerve through the pars nervosa of the jugular foramen (Fig. 3.3).

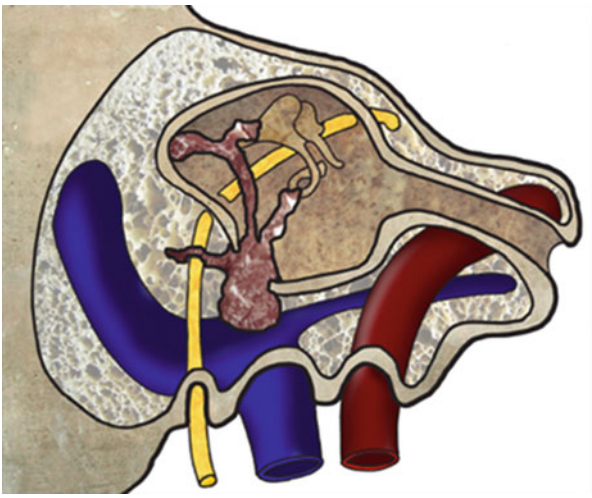

Fig. 3.1 Invasion route of jugular foramen paragangliomas involving the facial nerve and the middle ear through the hypotympanum

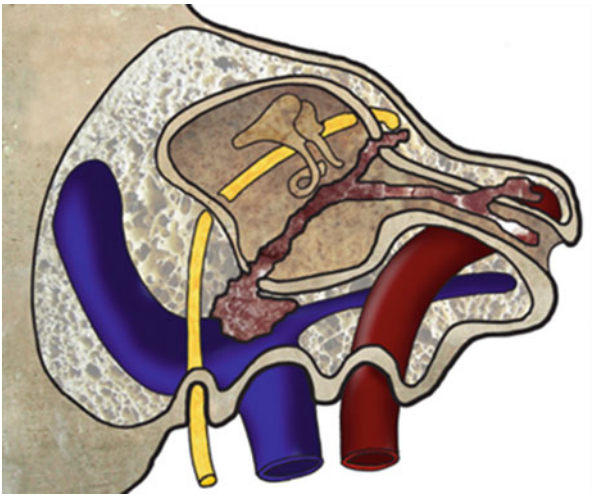

Fig. 3.2 Jugular foramen paragangliomas invading the middle ear, Eustachian tube, and carotid canal

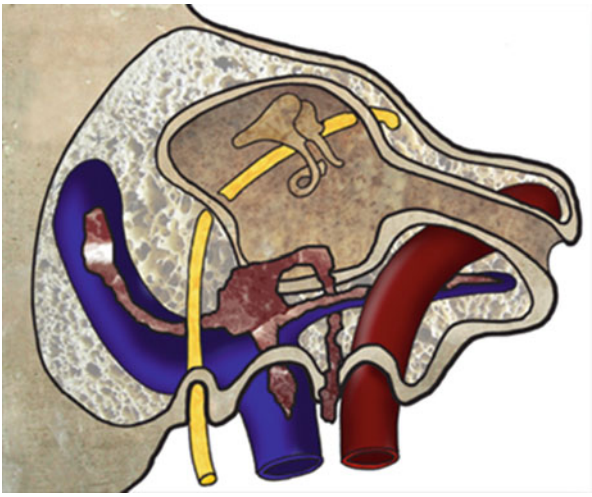

Fig. 3.3 Jugular foramen paragangliomas spreading into the jugular bulb, sigmoid sinus, inferior petrosal sinus, and high cervical region

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Chapter 4
Natural History, Clinical Symptoms, and Classifications

Natural History

The natural history of jugular foramen tumors depends on the histological diagnosis of the lesion. Paragangliomas present in the most cases a very slow growth rate. Within a mean follow-up period of 4.2 years Jansen et al. [1] observed in 60 % of head and neck paragangliomas an average increase of > 20 %, and in 60 % a median growth rate of 1.0 mm/year with a median tumor doubling time of 4.2 years. Radiologic progression in the overwhelming majority of tumors was in average less than 1 mm/year [2]. These findings would support the strategy of "wait and scan" as first treatment option in asymptomatic patients. Some studies found in patients with long follow-up a trend toward higher rates of tumor progression [2, 3].

Paragangliomas are in the majority of cases benign, slow-growing tumors and surgical removal is easier to be indicated if the patient presents progressive neurological deficits. Untreated patients, especially the young ones, may in the long term develop cranial nerve palsies due to tumor progression. In these cases, the "wait and scan" policy may lead to tumor infiltration of the lower cranial nerves making surgical removal more difficult or even impossible. Resection of small asymptomatic paragangliomas before they cause nerve paralysis seems advisable. Some paragangliomas present a more aggressive behavior and rarely possible malignancy. Malignant jugular foramen paragangliomas can metastasize to cervical lymph nodes, lungs, liver, spleen, and bone. Patient's age, clinical condition, natural history, and neurological status should be considered into any clinical decision concerning management. Paragangliomas may be part of an inherited autosomal-dominant tumor predisposition syndrome in about 10 % of cases. The affected individual has greatly increased risk (30–50 %) of developing tumors at any or several sites in the autonomic nervous system [4]. Conservative approach with close observation in asymptomatic patients may be a management strategy in those patients with a tumor detected through genetic counseling and screening for carriers in families with paragangliomas [5]. Rarely the tumor secretes catecholamines causing hypertensive crises.

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In these cases care has to be taken during any manipulation such as anesthesia, embolization, and surgery. Treatment of jugular foramen paragangliomas includes surgical removal, radiotherapy, and radiosurgery. Preservation of cranial nerves following radiotherapy and radiosurgery are comparable to observation, and both are superior to gross total tumor resection [1, 2].

Patients with sporadic schwannomas present tumors that are in most cases, benign, slow-growing, and encapsulated lesions. No study on the natural history of jugular foramen schwannomas could be found in the literature. These tumors arise from different cranial nerves (hypoglossal, accessory, vagal, glossopharyngeal, and sympathetic chain) and may produce different clinical symptoms. Several studies evaluating the natural history and growth rates of vestibular schwannomas have been published with different results. The natural history of vestibular schwannomas regarding tumor growth and biological behavior may be compared with schwannomas arising in the jugular foramen. Approximately 40–60 % of vestibular schwannomas do not enlarge during the period of observation [6–10], and those that do enlarge 75–80 % grow at a rate of 0.9–2 mm/year [9]. Growth rate is slower in elderly patients and in 4–12 % spontaneously involution may occur [11]. Malignant schwannomas are very rare and have poor prognosis [12, 13]. Higher grade tumors were more likely to have distant metastases. In 1981, Sordillo et al. published a series of 165 patients with malignant schwannomas of various sites [14]. Forty percent had evidence of neurofibromatosis type 1 and 58 % of patients of this group presented local recurrence and 52 % developed distant metastases to lungs, liver, and bones.

Most studies of natural history of incidental meningiomas have showed that the majority of patients presented minimal growth remaining asymptomatic during the follow-up period. In addition to knowing the natural history, identifying the risk factors for tumor growth is important to plan management of these tumors. Oya et al. [15], in a series of 244 patients with 273 meningiomas managed conservatively, regarded linear tumor growth (2-mm or larger increase in the maximum diameter), and volume increase greater than 8.2 % as significant. Linear growth was observed in 44.0 % with a mean follow-up of 3.8 years. Factors related to tumor growth were: age of 60 years or younger, absence of calcification, T2 signal hyperintensity in MRI, and edema. Volumetric growth was seen in 74.0 % of the cases. Factors associated with a higher annual growth rate were: male sex, initial tumor diameter greater than 25 mm, MR imaging T2 signal hyperintensity, presence of symptoms, and edema. The natural history of skull base meningiomas is not well known and few studies have addressed this matter [16]. Van Havenbergh et al. [17] evaluated 21 patients with petroclival meningiomas treated conservatively. In a mean follow-up period of 82 months radiological growth was observed in 76 % of the patients and functional deterioration in 63 %. Although the natural history of jugular foramen meningiomas is unknown, it might extrapolate the biological behavior of petroclival meningiomas to jugular foramen meningiomas. In 2006, we reported on a series of 10 primary jugular foramen meningiomas. A high incidence (6 cases) of malignant or aggressive tumor was found in this series [18]. Four patients presented meningotheliomatous meningiomas, three papillary, two anaplastic, and one microcystic.

The natural history of skull base chordomas shows that untreated patients will live in average 18 months [19, 20]. Even with treatment these dysembryogenetic tumors present a tendency to recur and the 5-year survival rate ranges from 50 % to 80 % and the 10-year survival rate ranges from 35 % to 70 % [21–26]. Tumor biological factors and clinical variables may affect the recurrence rates. In a recent report Boari et al. found that patient's age, rhinopharynx invasion, extent of tumor removal, and postoperative irradiation are factors that influence the prognosis [21]. Loss of heterozygosity of 1p36 chromosomal region was not an independent predictor of clinical outcome. Genetic and molecular studies may identify molecular markers for targeted therapy and improve the prognosis. Yakkioui et al. [27] studied the impact of cyclin-dependent kinase 4 (CDK4) expression and its relation to prognosis and other cell-cycle markers in chordomas, and found that expression of CDK4 ($p = 0.02$) and p53 ($p < 0.01$) were both significantly correlated with poor overall survival. Elevated Ki-67 proliferation index or deletion at 9p21 may be associated with a more aggressive clinical course and shorter survival [28].

Chondrosarcomas are slowly growing neoplasms arising from endochondrous cartilaginous remnants that in spite of presenting symptoms and signs similar to chordomas have better prognosis. They are usually classified as conventional type I–III, mesenchymal and dedifferentiated, and are graded based on cellularity, nuclear pleomorphism, and mitotic activity [29]. Mesenchymal chondrosarcomas occur more frequently in the younger age group (10–30 years). Dedifferentiated chondrosarcomas present a more aggressive behavior and poor prognosis. Tumor markers such as cytokeratin, vimentin, and S100 can differentiate chondrosarcomas from chordomas. Chordomas lack vimentin immunoreactivity and chondrosarcomas fail to express cytokeratin. S-100 protein expression is present in both [30]. Metastases from the skull base chondrosarcomas were reported in 10 % of 50 patients [31]. Skull base chondrosarcomas may be associated with Maffucci's and Ollier's syndrome [32]. Rosenberg et al. performed a clinicopathologic analysis of 200 patients with conventional chondrosarcomas of the skull base [33]. Grade 1 was found in 50.5 % of the tumors, 28.5 % had areas of grades 1 and 2, and 21 % were pure grade 2 neoplasms. Immunohistochemically, 96 of 97 (98.9 %) studied tumors stained for S-100 protein, 0 of 97 (0 %) stained for keratin. High-dose postoperative fractionated precision conformal radiation therapy was given to all patients with a dose that ranged from 64.2 to 79.6 Cobalt-Gray-equivalents. The 5- and 10-year local control rates were 99 % and 98 %, respectively, and the 5- and 10-year disease-specific survival rates were both 99 %.

Clinical Symptoms

Clinical presentation depends on the location and extension of the tumor. The most frequent presenting clinical symptom in patients with paragangliomas in our series was pulsatile tinnitus (80 %). Pulsatile tinnitus may have different etiologies. Vascular etiologies include: internal carotid atherosclerosis, arteriovenous

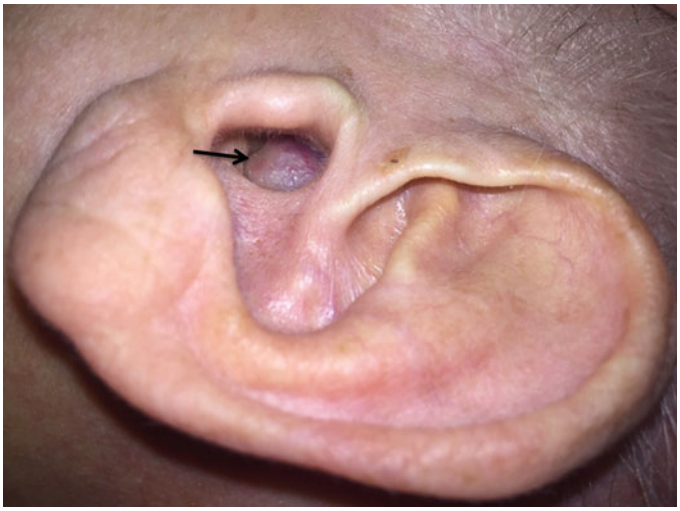

Fig. 4.1 At otoscopy a reddish tumor mass (paraganglioma) is observed in the ear (*arrow*)

malformation, dural arteriovenous fistula, aneurysms, tortuous internal carotid artery, venous abnormalities such as high jugular bulb idiopathic, jugular bulb dehiscence, jugular diverticula, and abnormal veins (condylar and mastoid emissary). Nonvascular etiologies include: sensorineural hearing loss, superior semicircular canal dehiscence, and myoclonic muscle contractions (tensor veli palatini, levator veli palatini, and superior constrictor). The patient may inform decreased pulsations with compression of the ipsilateral carotid (Aquino's sign). Audible bruit may be auscultated over the mastoid region. At otoscopy a reddish tumor protruding behind the tympanic membrane may be identified (Fig. 4.1). Other frequent symptoms are conductive hearing loss (75 %), hoarseness (35 %), and lower cranial nerves palsy (30 %); the most frequent deficit of caudal cranial nerves is in order: 10th nerve, followed by 9th nerve, 12th nerve and 11th nerve, middle ear mass (25 %), dysphagia (15 %), facial nerve paresis (5 %) (Fig. 4.2), neck mass (5 %) (Fig. 4.3), and tongue atrophy (5 %).

Hydrocephalus and cerebellar symptoms were present in two patients in our series. Tumors secreting catecholamines are rare. These tumors may produce symptoms similar to pheochromocytomas: perioperative hemodynamic instability, flushing, palpitations, and diaphoresis. In these cases serum catecholamines, urinary vanillylmandelic acid, and metanephrine should preoperatively be evaluated.

Patients with jugular foramen schwannomas present clinical symptoms mostly related to tumor location. Predominantly, intracranial tumors manifest most commonly with hearing loss, tinnitus and if the lesion is large, cerebellar dysfunction and hydrocephalus. Facial nerve palsy is usually rare and was observed in 20 % of the cases in a large series [34]. Predominately extracranial and jugular foramen tumors present slowly progressive lower cranial nerves deficits with common

Fig. 4.2 Left facial nerve palsy caused be a JF paraganglioma

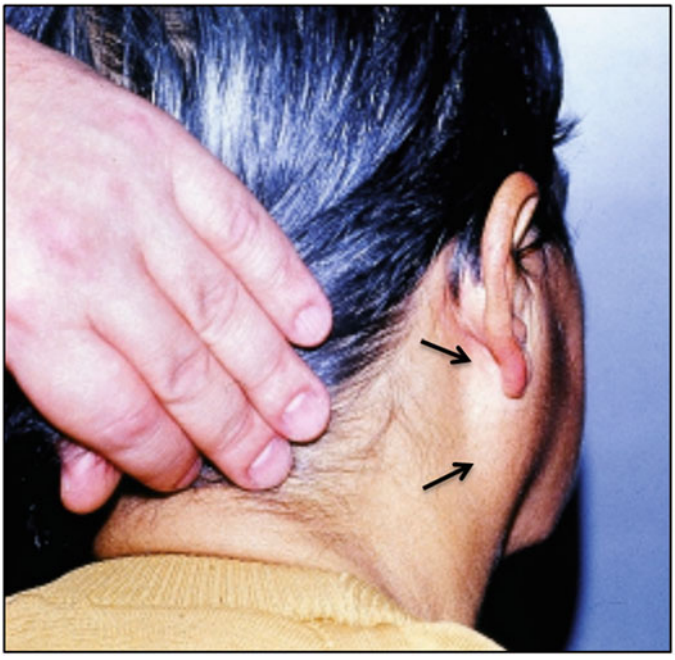

Fig. 4.3 Tumor mass in the parotid region—large JF paraganglioma (*arrows*)

symptoms dysphasia, tongue atrophy (hypoglossal nerve schwannomas), hoarse voice, palpable neck mass, hearing loss and tinnitus if the tumor extends into the middle ear, hydrocephalus and cerebellar symptoms if the tumor is large. Hearing

loss is the most frequent symptom in patients harboring a jugular foramen schwannoma. It was observed in 60–75 % of patients [35].

In our series of patients with jugular foramen meningiomas the clinical symptoms developed sooner than in patients with paragangliomas [18]. From 13 patients 10 presented with swallowing difficulties caused by paralysis of lower cranial nerves. Hearing loss, tinnitus, and headaches were the other complains of the patients. In a recent review of the literature Bakar (2010) found 96 published cases [36]. The most common presenting symptoms were: hearing loss in 45 patients (52 %), middle ear mass in 20 (23.2 %), dysphasia in 20 (23.2 %), tinnitus in 15 (17.4 %), dizziness in 15 (17.4 %), hoarseness in 12 (13.9 %), neck mass in 10 (11.6 %), ataxia in 10 (11.6 %), lower cranial nerve palsy in 5 (5.8 %), shoulder weakness in 5 (5.8 %), headache in 5 (5.8 %), glossal atrophy in 4 (4.6 %), facial nerve palsy in 3 (3.5 %), otalgia in 2 (2.3 %), hydrocephalus in 1 (1.1 %), and hemiparesis in 1 (1.1 %). The low incidence of lower cranial nerves paralysis contrasts with our series. It is possible that some series include patients with meningiomas arising in other regions presenting extensions into the jugular foramen.

Chordomas and chondrosarcomas usually manifest with headaches and diplopia. Clinical manifestations are mainly related to their location in the jugular foramen. Most common presenting symptoms are diplopia because of paralysis of VI cranial nerve in 50 % of cases [37], trigeminal numbness, lower cranial nerve dysfunction including dysphagia, hoarseness, aspiration, tongue paralysis, shoulder drop, and voice weakness, headaches, hearing loss, and tinnitus. The median period between presentation and diagnosis is 15 months [38]. Multiple cranial nerves deficits are more common with chondrosarcomas than chordomas [37].

Endolymphatic sac tumors can be locally destructive and the most common reported presenting symptom clinical presentation is hearing loss with tinnitus. The most commonly involved nerve is the facial nerve facial nerve. Multiple cranial neuropathies (vagal, glossopharyngeal, and trigeminal nerves) can develop in patients with large lesions. These tumors can be lethal [39, 40].

Classification

The Glasscock-Jackson [41] and Fisch [42] classifications of glomus tumors are the most commonly used. The Glasscock-Jackson (Table 4.1) classification differentiates glomus tympanicum vs jugular. Fisch's classification (Table 4.2) describes four stages of tumor development and is based on extension of the tumor to surrounding anatomic structures and is related to morbidity. De la Cruz [43] presented a classification (Table 4.3) based on surgical approach.

In 1988, our group developed a new classification (Table 4.4) based on localization, and pattern of extension of the lesion [44, 45]. This classification is simple, easy to recall, and anticipates the surgical difficulties.

Table 4.1 Glasscock-Jackson classification

Type	Characteristics
Glomus tympanicum	
I	Limited to the promotory
II	Fills completely the middle ear
III	Fills middle ear and extends to mastoid
IV	Extend into the external auditory canal and anteriorly may reach the internal carotid artery
Glomus jugulare	
I	Involves jugular bulb, middle ear, and mastoid
II	Extends under the internal auditory canal
	May have intracranial extension
III	Extends into the petrous apex
	May have intracranial extension
IV	Extends into clivus and infratemporal fossa
	May have intracranial extension

Table 4.2 Fisch classification

Type	Characteristics
A	Limited to the middle ear cleft (glomus tympanicum)
B	Limited to the tympanomastoid area with no infralabyrinthine compartment involvement
C	Tumor involves the infralabyrinthine compartment of the temporal bone and extends into the petrous apex
C1	Tumor with involvement of the vertical portion of the carotid canal
C2	Tumor invades the vertical portion of the carotid canal
C3	Tumor invasion of the horizontal portion of the carotid canal
D1	Intracranial extension less than 2 cm in diameter
D2	Intracranial extension larger than 2 cm in diameter

Table 4.3 De la Cruz classification

Classification	Surgical approach
Tympanic	Transcanal
Tympanomastoid	Mastoid/extended facial recess
Jugular bulb	Mastoid/neck (possible limited facial nerve rerouting)
Carotid artery	Infratemporal fossa ± subtemporal
Transdural	Infratemporal fossa/intracranial
Craniocervical	Transcondylar
Vagale	Cervical

Several anatomic classifications according to the patterns of growth of jugular schwannomas have been proposed. Pellet et al. [46] modified the classification proposed by Kaye et al. [35] and presented a grading system (Table 4.5).

Table 4.4 Curitiba classification—1988

Type	Localization	Characteristics
E	Ear	Limited to the ear. Mainly treated by ENT-surgeons
EN	Ear and neck	Extensions to the neck, invasion of jugular bulb and internal jugular vein, treated by ENT-surgeons and neurosurgeons
ENI	Ear, neck, and intradural	Treated by ENT-surgeons and neurosurgeons
M	Miscellanea	Subtype C—Combination of one of three previous types or isolated subtypes type N or I

Table 4.5 The modified classification of Kaye et al. proposed by Pellet et al.

Class	Definition
A	Primarily intracranial: with minimal extension into the jugular foramen
B	Primarily within the bone: with or without an intracranial component
C	Primarily extracranial: with only a minor extension into the jugular foramen or into the posterior fossa
D	Saddlebag- or dumbbell-shaped intra- and extracranial extension

Table 4.6 Mazzoni et al. classification

Class	Description
A	Tumor present in the neck, <2 cm in diameter
A+	Tumor present in the neck, >2 cm in diameter
C	Tumor in jugular foramen without involvement of petrous internal carotid artery
C+	Tumor in jugular foramen with involvement of petrous internal carotid artery
D	Intradural tumor <2 cm in diameter
D+	Intradural tumor >2 cm in diameter

Each tumor case is identified with its A, C, or D component or components

Table 4.7 Samii's modified classification

Tumor classification	Definition	Surgical approach
A	Tumor arising from cisternal part of the nerves, without significant extension into the Jugular foramen	Retrosigmoid (RS)
B		
B1	Intraosseous tumor inside the JF	Endoscopic assisted-RS infralabyrinthine (suprajugular approach)
B2	Intraosseous tumor with significant extension into the cisternal space	Endoscopic assisted-RS infralabyrinthine (suprajugular approach)
B3	Intraosseous tumor with significant extension into the infratemporal fossa	Endoscopic assisted-transcervical approach
C	Tumor arising from peripheral part of the nerve (extracranial type)	Transcervical approach
D	Triple dumbbell-shaped tumor with intracranial, intraosseous and extracranial parts	Combined transcervical and endoscopic-RS infralabyrinthine (suprajugular approach)

RS, retrosigmoid approach; JF, jugular foramen; EA-RS, endoscope assisted-retrosigmoid approach

This expanded classification was subsequently modified by Mazzoni et al. [34] considering the size of neck component (Table 4.6).

Recently, Samii et al. [47] modified his previous classification [48] differentiating tumors that present various intraosseous extensions (Table 4.7).

Due to the scarceness with small series reported in the literature, there is no proposed classification for primary jugular foramen meningiomas. According to our experience this tumors can be mainly within the jugular foramen with intradural extension or with intradural and extradural extensions involving the high neck region and the spinal canal.

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Chapter 5
Surgical Anatomy

The anatomy of the jugular foramen region is complex and important neurovascular structures are involved. These structures are in close relation with the cervical region, ear, and brainstem. A precise knowledge of this anatomical relationship is fundamental to properly expose a tumor originating at or involving the jugular foramen. The Jugular foramen is located on the medial and inferior surface of the petrous pyramid and is formed by the occipital and temporal bones. It is a depression around the sigmoid sinus, jugular bulb, and inferior petrous sinus in close relationship with the magnum foramen, internal auditory canal, and the hypoglossal canal (Figs. 5.1–5.4) [1, 2]. In most cases the width of the right jugular foramen is larger than that of the left one [3].

Classically the JF is described as having two portions [4]. The nervous portion with the glossopharyngeal nerve, the inferior petrosal sinus, and the meningeal branches of ascending pharyngeal artery and the venous portion with the sigmoid sinus, vagal, and accessory nerves (Fig. 5.5). The vascular structures within the jugular foramen are: the sigmoid sinus, the jugular bulb, the inferior petrous sinus, and branches of the ascendant faringeal and occipital arteries. The jugular bulb connects the sigmoid sinus and the internal jugular vein. It is located under the floor of the middle ear and its upper portion lies in the jugular fossa (Fig. 5.6). The jugular bulb has a size of approximately 15 mm wide and 20 mm high [5]. Large jugular bulbs enter into the middle ear. In these cases the floor of the middle ear may be dehiscent and this anatomic variation may cause pulsatile tinnitus.

The cranial nerves (IX, X, and XI) are located anterior and medial to the jugular bulb. These nerves cross a connective tissue septum that is in continuity with the pericranium and dura mater. The position of these cranial nerves is an important anatomical parameter because it allows a posterior surgical approach to the jugular bulb with preservation of the nerves. The lower cranial nerves present a multifascicular histoarchitecture (particularly the X cranial nerve) [6]. The tympanic branch of the glossopharyngeal nerve (Jacobson's nerve) and the auricular branch of the vagal nerve (Arnold's nerve) may be the site of origin of paragangliomas (Fig. 5.7).

R. Ramina, M.S. Tatagiba, *Tumors of the Jugular Foramen*,
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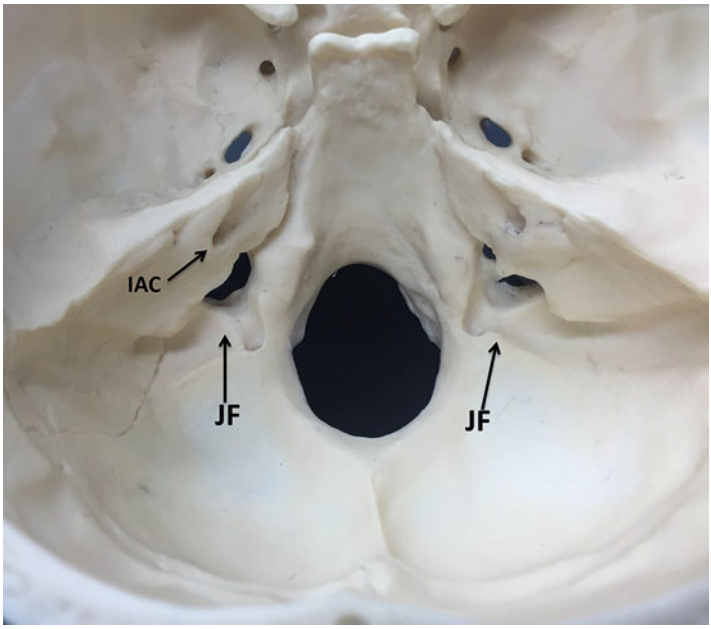

Fig. 5.1 Superior view of both jugular foramen (JF) and its relationship with the internal auditory canal (IAC)

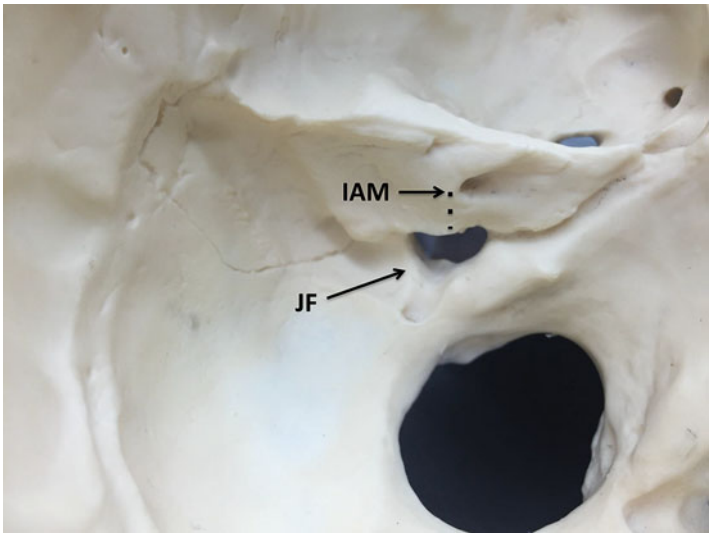

Fig. 5.2 Left jugular foramen (JF) and internal auditory meatus (IAM)

In 1997, Katsuta and Rhoton [7] divided the jugular foramen in three portions: two venous and one nervous (intrajugular) with the nerves IX, X, and XI, between the two venous. Anatomical variations are described in the course of the cranial

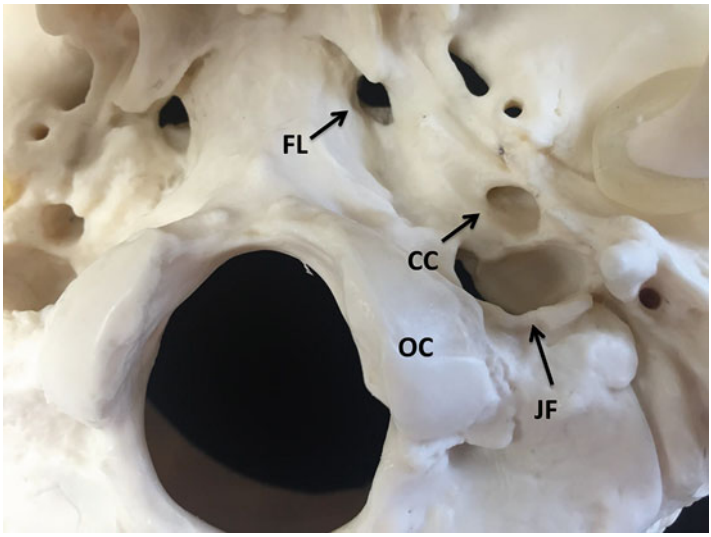

Fig. 5.3 Inferior view showing the jugular foramen (JF) and other cranial base foramina. CC, carotid canal; FL, foramen lacerum; OC, occipital condyle

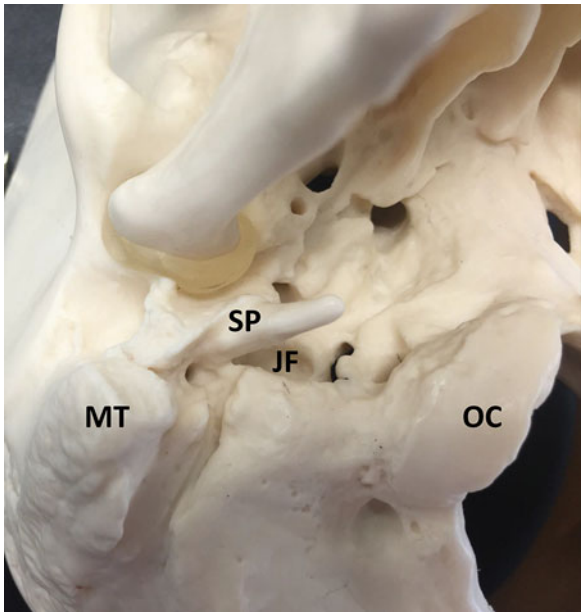

Fig. 5.4 Jugular foramen (JF), occipital condyle (OC), mastoid tip (MT), and styloid process (SP)

nerves through the jugular foramen. The vagal nerve is usually formed by multiple fascicles, the glossopharyngeal nerve by one [6], and the accessory nerve is formed by two fascicles: one spinal and one cranial.

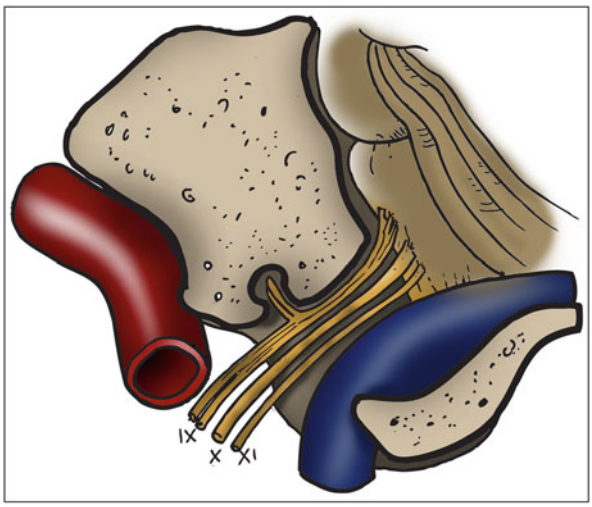

Fig. 5.5 Drawing showing the relationship between the jugular bulb and the cranial nerves

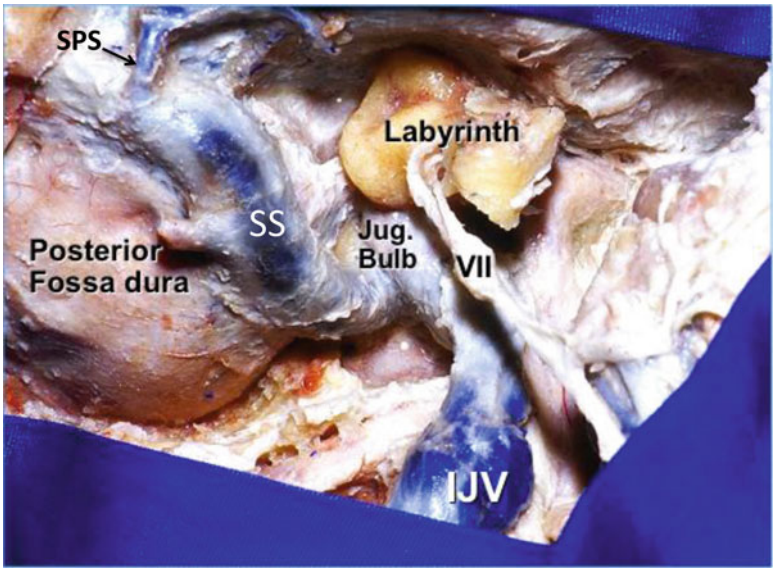

Fig. 5.6 Jugular bulb, facial nerve (VII), internal jugular vein (IJV), sigmoid sinus (SS), and superior petrosal sinus (SPS)

Intradural the jugular foramen is related to the cranial nerves IX, X, and XI (with its spinal portion) (Fig. 5.8), superiorly with the VII and VIII cranial nerves with the vertebral, posterior inferior and anterior inferior cerebellar arteries, the medulla oblongata, pons, and upper cervical cord (Fig. 5.9). The internal carotid artery (ICA) is located anterior to the jugular bulb and enters the skull through the carotid canal (Figs. 5.10 and 5.11). The glossopharyngeal, vagus, accessory, and hypoglossal

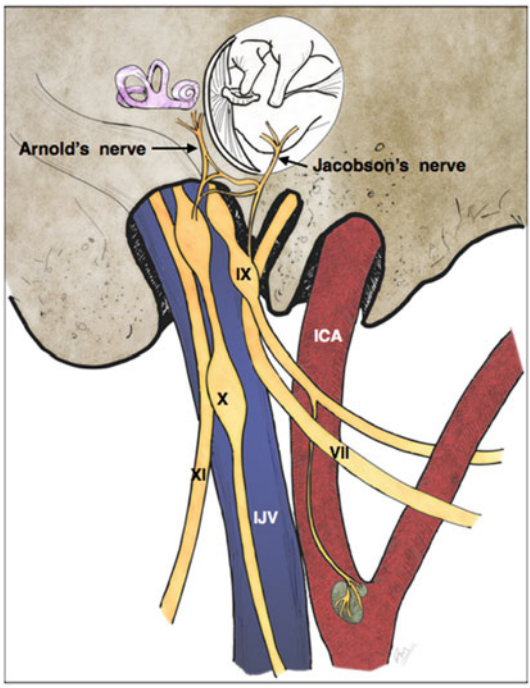

Fig. 5.7 Drawing showing the origin of Jacobson's nerve from IX cranial nerve and Arnold's nerve from X cranial nerve

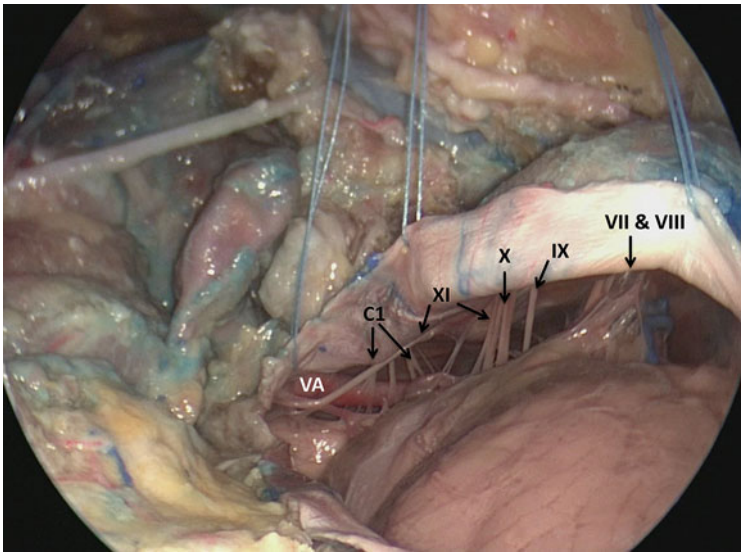

Fig. 5.8 Intradural exposure of the jugular foramen region. VA, vertebral artery; C1 rootlets, cranial nerves VII, VIII, IX, X, and XI

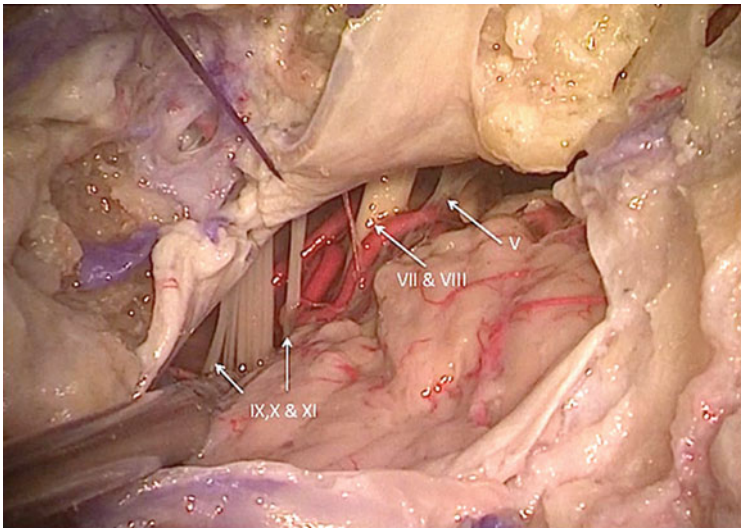

Fig. 5.9 Intradural view of the jugular foramen with the cranial nerves IX, X, and XI

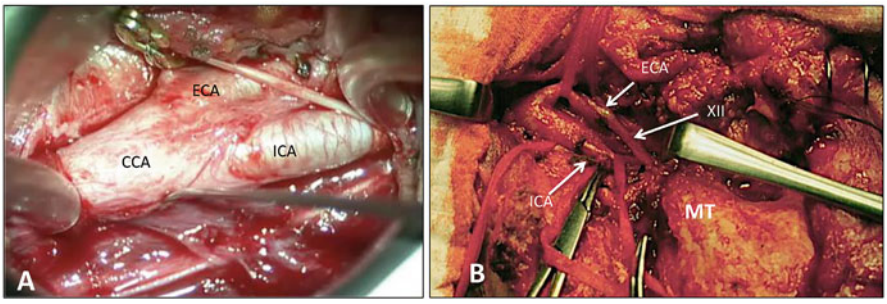

Fig. 5.10 (**a**) Common carotid artery (CCA), external carotid artery (ECA), and internal carotid artery (ICA) in the neck. (**b**) ICA before entering the skull. MT, mastoid tip

nerves run between the ICA and the internal jugular vein (Fig. 5.12). The C2 or petrous segment of the ICA is inside the petrous portion of the temporal bone. This segment has three portions: an ascending (vertical), the genu, and the horizontal portion (Fig. 5.13). The ICA is located anterior to the tympanic cavity, Eustachian tube, and cochlea (Fig. 5.14). Anatomical vascular variations within the temporal bone as aberrant ICA, high jugular bulb, dehiscent carotid canal, stapedial artery, and high jugular bulb may mimic glomus tumors. They are rare but very important anomalies because misdiagnosing may lead to massive hemorrhage. The carotico-tympanic branches of the petrous segment of the ICA may feed the ear portion of the tumor (Fig. 5.15). The C3 (lacerum) segment of the ICA passes through the superior part of the foramen lacerum, is surrounded by periosteum, and gives the vidian artery [8].

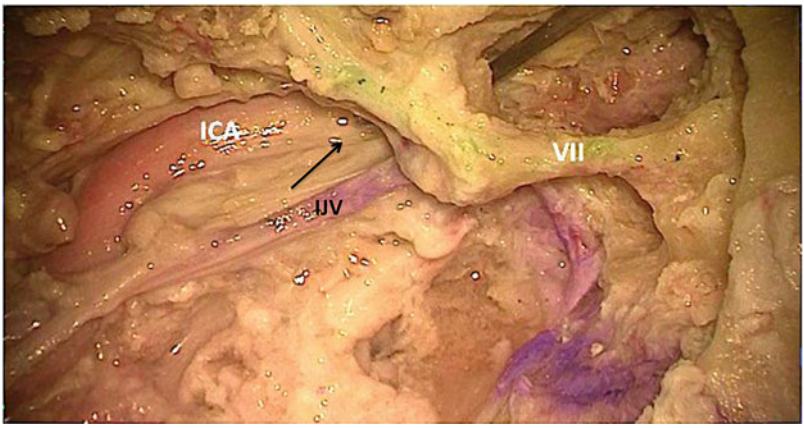

Fig. 5.11 Internal carotid artery (ICA) at its entrance in the skull (*arrow*). VII, facial nerve. IJV, internal jugular vein

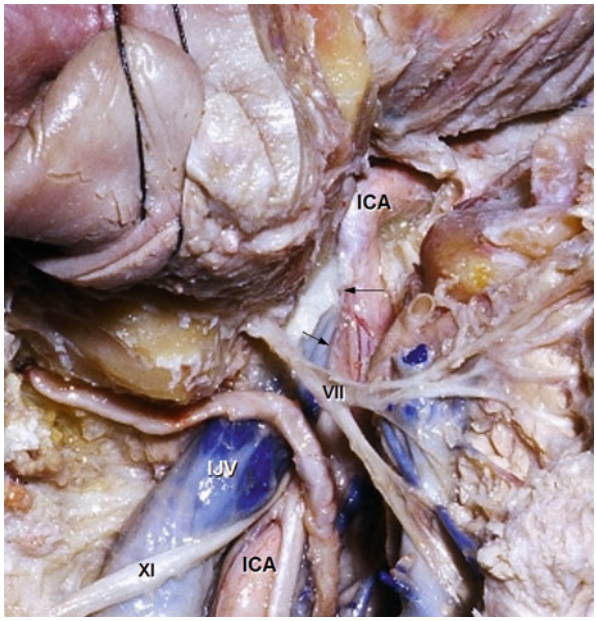

Fig. 5.12 Internal jugular vein (IJV) in close relationship with the internal carotid artery at its entrance in the skull

The facial nerve is frequently involved in cases of jugular foramen lesion. This nerve emerges from the brainstem and enters the internal auditory canal with the VIII cranial nerve. The facial nerve has the following portions: cisternal, meatal, labyrinthine, tympanic, mastoid, and extratemporal (stylomastoid, parotid, and peripheral) (Fig. 5.16). Jugular foramen tumors may involve the facial nerve from the brainstem to the parotid gland. The anatomical parameters to expose the facial nerve at the stylomastoid foramen region are: the mastoid tip, the cartilage of the

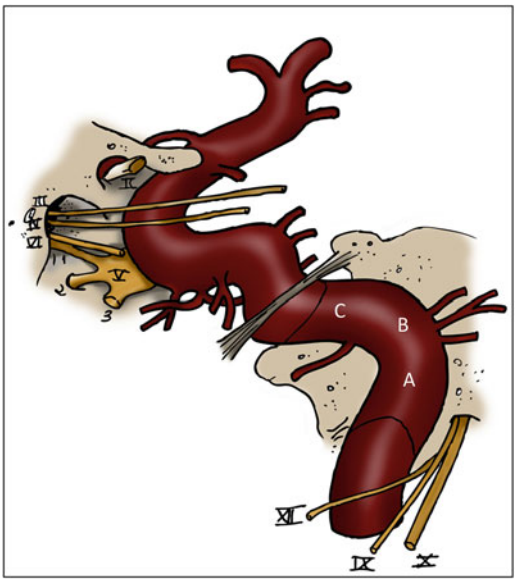

Fig. 5.13 Drawing showing the three portions of the petrous segment of the internal carotid artery. *A*, Ascending (vertical); *B*, genu; and *C*, horizontal

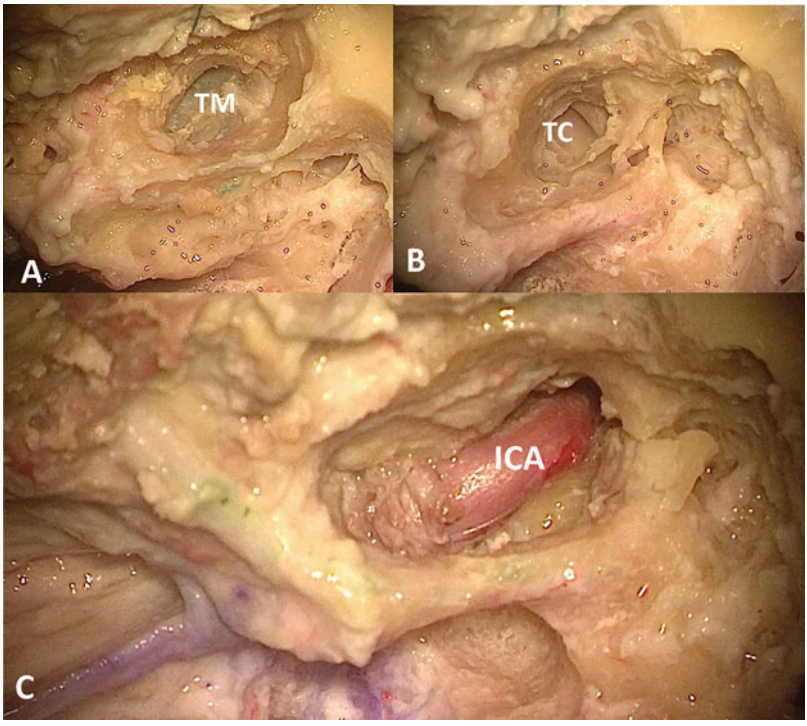

Fig. 5.14 (**a**) Ear dissection showing the tympanic membrane (TM). (**b**) After removal of TM the tympanic cavity is exposed. (**c**) Position of the internal carotid artery in the ear anterior to the tympanic cavity

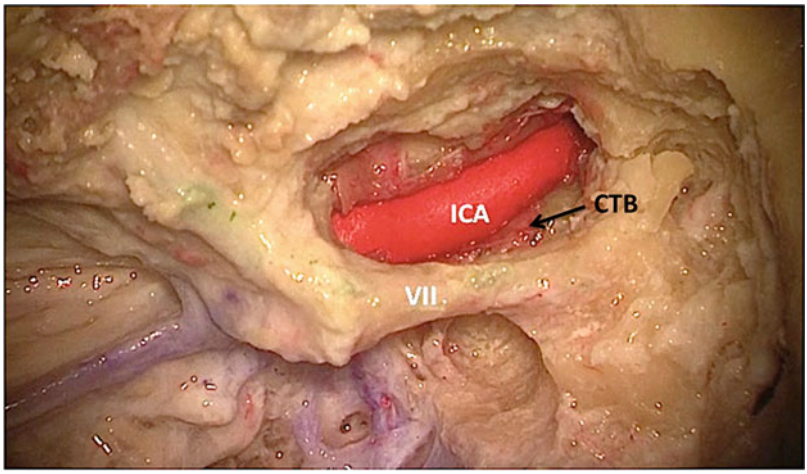

Fig. 5.15 Internal carotid artery (ICA) in the ear and the caroticotympanic branches (CTB), VII—facial nerve

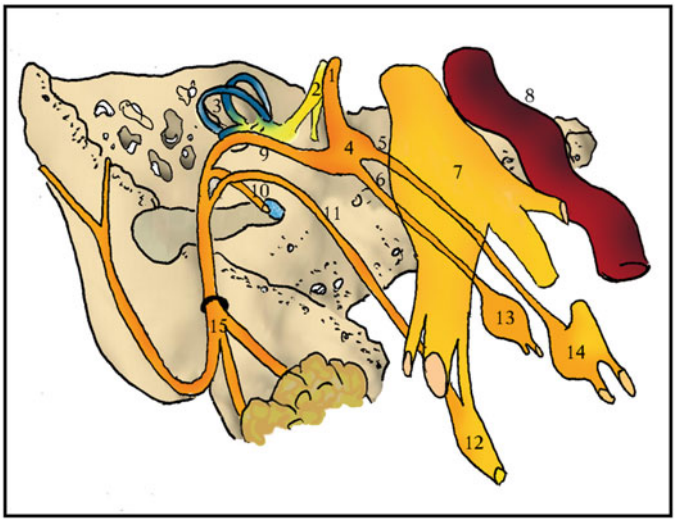

Fig. 5.16 Drawing showing facial nerve anatomy. *1*, intracanalicular portion; *2*, cochlear nerve; *4*, geniculate ganglion; *7*, Gasserian ganglion; *9* labyrhintic and mastoid portions; *15*, extratemporal portion

external ear canal ("pointer"), and the posterior belly of the digastric muscle (Fig. 5.17) [9]. In the mastoid cavity the facial nerve runs downwards to the stylomastoid foramen anterior and medial to the sigmoid sinus and digastric ridge. Radical mastoidectomy is performed to expose the tumor in this region, the jugular bulb, and hypotympanum (Figs. 5.18 and 5.19) After opening the mastoid antrum

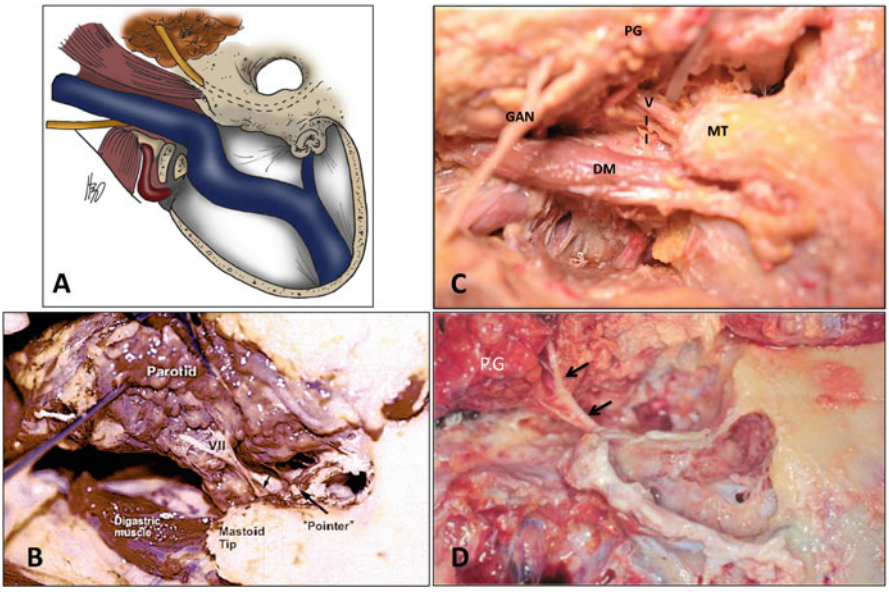

Fig. 5.17 (**a**) Drawing representing the course of facial nerve in fallopian canal. (**b** and **c**) Anatomical parameters used to identify the facial nerve (VII): pointer, digastric muscle (DM), mastoid tip (MT). PG, parotid gland. (**d**) Extracranial portion of facial nerve (*arrows*)

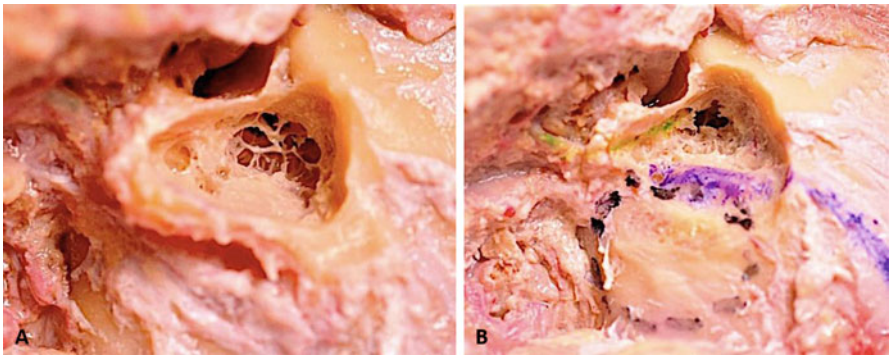

Fig. 5.18 (**a**) Mastoidectomy with exposition of the antrum. (**b**) Mastoidectomy and the planned craniotomy

the short process of the incus is identified. It points to the Fallopian canal medial to the lateral semicircular canal (Fig. 5.20).

The jugular foramen has relationship with anatomical structures of the neck. Neck dissection is indicated to approach tumors extending to this region. The surgical anatomy of the neck region related to the jugular foramen is complex and includes different muscles, vessels, and nerves. The muscles are: sternocleidomastoid (SCM), digastric, splenius capitis, obliquus capitis superior and inferior, rectus capitis posterior

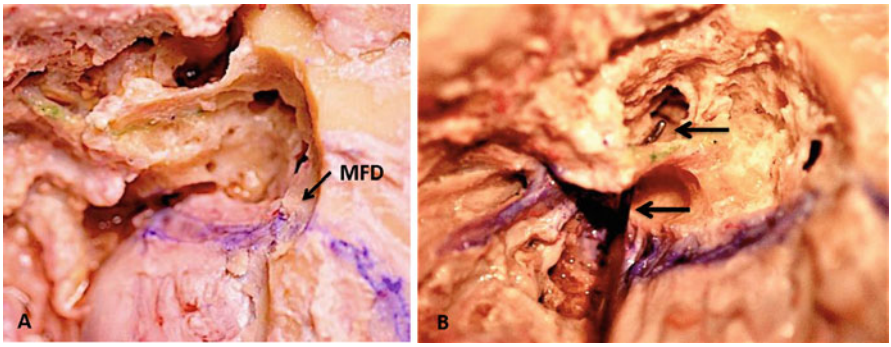

Fig. 5.19 (**a**) Radical mastoidectomy and posterior fossa craniectomy. MFD, middle fossa dura. (**b**) Hook through the hypotympanum communicating the JF with the ear (*arrows*)

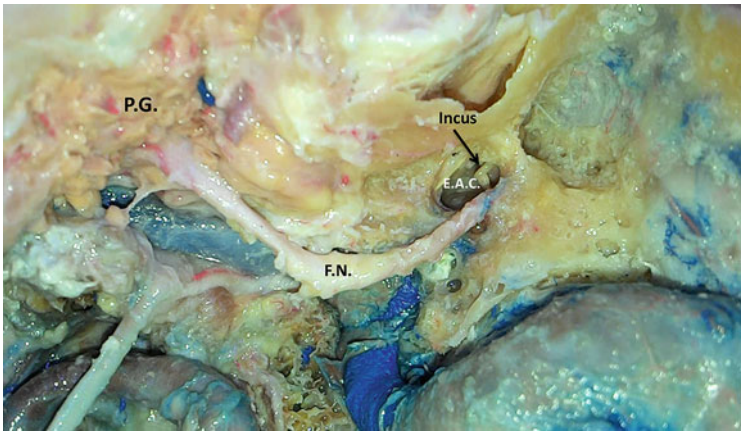

Fig. 5.20 Facial nerve (FN) removed from fallopian canal. Short process of the incus (*arrow*) points to facial nerve in the ear. EAC, external auditory canal

major, and splenius cervicis; the arteries: common carotid, external carotid, and its branches, internal carotid, vertebral artery at the cranial cervical junction; the veins: common facial, external and internal jugular veins; and the nerves: greater auricular, cranial nerves X, XI, and XII, and the sympathetic trunk (Fig. 5.21).

The common carotid artery as well as the external and ICA runs medial to the internal jugular vein. The vagus nerve courses between the internal jugular vein and the common carotid artery and before the entrance in the skull lateral to the ICA (Fig. 5.22). The common carotid artery is covered by the superficial cervical fascia, platysma muscle, deep cervical fascia, and the anterior margin of the SCM. In the carotid triangle of the neck, bounded behind by the SCM and superiorly by the stylohyoideus and digastric muscle, the ICA is latero-posterior to the external carotid artery (ECA). The internal jugular vein is lateral to both (Fig. 5.22). The ICA has no

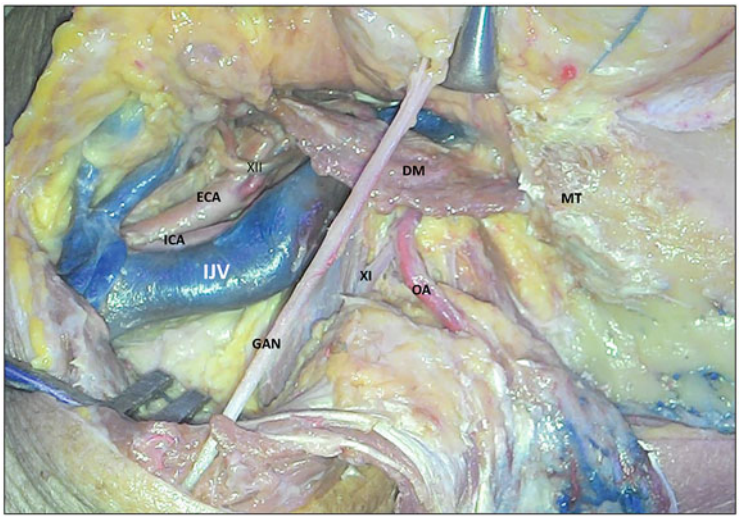

Fig. 5.21 Neck dissection showing the external (ECA) and internal carotid artery (ICA) internal jugular vein (IJV), cranial nerves XI, XII. DM, digastric muscle; MT, mastoid tip

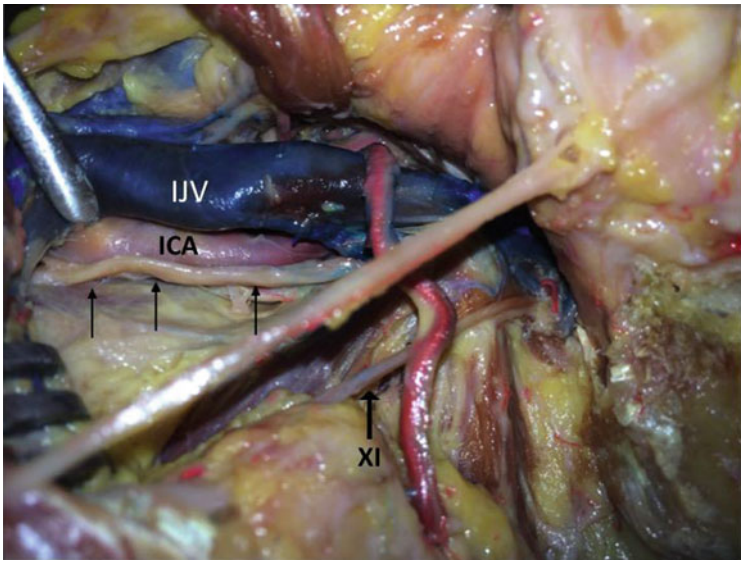

Fig. 5.22 Neck dissection showing the course of the vagal nerve (*arrows*), the internal Jugular vein (IJV), the internal carotid artery (ICA), and the XI cranial nerve

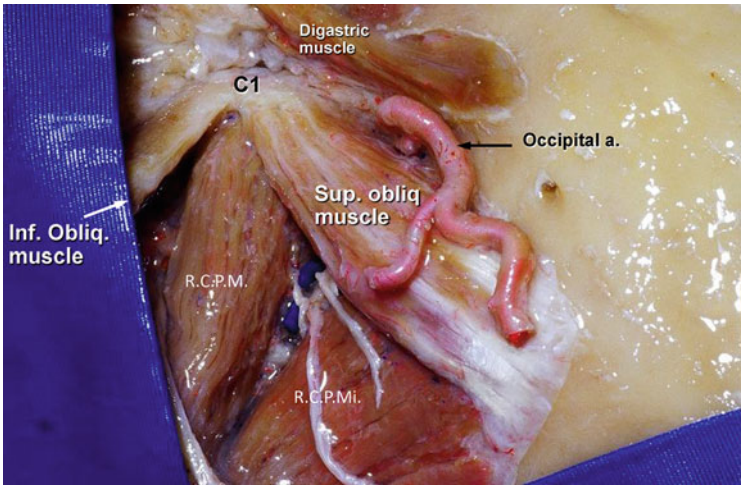

Fig. 5.23 Muscles related to the C1/C2 vertebral artery segment. Superior and inferior obliquus muscles. Rectus capitis posterior major (RCPM) and minor (RCPMi) muscles

branches in the neck. The hypoglossal nerve crosses the ICA and the ECA (Fig. 5.9). The vagus nerve is located in a plane posterior to the ICA (Fig. 5.19). The second segment of the vertebral artery (VA) ascends through the transverse foramina of the upper six cervical vertebrae. The cervical roots are posterior to the VA. The VA is covered with a plexus of veins. This plexus is largest in the region of C1-C2 joint. After its exits from the transverse foramen of C3 the VA makes a loop close to the articular facet and courses through the transverse foramen of C2 vertebra, anterior to the two roots of the C2 ganglion. Branches (muscular and a small artery along the C2 ganglion) arise in this portion. Posteriorly the muscles related to the C1/C2 segment of the VA in the suboccipital triangle are: semispinalis cervicis from the C2 to C5 to the transverse process of the upper thoracic vertebrae, the superior oblique from the transverse process of C1 to the inferior nuchal line, the inferior oblique, the rectus capitis posterior major (medial limit of the suboccipital triangle), rectus capitis minor, scalenus medics, and the elevator scapulae (Fig. 5.23). Anteriorly the muscles involved are: anterior and lateral rectus capitis, longus capitis, longus colli, and longus capitis. Exiting the transverse process foramen of C1 the VA makes a right angle loop medially along the groove on the superior surface of the arch of the C1 and turns anteriorly to enter the spinal canal in front of the ligamentum denticulatum (Fig. 5.24). Then, it bends upwards in relation with the first cervical nerve, the spinal branch of the accessory nerve and the hypoglossal nerve. Figure 5.25 shows the entire surgical exposure (neck dissection, mastoidectomy, meatotomy, craniotomy, ICA dissection, and intradural) for jugular foramen involving the high cervical region, ear, ICA, and intradural.

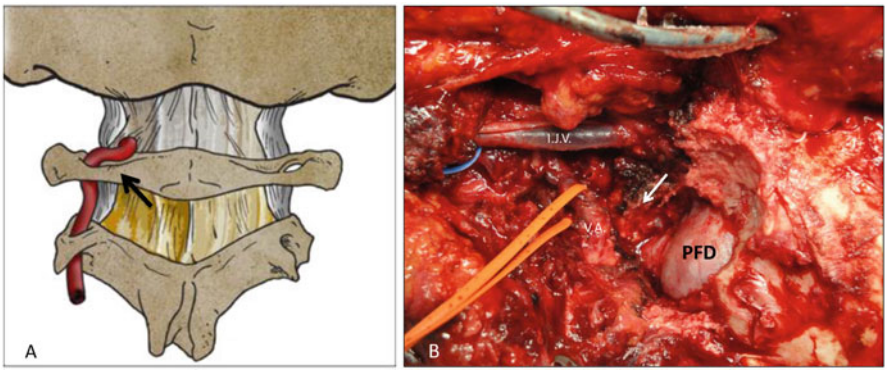

Fig. 5.24 (**a**) Drawing showing the vertebral artery at the C1/C2 junction and the vertebral groove at C1 lamina before entering the skull (*arrow*). (**b**) Surgical picture, the vertebral artery (VA) has been removed from its canal at C1 (*arrow*). IJV, internal jugular vein; PFD, posterior fossa dura

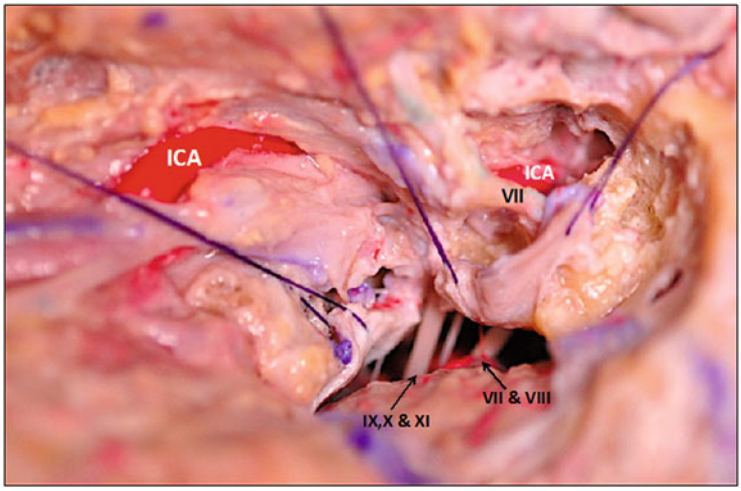

Fig. 5.25 Anatomic dissection showing complete surgical exposure of the jugular foramen extra and intradural, the internal carotid artery in the neck and ear, and the facial nerve

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Chapter 6
Radiological Diagnosis

Contrast-enhanced computed tomography (CT), magnetic resonance imaging (MRI), and angiography are usually required for adequate diagnosis, localization, and evaluation of extension patterns of jugular foramen tumors. High-definition CT scan with thin section of temporal bone is the best resource to differentiate glomus jugulare tumors from glomus tympanicum [1]. Glomus jugulare erodes jugular fossa and glomus tympanicum occupies middle ear. Jugular paragangliomas erode bone, glomus tympanicum arises from the cochlear promontory and usually does not destroy the ossicular chain. Thin CT scans (13 mm) performed with a detailed bone algorithm and coronal reconstruction gives detailed information of cranial base bone structures, bone erosion, tumor calcification, and hyperostosis (Fig. 6.1). The bony margins of the tumor are irregularly eroded with a "mouth-eaten" pattern. It also provides information about the position of the jugular bulb and jugular foramen, and the enlargement of the canal, which usually appears as a sharp, rounded shape with sclerotic rims (bone scalloping). CT is useful in differentiated schwannomas, meningiomas, aneurysmatic bone cysts, and chondrosarcomas. Schwannomas typically promote smooth erosion of jugular foramen, paragangliomas tend to erode irregularly the margins and destroy the jugular spine and caroticojugular spine (Fig. 6.2). Meningiomas may be difficult to distinguish from schwannomas, and frequently invade the bone causing hyperostosis and calcifications (Fig. 6.3). Other bony structures of the middle ear, mastoid (facial nerve canal), internal auditory canal, and high cervical spine are adequately studied with thin CT scans.

Diagnostic MR imaging, with its multiplanar capabilities and gadolinium (Gd), is very useful to demonstrate the characteristics of tumor, its vascularization, extension, and relationship with neighboring structures. MRI is superior than CT scans in determining tumor vascularity, intracranial extension, extension along vessels, nerves and skull base structures, the presence of other tumors (multifocality and multicentricity), and relationship with brainstem. Tumor extent may be overestimated on T1WI [2]. Paragangliomas are usually hypointense on T1WI (Fig. 6.4). These highly vascularized lesions, with pronounced heterogeneous gadolinium

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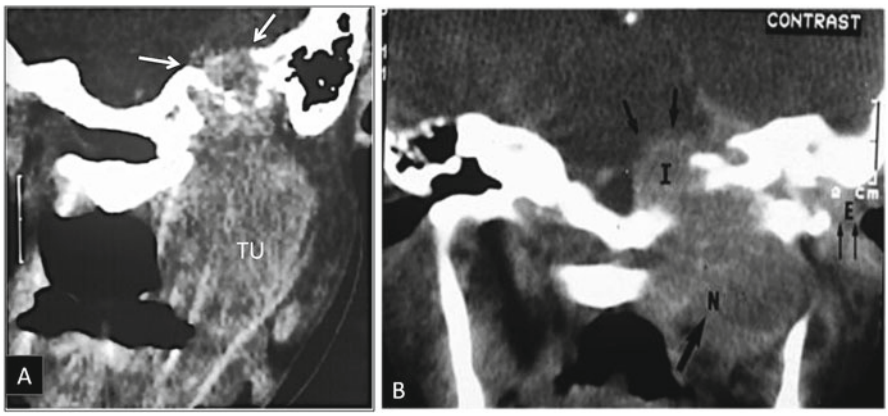

Fig. 6.1 CT scan (coronal view) of a case of jugular foramen paraganglioma, showing bone erosion, enlargement of jugular foramen (*arrows*) (**A**). Calcifications and tumor extension in the cervical region (TU). I, intradural; E, ear; N, neck (**B**)

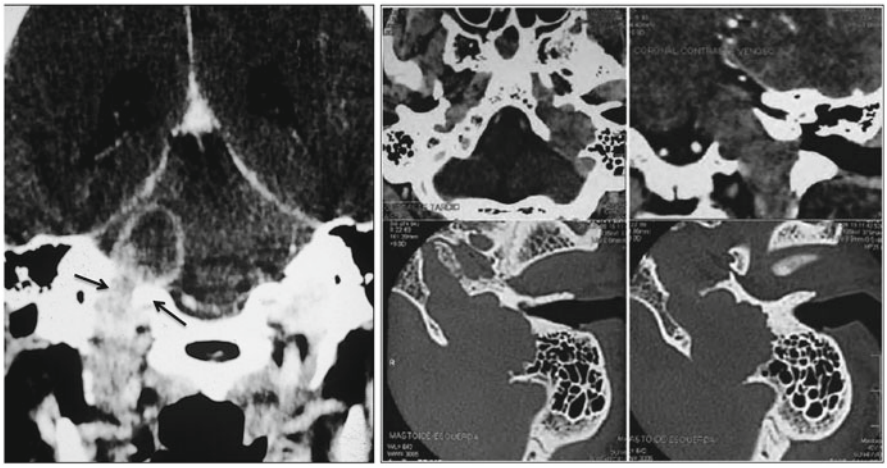

Fig. 6.2 *Left*: CT scan (coronal view) of a case of a jugular foramen schwannoma with intradural and cervical region extensions. The jugular foramen is eroded (*arrows*). *Right*: CT scan (axial views) showing sharp erosion of the jugular foramen

enhancement (Fig. 6.5), present characteristic vascular flow voids patterns with "salt and pepper" characteristics (Fig. 6.6). The "pepper" component are the multiple areas of signal void and the "salt" component are hyperintense foci produced by slow flow or subacute hemorrhage on both long TR and short TR images [3]. MRI shows the vascular nature of these lesions, low signal areas characteristic of rapid arterial and venous blood flow were present in the matrix of these tumors on both T1 and T2WI. Other tumors like schwannomas have a less vascular appearance in their internal matrix [4]. Paragangliomas of jugular foramen may cause occlusion of jugular vein and sigmoid sinus, intracranial extension through an eroded jugular

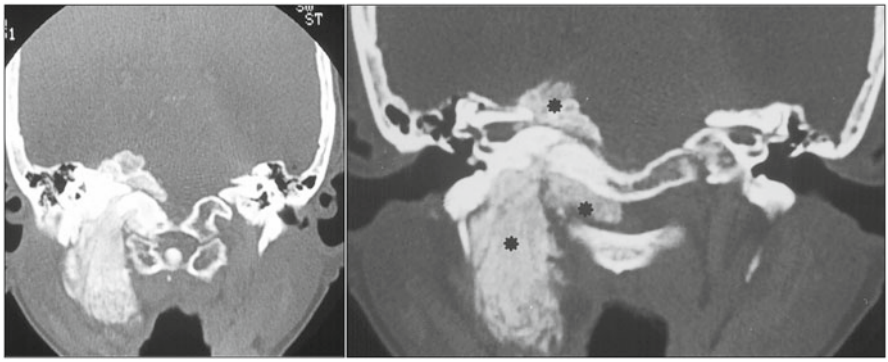

Fig. 6.3 CT scan (coronal view) of a case of large jugular foramen meningioma demonstrating tumor extensions in the spinal canal and intradural, reaching the internal auditory canal (*)

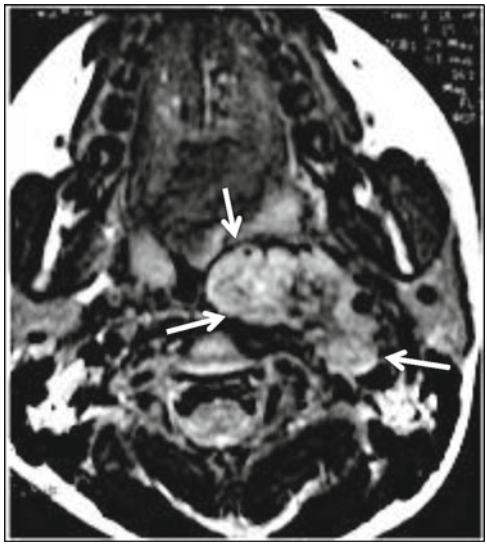

Fig. 6.4 T1W-MRI without contrast of jugular foramen paraganglioma (*arrows*)

foramen, invasion of fallopian canal, and involvement of the internal carotid artery, middle ear, mastoid, and structures in the neck. All these extensions can be demonstrated with high field MRI. This examination method can also diagnosis the presence of a glomus vagal tumor and differentiate a glomus tympanicum from glomus jugular. Jugular foramen paragangliomas are the only tumors at the cranial base that present the "dropout" phenomenon (seen in time-intensity curves) after intravenous injection of high-dose gadolinium (0.3 mmol/kg) [5].

In non-enhanced CT images, schwannomas are isodense to the brain parenchyma. The smoothly scalloped well-corticated enlargement of the jugular foramen contrasts to the mouth-eaten pattern seen with paragangliomas [6]. Schwannomas of jugular foramen have the same characteristics as other intracranial schwannomas on MRI, are smooth contoured masses, iso-intense on T1WI, and high signal intensity on T2WI (Fig. 6.7) [7] that gradually enlarges the jugular foramen by pressure

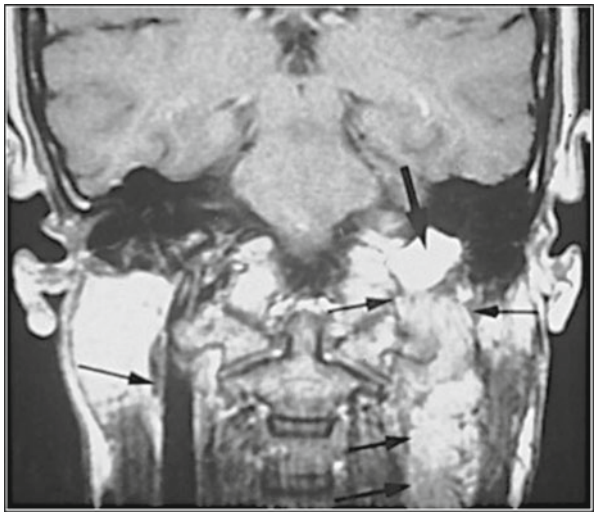

Fig. 6.5 T1W-MRI of jugular foramen paraganglioma (*arrows*) showing gadolinium enhancement

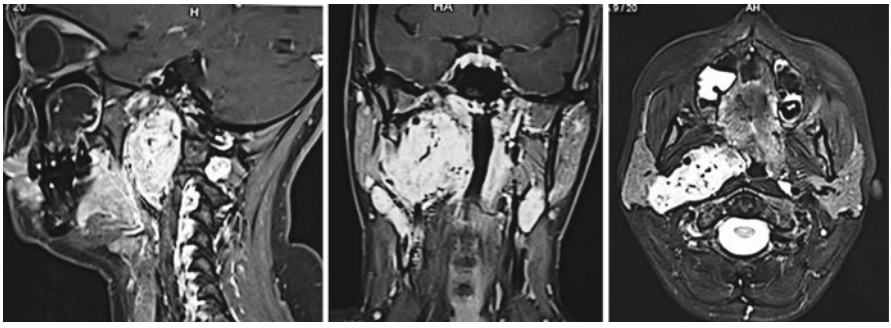

Fig. 6.6 T1W-MRI with gadolinium of jugular foramen paraganglioma presenting characteristic "salt and pepper" patterns

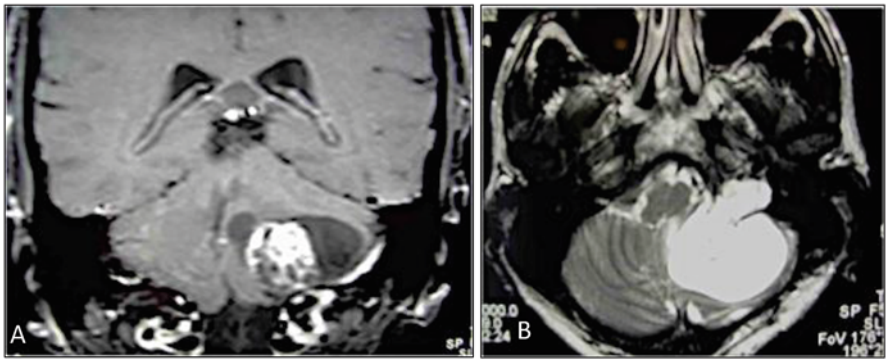

Fig. 6.7 (**a**) T1W-MRI with gadolinium of jugular foramen schwannoma. (**b**) Presenting high signal in T2W-MRI

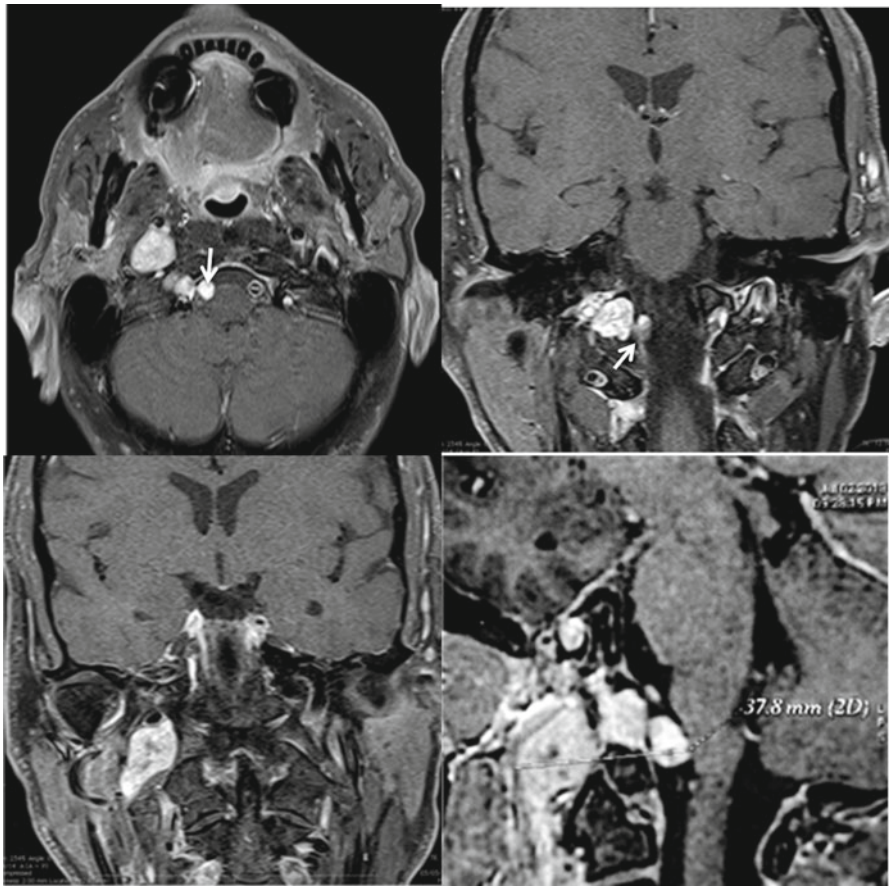

Fig. 6.8 T1W-MRI with gadolinium of jugular foramen schwannoma originated from the right hypoglossal nerve with extension within the spinal canal (*arrows*)

erosion and gives an expanded and scalloped but well-defined corticate margin to the jugular foramen. These tumors present moderate to significant homogenous gadolinium enhancement (Fig. 6.8). They may be cystic, with no flow void characteristic of paragangliomas and other highly vascular tumors observed. They may present a large posterior fossa mass (Fig. 6.9) and a dumbbell extension into the high cervical region. Calcifications are rarely seen and jugular foramen schwannomas do not invade the lumen of the internal jugular vein and jugular bulb. These tumors may occlude these structures by compression. Jugular foramen chondromas may also be misdiagnosed with schwannomas. These very rare tumors present homogeneous enhancement on MRI (Fig. 6.10).

In non-enhanced CT, meningiomas of the jugular foramen are isodense to the brain, and markedly enhanced. Calcifications, infiltration of the skull base, and hyperostosis are characteristics of meningiomas (Fig. 6.3) [8, 9]. On MRI they are

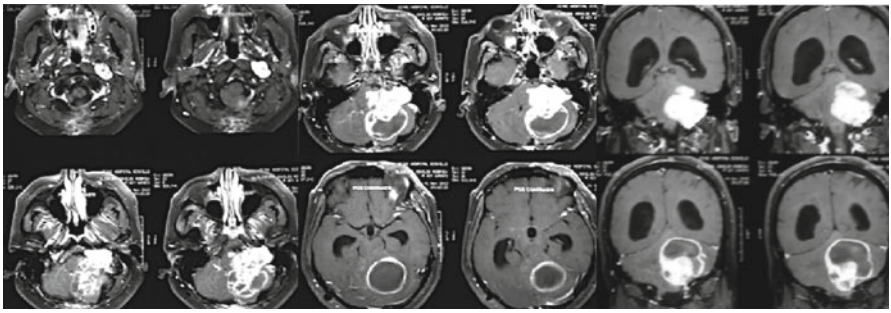

Fig. 6.9 Large jugular foramen schwannoma with posterior fossa cyst, T1W-MRI with gadolinium

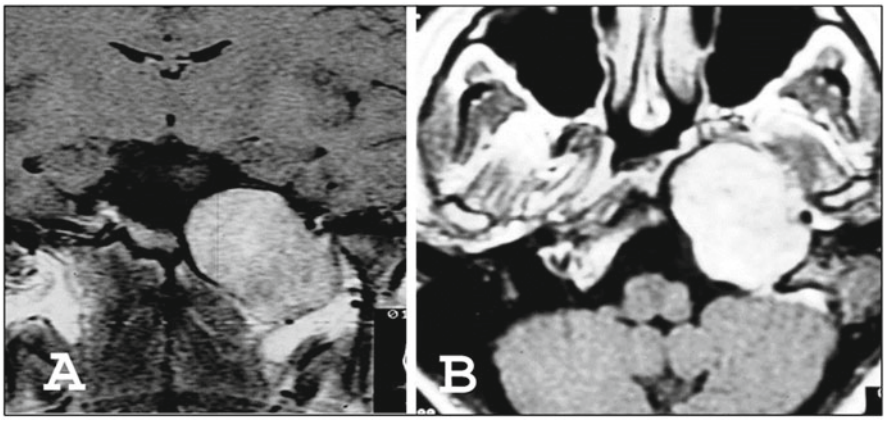

Fig. 6.10 MRI of a large jugular foramen chondroma. T1W-with gadolinium: (**a**) coronal view and (**b**) axial view

usually iso-intense to grey matter (Fig. 6.11), present gadolinium enhancement, and a "dural tail" may be present (Fig. 6.12). Meningiomas usually have a lower T2-weighted signal and a higher precontrast CT attenuation when compared with schwannomas [10]. Primary meningiomas of the jugular foramen usually infiltrate the skull base and the foramen. These features may differentiate meningiomas arising primarily in the jugular foramen from meningioma that involves the jugular foramen secondarily.

Chordomas (Fig. 6.13) and chondrosarcomas (Fig. 6.14) are heterogeneous, lobulated masses, presenting some areas with contrast enhancement. These tumors cause irregular bone destruction and are hypointense on T1WI and hyperintense on T2WI. Calcifications are seen in about 50 % of the cases [6].

MRI is also useful to differentiate jugular foramen paragangliomas from vascular abnormalities like high jugular bulb and aberrant internal carotid artery [11]. Radiological findings of aberrant internal carotid artery are: middle ear soft tissue mass from the promontorium to the tympanic membrane, absence of proximal part of the carotid canal.

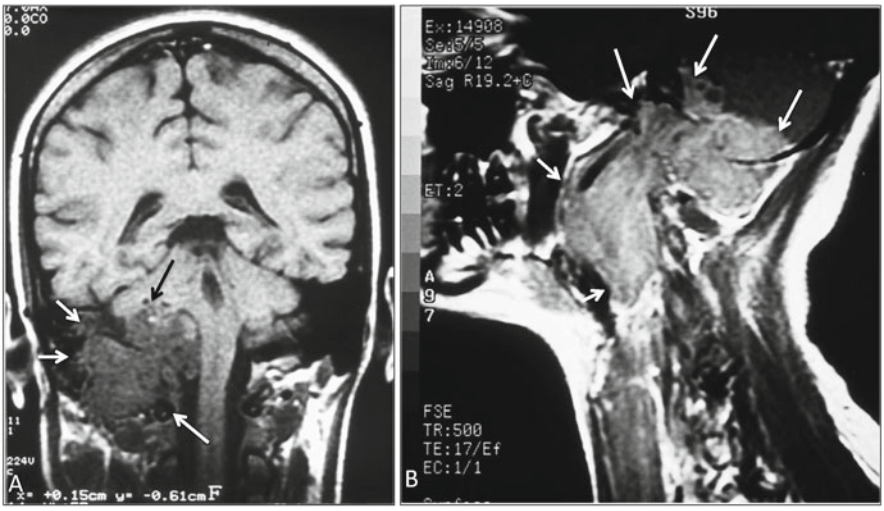

Fig. 6.11 Large jugular foramen meningioma (*arrows*). (**a**) T1W without gadolinium. (**b**) With gadolinium

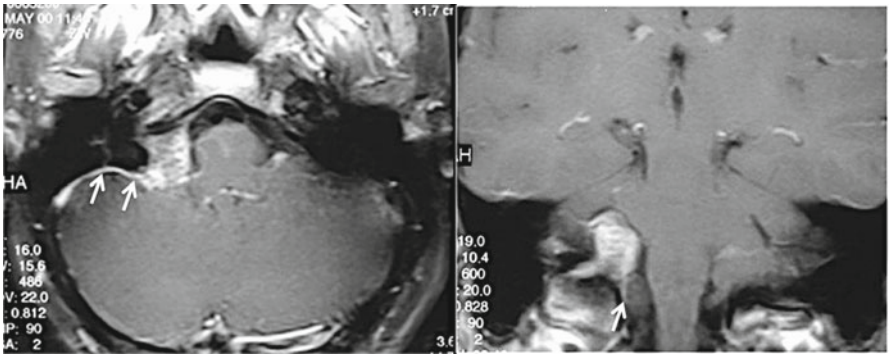

Fig. 6.12 Jugular foramen meningioma T1W-MRI with gadolinium showing "dural-tail" (*arrows*)

Digital subtraction angiography (DSA) is performed for diagnosis and to guide preoperative embolization in cases of highly vascularized lesions. This examination is routinely performed when the lesion is well vascularized. DSA is superior than magnetic resonance angiography and computerized angiotomography (Fig. 6.15) to evaluate tumor feeders, invasion of the internal carotid artery wall, involvement of the vertebral artery, and identify multicentric disease. The venous phase of DSA permits adequate visualization of the sinuses and veins as well as the position and patency of jugular bulb. High located and hypertrophic jugular bulbs are easily demonstrated by the venous phase of DSA. This anomaly may cause symptoms of tinnitus and hearing loss.

The primary arterial supply of jugular foramen paragangliomas is through the inferior tympanic artery (branch from the ascending pharyngeal artery) (Fig. 6.16),

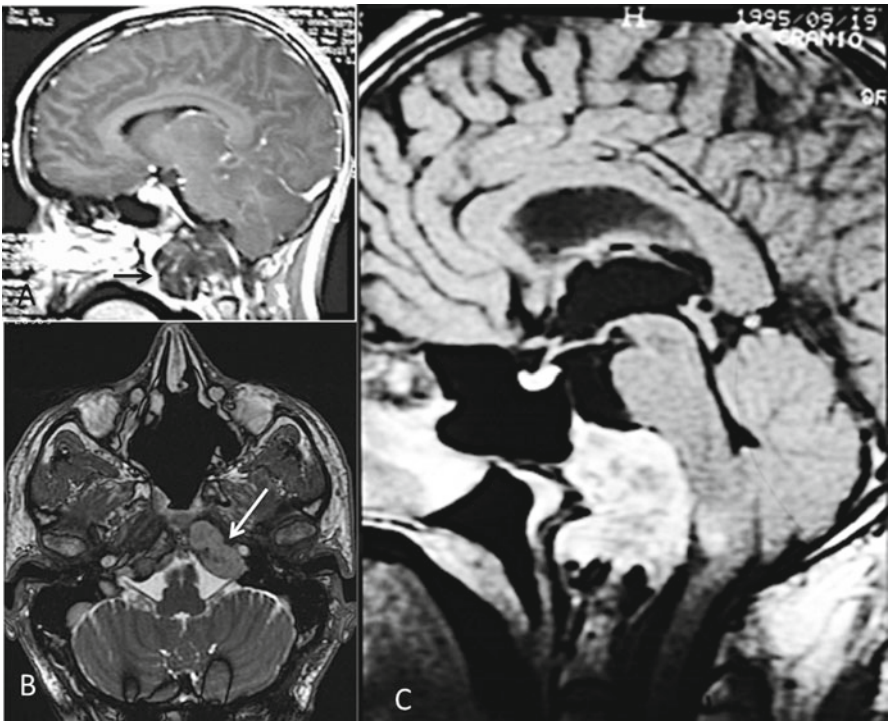

Fig. 6.13 Jugular foramen chordomas. (**a**) T1W-MRI without gadolinium, (**b**) T2W-MRI, (**c**) T1W-MRI with gadolinium

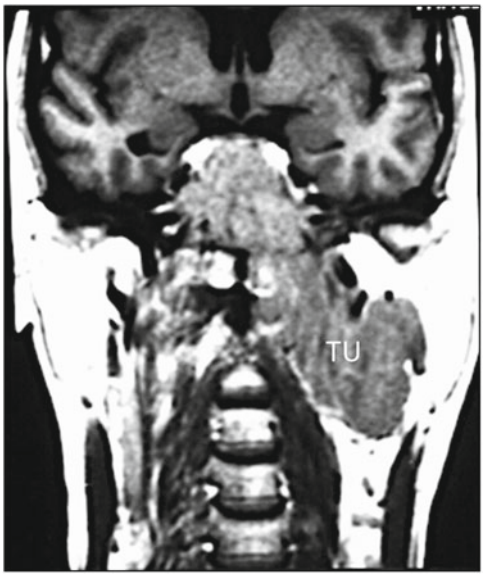

Fig. 6.14 Large jugular foramen chondrosarcoma, T1W-MRI without gadolinium (TU)

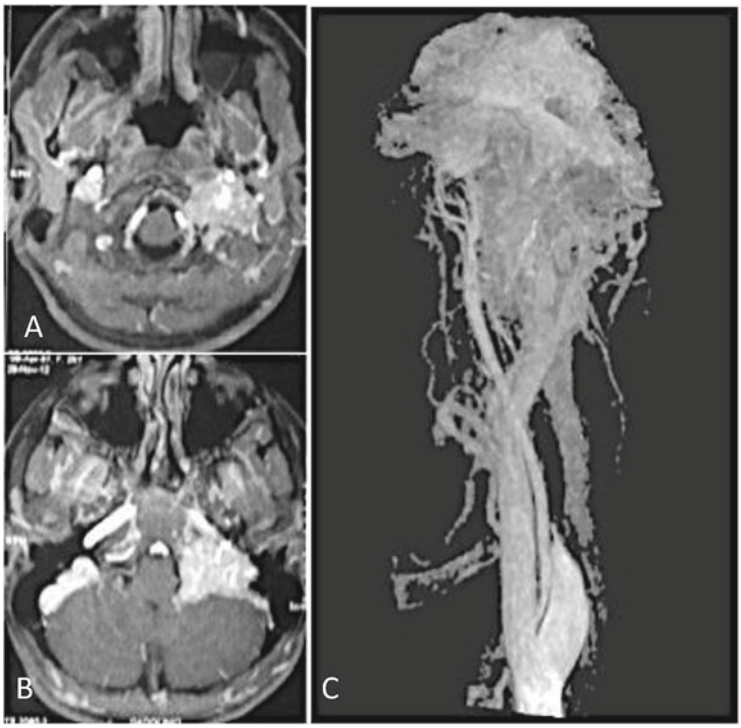

Fig. 6.15 (**a** and **b**) T1W-MRI jugular foramen paraganglioma. (**c**) Angiotomography showing tumor vascularization

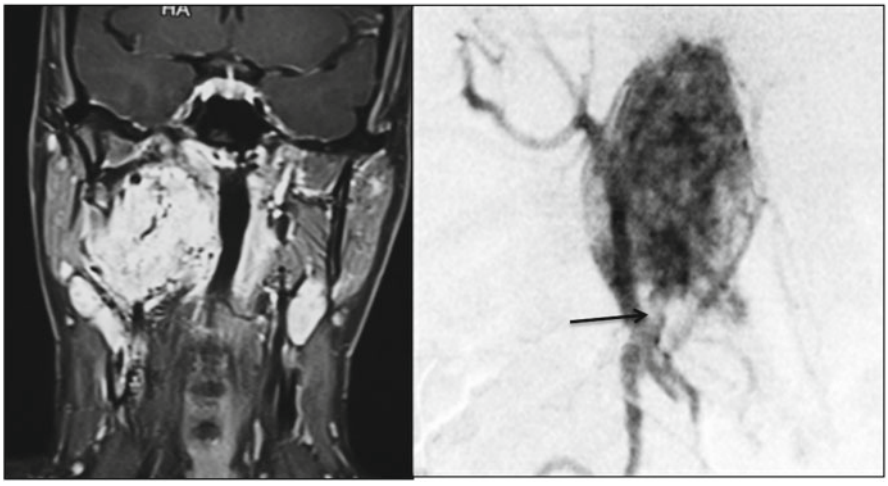

Fig. 6.16 Large jugular foramen paraganglioma. The ascending pharyngeal artery (*arrow*) is the main feeder of this tumor

the stylomastoid artery, occipital artery, posterior auricular artery, middle meningeal artery, internal carotid artery (carotid tympanic branches), and external carotid artery [12]. According to Moret [13, 14] and Young [15] the arterial supply of jugular foramen paragangliomas is separated in different compartments: inferomedial (jugular bulb and hypotympanum), posterolateral (posterior tympanic cavity, mastoid), anterior (protympanum and pericarotid region), and superior (epitympanum, supralabyrinthine). These compartments are hemodynamically independent and about 85 % of the glomus tumors are multicompartmental. Blood supply of each compartment is as follows: inferomedial by the inferior tympanic branch of ascending pharyngeal artery, posterolateral by the stylomastoid artery, anterior by the anterior tympanic branch of internal maxillary and caroticotympanic branches, and superior by the superior tympanic branch of middle meningeal artery.

Patients with tumors that involve or embed the internal carotid artery (Fig. 6.17) are submitted to balloon test occlusion to select patients for eventual carotid sacrifice. The walls of the internal carotid artery may be invaded. The angiography may show findings suggesting invasion of the walls (Fig. 6.18). Cerebral infarction and mortality may be high if the internal carotid artery is occluded [16]. Bypass surgery between the external or internal carotid artery and M2 branches of the middle cerebral artery may be performed in selected cases. Insertion of stents is also an alternative to protect the internal carotid artery during tumor dissection.

Hypervascularized tumors are preoperatively embolized. Feeders from the external carotid artery (ascending pharyngeal, internal maxillary, and occipital arteries), from the internal carotid (carotid tympanic branches), and vertebral artery (posterior inferior cerebellar artery) are embolized with Gelfoam®, Ivalon® particles, or Onyx® through super selective catheterization, 3–5 days prior to surgery.

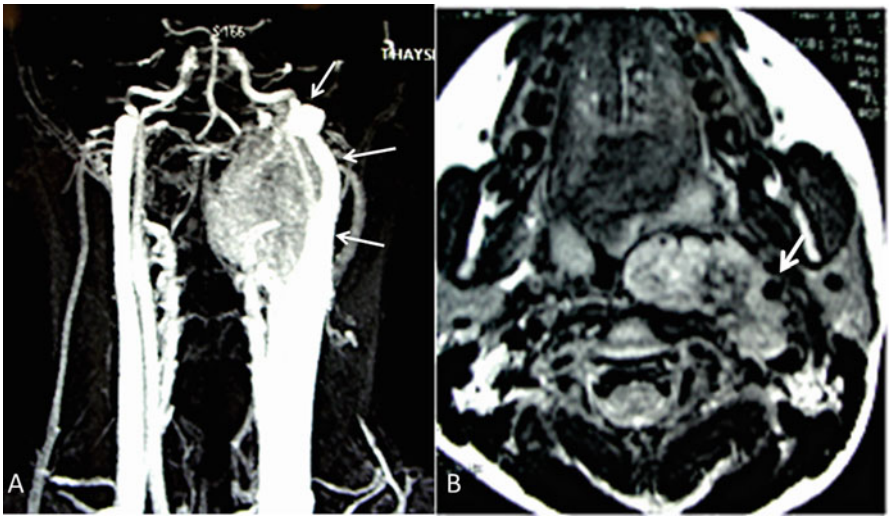

Fig. 6.17 (**a**) Magnetic resonance angiography showing involvement of the internal carotid artery by a jugular foramen paraganglioma (*arrows*). (**b**) MRI shows the ICA embed in the tumor (*arrow*)

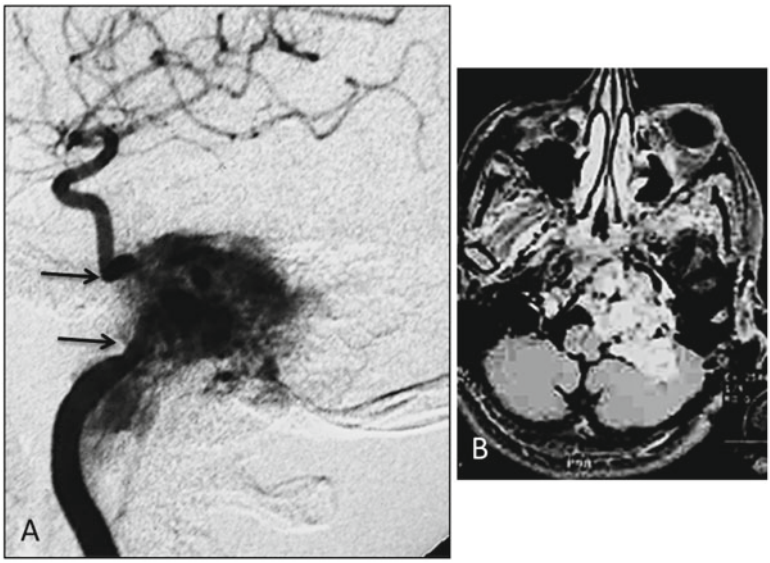

Fig. 6.18 (**a**) Digital subtraction angiography showing signs of internal carotid artery infiltration (*arrows*) by a jugular foramen paraganglioma. (**b**) MRI-T1W with gadolinium shows the tumor

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Chapter 7
Evidence-Based Treatment, Surgical Indications, Contra-indications, Preoperative Clinical Evaluation, and Preoperative Preparation for Anesthesia

Evidence-Based Treatment

Evaluation of evidence-based treatments for jugular foramen tumors should take into account various factors. The first one is to discuss with the patients their individual values, needs, and goals. Tumors of distinct histologies originate or involve the jugular foramen, and will require different modalities of treatment. Other important associated factors to decide how to manage these tumors are: patient age, clinical condition, presence of preoperative cranial nerves deficits, and grade of involvement or infiltration of the internal carotid artery. Based on relevant clinical studies the applicability and validity of the treatment modality should be decided in each case.

Paragangliomas

The proposed types of treatment are: clinical observation, surgical removal (with or previous embolization and/or radiotherapy), and irradiation therapy (all modalities) as primary treatment.

Surgical series, of benign paragangliomas, reported in the literature (Table 7.1) present a mean follow-up between 48.4 and 85.7 months. Gross total resection ranges between 51 % and 97.2 %. Grade of gross total resection depends on the size of tumor and grade of involvement of cranial nerves and the internal carotid artery. Recurrence varies from 0.7 % to 11.8 % depending on the length of follow-up period. Surgical mortality is very low and is related to tumor size and postoperative deficits of the lower cranial nerves. Postoperative morbidity is mainly related to the damage of cranial nerves and CSF fistula.

Surgical removal is the only method that offers cure and long-term control. Preservation of neurologic function is a priority and less-aggressive surgical resection achieves acceptable outcomes. Most patients carry out normal life activities even with mild deficits.

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Table 7.1 Results of surgical removal of jugular foramen paragangliomas

Authors	Resection	No of cases	Follow-up	Recurrence	Clinical improvement	Complications
Li et al. [1]	Subtotal 43.1 % Gross total 51 %	51	Mean 85.7 months	11.8 %	90 %	23 (45.1 %)
Patnaik et al. [2]	Subtotal 2.8 % Gross total 97.2 %	145	Mean 48.4 months	1 (0.7 %)	VII nerve Preserved 143	0
Jackson et al. [3]	Lateral skull base resection	176	Tu. resection between 1972 and 1998	Control 85 % 9 recurrences (5.5 %)	Tinnitus 54 % Other 34.5 %	CSF leak 4.5 % New CN deficits (21–39 %) Mortality 5 (2.7 %)

Table 7.2 Results of jugular foramen paragangliomas treated by irradiation

Authors	Method	No of cases	Follow-up	% Tu growth control	Clinical improvement	Complications
Hafez et al. [4]	GKS	22	Mean 56 months (36–108 months)	Unchanged 12 Decrease 8 Growth 1	12	3
Liscak et al. [5]	GKS	45	Median 118 months (12–217 months)	Unchanged 9 Decrease 34 Growth 1	19	2
Gandía-González et al. [6]	GKS	75	Mean 86.4 months	Control 94,8 % Decrease 67.2 %	Tinnitus 54 % Other 34.5 %	NR
Scheick et al. [7]	LINAC	11	Median 5.3 years	81 %	NR	0 %
Gilbo et al. [8]	Fractionated RT	131	Mean 11.5 years Median 8.7 years	99 %—5 years 96 %—10 years	NR	No severe

Irradiation therapy is utilized as postoperative treatment after subtotal removal and as primary treatment. Control of tumor growth is high but no patient will be cured with this method. Table 7.2 shows recent results of patients treated with radiosurgery (gamma knife, LINAC, and conventional irradiation therapy).

According to these results irradiation therapy has been demonstrated to be efficient and safe. It should be considered as an alternative for elderly patients and in small tumors with proven growth.

Schwannomas

Clinical observation, surgical removal, and irradiation therapy (all modalities) are the proposed treatment for jugular foramen schwannomas. These tumors, usually benign lesions, do not infiltrate bone, vessels, and nerves. Therefore, complete surgical removal is curative in the majority of the cases. Small lesions are more favorable for surgical resection with preservation of the involved, non-infiltrated, nerves. Larger tumors compress the non-affected lower cranial nerves and surgical dissection may cause deficits (in most cases temporary). In the literature reported surgical series present favorable outcomes in the majority of cases (Table 7.3).

Radiosurgery as primary treatment or after subtotal removal for jugular foramen schwannomas has been proposed in the literature (Table 7.4). Goals of this modality of therapy are to control tumor growth and avoid new deficits of the lower cranial nerves. Small tumors achieve better results; however, these lesions would also have better results with radical surgical resection. Elderly patients probably would have more benefit with this treatment. The reported results indicated that radiosurgery is a safe alternative to surgery in selected patients.

Table 7.3 Results of surgical removal of jugular foramen schwannomas

Authors	Resection	No of cases	Follow up	Recurrence	Clinical improvement	Complications
Samii et al. [9]	Gross total 16 (100 %)	16		0 %	100 %	CSF 2 cases
Sedney et al. [10]	Gross total Subtotal	81		5.7 % 10.7 %		
Sanna et al. [11]	Gross total 21 Subtotal 2	23		0 %		CSF 1 New CN deficits 50 %

Table 7.4 Results of jugular foramen schwannomas treated by irradiation

Authors	Method	No of cases	Follow-up	Tu growth control	Clinical improvement	Complications
Hasegawa et al. [12]	GKS	117	Median 52 months	Unchanged 42 Decrease 62 Growth 13	63 %	20 (17 %)
Peker et al. [13]	GKS	17	Mean 64 months	Unchanged 4 Decrease 13	19	2
Martin et al. [14]	GKS	35	Mean 83 months	Unchanged 16 Decrease 17 Growth 2	20 %	1

Meningiomas

Jugular foramen meningiomas are very rare and pose a challenge concerning radical surgical removal and preservation of cranial nerves. In the largest published series Huang et al. [15] evaluated 28 patients undergoing microsurgical removal. Radical tumor resection was achieved in 18 cases. In a mean follow-up period of 3 years with 22 patients, 12 presented hoarseness or bucking and 2 died of tumor recurrence. In another study with 13 patients gross total removal was achieved in 11 cases, no patient recovered from the preoperative deficits of lower cranial nerves and 61.5 % of the patients presented postoperatively new lower cranial nerves deficits [16].

An alternative to surgical removal is irradiation therapy. Due to the rarity of these tumors there is no published series comparing surgical results for jugular foramen meningiomas and radiotherapy/radiosurgery. Radiosurgery is indicated for small lesions. A long-term follow-up of a larger number of patients is, however, needed to evaluate the efficacy of irradiation in controlling tumor growth and preserving the function of lower cranial nerves.

Chordomas

Jugular foramen chordomas are rare and the management of these tumors follows the general treatment strategy of chordomas arising in other sites. Treatment of choice is surgical resection as radical as possible, followed by irradiation therapy (proton bean or radiosurgery) [17]. In the jugular foramen involvement of lower cranial nerves and infiltration of the skull base bones are the limiting factors for gross total of these lesions. Several surgical approaches have been used to remove these tumors. Transnasal endoscopic approach is currently one of the main surgical accesses to clivus chordomas [18]. Jugular foramen chordomas are not located in the midline region and endoscopic approaches are limited in these cases, but they may be associated with other cranial base approaches in order to resect tumors involving the clivus. Adjuvant radiotherapy improves outcome following subtotal removal [19].

Chondrosarcomas

Intracranial chondrosarcoma are rare tumors in the jugular foramen region they are even very rare [20]. They present a slow growing pattern and better prognosis than chordomas. According to the degree of cellularity, atypias, and mesenchymal type (more aggressive) they are classified in grade 1, 2, and 3. Complete surgical resection should be the primary treatment [21]. Radical surgical removal of skull base chondrosarcomas may be achieved with low mortality and morbidity [22]. Involvement of the lower cranial nerves may be a factor for subtotal resection. Radiotherapy/radiosurgery is usually indicated for subtotally removed lesions or high-grade tumors [23].

Surgical Indications

Most tumors arising in this region are benign and present a natural history of low growing lesions causing slight symptoms. Often these tumors are discovered through radiological examination for other symptoms. Surgical removal should achieve better results than the natural evolution of the disease. Several factors such as clinical condition, age, comorbidities, life expectancy, tumor stage, and in cases of paragangliomas if it is a solitary tumor of part of a genetic syndrome should be taken into consideration to indicate surgical resection of a jugular foramen tumor. Other factors such as grade of clinical involvement of lower cranial nerves, nature of the lesion, and involvement of the internal carotid artery are important to select the best or most appropriate management.

The preoperative function of lower cranial nerves plays a very important role in indication for surgery and for the radicality of the procedure. If preoperatively the patient presents complete deficits of the lower cranial nerves, manipulation or even resection of infiltrated nerves will be well tolerated postoperatively. However, if preoperatively there is no deficit of these nerves, surgical dissection of tumor capsule from vagal and glossopharyngeal nerves, particularly when there is a large parapharyngeal tumor, may cause severe swallowing troubles. Acute lesion of these nerves may produce severe life treating aspiration. Involvement of the lower cranial nerves is more common with paragangliomas and meningiomas. These tumors, even being histologically benign, may infiltrate the nerves, dura mater, and bone. In some cases it is preferably to remove subtotally the lesion to preserve the function of these nerves and avoid deterioration on quality of life. Elderly patients are in a higher operative risk because they present worse recovery of postoperative cranial nerves deficits and may never compensate vagal nerve palsy. In these cases, with larger lesions, decompression of the brainstem followed by radiological control of the tumor remaining and eventual radiotherapy/radiosurgery should be the treatment option.

Involvement of the internal carotid artery is other surgical difficulty to indicate radical removal of the tumor. Four-vessel carotid and vertebral angiography with cross flow studies should be performed. Paragangliomas and meningiomas may involve or even infiltrate the internal carotid artery. Preoperatively a balloon test occlusion is carried out when this artery is involved. If the patient tolerates occlusion sacrifice of the internal carotid artery and radical tumor resection may be considered for young patients. However, even if the patient "passes" the test occlusion, delayed stroke or ischemia may occur. Bilateral synchronous filling of cortical vein at digital suppression angiography is also used as predictor of tolerance for internal carotid artery occlusion. Therefore, our strategy in these cases has been to perform a high-flow bypass between the external or internal carotid artery and the M2 segment of the middle cerebral artery using a radial artery graft followed by radical removal of the lesion with the infiltrated carotid artery. We indicate this procedure only if radical resection is possible and for young patients with benign lesions. In three of our cases an alternative was the insertion of a covered stent to protect the vessel during tumor dissection [24]. Usually the stent is placed 3 months before surgical removal to allow re-epithelization of the device. The patient is maintained under aspirin to avoid throm-

bosis of the stent. Tumor dissection from the artery wall was possible in these cases without injury of the vessel. Elderly patients, patients with poor clinical condition or with malignant tumors with involvement or infiltration of the internal carotid artery are treated by subtotally removal followed by clinical observation and radiotherapy or radiosurgery if the tumor rest presents growth. Small tumors in elderly patients, without clinical symptoms, may be conservatively treated with MRI examinations every 6 months. If the tumor progresses or the patient develops clinical symptoms, radiosurgery is the management option in cases of paragangliomas and meningiomas. In cases of schwannomas a surgical resection may be considered if the clinical condition of patient is good. Benign schwannomas do not infiltrated cranial nerves and surgical resection of small lesions is safe with preservation of the cranial nerves.

Preoperative hearing is an additional factor for surgical indication, choice of approach, and grade of tumor resection. Tumors involving the internal auditory canal and middle ear may leave the patients deaf if the tumor is on the side of the only hearing ear.

Contra-indications

According to our experience, the factors that will contra-indicated surgical removal of a jugular foramen tumor are: patient's age, general health condition, presence of comorbidities, life expectancy, function of lower cranial nerves, and patient's personal choice. Size of tumor may be also a contra-indication for surgery. Small tumors may be followed by radiological imaging or treated by radiosurgery. High malignant tumors like carcinomas or sarcomas are usually treated by biopsy followed by radio- and/or chemotherapy.

Preoperative Clinical Evaluation

All cranial base surgeries must include careful general and neurological examination. Jugular foramen lesions require comprehensive otolaryngologic and neurological evaluations, as well as high-resolution imaging. This evaluation should determine the grade of involvement of cranial nerves, the extent of disease, if possible establish a diagnosis and plan treatment. The preoperative clinical examination should focus on identifying signs of involvement of lower cranial nerves, facial nerve, and hearing. Preoperative cranial nerves deficits predict the postoperative neurological prognosis and contribute to the surgical strategy. As preservation of swallowing is one of the most important surgical goals to be achieved, careful preoperative examination of the lower cranial nerves is mandatory. Hearing function must be carefully evaluated. The function of the contralateral ear should be accessed due to the risk of hearing loss by the surgical procedure. At otoscopy a red highly vascularized mass behind the tympanic membrane may be observed in cases of paragangliomas with middle ear extension. Biopsy of this lesion causes bleeding. Vasoactive secreting

paragangliomas, like pheochromocytomas, are rare. Dangerous hypertensive crises can occur during surgery if these lesions remain undiscovered. Preoperative examination of plasma metanephrine levels will help to avoid this condition. Tumor mass in the neck or parotid region may be associated with large paragangliomas or schwannomas. Usually patients with benign jugular lesions do not complain about ear pain. Malignant tumors frequently present rapid development of symptoms and pain in the ear or temporal bone region.

Preoperative Preparation for Anesthesia

Preparation for anesthesia and anesthetic management of jugular foramen lesions are focused on general and neuroanesthetic principles. Central and peripheral venous accesses, as well as arterial access for invasive measurement of blood pressure, are established. Anesthesia is induced using short acting neuromuscular blocking agents. Long-acting neuromuscular agents are not employed during the surgical procedure to permit adequate intraoperative monitoring. A nasogastric tube to prevent postoperative aspiration and a vesical catheter are inserted. Lumbar drainage is very rarely used and inserted at the end of surgery in tumors causing large bone defects and the cranial base reconstruction was not satisfactory. Prophylactic antibiotics are given at induction of anesthesia and continued during the first operative day every 8 h. Measures to prevent deep venous thrombosis with elastic stockings or calf length pneumatic compression devices are utilized. Facial nerve function, the lower cranial nerves, and the hypoglossal nerve are monitored. Brainstem evoked potential is recorded. Blood loss can be important in cases of highly vascularized tumors and blood units should be available. Goals of anesthesia are maintenance of oxygenation, hemodynamic stability, adequate cerebral perfusion, and intracranial pressure. Controlled hypotensive anesthetic techniques (systolic pressure between 70 and 80 mm Hg) may be necessary as well as brain protection in cases of temporary main vessel occlusion. The criteria used to determine if the patient is ready for extubation are: level of consciousness and function of lower cranial nerves.

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Chapter 8
Preoperative Embolization

Tumors of the jugular foramen (JF) present special features concerning their diagnosis and management. Important neurovascular structures at JF, cranial base, high cervical and posterior fossa regions are involved by these lesions. Paraganglioma is the most frequent and the most vascularized JF tumor. The combined expertise of neurosurgeons, otolaryngologists (ENT) surgeons, and interventional radiologist can lead to a better planning of diagnosis, preoperative evaluation, and management of these lesions. Surgical removal of these lesions with preservation of cranial nerves and vessels is the aim of the treatment. Focused on these aspects neuroradiologic techniques have provided a better choice for total removal of these tumors [1].

Therapeutic occlusion of the vessel with embolic particulate agents was first introduced by Luessenhop and Spence in 1960 [2]. In neoplasic lesions the primary goal of preoperative embolization is to reduce the blood loss in the surgical field, minimize the risk of operative complication, and prevent recurrence by contributing to a complete resection [3].

Embolization can be safely performed with digital subtraction angiography (DSA) for preoperative devascularization of the tumor to decrease the risk of intraoperative bleeding or along with irradiation to reduce the size of the tumor. It also provides considerable symptomatic relief and improves the quality of life in those for whom surgery is not available or not indicated [4].

Embolization is a dynamic procedure, and a number of techniques is currently available for endovascular occlusion based on the type and location of the lesion.

Particle embolization refers to mechanical blockage of vessels with individual particles of uniform size and shape. There is no specific type of particles for all sorts of occlusion nor can the therapeutic goal always be achieved in one session. In these cases, a combination of other particles or staging of the embolization is indicated.

Currently the polyvinyl alcohol is the most commonly used embolizing agent although Onix® has attained some highlight in literature [5]. A careful preoperative study of tumor vascularization must be performed to evaluate indication for vascular embolization.

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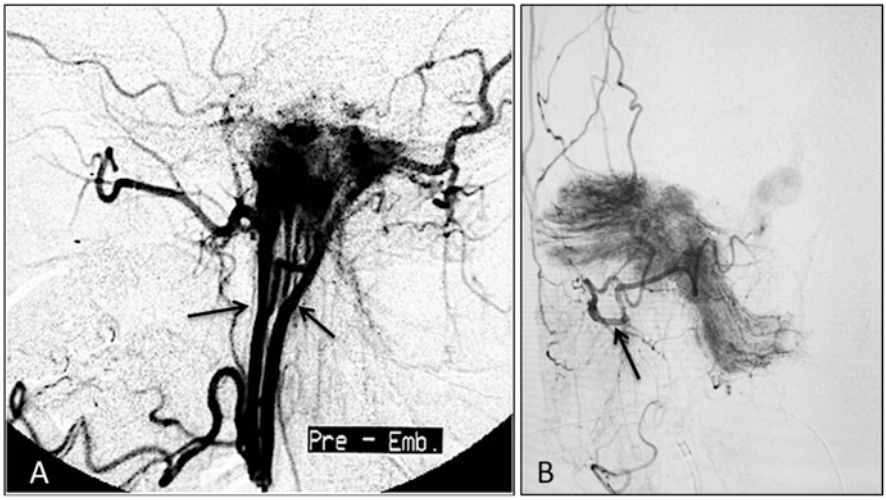

Fig. 8.1 Digital subtraction angiography of the external carotid artery showing the feeders of jugular foramen paragangliomas. (**a**) Ascendant pharyngeal artery. (**b**) Occipital artery

Jugular Foramen Paragangliomas

Guild, in 1942, identified tiny vascular structures at the dome of jugular bulb and promontorium and called them as glomera Jugulare [6]. Rosenwasser (1945) was the first to indicate the similarity and relationship between the glomus tumors and the glomus body [7].

Typically they occur in women in a 6:1 ratio and are mostly diagnosed in individuals ranging from 30 to 60 years of age. Familial occurrence is likely to occur in 10 % of patients with an autosomal dominant pattern of transmission [8].

As a role these lesions are solitary and slow-growing, with malignancy difficult to be histologically established and usually based on the presence of metastatic disease [9].

The most common symptoms found are hearing loss, tinnitus, ear pain, dizziness, ear discharge, and bleeding [1].

The expanding and destructive behavior of these benign tumors may present a life-threatening condition depending on the region involved. A combination on therapeutic modalities is needed for an adequate treatment.

Preoperative angiography helps to elucidate tumor origin, its vascular supply and extension. Optimal therapeutic option for paragangliomas usually consists of preoperative embolization and in some cases combined with pre or postoperative radiotherapy.

Characteristically they are highly vascularized lesions with main vascular supply from the ascendant pharyngeal artery. The occipital artery has also been linked as the second most common feeder artery (Fig. 8.1).

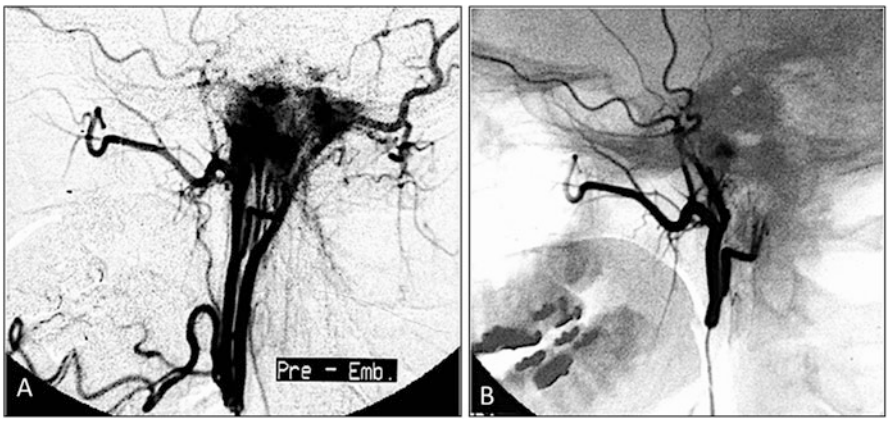

Fig. 8.2 Digital subtraction angiography of the external carotid artery in case of a jugular foramen paraganglioma. (**a**) Pre-embolization. (**b**) Post-embolization showing marked reduction of tumor vascularization

Hekster (1973) reported the first embolization of glomus tumor. Since then the indication of preoperative embolization has raised in order to minimize the surgical morbidity [10].

The primary goal of preoperative embolization of glomus tumors is to decrease the tumor volume to a certain extent and to reduce the operative blood loss. Around 80–90 % of tumor blood flow reduction has been reported in the literature, but there is no standard of measurement for technical evaluation of embolization and only qualitatively access to the blood reduction can be experienced by the surgeon.

Murphy and Brackmann reviewed 35 cases of glomus jugulare tumors. Eighteen patients had been submitted to preoperative embolization. A reduction in blood loss and surgical time was observed, but no significant reduction in postoperative neurological deficits [11].

However, some complications have been reported in literature. Cranial nerve palsy after onyx embolization was reported by Gaynor et al., in two cases from a series of 11 patients [5]. Lower particles usage can explain this occurrence, since they reach the small vasculature of vasa vasorum. Even with lack of good evidence to indicate preoperative embolization in glomus tumors it has been a current practice in the treatment of these patients. New prospective studies with an adequate tool of measurement should be developed in the future. Our strategy is to embolize medium- and large-sized jugular foramen paragangliomas with onyx® or gelfoam® 3 days before surgery (Figs. 8.2 and 8.3). According to our experience preoperative embolization reduces the intraoperative bleeding and surgical time. It is also helpful in cases of recurrent tumors (Fig. 8.4).

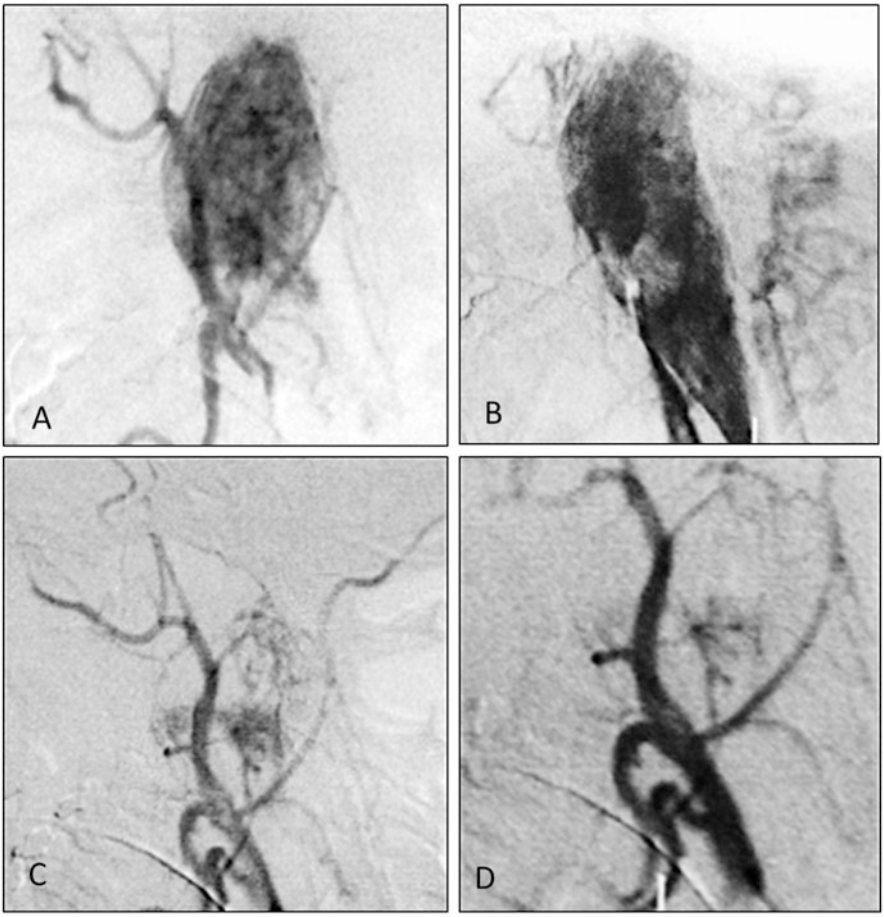

Fig. 8.3 Digital subtraction angiography of a jugular foramen paraganglioma. (**a, b**) Pre-embolization. (**c, d**) Post-embolization

Schwannomas

Intracranial schwannomas represent approximately 8 % of all primary intracranial tumors [12]. Schwannomas arising from the jugular foramen are very rare and account for only 2.9 % of all intracranial schwannomas [13]. They may be located within the jugular foramen or may extend intracranially and/or extracranially.

Jugular foramen schwannomas may arise from the glossopharyngeal, vagus, or accessory nerve or from the cervical sympathetic chain within the jugular foramen. However, the tumor origin remains undetermined in many cases [14].

Tumors with major extensions into the jugular foramen and extracranial extensions mainly produce hoarseness and dysphagia, and sometimes cause shoulder weakness, because of the involvement of the accessory nerve as the first symptoms [15].

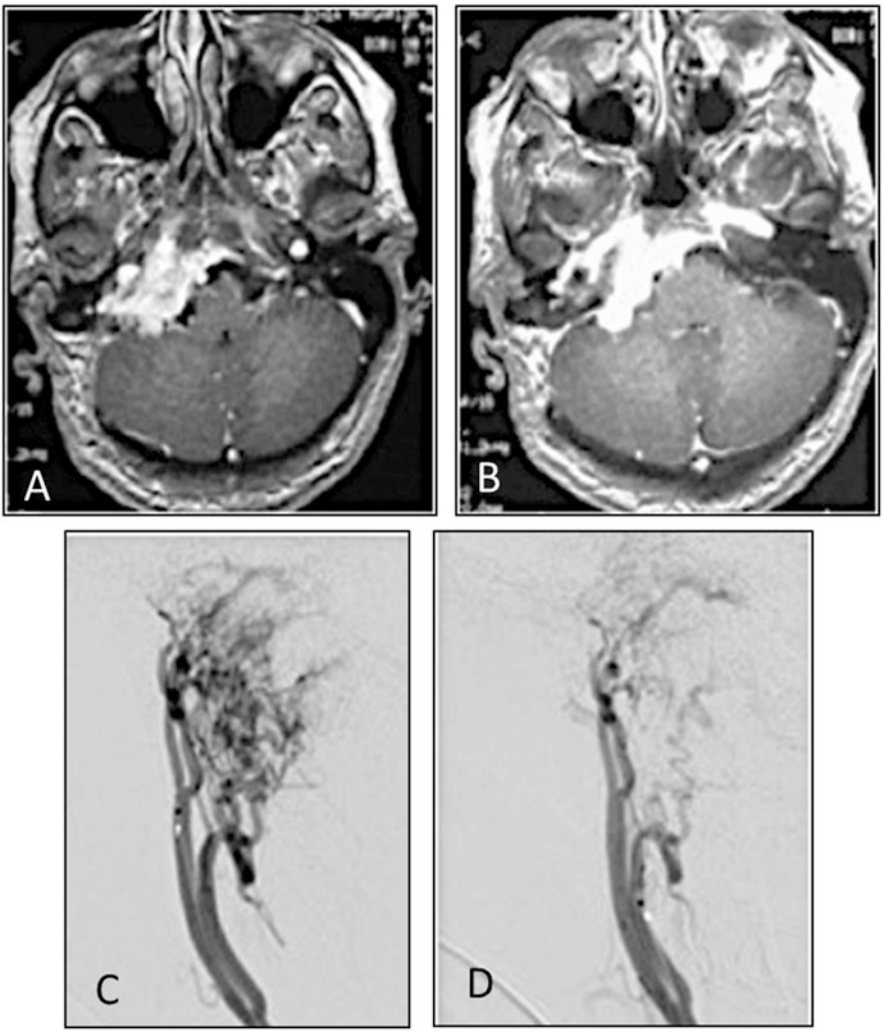

Fig. 8.4 Recurrent jugular foramen paraganglioma. (**a**) Pre-embolization. (**b**) Post-embolization

Surgical treatment has been the mean option of treatment for these lesions and many surgical approaches to access the jugular foramen have been described based primarily on the tumor extensions [16, 17].

Concerning to preoperative embolization in treating these lesions there is no report of preoperative embolization on the treatment of jugular foramen schwannomas and that is also the experience of the authors. In this way, the exclusive surgical treatment and radiation therapy are considered as the main modality of treatment and new studies testing preoperative embolization must be carried on to support these.

Meningiomas

Primary meningiomas of the jugular foramen are very rare. In a review of the literature the largest series report consisted of only ten cases [18].

The exact origin of the lesion is not clear. Usually, these tumors are very large and involve the jugular foramen, jugular fossa, posterior fossa, and high cervical region. Arnautović and Al-Mefty used the term "jugular fossa meningiomas" [19]. In many cases it is impossible to know whether the exact origin of this lesion is in the jugular fossa or within the jugular foramen. In a review of literature presented by Tekkök et al., the most frequent symptom was a mass in the neck followed by hearing loss and hoarseness [20].

Radiological features of jugular foramen show centrifugal tumor infiltration surrounding the skull base with sclerotic appearance of the bone margins, proeminent dura-tail, and absence of flow void [20].

The jugular foramen structures have embryological and histological ability to develop extracranial meningiomas [21]. Within the jugular foramen, the cranial nerves are not covered by the dura, they are involved with connective mesodermic tissue [22]. Some authors believe that arachnoidal cells concentrated in the arachnoid villosity are responsible for meningiomas of these regions [23].

The current treatment paradigm for these lesions consists of safe, gross-total resection including the adjacent involved dura and bone, although some small incidental lesions can be primarily followed with active surveillance [24]. Preoperative embolization may facilitate surgery by reducing blood loss and operating time [25]. However, embolization is associated with a number of serious risks including tumor hemorrhage, ischemia from untargeted vessel embolization, edema, worsening mass effect, hydrocephalus, cranial nerve deficits, seizures, and infection [26, 27].

Although first described in the early 1970s, preoperative embolization for meningiomas has generally been reserved for a minority of lesions [28].

In a systematic review of 36 studies totalizing 459 patients with meningiomas submitted to preoperative embolization, from every 20 patients preoperatively treated with embolization one will suffer from a complication (transient or sustained), varying from cranial palsy to hemiparesis. This complication rate does not take into account the potential additional benefit of embolizaton, e.g., the reduced surgical morbidity [12].

In all recent series of meningiomas evaluating preoperative embolization there are no substantial quantity of control groups of meningioma patients without embolization, ending in no report of specific outcomes.

The reason why preoperative embolization is not more common is understandable due to the possibility of intraoperative tumor devascularization when treating cranial vault meningiomas. Large skull base meningiomas have their blood supply arising from petrous, cavernous, pial internal carotid artery branches, or vertebrobasilar branches which are difficult or impossible to be selectively catheterized safely. In the authors' opinion, only rare jugular foramen meningiomas with exuberant and multidirectional blood supply could have benefit with preoperative

embolization. In this concept, neurosurgeons must carefully perform a vascular study to identify parent vessels and effectively plan a vascular control [28]. In order to achieve this goal, the indication to embolize meningiomas must be managed on case-by-case basis.

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Chapter 9
Surgical Treatment and Postoperative Management

Surgical Approaches

Most authors use the postauricular infratentorial surgical approaches proposed by Fisch [1] to treat glomus tumors. Three distinct variations of Fisch's approaches are used in specific clinical situations. All three approaches include mastoidectomy, facial nerve transposition, and conductive hearing deficit due to obliteration of external and middle ear. Type-A approach is employed for management of paragangliomas, neuromas, and meningiomas of the jugular foramen. Radical mastoidectomy and cervical dissection are performed, the facial nerve is anteriorly transposed. This approach provides access to the infratemporal fossa and jugular foramen and to the vertical portion of the internal carotid artery (ICA). Jugular foramen paragangliomas with larger intradural extensions (2 cm or more) are resected in two stages. Type-B approach is used to remove lesions of the petrous apex and mid-clivus (petrous apex cholesteatomas, chordomas, cholesteatomas, and some meningiomas). This approach allows exposure of the horizontal ICA, petrous apex, superior infratemporal fossa, and foramen ovale. Type-C approach is used to resect nasopharyngeal angiofibromas and some nasopharyngeal carcinomas.

Our strategy of surgical treatment of jugular foramen tumors differs from that proposed by Fisch because according to our experience a multidisciplinary team composed by neurosurgeons, ENT-surgeons, otologists, neuroradiologists, endovascular surgeons, and intensivists offer the patients the best chance of radical removal in one surgery with functional preservation (Fig. 9.1). In our opinion this multidisciplinary team should be prepared to manage all possible surgical difficulties and complications as: involvement of ICA requiring reconstruction of the vessel, high- and low-flow bypasses between the ICA and the middle cerebral artery, reconstruction of affected cranial nerves, reconstruction of larger skull base defects caused by tumor infiltration and extensive bone removal at skull base, and tumor dissection from brainstem and intracranial vessels [2–4]. Glomus tympanicum develops inside the middle ear without invasion of the jugular foramen.

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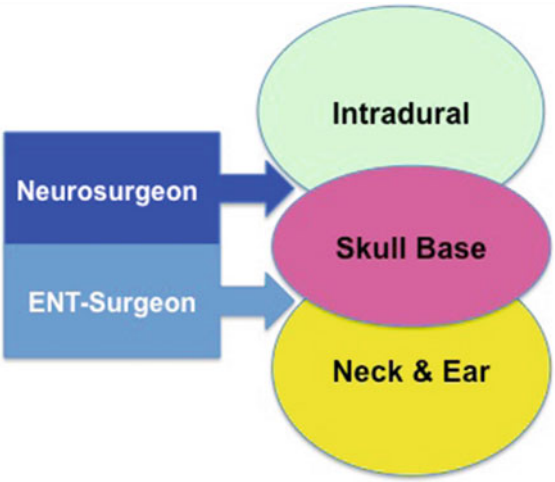

Fig. 9.1 Jugular foramen tumors originate in the skull base and may invade the ear, neck, and intradural regions

Small glomus tympanicum on promontory is removed through a transcanal approach. Larger tumors are removed through an incision behind the ear, drilling the facial recess and mastoid to approach the middle ear. As these tumors do not involve the jugular foramen and the posterior fossa, the surgical approaches to these tumors will not be discussed in this chapter.

According to the extension of the tumor two main surgical approaches have been used to treat the jugular foramen tumors in our series [5–8]. (a) The modified retrosigmoid approach indicated when the tumor is predominantly intradural without extensions to the cervical region without involvement of the ICA. Tumor infiltration or extension within the jugular foramen, mastoid, and middle ear can be removed by drilling the posterior wall of the jugular foramen and mastoid exposing the sigmoid sinus, retrofacial mastoid cells, semicircular channels, and hypotympanum. Meningiomas, schwannomas, chordomas, chondrosarcomas, and some paragangliomas are the most frequent jugular foramen tumors removed through this approach. (b) The cranio-cervical approach: indicated when the tumor extends into the cervical region, retropharyngeal space, involves the clivus, the ICA, the vertebral artery, the jugular bulb, and the internal jugular vein (IJV). Paragangliomas, schwannomas, and large meningiomas are the most frequent lesions requiring a cranio-cervical approach.

Retrosigmoid Approach

The patient may be placed in semi-sitting position (preference at University of Tübingen) (Fig. 9.2), dorsal decubitus or “mastoid position” (preference at the Neurological Institute of Curitiba) (Fig. 9.3), or “park-bench position.” The anesthesiologist should check the lateral neck on both sides for jugular vein

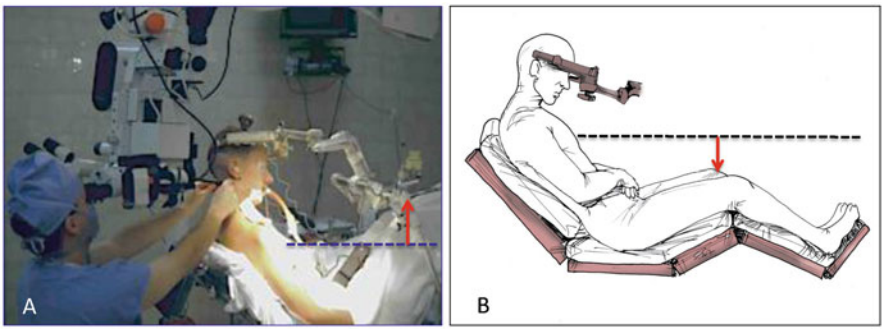

Fig. 9.2 (**a**) Patient in semi-sitting position. The legs are above the level of heart to avoid air embolism. (**b**) Sitting position, the legs are below the heart level

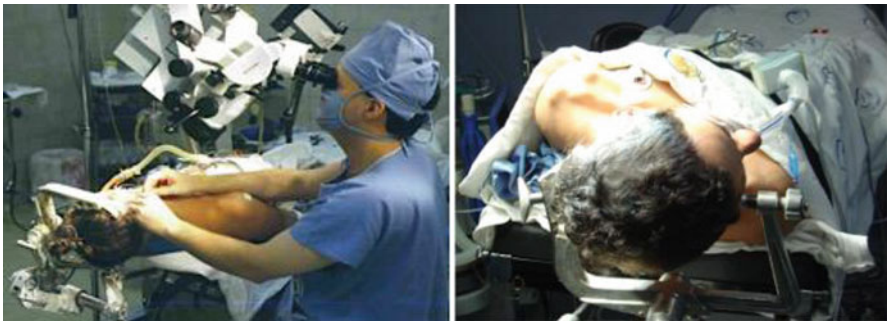

Fig. 9.3 Patient in dorsal position with the head rotated to the opposite side

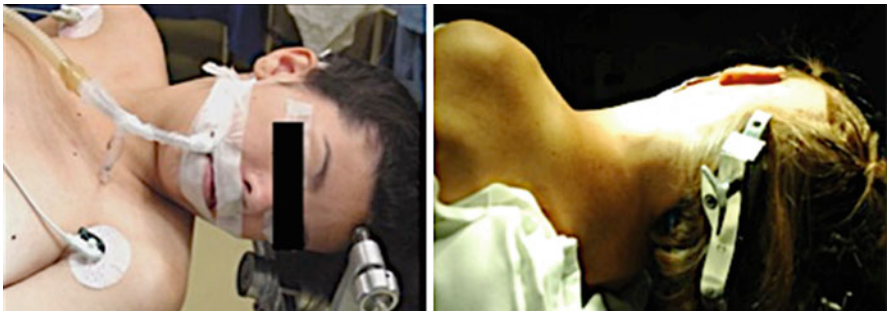

Fig. 9.4 Patient in dorsal position the head is slightly extended. A pillow is placed under the shoulder to avoid excessive rotation of the head

compression to avoid air embolism. In dorsal decubitus the head is rotated about 30° to the opposite side with light lateral extension. A pillow is placed under the shoulder to avoid excessive rotation of the head and compression of vertebral artery at the cranio-cervical junction. The opposite IJV must be checked to assure that it is not compressed (Fig. 9.4).

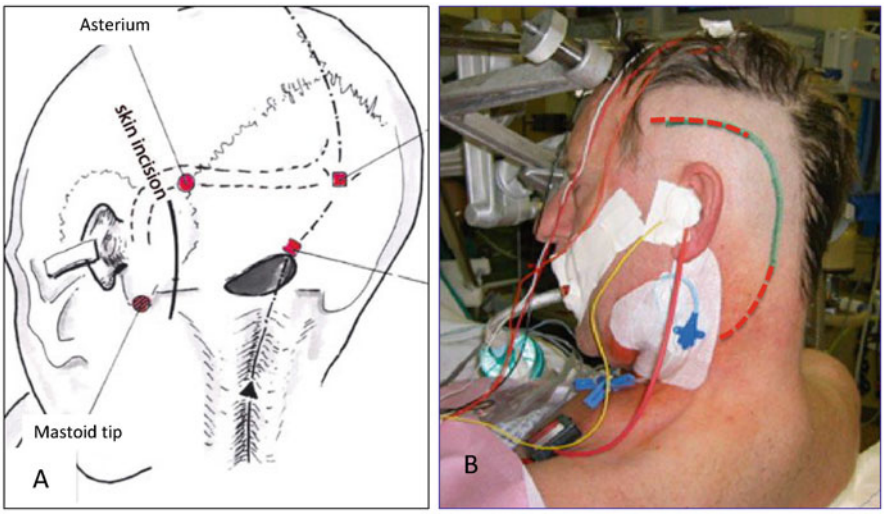

Fig. 9.5 Patient in semi-sitting position. (**a**) Skin incision. (**b**) Incision may be extended to the temporal and cervical regions

In semi-sitting position the legs are placed above the level of the heart with the knees slightly flexed (Fig. 9.5). The head is rotated 30° toward the affected side, hyperextended, and flexed. Bilateral SEPs are continuously monitored during positioning. In order to check the occurrence of air embolus, transesophageal echocardiography or precordial doppler is used. Neurophysiological monitoring of cranial nerves V, VI, VII, VIII, IX, X, XI, and XII is performed (Figs. 9.6, 9.7, and 9.8).

Skin incision (straight or slightly curved) starts in the retromastoid region about 5 cm behind the external auditory canal and extends 2 cm behind the mastoid tip, ending in the upper neck (Fig. 9.9). The inferior extension of the skin incision depends on the tumor extension. Scalp is elevated with the periosteum. Fascia and muscles are cut straight down exposing the occipital bone, the asterium, and the retromastoid region and held with a self-retaining retractor (Fig. 9.10). With the aid of neuronavigation a burr hole is performed at the transversus and sigmoid sinuses junction (usually at the asterion) (Fig. 9.11). A 4 cm diameter craniotomy is cut (Fig. 9.12). With a high-speed diamond drill the transverse and sigmoid sinuses are exposed. Part of squamous occipital bone is removed with rongeurs until the jugular bulb. Craniectomy is also an option in cases of dura adherence to the occipital bone (elderly patients). The mastoid emissary vein is coagulated and cut. In semi-sitting position care should be taken to avoid air embolism when the sinuses and the emissary veins are exposed. Jugular vein compression in the neck or Valsalva maneuver helps to identify venous bleeding. Small sigmoid sinus lacerations are repaired either with sutures or small pieces of muscle fascia and fibrin glue (Fig. 9.13). Care should be taken to not occlude the sinus by packing lacerations with hemostatic material or muscle. The opened mastoid cells are packed with bone wax or muscle pieces and fibrin glue. Mannitol is administered intravenously before opening of the

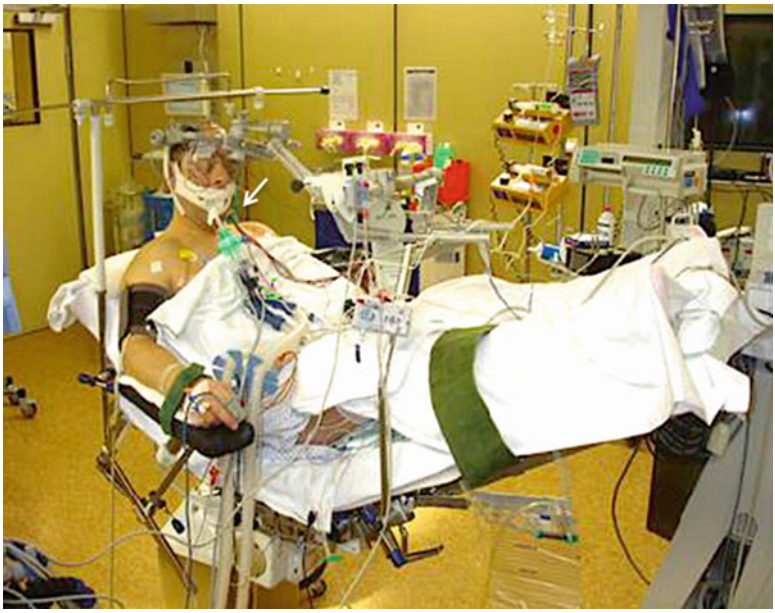

Fig. 9.6 Transesophageal echocardiography and precordial doppler are used to check the occurrence of air embolus

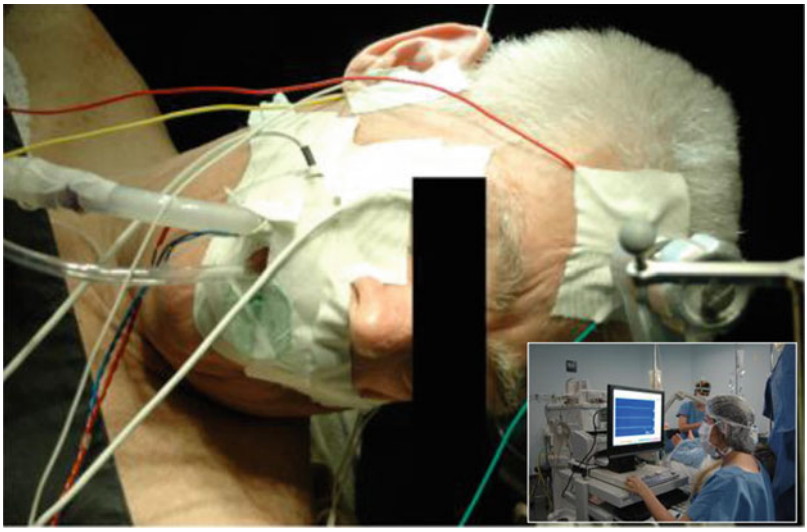

Fig. 9.7 Neurophysiological monitoring of cranial nerves V, VII, and VIII

dura mater. Under the magnification of the operation microscope, the dura mater is incised in a C-shaped fashion, parallel to sigmoid sinus (Fig. 9.14). The lateral aspect of cerebellum is slightly retracted and the cerebellomedullary cistern is

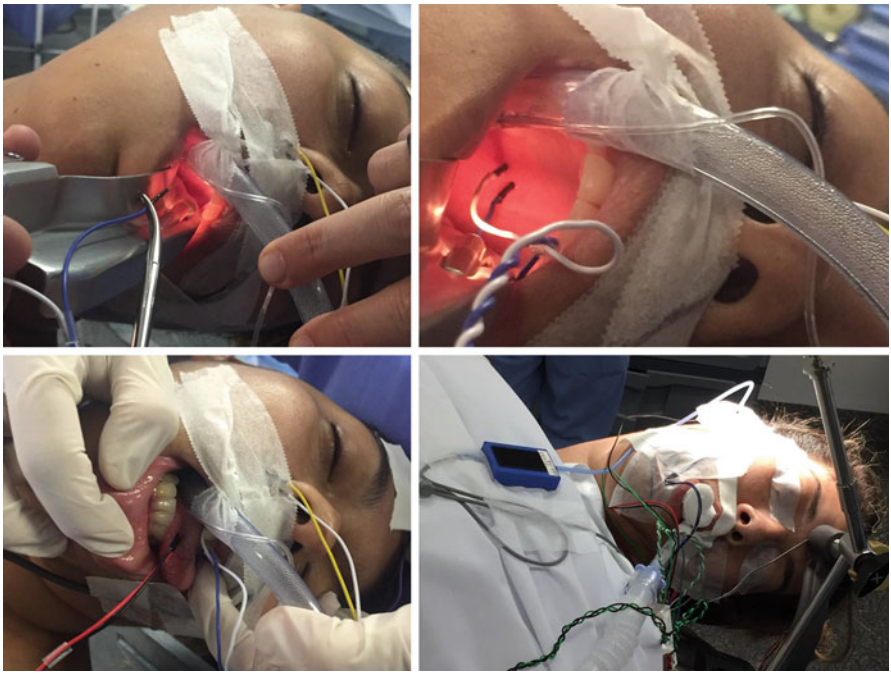

Fig. 9.8 Neurophysiological monitoring of lower cranial nerves

opened relaxing the posterior fossa. This maneuver is carried out with cotton strips or a rubber strip to protect the cerebellum against lacerations. Brain retractor is used to protect rather than retract the cerebellum. The lower cranial nerves are mostly involved or infiltrated by the tumor. The VI, VII, and VIII cranial nerves, the PICA, the vertebral artery, and the brainstem are usually attached to the tumor capsule (Fig. 9.15). In cases of meningiomas, paragangliomas, and aggressive tumors, the cranial nerves IX, X, and XI may be embedded or even infiltrated. The posterior wall or the jugular foramen is exposed (Fig. 9.16). A C-shaped dura incision based on the posterior lip of the jugular foramen is carried out and the foramen is opened with high-speed diamond drill (Fig. 9.17). Very careful dissection of the nerves within the jugular foramen is performed, under monitoring, to avoid damage to these structures and to the jugular bulb. The use of endoscope is helpful to dissect the tumor from cranial nerves within the jugular foramen (Fig. 9.18). If these nerves are infiltrated and the patient preoperatively has no deficit, radical resection is not attempted. In these cases, benign lesions are treated postoperatively with radiosurgery only if growth of the tumor rest is observed. Solid tumors are initially intracapsular enucleated. Gently dissection of the tumor capsule shows the arachnoid interface between the tumor and the surrounding structures. After coagulation of the dural attachments, intracapsular piecemeal resection is carried out. In contrast to solid tumors, cystic schwannomas have strong adherence to cranial nerves and the

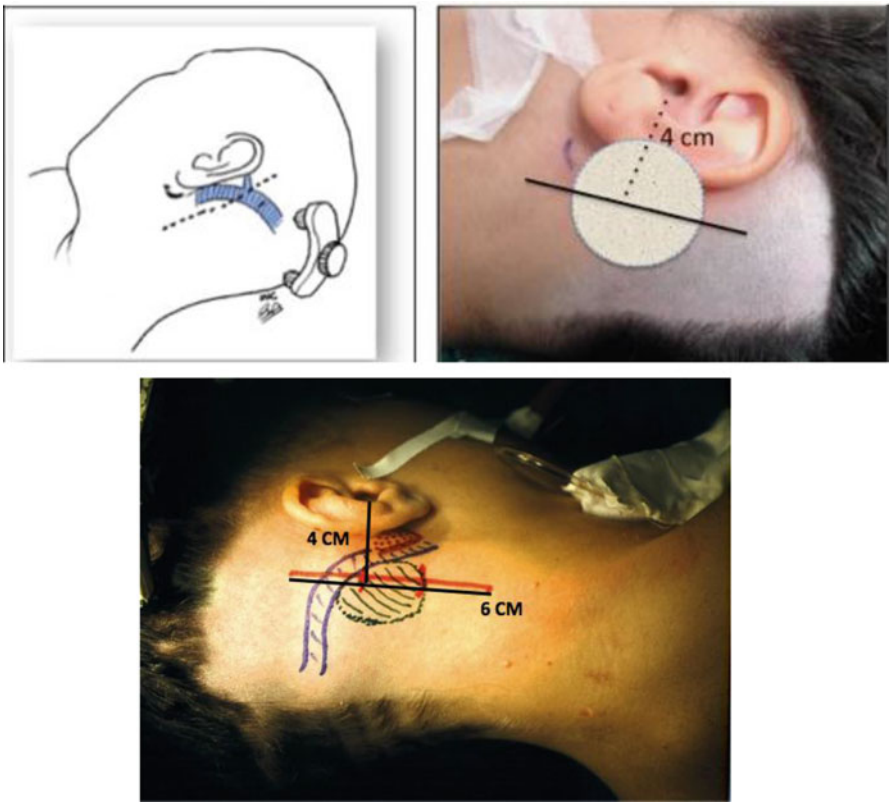

Fig. 9.9 Skin incision

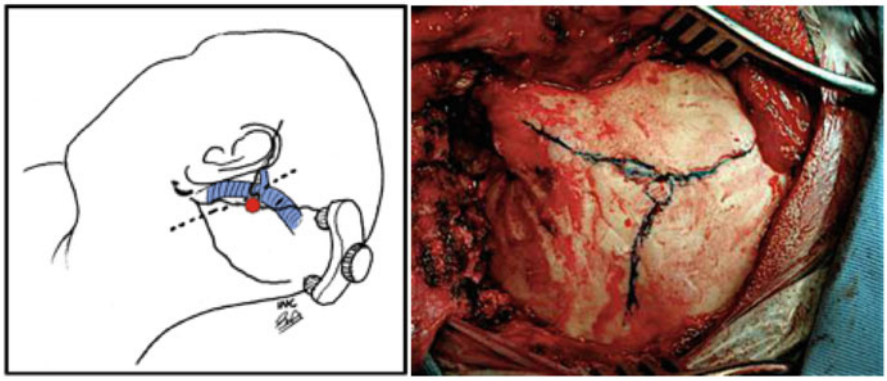

Fig. 9.10 Identification of the asterium

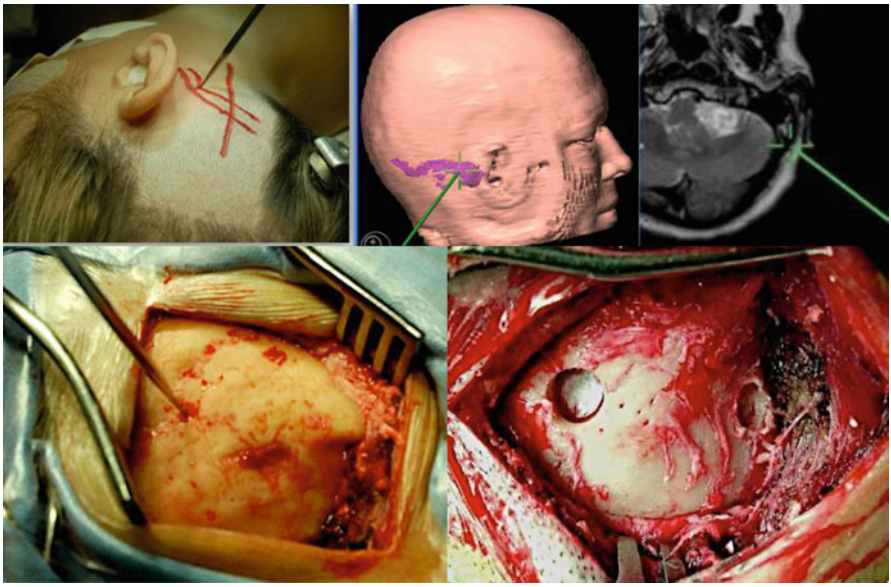

Fig. 9.11 Identification of sigmoid and tranverse sinuses junction with neuronavigation

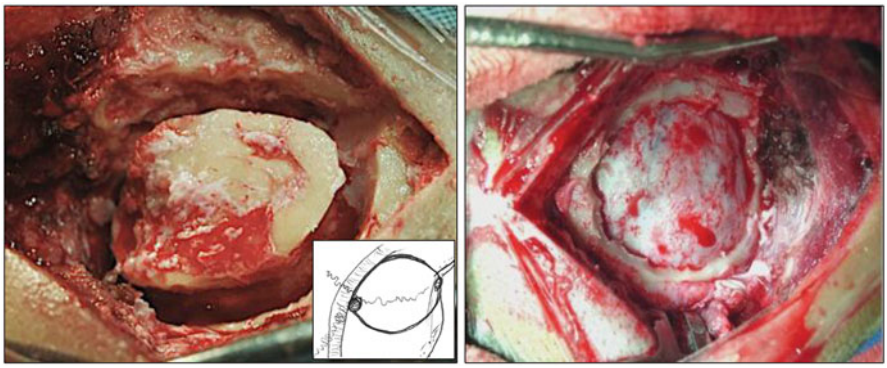

Fig. 9.12 Retrosigmoid craniotomy

arachnoid interface should be first identified and dissected, avoiding opening the cyst [9–11]. Meticulous sharp dissection of the arachnoid plane followed by evacuation of the cyst will permit removal of the cyst wall from the surrounding structures (Fig. 9.19). After tumor removal, watertight continuous suture of dura mater is performed. The bone flap is replaced and fixed with mini-plates or cranioplasty with methyl methacrylate is performed. The wound is sutured in usual fashion and no drain is used.

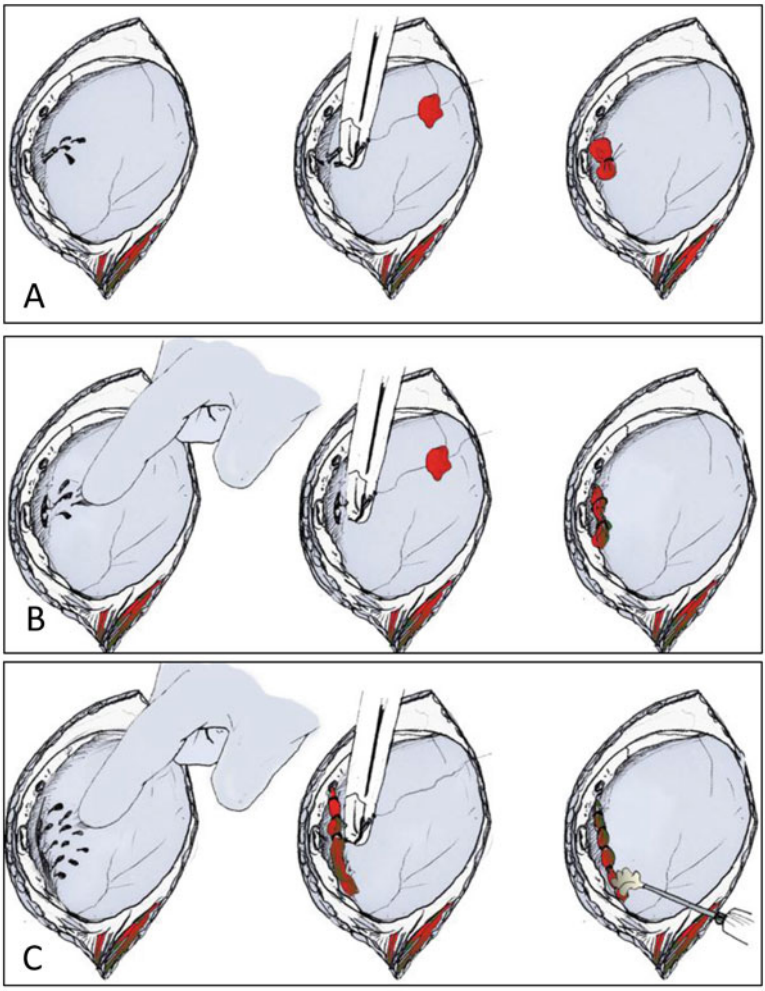

Fig. 9.13 Drawings showing management of emissary vein lesion (**a**), small (**b**) and large injury of the sigmoid sinus

Cranio-cervical Approach

Position of Patient and Skin Incision

The positioning of the patient is discussed with the anesthesiologist. Intermittent compression of the lower limbs to prevent deep vein thrombosis is used for patient at risk of this complication. A nasoenteral tube is inserted. For the cranio-cervical approach the patient is placed in dorsal position with the head fixed in a cranial clamp (Mayfield) slightly extended and rotated between 30° and 45° to the

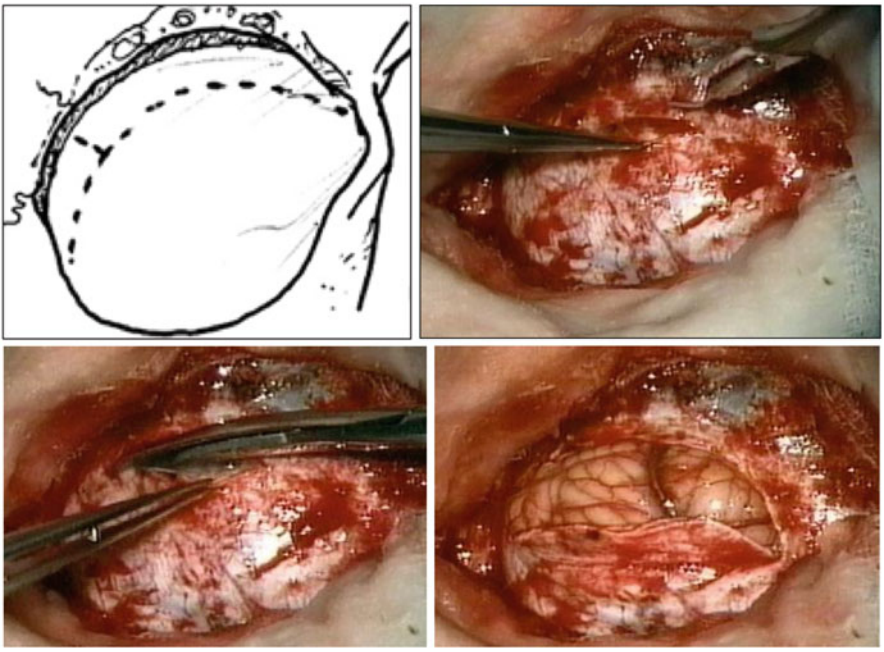

Fig. 9.14 Opening of the dura mater parallel to the sigmoid sinus

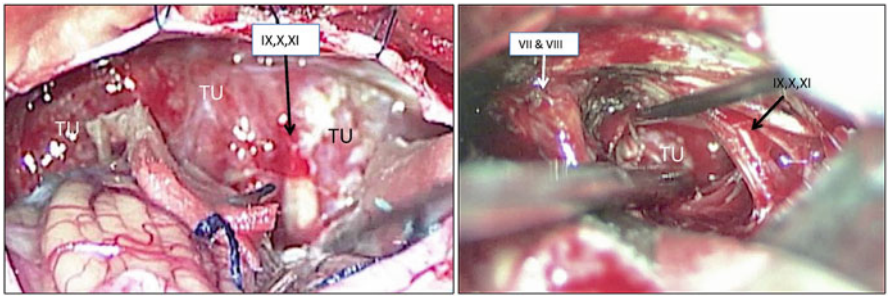

Fig. 9.15 Large jugular foramen meningioma. Dissection of lower cranial nerves from tumor capsule

contralateral side (Fig. 9.20). The ipsilateral shoulder is elevated and the opposite IJV must be free (Fig. 9.21). All body contact areas must be checked due to the long duration of the surgery. A nasogastric tube is inserted. Electrophysiological monitoring of cranial nerves V, VI, VII, VIII, IX, X, XI, and XII, as well as bilateral somatosensory evoked responses (SAEPs), are performed according to the extension of the tumor. All parameters for neuronavigation are checked.

A C-shaped skin incision starts in the temporal region about 5 cm superior to the zygomatic arch circumscribes the ear and the mandible angle, and continues in a

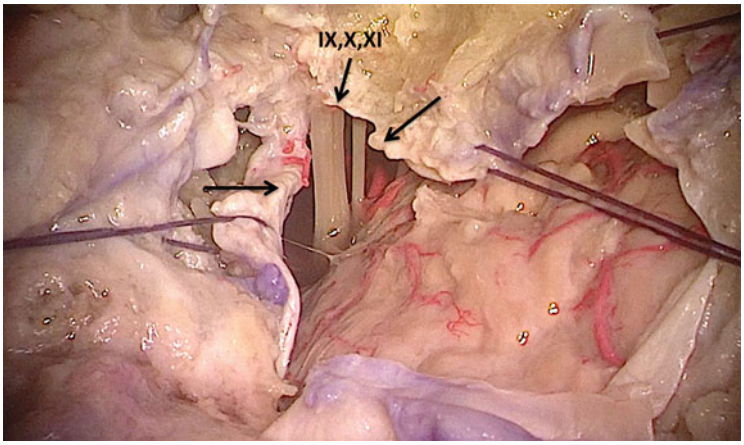

Fig. 9.16 Anatomical specimen showing the lower cranial nerves after opening the JF (*arrows*) through a retrosigmoid approach

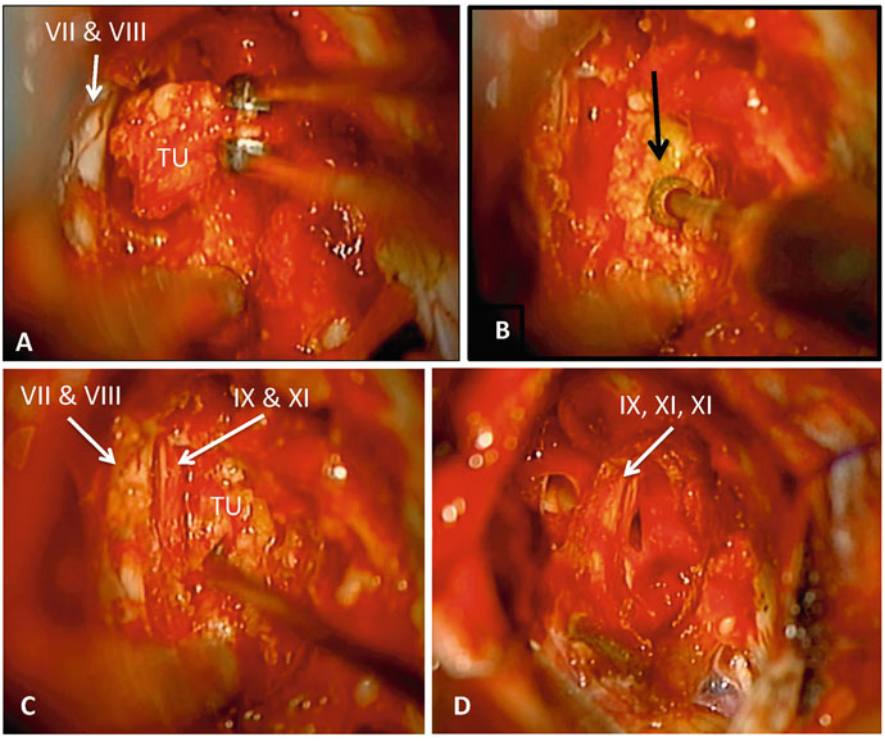

Fig. 9.17 (**a**) JF meningioma (TU). (**b**) Intradural drilling of jugular foramen (*arrow*). (**c**) Tumor dissection from lower cranial nerves. (**d**) Total tumor removal

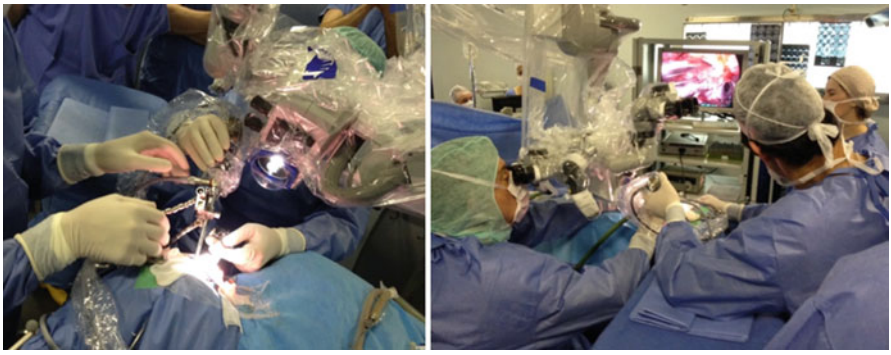

Fig. 9.18 Endoscopic assisted microsurgical removal of JF meningioma

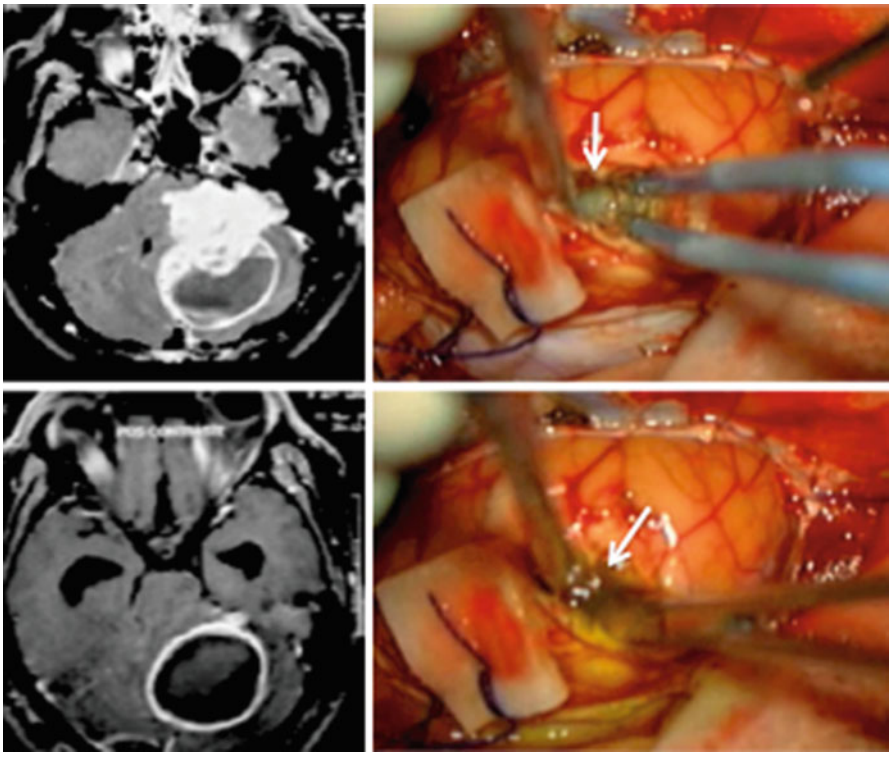

Fig. 9.19 Large cystic JF schwannoma. Transcerebellar evacuation of the cyst (*arrows*)

cervical fold over the border of the sternocleidomastoid muscle (SCM) reaching the midline (Fig. 9.22). The great auricular nerve is identified and dissected (Fig. 9.23). This nerve may be used as graft for reconstruction of the facial nerve in those cases when the VII nerve is infiltrated by the tumor and must be resected. The skin flap is

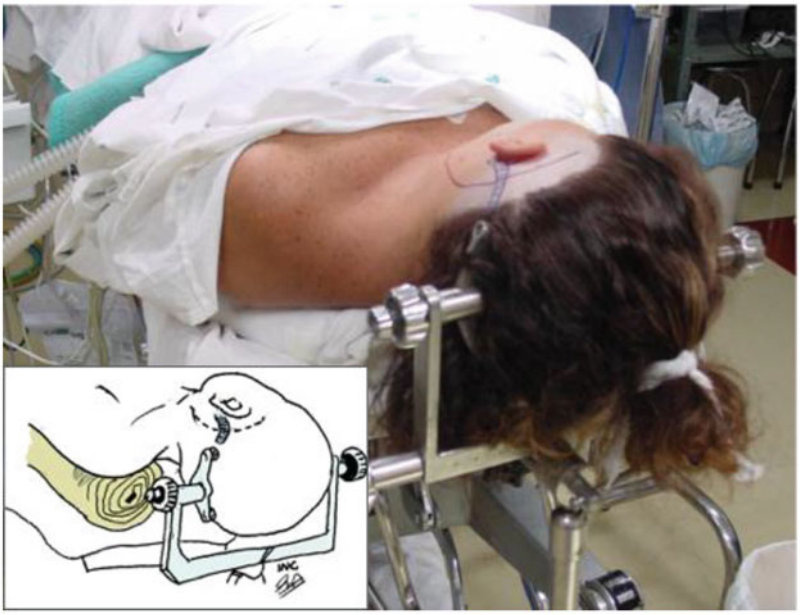

Fig. 9.20 Patient's position for cranio-cervical approach to the JF

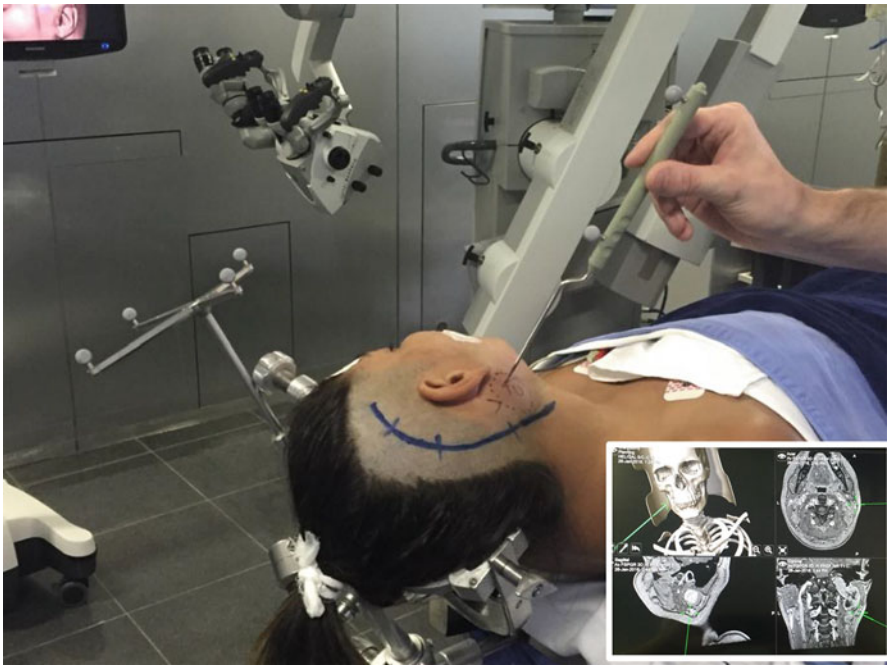

Fig. 9.21 Neuronavigation is used to define tumor margins

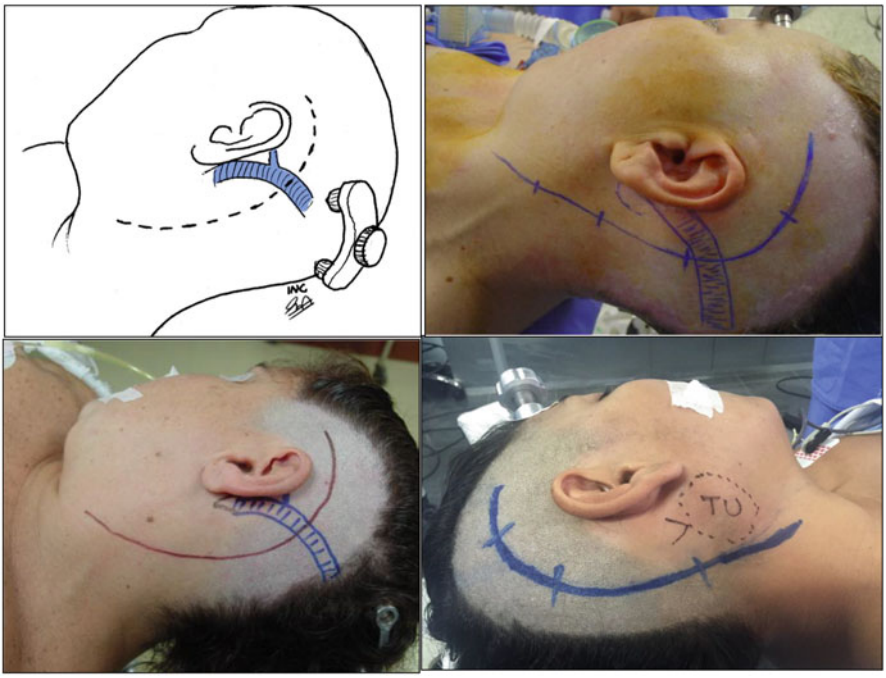

Fig. 9.22 C-shaped skin incision for cranio-cervical approach

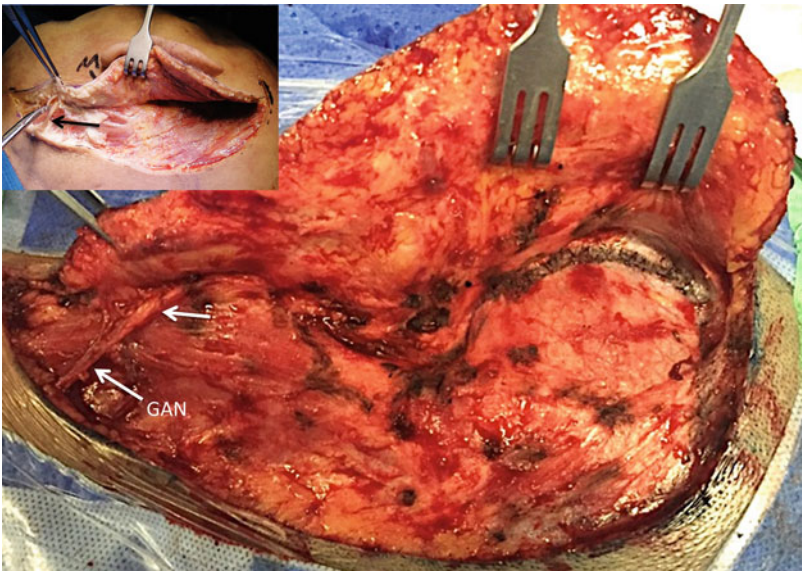

Fig. 9.23 Rotation of skin flap and dissection of great auricular nerve (GAN)

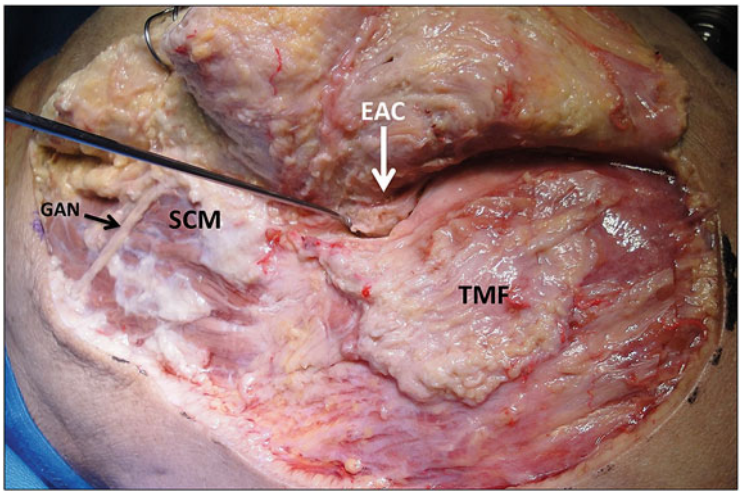

Fig. 9.24 Anatomic specimen showing the anterior border of sternocleidomastoid muscle (SCM), external auditory canal (EAC), temporal muscle fascia (TMF), great auricular nerve (GAN)

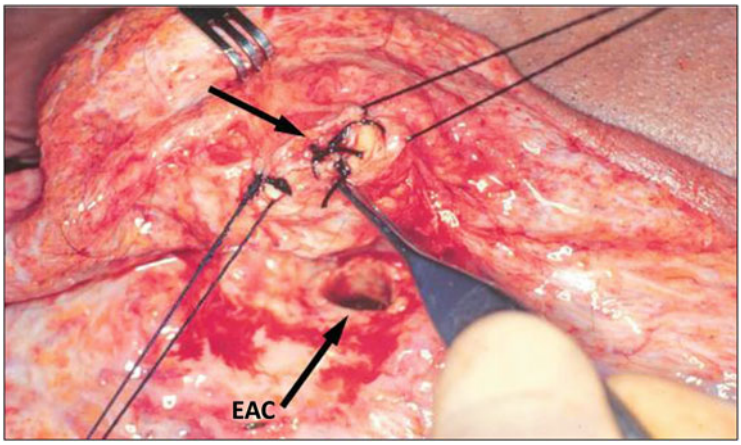

Fig. 9.25 The external auditory canal (EAC) is cut at the osseocartilaginous junction. The external auditory meatus is sutured in two layers (*arrow*)

rotated anteriorly exposing the temporal muscle fascia, the external auditory canal, the mastoid tip, and the anterior border of the SCM muscle (Fig. 9.24). If the tumor invades the middle ear, destroying the ossicular chain extending to the external auditory canal, the canal is cut at the osseocartilaginous junction (Fig. 9.25). To avoid postoperative CSF leak the external auditory meatus is sutured in two layers (Fig. 9.25).

Reconstruction of the Cranial Base

In order to expose adequately the jugular foramen, extensive bone removal at skull base (mastoidectomy, craniectomy, and removal of the transverse process of C1) is necessary. This extensive skull base approach will result in a large surgical defect. Postoperative CSF-leak is one of the main complications of this approach. A planned reconstruction strategy of the skull base is very important to avoid postoperative CSF-fistula. A special surgical technique of skull base reconstruction using vascularized flaps was developed [1]. This technique reduces CSF-leak and promotes a very good cosmetic result. The large surgical defect is reconstructed in three planes. The first one is watertight dura mater closure. This is carried out under the magnification of the operation microscope. If the dura mater is infiltrated and has to be resected, a temporalis muscle fascia graft and fibrin glue are used. Abdominal fat grafts are avoided because an additional abdominal skin incision is required and this may increase the postoperative risk of infection. The other plane is formed by the temporalis muscle fascia, cervical fasciae, and the SCM. The temporalis muscle fascia is elevated and dissected with the cervical fascia that is incised close to the external auditory canal, mastoid tip, and over the SCM (Fig. 9.26). These both fasciae remain attached to the SCM that is dissected in the neck and removed from its insertion at the mastoid. This large vascularized muscle-fasciae flap will be rotated back, over the posterior half of the temporalis muscle that was turned down (Fig. 9.27). The temporalis muscle is dissected from the squamous portion of the temporal bone to cover the dura mater and the mastoid cavity

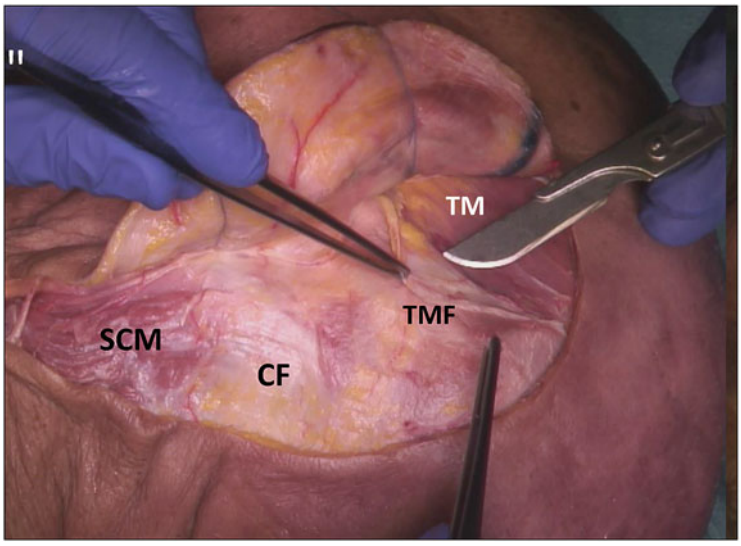

Fig. 9.26 Anatomical specimen: The temporalis muscle fascia (TMF) is dissected with the cervical fascia (CF) and sternocleidomastoid muscle (SCM)

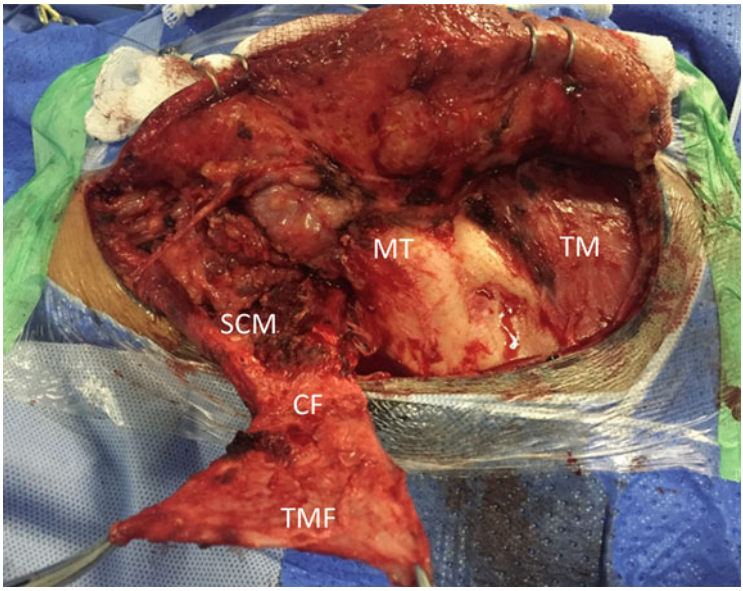

Fig. 9.27 The temporalis muscle fascia (TMF), cervical fasciae (CF), and the sternocleidomastoid muscle (SCM) are dissected to form a large vascularized muscle-fasciae flap. TM, temporal muscle; MT, mastoid tip

(second vascularized layer) (Figs. 9.28 and 9.29). If this muscle flap does not reach the dura defect, a back-cut is performed maintaining the vascularization of the flap and covering the dura and the mastoid cavity (Fig. 9.30). The flap is sutured in the cervical and parotid fasciae. The large muscle-fasciae flap is turned back and attached to the bone with sutures using small burr holes to cover at the entire surgical field at the end of surgery (Figs. 9.31 and 9.32). The contour of the SCM is preserved and the cosmetic results are excellent (Fig. 9.33). After this planned skull base reconstruction technique the next surgical step is neck dissection.

Neck Dissection

The great auricular nerve is dissected until the parotid region and not cut. The external jugular vein and the common facial vein are ligated with suture/ligature and cut. The SCM is retracted and the digastric muscle, a "key" landmark for neck dissection, is identified (Fig. 9.34). The facial nerve is at its superior border and the hypoglossal nerve at its posterior inferior border. The posterior belly of the digastric muscle and the superior belly of the omohyoid muscle, and the anterior margin of the SCM delimit the carotid triangle. This triangle contains the carotid sheath, the IJV, and deep cervical lymph nodes. The major vessels of the neck [common CA, ICA, external CA and its branches, and IJV] are identified (Fig. 9.35). The digastric muscle is removed from its insertion in the mastoid groove and rotated down. At the

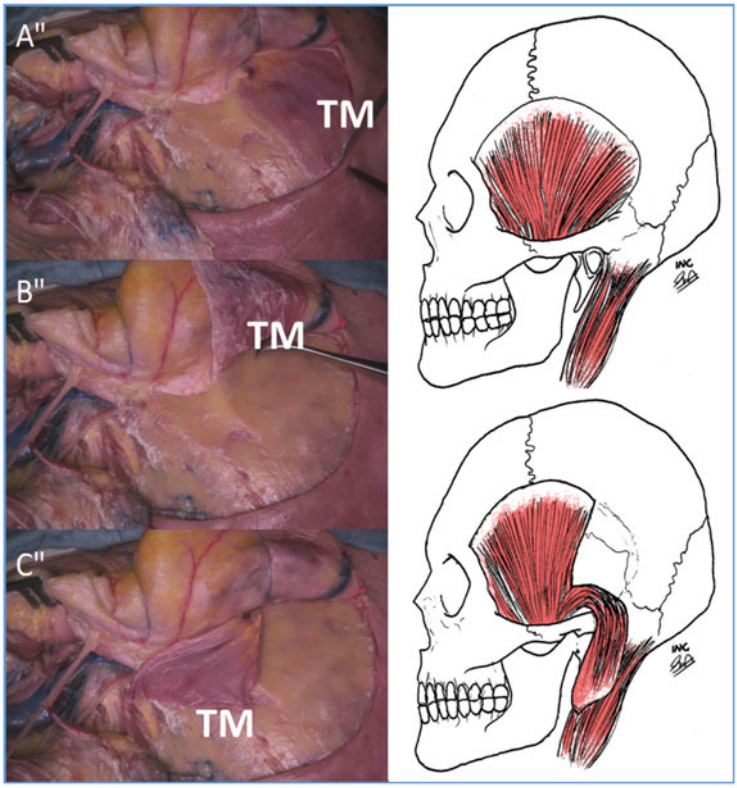

Fig. 9.28 Anatomical specimen showing dissection and rotation of the temporal muscle (TM) according to the drawings right

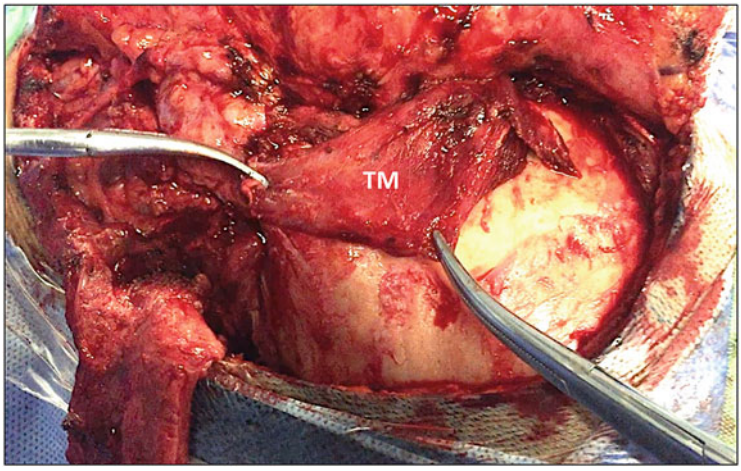

Fig. 9.29 Posterior 1/3 of the temporal muscle (TM) is cut and rotated down to cover the surgical defect

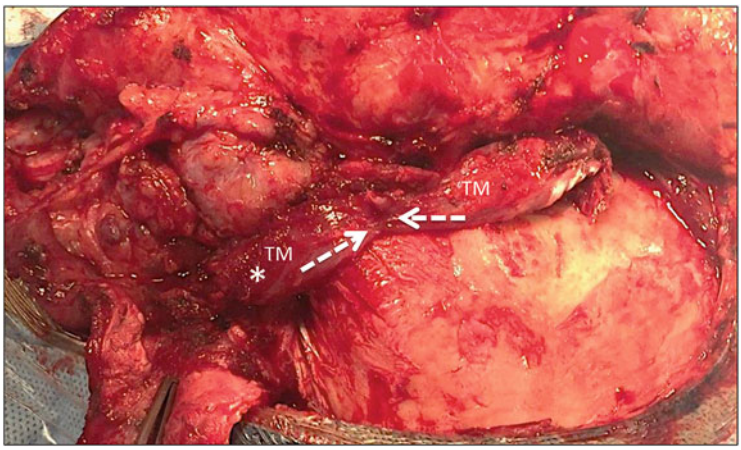

Fig. 9.30 If the temporal muscle (TM) is small a "back cut" is performed (*arrows*) and the vascularized TM muscle flap (*) is rotated to cover the surgical field

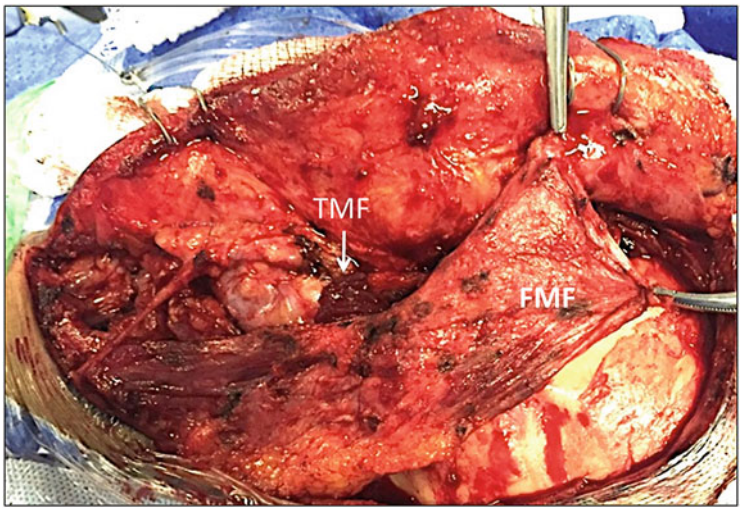

Fig. 9.31 The large vascularized fasciae-muscle flap (FMF) is rotated back to cover the entire surgical field over the temporalis muscle flap (TMF)

end of surgery it can be used to fill the mastoid cavity and the jugular foramen (Fig. 9.36). The cranial nerve XII passes to the submandibular region where the ansa cervicalis is identified and reaches the tongue. This nerve crosses the external carotid artery (Fig. 9.37). The vagal nerve and the sympathetic trunk are latero-inferior to the common carotid artery (Fig. 9.38). The occipital artery is coagulated and cut. The transverse process of C1 vertebra is identified, the XI nerve runs immediately inferior to the transverse process of C1, in most cases lateral to the IJV,

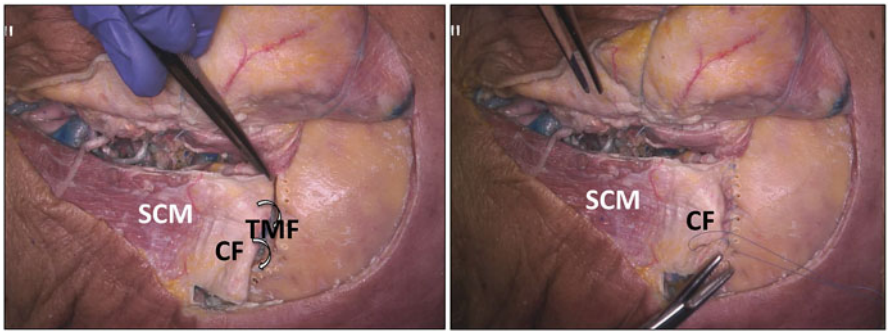

Fig. 9.32 Anatomical specimens show: (**a**) Rotation of the temporal muscle fascia (TMF) to cover the rotated temporal muscle. (**b**) The cervical fasciae flap (CF) is sutured in the occipital bone. SCM, sternocleidomastoid muscle

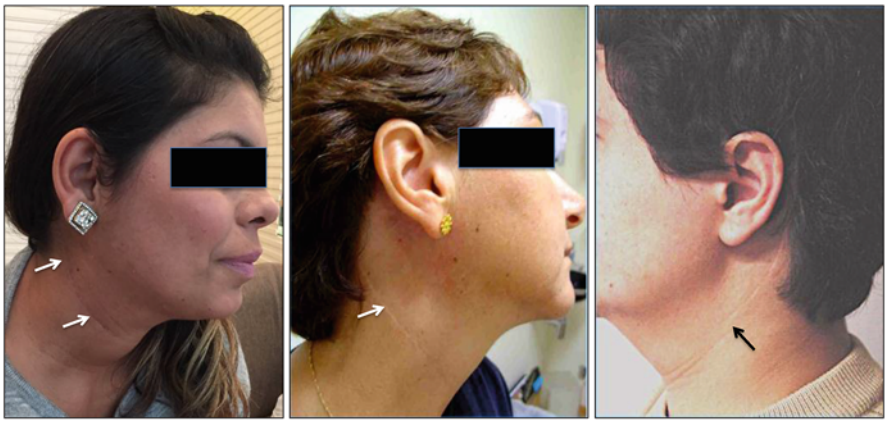

Fig. 9.33 Cosmetic results using the skull base reconstruction technique with vascularized fasciae-muscle flaps. Skin incision (*arrows*)

entering the SCM (Fig. 9.39). The transverse process of C1 is a "key point" to dissect the accessory nerve and the vertebral artery (Fig. 9.40). The superior and inferior capitis obliquus muscles insertion at the transverse process of C1 is cut and the groove of the vertebral artery in the C1 lamina is identified. Usually a large venous plexus involve the vertebral artery. The transverse process of C1 is removed with a rounger (Fig. 9.41). Care must be taken when dissecting this venous plexus to avoid bleeding. Bipolar coagulation and Surgicel® are used to control hemorrhage. The vertebral artery may be removed from the transverse foramen and rotated posteriorly (Fig. 9.42). This maneuver associated with removal of the transverse process of C1 vertebra enlarges the approach to the jugular foramen. The glossopharyngeal nerve leaves the cranium through the jugular foramen and runs down anterolateral to the ICA. The IJV is dissected up to the jugular foramen. The ICA is also dissected

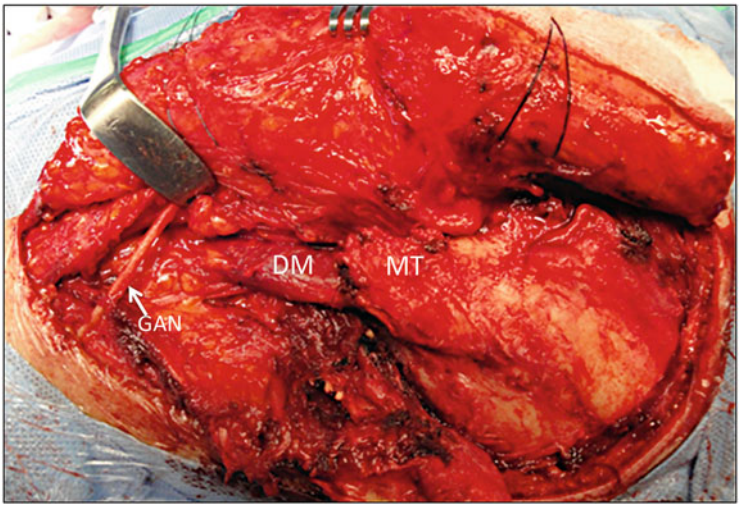

Fig. 9.34 Neck dissection exposing the digastric muscle (DM). MT, mastoid tip; GAN, great auricular nerve

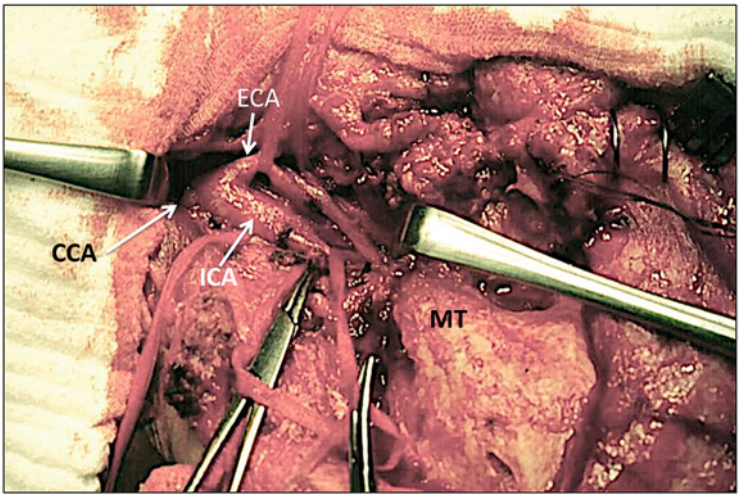

Fig. 9.35 Neck dissection: dissection of the common carotid artery (CCA), external carotid artery (ECA), and internal carotid artery (ICA). MT, mastoid

upwards until the skull base. Very often there is tumor compressing or involving this vessel. Careful dissection under the operation microscope is recommended. If vasospasm due to the dissection occurs, a cotton embedded with papaverine is placed around the ICA.

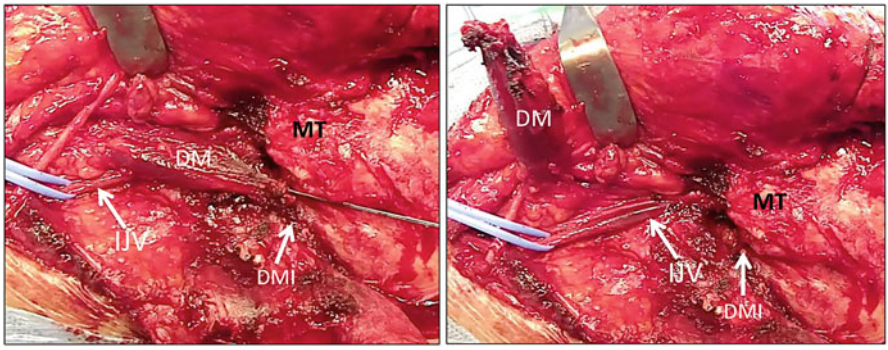

Fig. 9.36 Neck dissection: removal of digastric muscle (DM) from its insertion at the mastoid. DMI, digastric muscle incisura at mastoid; IJV, internal jugular vein; MT, mastoid tip

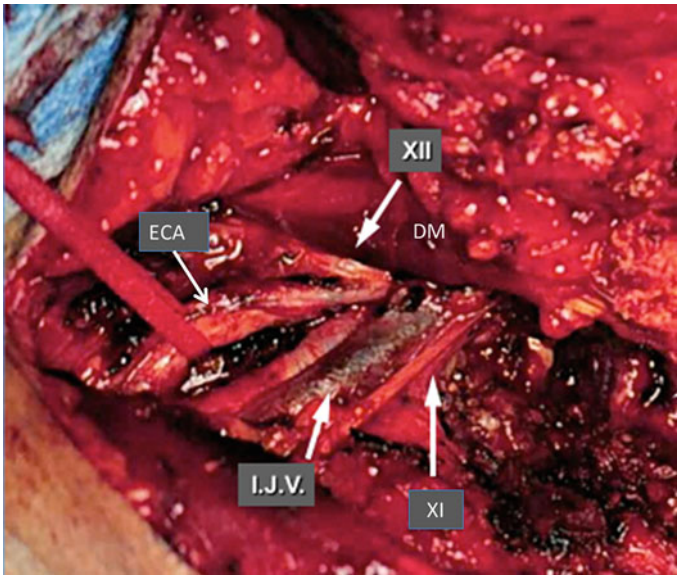

Fig. 9.37 Neck dissection: dissection of the XI and XII cranial nerves. ECA, external carotid artery; IJV, internal jugular vein; DM, digastric muscle

Facial Nerve Management

The facial nerve is identified at its exit from the stylomastoid foramen. The following anatomic landmarks are helpful to dissect the VII cranial nerve: the mastoid tip, the posterior belly of the digastric muscle, the "tragal pointer," and the tympanomastoid suture (Fig. 9.43) [2, 3, 12]. The stylomandibular artery lies superficial to the facial nerve. In the mastoid the facial nerve canal is exposed. If the nerve is not infiltrated by the tumor, it remains in the fallopian canal (Fig. 9.44). Re-routing of the nerve is avoided because most patients present postoperative temporarily facial paresis.

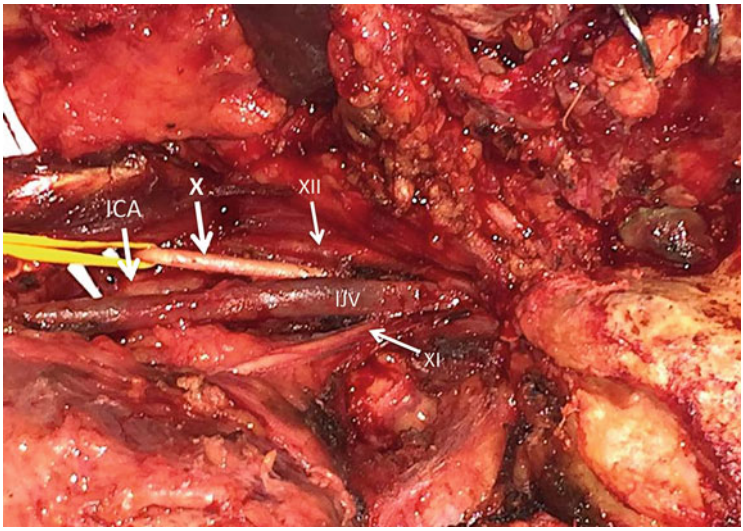

Fig. 9.38 Neck dissection: dissection of the X cranial nerve. ICA, internal carotid artery; IJV, internal jugular vein; XII, cranial nerve

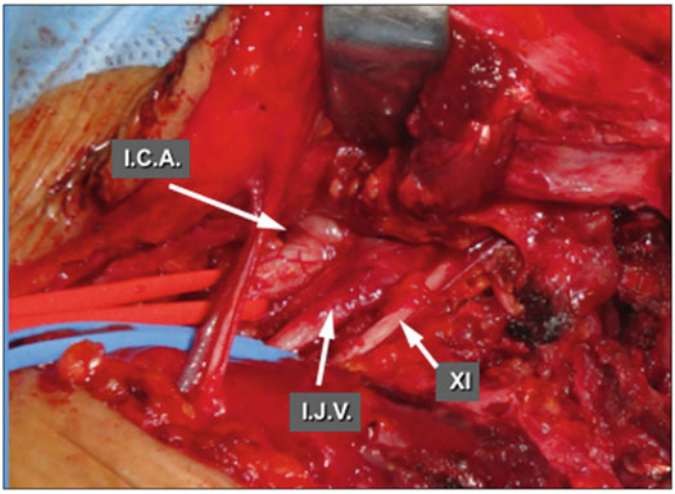

Fig. 9.39 Neck dissection: dissection of XI cranial nerve lateral to the internal jugular vein (IJV). ICA, internal carotid artery

After transposition of the facial nerve in 18 patients, 10 (56%) developed facial paralysis (House-Brackmann [HB] grade V or VI) as assessed 1 month after surgery. At 1 year after surgery, six patients recovered to a grade of III or IV weakness (60%) [13]. If the nerve is infiltrated, most commonly infiltration occurs with paragangliomas and meningiomas, the nerve is resected and grafted with the great auricular nerve or sural nerve graft (Figs. 9.45 and 9.46).

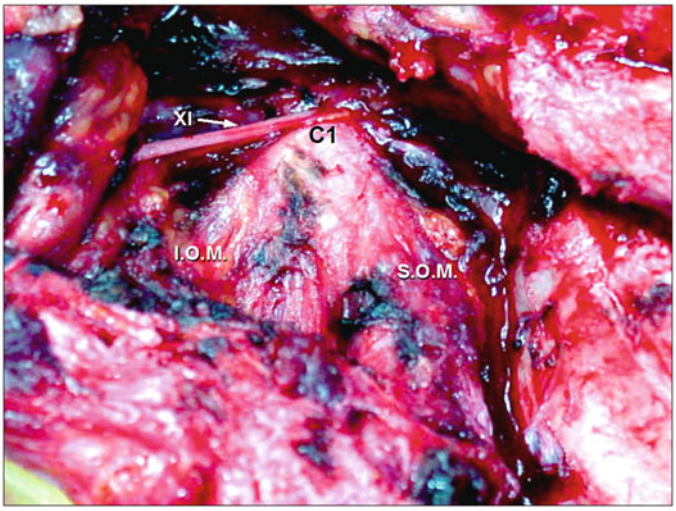

Fig. 9.40 Neck dissection: dissection of transverse process of C1 vertebra. XI, cranial nerve; SOM, superior capitis obliquus muscle; IOM, inferior capitis obliquus muscle

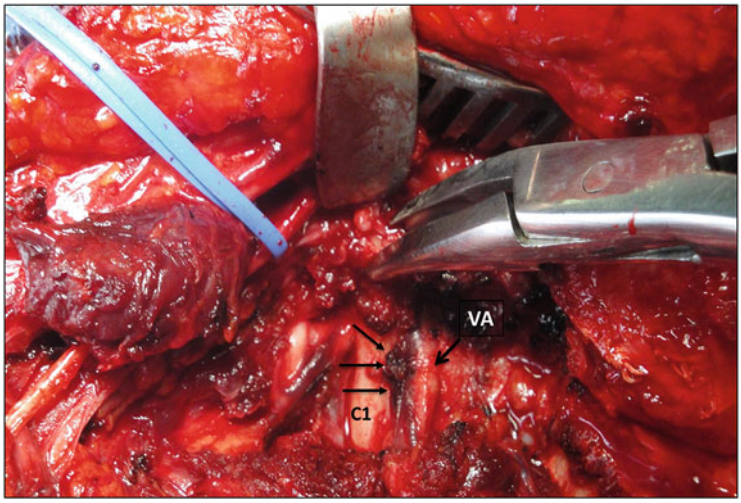

Fig. 9.41 Removal of C1—transverse process. VA, vertebral artery; small vertebral groove of C1 lamina (*arrows*)

Temporal Bone Dissection

Radical mastoidectomy and antrotomy are performed exposing the mastoid antrum, ossicles chain, sigmoid sinus, superior petrous sinus, the labyrinth, and the sinus dural angle (Figs. 9.47, 9.48, and 9.49). This exposure is modified according to the

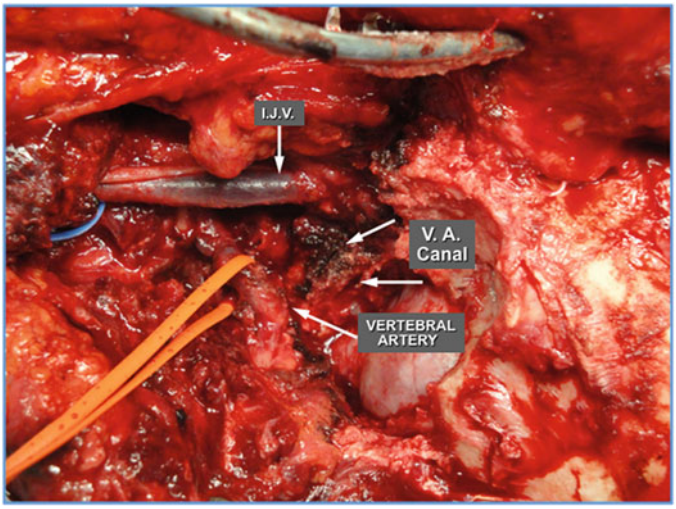

Fig. 9.42 Removal of vertebral artery from its canal at C1/2 vertebrae, IJV, internal jugular

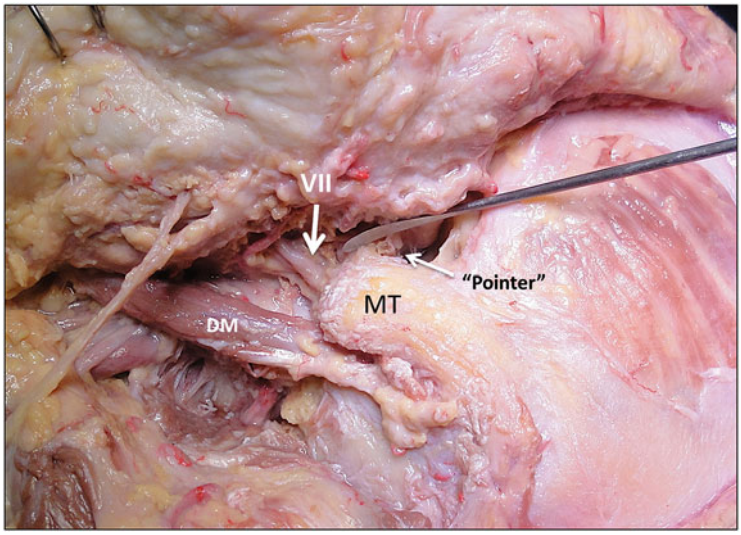

Fig. 9.43 Anatomical specimen showing the landmarks to dissected the extracranial portion of facial nerve. DM, digastric muscle; MT, mastoid tip; "pointer"—cartilage of the external auditory

tumor extension. The lateral semicircular canal and the short process of the incus are the anatomic landmarks to identify the facial nerve (Fig. 9.50). In the mastoid the facial nerve is exposed by drilling the bone over and parallel to the nerve with a diamond burr larger than its diameter. A fine curette is used to remove small bone fragments close to the nerve. The retrofacial mastoid cells are removed.

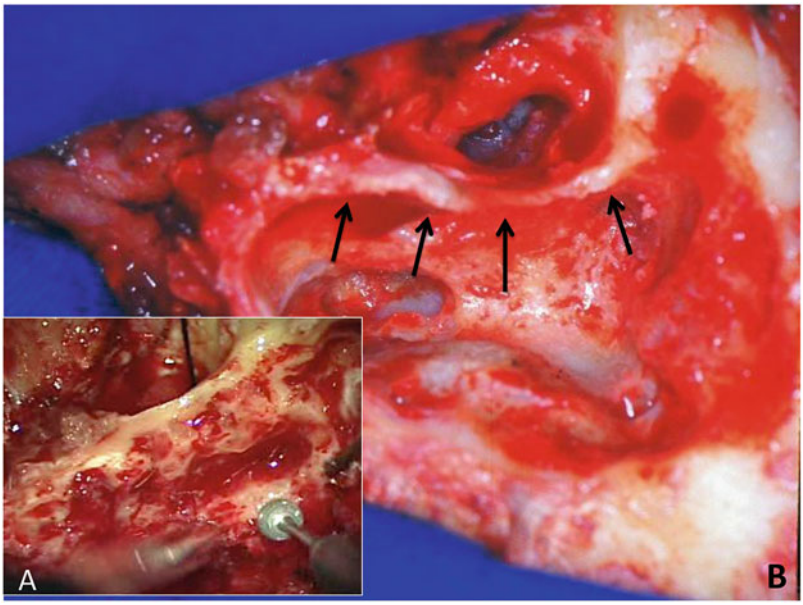

Fig. 9.44 Dissection of mastoid portion of facial nerve. (**a**) Removal of retrofacial mastoid cells. (**b**) If the facial nerve is not infiltrated, it remains in the Fallopian canal (*arrows*)

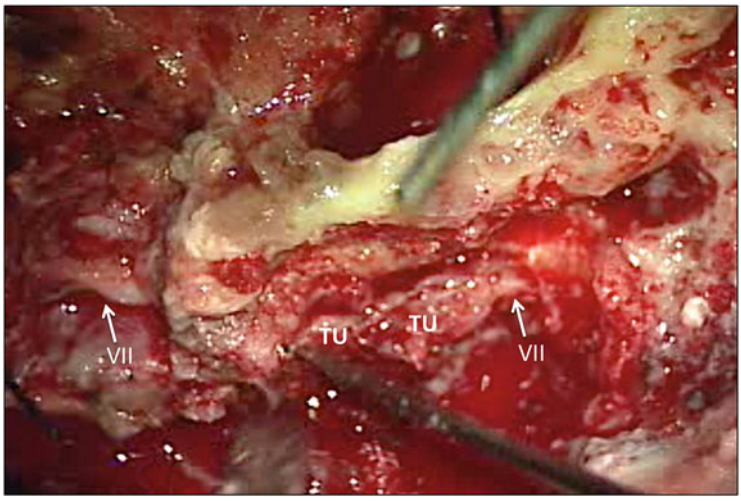

Fig. 9.45 The facial nerve (mastoid portion) is infiltrated by the tumor (TU)

Tumor extension in the mastoid is removed in front and behind the facial nerve. The sigmoid sinus and the jugular bulb are completely skeletonized. The posterior and anterior walls of the external auditory meatus are drilled when the tumor extends to the ear canal (Fig. 9.51). Jugular foramen paragangliomas usually invade the

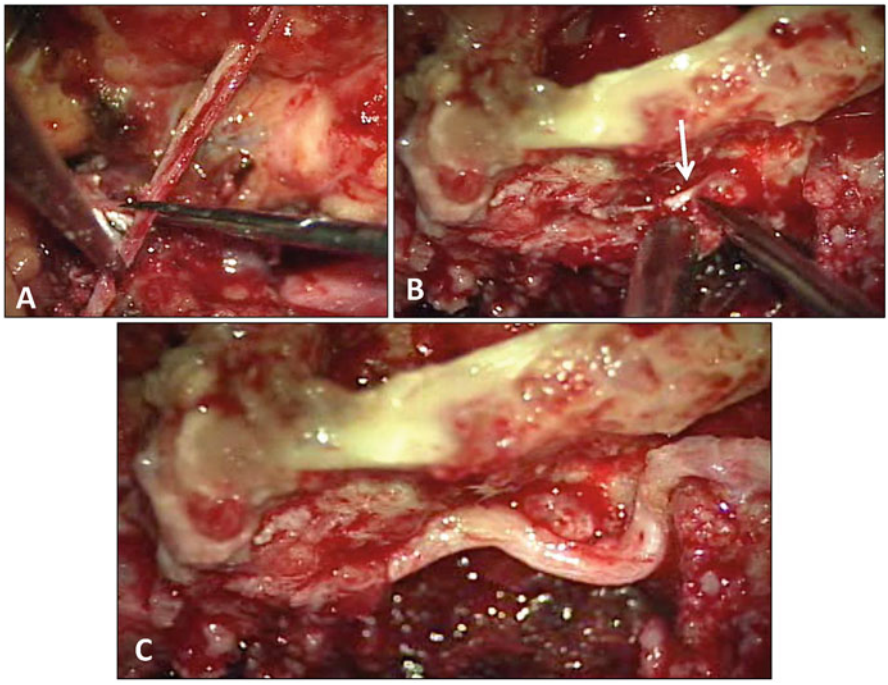

Fig. 9.46 (**a**) A graft from the great auricular nerve is removed. (**b**) The facial nerve is cut (*arrow*). (**c**) Facial nerve reconstructed with great auricular nerve graft

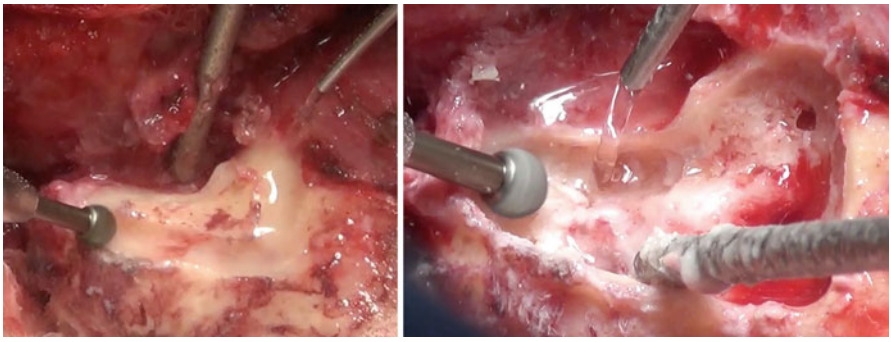

Fig. 9.47 Radical mastoidectomy

middle and external ear through the hypotympanum (Fig. 9.52). Tumor extensions within the ear, eustachian tube, and mastoid cells are resected after removal of the tympanic membrane. The ICA travels through the temporal bone. It is anterior to the jugular foramen and medial to the eustachian tube. The ICA can be dissected by removal of the tympanic bone (distal control of the ICA) (Fig. 9.53). Paragangliomas and meningiomas may be feed by carotid–tympanic branches of the ICA. Bipolar coagulation is used to secure these tumor feeders.

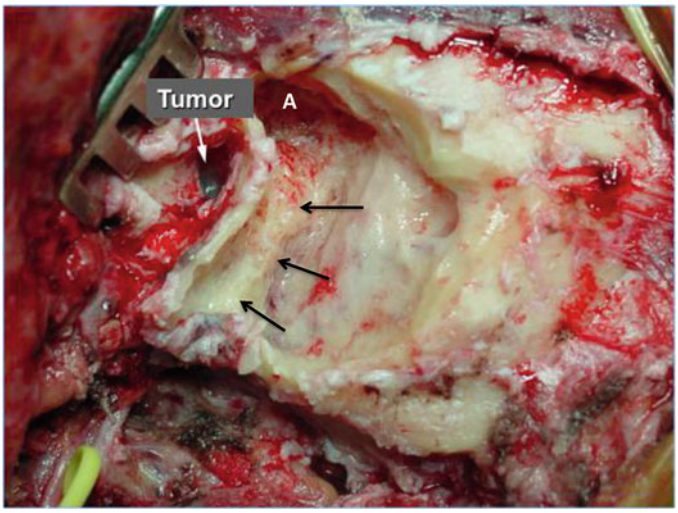

Fig. 9.48 Radical mastoidectomy, facial nerve remains in its fallopian canal (*arrows*). (**a**) Mastoid antrum

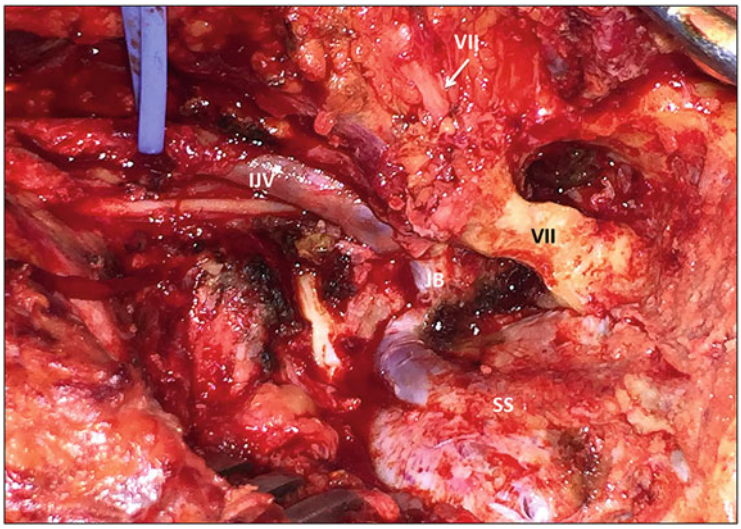

Fig. 9.49 Radical mastoidectomy, VII, facial nerve; SS, sigmoid sinus; JB, jugular bulb; IJV, internal jugular vein

Craniectomy and Opening of the Jugular Foramen

A burr hole is placed behind the sigmoid sinus and a craniectomy is performed with 3 cm in diameter (Fig. 9.54). The retrosigmoid dura mater is exposed and the emissary mastoid vein is coagulated; the bone over the sigmoid sinus is removed with

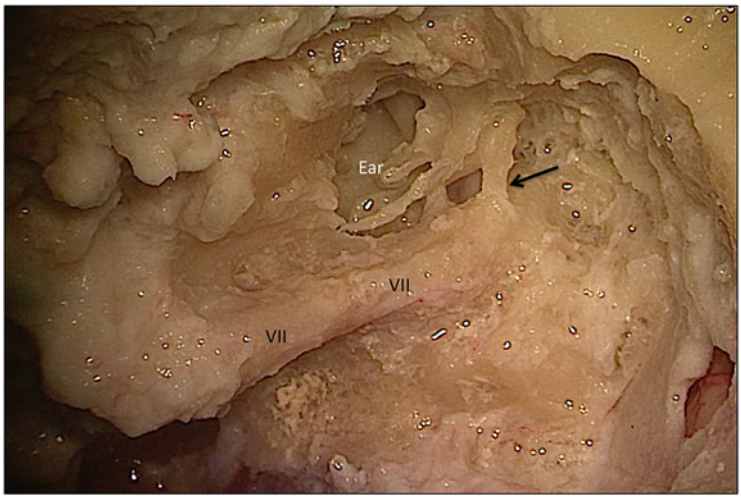

Fig. 9.50 Anatomical specimen showing radical mastoidectomy. Short process of the incus (*arrows*) pointing to the facial nerve

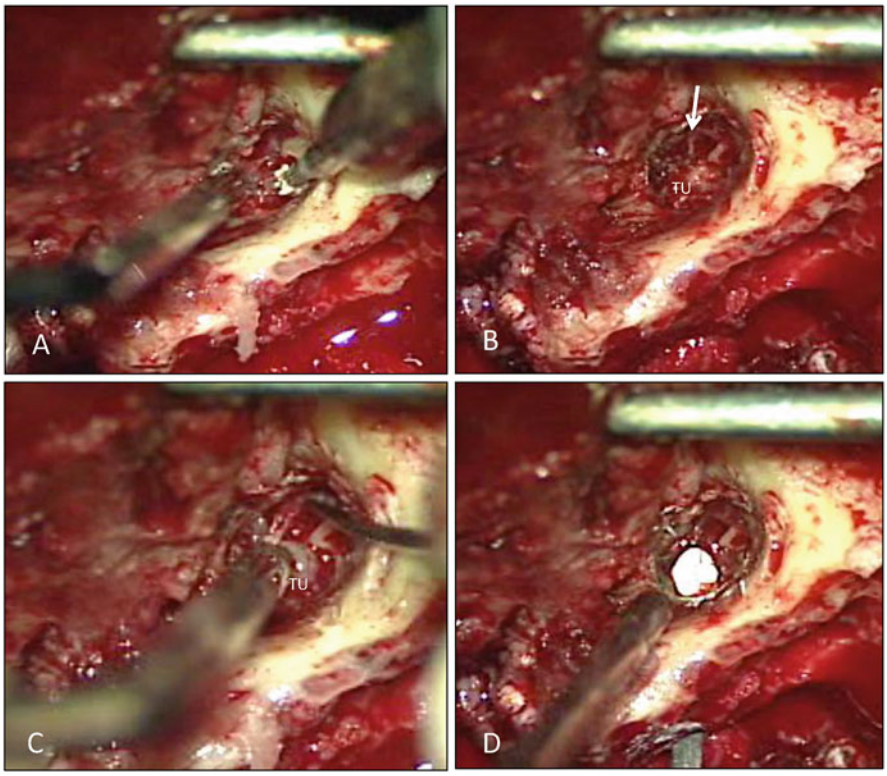

Fig. 9.51 (**a**) Drilling of posterior wall of external auditory canal. (**b**) Tumor in ear (TU), carotid tympanic vessels (*arrow*). (**c**) Tumor dissection. (**d**) Connecting the hypotympanum with the ear

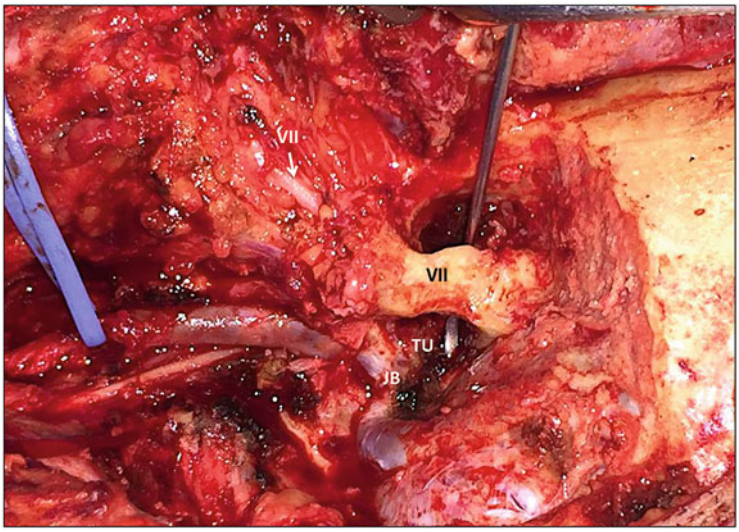

Fig. 9.52 A hook showing the route of tumor invasion from the jugular foramen into the ear through the hypotympanum. JB, jugular bulb with tumor (TU). VII, facial nerve

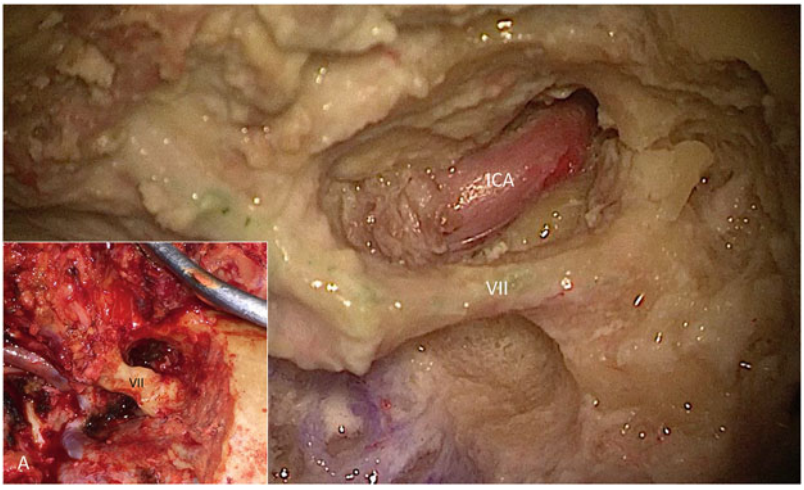

Fig. 9.53 Anatomical specimen showing the position of the internal carotid artery (ICA) in the ear. (**a**) Surgical view. VII, facial nerve

diamond burr and curettes, and the sinus is followed down to the jugular bulb. A diamond burr is used to remove bone at mastoid tip, behind the facial nerve. The posterior portion of the jugular bulb is widely opened with Kerrison rongeurs communicating the jugular bulb with the IJV (Figs. 9.55 and 9.56). The dura mater anterior to the sigmoid sinus is dissected.

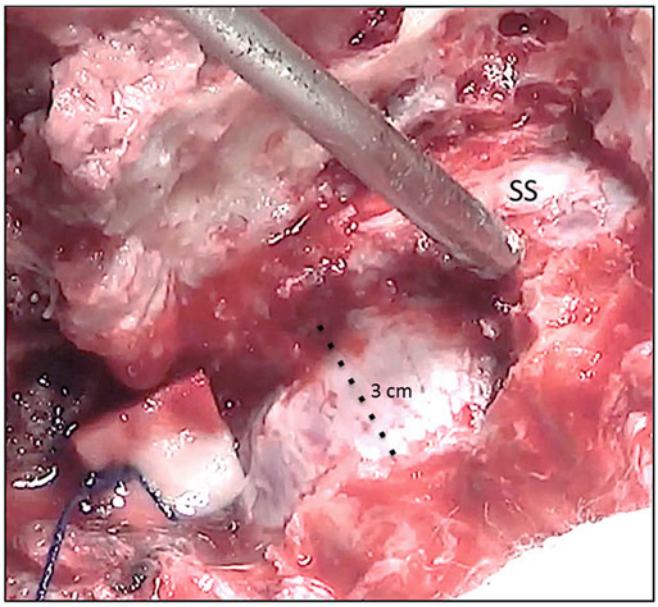

Fig. 9.54 Retrosigmoid (3 cm in diameter) craniectomy. SS, sigmoid sinus

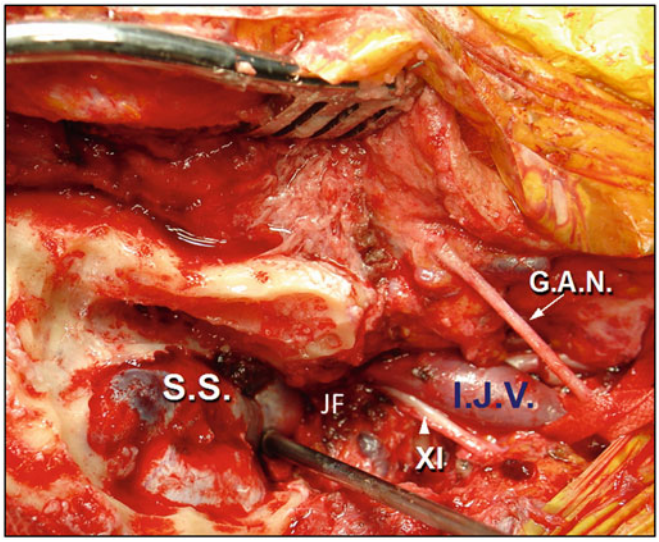

Fig. 9.55 The right jugular foramen (JF) is extradurally exposed. SS, sigmoid sinus; IJV, internal jugular vein; GAN, great auricular nerve

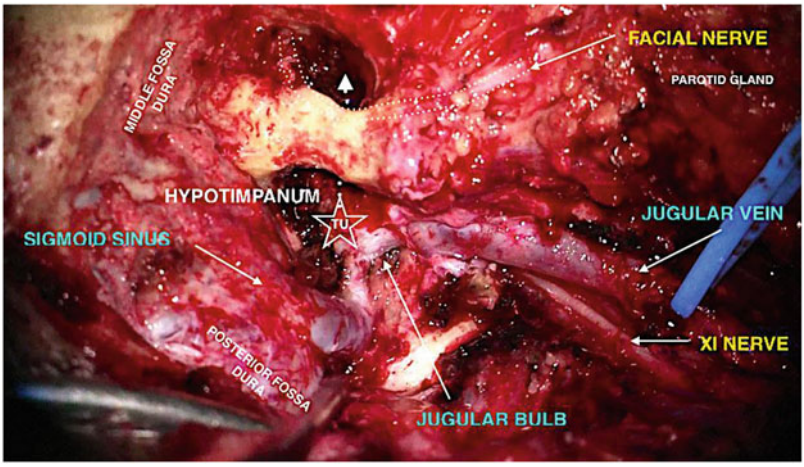

Fig. 9.56 The extradural approach to the right jugular foramen (JF) is completed

Extradural Tumor Removal

In cases when the jugular bulb is occluded by the tumor (mainly in paragangliomas and meningiomas cases) the sigmoid sinus is ligated. Small dura mater openings in front and behind the sigmoid sinus, below the superior petrous sinus, are carried out (Fig. 9.57). A cotton pledge is inserted below the sinus to protect the cerebellum and a fine hemostatic clamp is used to pass two non-absorbable threads and ligate the sigmoid sinus (Figs. 9.58, 9.59, and 9.60). The IJV is double ligated with two non-absorbable sutures and cut (Fig. 9.61). Safe ligation (suture-ligature) of the IJV is very important to avoid postoperative bleeding due to the increase of venous pressure from coughing or other causes. The posterior wall of the sigmoid sinus is incised exposing the tumor portion within the sinus and jugular bulb. Removal of the portion of the lesion inside the jugular vein is accomplished with the ligated IJV (Figs. 9.62, 9.63, and 9.64). Bleeding from the inferior petrous sinus (within the jugular bulb) is controlled with Surgicel® or Gelfoam®. The caudal cranial nerves are located anterior to the venous lumen and there is a thin membrane between these two structures. In some cases (mainly with schwannomas) the jugular bulb is not occluded, and removal of the extradural portion of the tumor is possible with preservation of the venous structures. In some cases (familiar cases of paragangliomas) patients may present concomitant carotid bifurcation paragangliomas. These tumors are resected at the same surgical procedure (Fig. 9.65).

Some tumors may have anterior extensions to the hypoglossal canal and following the ICA. In these cases the ICA is dissected from the ear until its entrance at skull base (Fig. 9.66). If the carotid wall is infiltrated by the tumor the following strategies are employed: (1) if patient tolerates a balloon occlusion test the internal carotid may be sacrificed; (2) if patient does not tolerate the balloon occlusion test. (a) In elderly patients, radical resection of the lesion is not possible in malignant tumors.

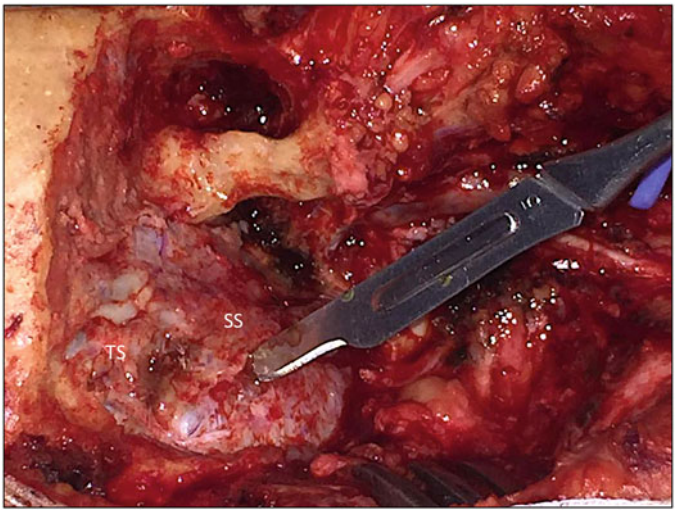

Fig. 9.57 Sigmoid sinus ligation: Dura incision behind and in front of sigmoid sinus (SS) is performed. TS, transverse sinus

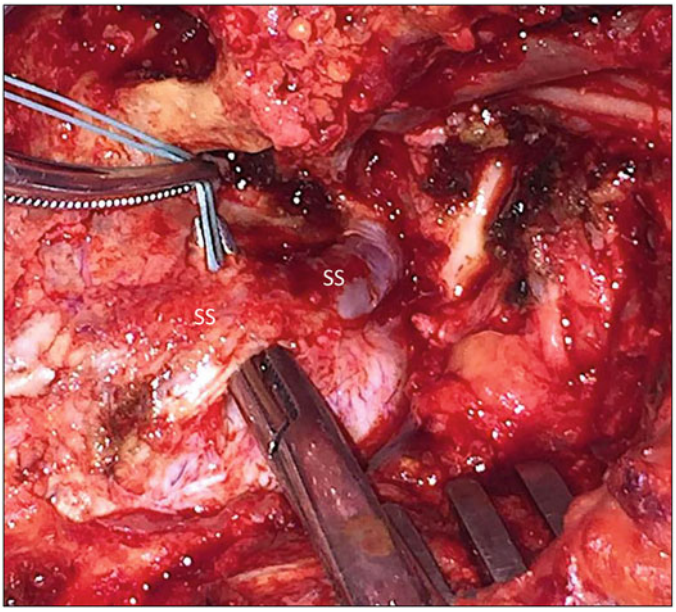

Fig. 9.58 Sigmoid sinus ligation: a fine hemostatic clamp is passed under the sigmoid sinus (SS)

Tumors around the ICA are left behind and postoperative radiotherapy or radiosurgery is indicated. (b) In young patients, benign tumor and total removal is possible. A high-flow bypass between the external or ICA and the middle cerebral artery is

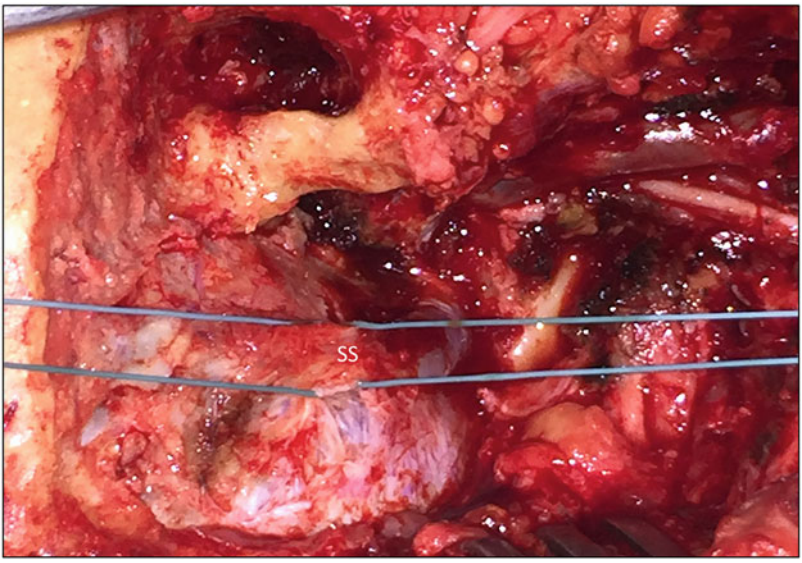

Fig. 9.59 Sigmoid sinus ligation: two non-absorbable threads are used to ligate the sigmoid sinus (SS)

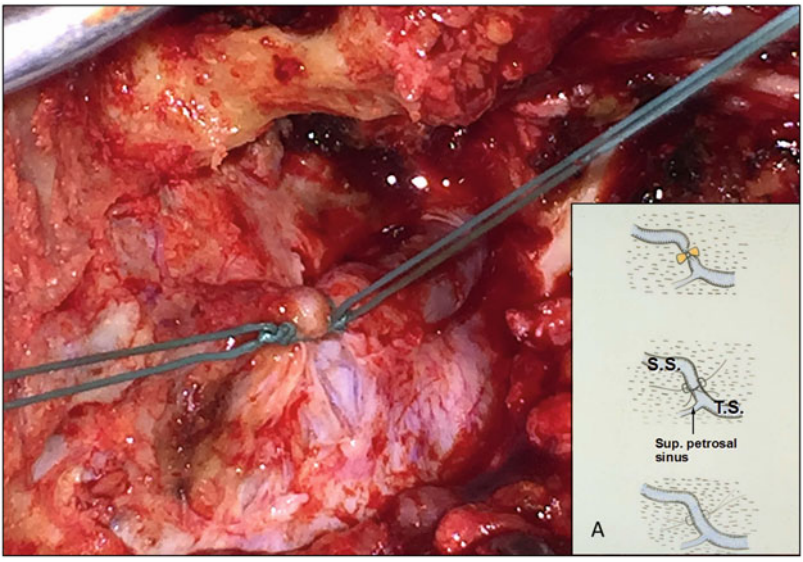

Fig. 9.60 Sigmoid sinus ligation: the sigmoid sinus (SS) is double ligated with non-absorbable sutures below the superior petrosal sinus (**a**)

performed (Fig. 9.67). Patency of the bypass is checked and the ICA is ligated below the posterior communicating artery and in the neck. The infiltrated vessel is removed with the tumor. (c) Alternatively, the insertion of a covered stent may be used.

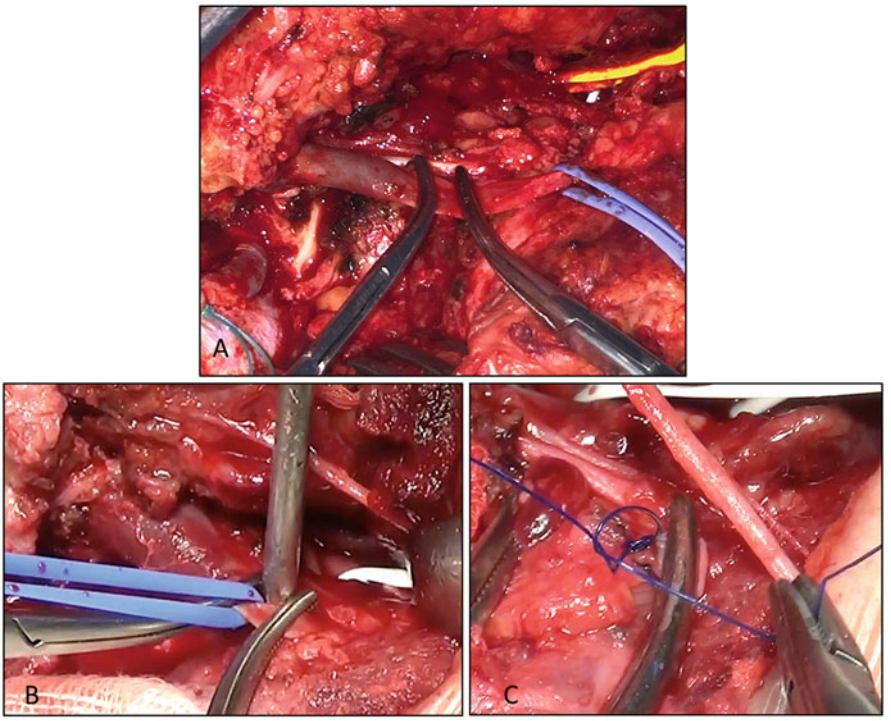

Fig. 9.61 Internal jugular vein ligation: (**a**) The internal jugular vein (IJV) is occluded with two hemostatic clamps and cut (**b**). (**c**) Double suture–ligature of the IJV is carried out with non-absorbable threads

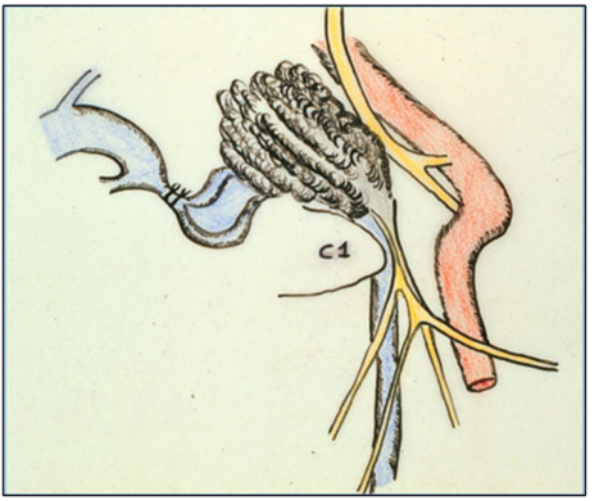

Fig. 9.62 Drawing showing the opening of the ligated sigmoid sinus and tumor removal from the jugular bulb

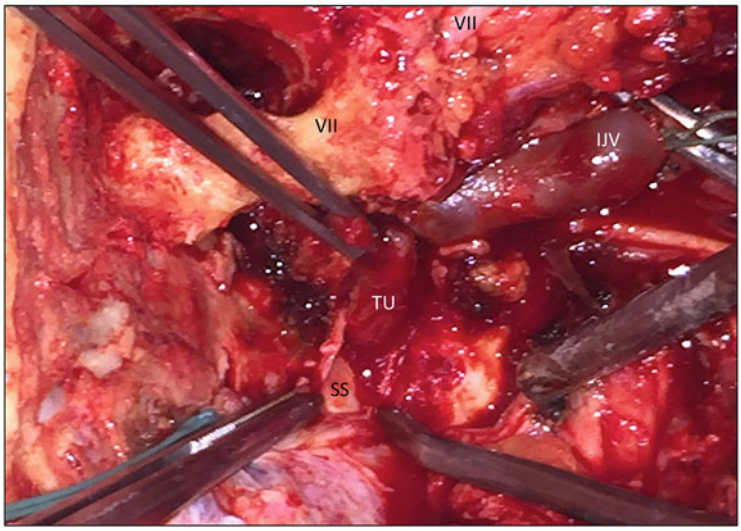

Fig. 9.63 The ligated sigmoid sinus (SS) is incised to expose the jugular foramen paraganglioma (TU) in the jugular bulb. IJV, internal jugular vein

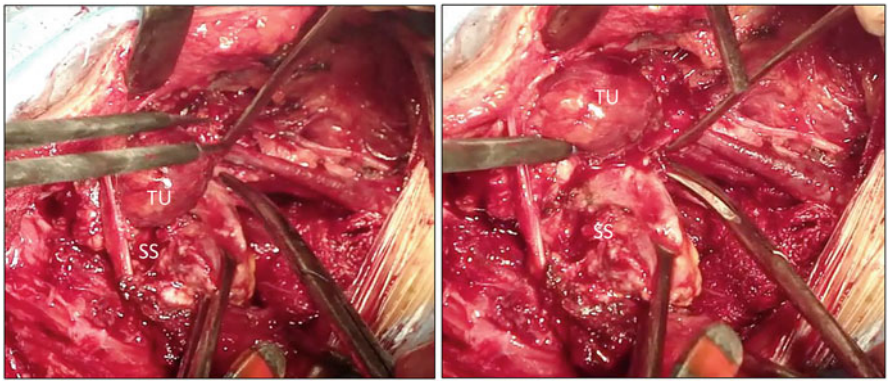

Fig. 9.64 Extradural removal of a paraganglioma (TU) within the jugular bulb. SS, sigmoid sinus

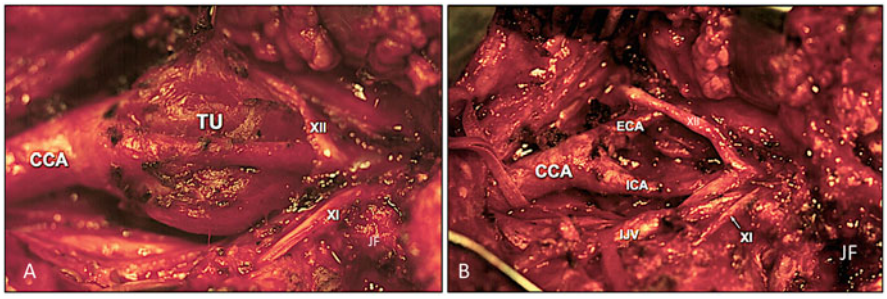

Fig. 9.65 Familiar case of paragangliomas. (**a**) Paraganglioma at common carotid bifurcation (CCA) and in the jugular foramen (JF). (**b**) After removal of both lesions

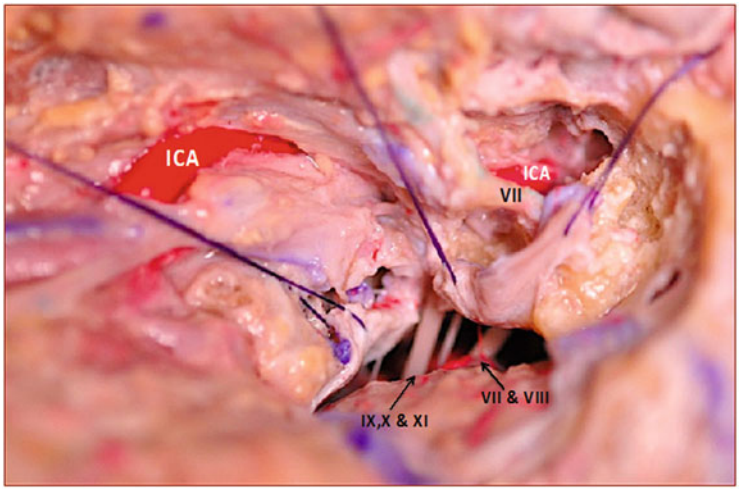

Fig. 9.66 Anatomical specimen showing the internal carotid artery (ICA) dissected in the neck and in the ear. The jugular foramen is exposed intra- and extradurally. Cranial nerves VII, VIII, IX, X, and XI are identified

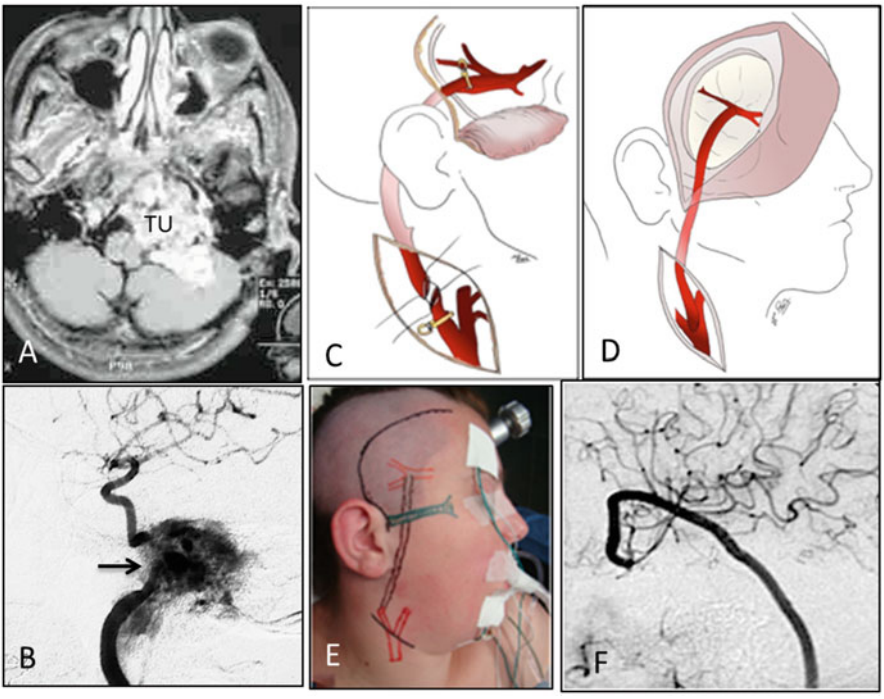

Fig. 9.67 (**a**) and (**b**) Large jugular foramen paraganglioma with infiltration of the internal carotid artery walls (*arrows*). Technique of high-flow bypass. (**c**) Saphenous vein graft behind the ear. (**d**) Radial artery graft in front of the ear. (**e**) Surgical planning and incisions. (**f**) Angiography post bypass

The patient is placed under aspirin for three months until re-epithelialization inside the stent occurs. After this time the tumor can be dissected from the carotid wall under protection of the stent.

Intradural Tumor Removal

After removal of the extradural portion of the tumor, the dura mater is opened. If the sigmoid sinus was not ligated, the dura mater is incised parallel to the sigmoid sinus. In cases of sigmoid sinus ligation dura mater incision is carried out in the medial wall of the sinus (Fig. 9.68). The cerebellomedullary cistern is drained and minimal retraction of the cerebellum is needed to expose the intradural posterior fossa structures. Tumor within the jugular foramen around the lower cranial nerves is identified. The cranial nerves VII and VIII, the vertebral artery, the PICA, and brainstem are exposed. When the intradural tumor extension is small, the lower cranial nerves are easily identified at the brainstem and preserved (Fig. 9.69). Intra- and extradural dissection of these nerves from tumor capsule, under electrophysiological monitoring, is important to preserve anatomically and functionally the caudal cranial nerves. Some fascicles may be infiltrated or embedded by benign tumors like paragangliomas and meningiomas [14, 15]. If fascicles of the IX and X cranial nerves are infiltrated

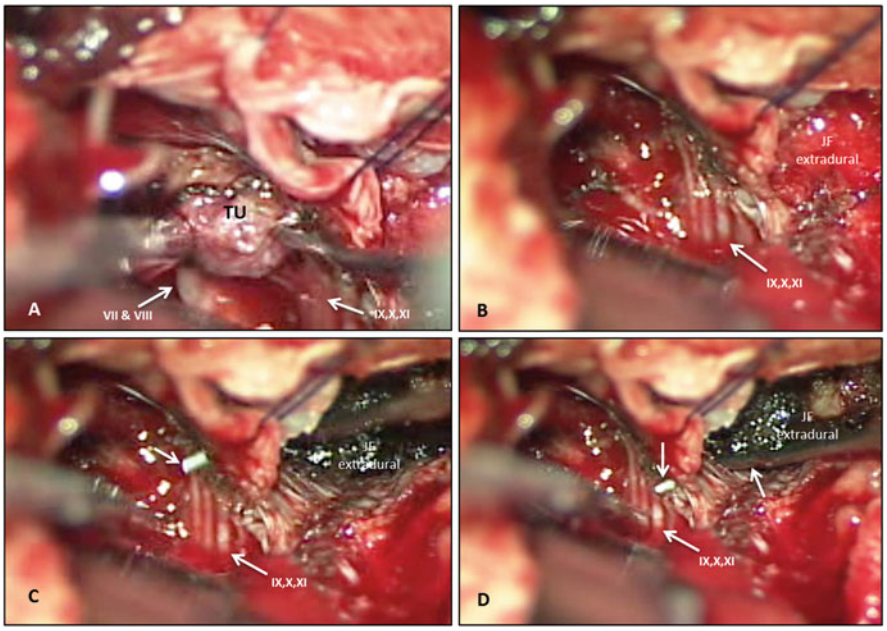

Fig. 9.68 (**a**) Intradural portion of tumor (paraganglioma). (**b**) After total removal with preservation of cranial nerves IX, X, and XI. (**c**) and (**d**) A hook (*arrows*) communicating the extra and intradural portion of the JF

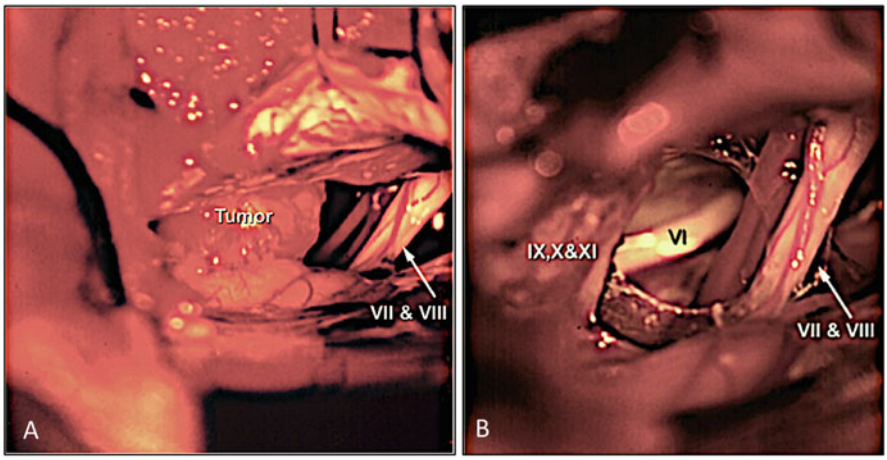

Fig. 9.69 (**a**) Intradural jugular foramen paraganglioma. (**b**) After total removal with preservation of cranial nerves IX, X, and XI

and no deficits from these nerves were seen preoperatively, subtotal removal is preferred. Postoperatively if proven growth of this tumor rest, radiotherapy, or radiosurgery is indicated. Total removal will only be attempted if the patient presented preoperative deficits of the lower cranial nerves. Tumors with large intradural extension need different surgical strategy (Fig. 9.70). In these cases identification of the cranial nerves is difficult, because these structures are embedded in the lesion. Bipolar coagulation of the tumor capsule and intracapsular tumor removal under monitoring of the cranial nerves will allow identification of the nerves, at first, at brainstem, and then at the jugular foramen [5, 7]. Dissection of tumor capsule is easier with schwannomas than with paragangliomas and meningiomas. Closure of the wound is performed using the reconstruction technique described above. Postoperative lumbar drainage is used only in cases with very large skull base and the dural defect could not be closed in a watertight fashion.

Postoperative Management

Patients are monitored in an intensive care unit (ICU) setting as for all major intracranial surgeries. Intravenous access is maintained until the need for drug and fluid replacement. The patient remains intubated in the ICU until an adequate evaluation of the lower cranial nerves is feasible with strict blood pressure control. Aspiration pneumonia due to palsy of these nerves is one of the most dangerous complications of these surgeries. The function of these nerves should be carefully evaluated before extubation and continued for some days after surgery. The nasoenteral tube for feeding is kept in place and eventually a percutaneous endoscopic gastrostomy must be performed. Adequate swallow evaluation is required before allowing the patient to

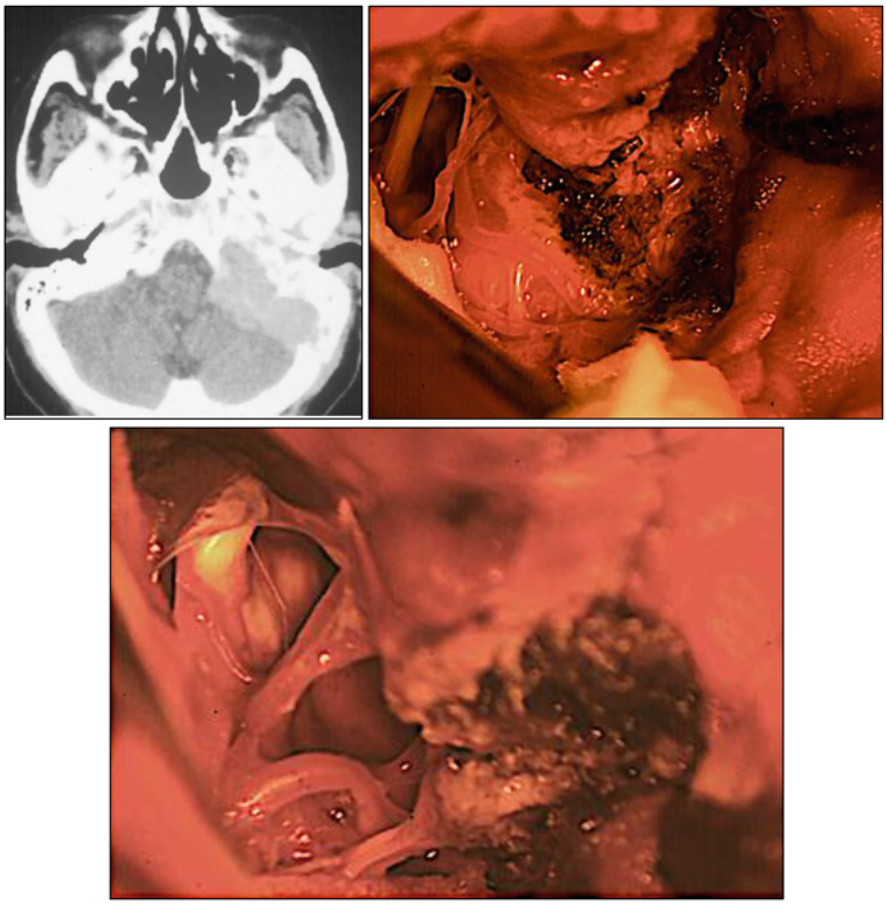

Fig. 9.70 (**a**) Large intradural invasion of a jugular foramen paraganglioma. (**b**) Intradural tumor (TU), jugular foramen (JF). (**c**) Removal of intradural jugular foramen paraganglioma with preservation of cranial nerves IX, X, and XI

resume oral intake. Tracheostomy should be performed as soon as possible, if early recovery of swallow function is not expected. Few of our patients require a tracheostomy. Usually the patients do not complain of postoperative pain and regular analgesics or diclofenac are sufficient. Additional analgesia can be achieved by morphine infusion. Nausea and vomiting are controlled with ondansetron. If the patient presents postoperatively facial nerve palsy due to manipulation of the nerve care must be taken to avoid corneal ulcer. When the facial nerve was resected with the tumor and grafting was performed, a tarsorrhaphy is carried out at the end of surgery. When a lumbar drainage of CSF has been placed, the drain is maintained for 48–72 h. The drain is clamped for 24 h and if there is no CSF leak or swelling of the wound it is removed. Prophylactic antibiotics are continued for 24 h. A CT-scan examination is performed in the first 24 h and an MRI before discharge from the hospital. Skin sutures are removed from the scalp after 8 days.

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Chapter 10
Clinical Examples and Videos

Paragangliomas

Case 1

This 37-year-old woman presented to our institute with left-sided hearing loss and swallowing difficulties. She reported a 2-year history of tinnitus. Magnetic resonance imaging (MRI) demonstrated a large tumor in the left jugular foramen with extensions to the neck, ear and a small intradural extension (Fig. 10.1). This tumor was an ENI tumor type according to our classification. She underwent total tumor removal through a craniocervical approach. The large surgical defect of the skull base (Fig. 10.2) was reconstructed with vascularized flaps. The lower cranial nerves could be dissected from tumor capsule and preserved. Postoperative a nasal enteral tube was placed and it could be removed 2 weeks after surgery. The swallowing deficits improved gradually. Histological diagnosis was paraganglioma.

Case 2

A 23-year-old woman had complaint of headaches, tinnitus, and progressive swallowing difficulties for 1 year. About 6 months before admission to our institute she started to complain of change in her voice. On admission she was found to have dysfunction of cranial nerves IX, X, and XI. MRI showed a large enhancing tumor (Fig. 10.3) in the right jugular foramen with extensions to the neck (Tumor type EN). The characteristic sign of paragangliomas "salt and pepper" pattern after gadolinium injection can be observed. The main feeders to this tumor came from the

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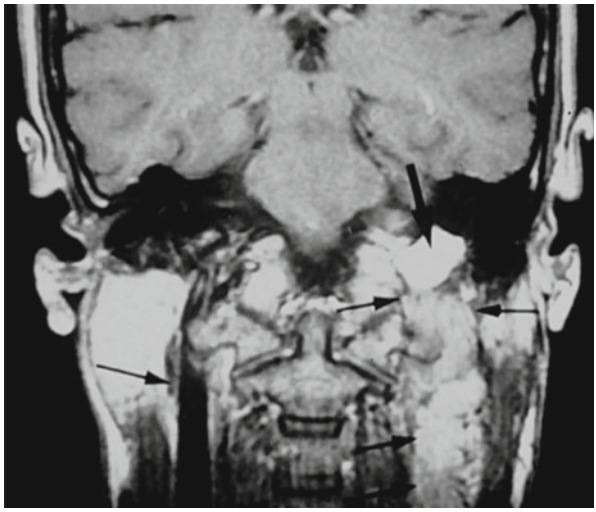

Fig. 10.1 Case 1: Large left-sided jugular foramen paraganglioma with tumor extensions in the neck, jugular foramen and intradural (*arrows*). The right internal jugular vein is identified (*arrow*)

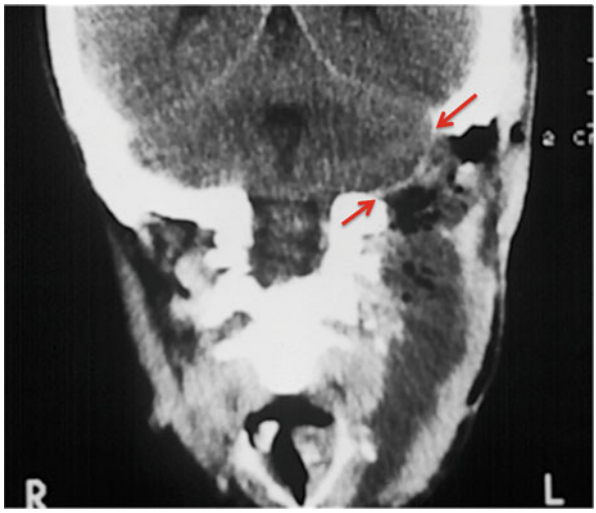

Fig. 10.2 Case 1: Postoperative CT scan showing total removal of the tumor and the large surgical defect at the cranial base (*arrows*)

ascending pharyngeal artery and were preoperatively embolized (Fig. 10.4). The lesion was radically resected through a craniocervical approach and the postoperative follow-up was uneventful. Histology revealed non-secreting paraganglioma. A postoperative MRI control demonstrated the radical removal of the tumor (Fig. 10.5).

Case 3

This 48-year-old woman presented since 1 year swallowing deficits and pulsatile tinnitus on the left ear. An MRI examination (Fig. 10.6) disclosed a large enhancing tumor in the left jugular foramen region with extensions to the ear, neck and

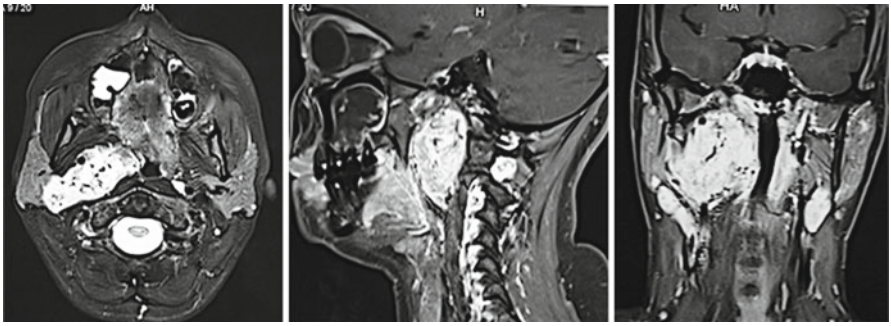

Fig. 10.3 Case 2: Large tumor in the right jugular foramen and neck displacing the esophagus and trachea. With gadolinium enhancement the "salt and pepper" characteristic sign of a paraganglioma can be seen

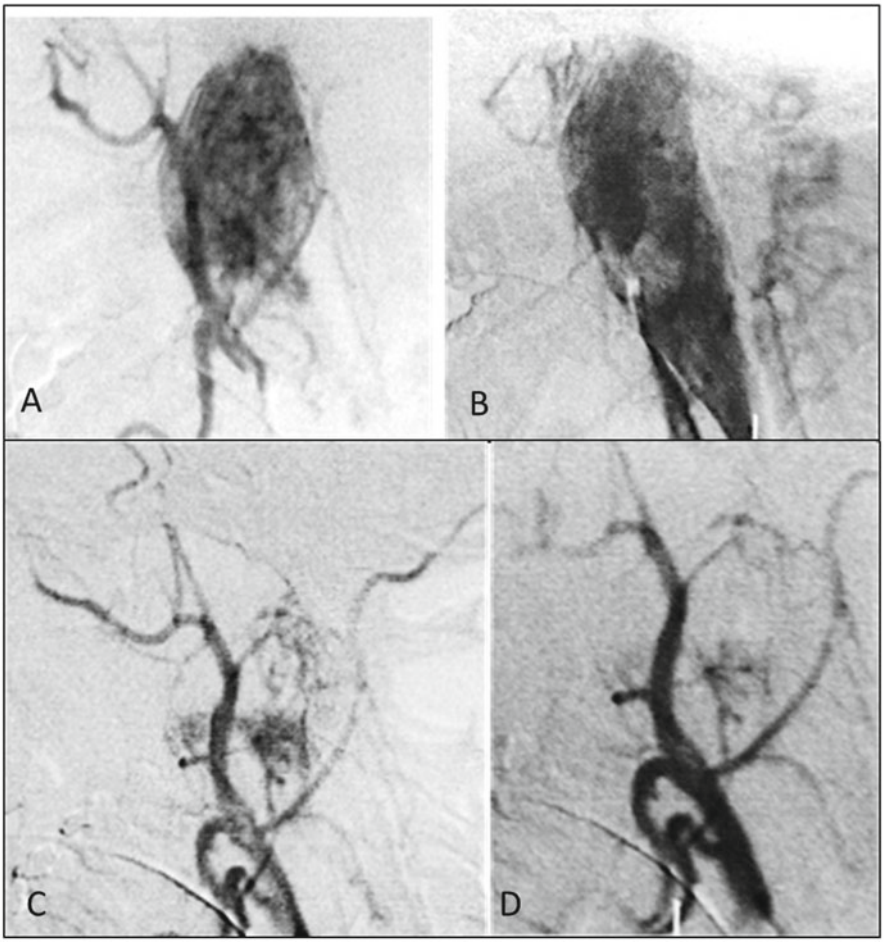

Fig. 10.4 Case 2: Selective digital angiography shows the tumor blush and main feeders from the ascending pharyngeal artery (**a** and **b**). These feeders were embolized with particles and an expressive reduction of tumor blush is observed (**c** and **d**)

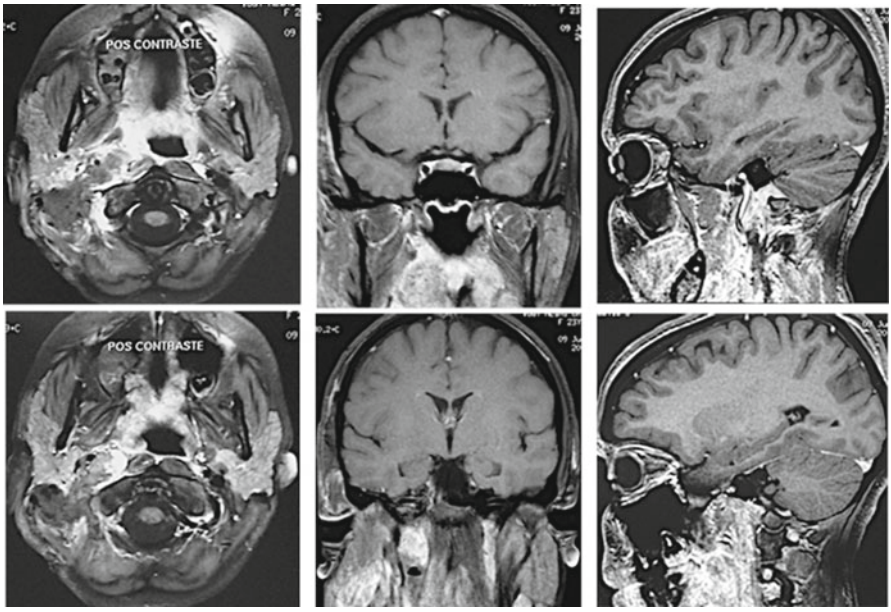

Fig. 10.5 Case 2: Postoperative MRI showing complete removal of the tumor

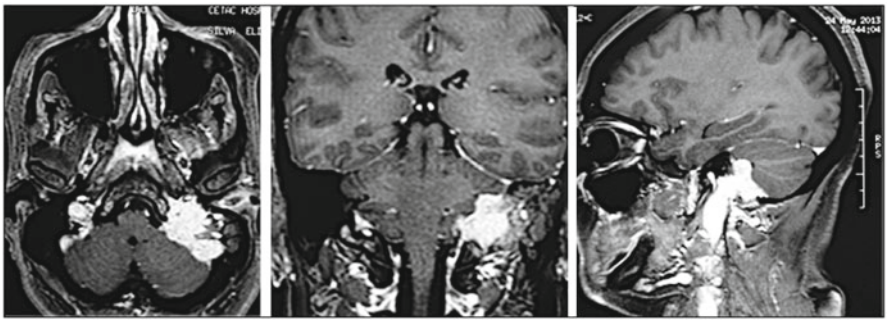

Fig. 10.6 Case 3: Large tumor in the left jugular foramen with gadolinium enhancement. The tumor invasion in the neck, intradural posterior fossa, and ear can be seen

intradural (ENI tumor). The tumor could be totally removed through a craniocervical approach with preservation of the lower cranial nerves. Postoperative the patient developed a complete palsy of the cranial nerves IX, X and facial nerve palsy (H&B III). The postoperative MRI showed complete tumor resection (Fig. 10.7). Histological diagnosis was benign paraganglioma. The swallowing difficulties improved progressively with phonoaudiology rehabilitation program and vocal cord medialization. The facial palsy improved to grade I 6 months after surgery.

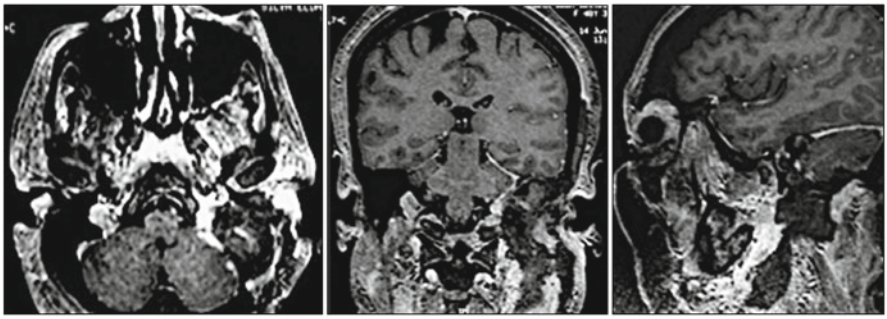

Fig. 10.7 Case 3: Postoperative MRI demonstrating radical resection of the paraganglioma with intradural invasion

Case 4

This 54-year-old woman was operated on a jugular foramen paraganglioma in 2002 in other hospital. Sub-total resection was performed. After surgery she developed palsy of the IX and X cranial nerves. In 2009 she noted again pulsatile tinnitus in the right ear and MRI disclosed regrowth of the tumor (Fig. 10.8). She was referred to our institute for treatment. Preoperative embolization with Onyx was performed (Fig. 10.8). Radical resection of the lesion was possible (Fig. 10.9). The preoperative deficits remained after surgical removal of the lesion and vocal cord medialization with Teflon injection improved the voice.

Case 5

A female patient, 26-year-old, was experiencing hearing loss, dysphonia, and dysphagia for about a year. MRI revealed a left jugular paraganglioma (Fig. 10.10), confirmed with angiography, which has showed the ascending pharyngeal artery as the main feeder (Fig. 10.10). Attempt of embolization was unsuccessful due to unfavorable venous drainage and anastomosis with the internal carotid artery and vertebral artery. Only the superior 1/5 portion of the tumor could be embolized (Fig. 10.11). The tumor invaded the neck, ear, and posterior fossa (ENI type). It could be completely resected through a craniocervical approach. Postoperative the patient presented discrete worsening of dysphagia that gradually improved (Fig. 10.12). There was no need for tracheostomy. At the control follow-up 3 years after surgery there was no recurrence of the tumor and the only neurological deficit was hoarse voice (preoperative deficit).

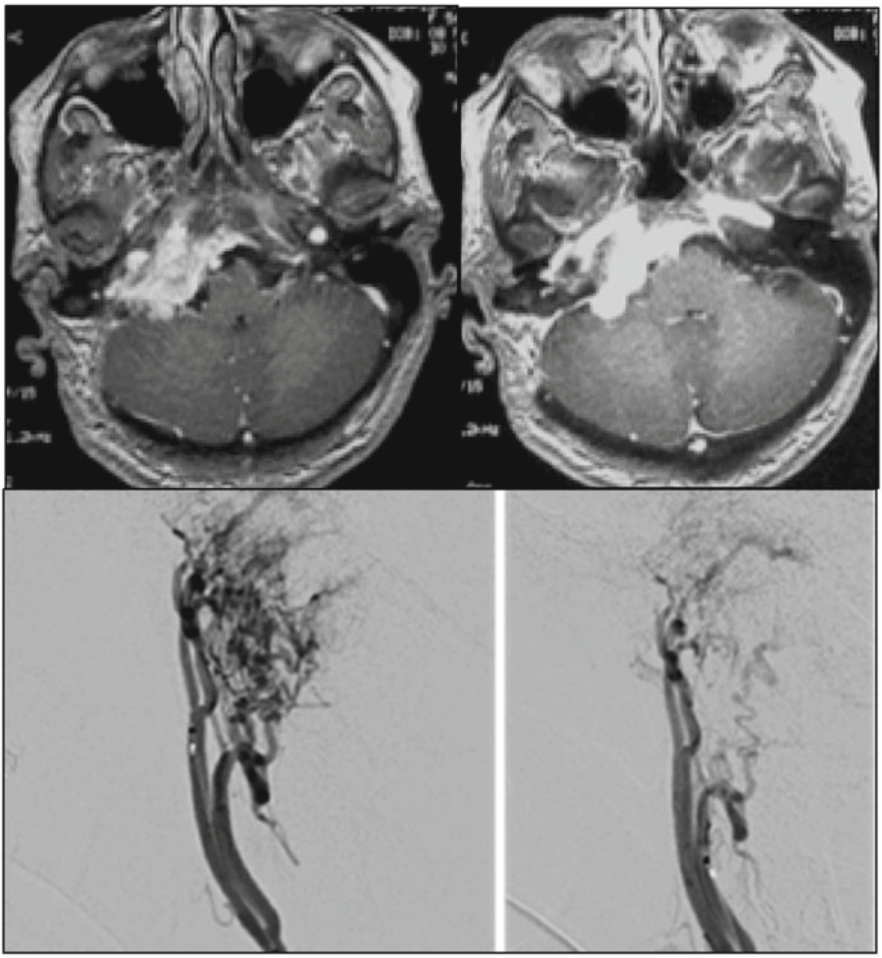

Fig. 10.8 Case 4: MRI showing a recurrent paraganglioma of the right side. This tumor was preoperatively embolized

Case 6

This 14-year-old girl complained of swallowing difficulties and noted the presence of a neck mass 6 months before admission to our Institute. MRI disclosed a large cervical tumor involving the internal carotid artery with extension to the jugular foramen (Fig. 10.13). Tumor enhancement ("salt and pepper" pattern) suggested the presence of a paraganglioma. Radical removal of the lesion (tumor type NI) was possible with preservation of the internal carotid artery (Fig. 10.14).

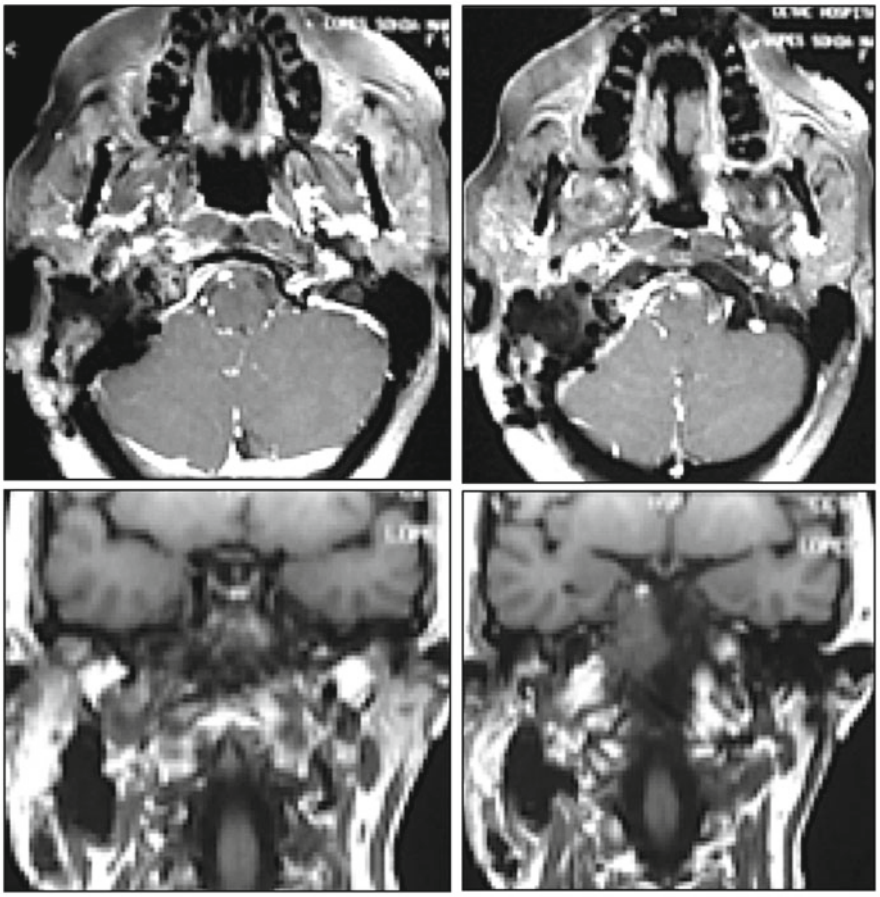

Fig. 10.9 Case 4: Postoperative MRI of a recurrent paraganglioma. Radical removal of the tumor was achieved

Schwannomas

Case 7

This 42-year-old man had been complaining of headaches and dizziness for 2 years. One year before admission to our Institute he started to present progressive hearing loss on the left side, gait disturbance, and swallowing difficulties. An MRI was performed and a large posterior fossa cystic tumor with involvement of the jugular foramen and the high cervical region was discovered (Fig. 10.15). Surgical resection of the tumor was tried in other hospital but the procedure was aborted due to

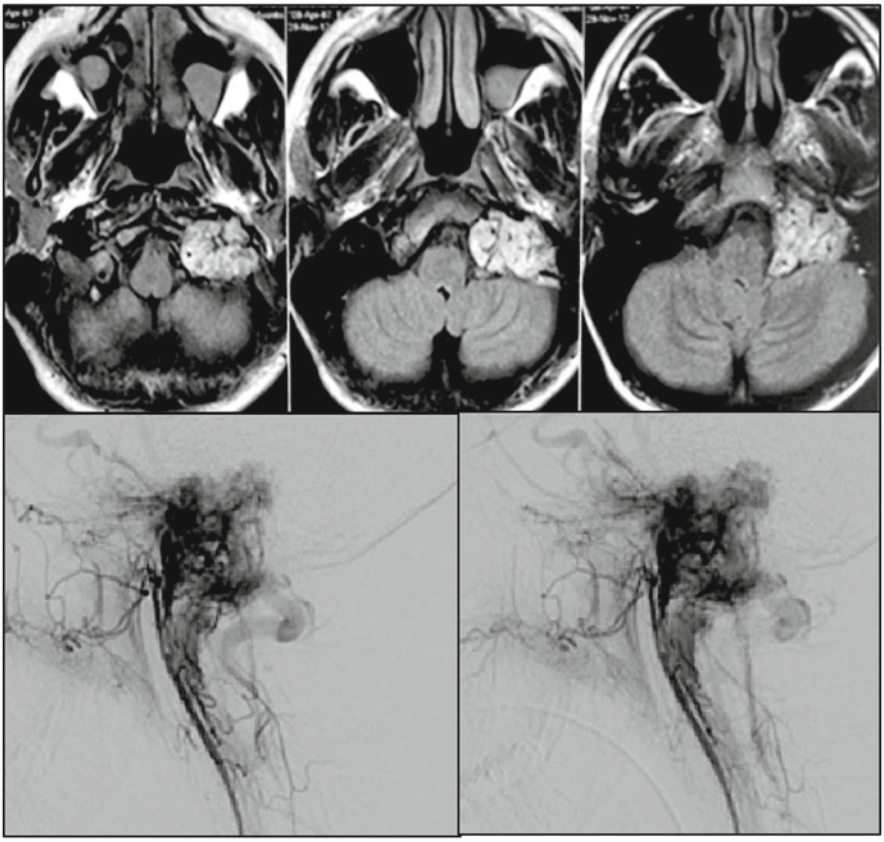

Fig. 10.10 Case 5: Large left-sided jugular foramen paraganglioma. The main feeders of the lesion originated from the ascending pharyngeal artery

severe bradycardia after opening of the dura. A ventricular shunt was inserted and the patient was referred to our institute. On admission the patient presented cerebellar ataxia, palsy of the IX, X, and XI cranial nerves, double vision due to left-sided abducens palsy and complete hearing loss on the left side. A craniocervical approach was performed and after drainage of the large posterior fossa cyst the patient presented sudden severe bradycardia that was reversed with atropine. The tumor was totally removed (Fig. 10.16). Histologically the tumor was classified as benign schwannoma. Postoperative the patient required tracheostomy and gastrostomy due to severe swallowing difficulties and worsening of the cerebellar ataxia. Three months after surgery the swallowing deficits improved and the tracheostomy and the gastrostomy could be removed. At the follow-up examination 2 years after tumor removal the patient was able to walk without help, could eat solid food but remained with diplopia.

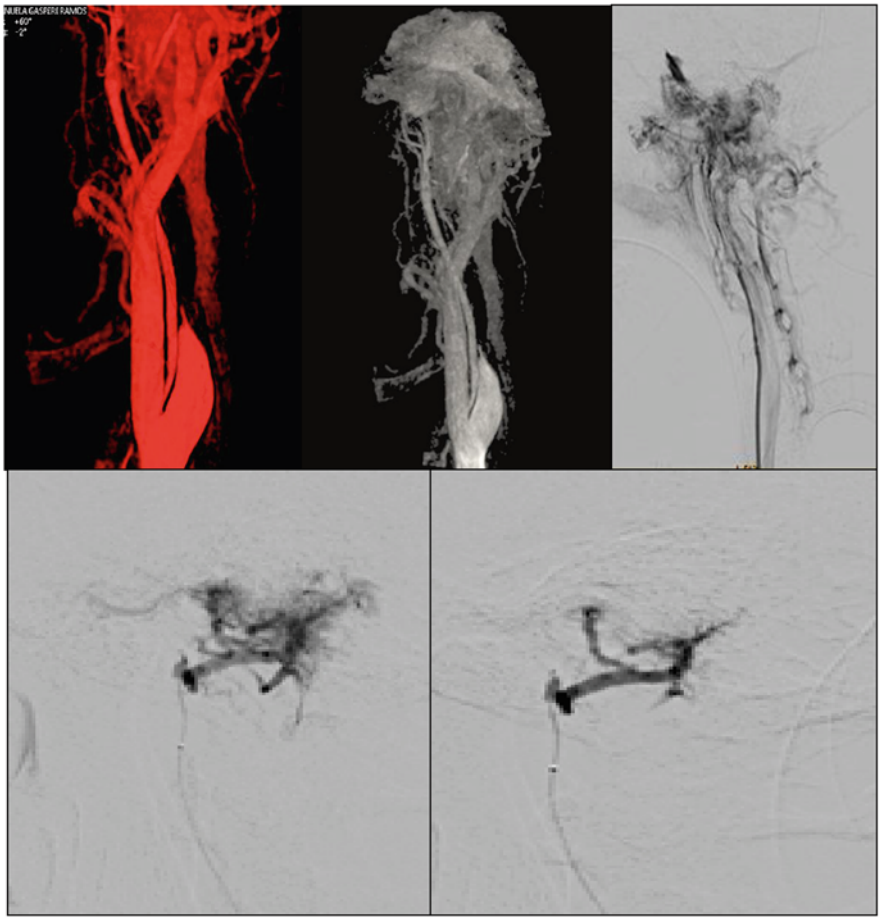

Fig. 10.11 Case 5: DSA showing tumor blush and feeders from the ascending pharyngeal artery that were preoperatively embolized

Case 8

This 48-year-old woman presented with a history of headaches and tinnitus in the left ear. On imaging she was found to have a left-sided sandglass jugular foramen schwannoma (Fig. 10.17). The tumor could be totally removed through a modified retrosigmoid approach. The jugular foramen was intradurally drilled to expose the extradural portion of the lesion. The patient presented uneventful recovery.

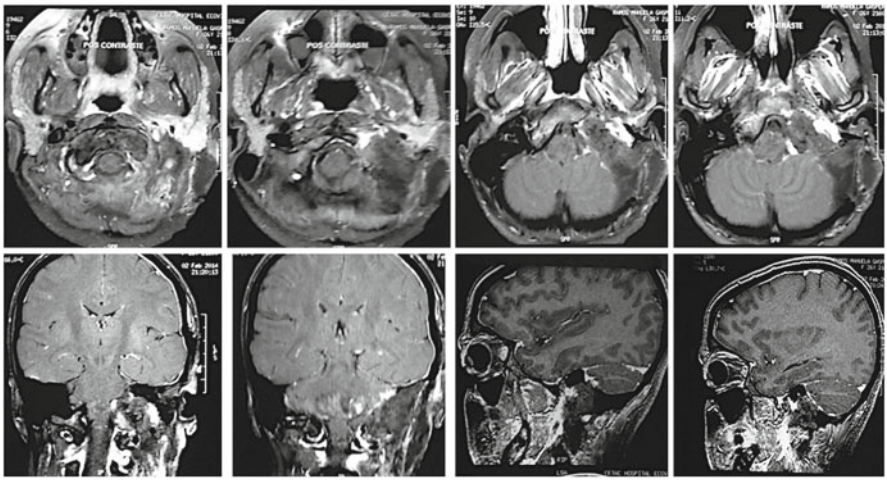

Fig. 10.12 Case 5: Postoperative MRI showing complete removal of the large benign jugular foramen paraganglioma on the left side

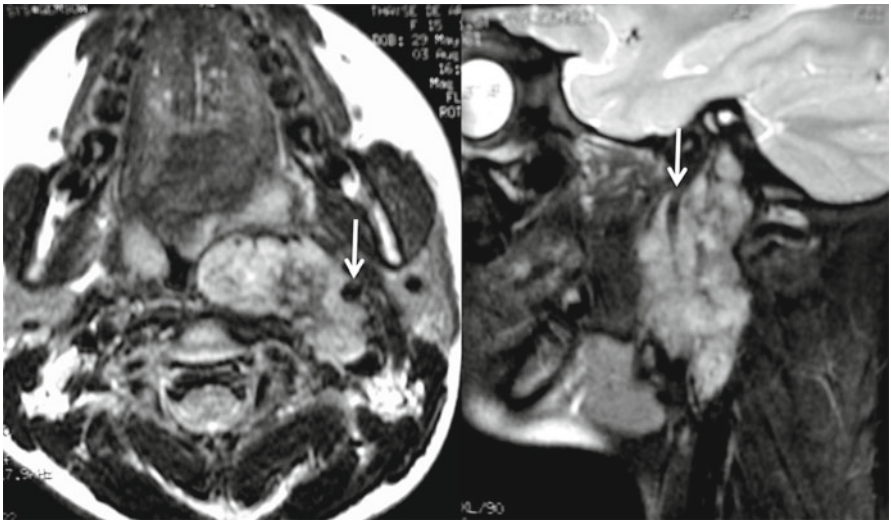

Fig. 10.13 Case 6: Preoperative MRI showing a large neck mass involving the internal carotid artery (*arrows*) with involvement of the left jugular foramen, displacing the trachea. "Salt and pepper" enhancement pattern suggests the presence of a paraganglioma

Case 9

A 72-year-old man started 2 years before admission with hoarse voice and left-sided tongue fasciculations. Clinical examination revealed unilateral right tongue atrophy, hoarse voice, and palatal palsy. MRI revealed an enhancing tumor in the

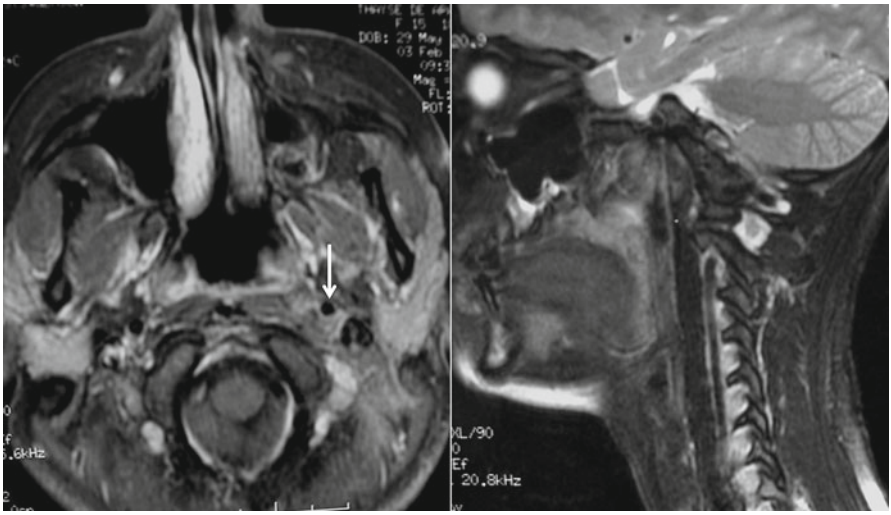

Fig. 10.14 Case 6: Postoperative MRI demonstrating radical removal of the tumor with preservation of the internal carotid artery (*arrow*)

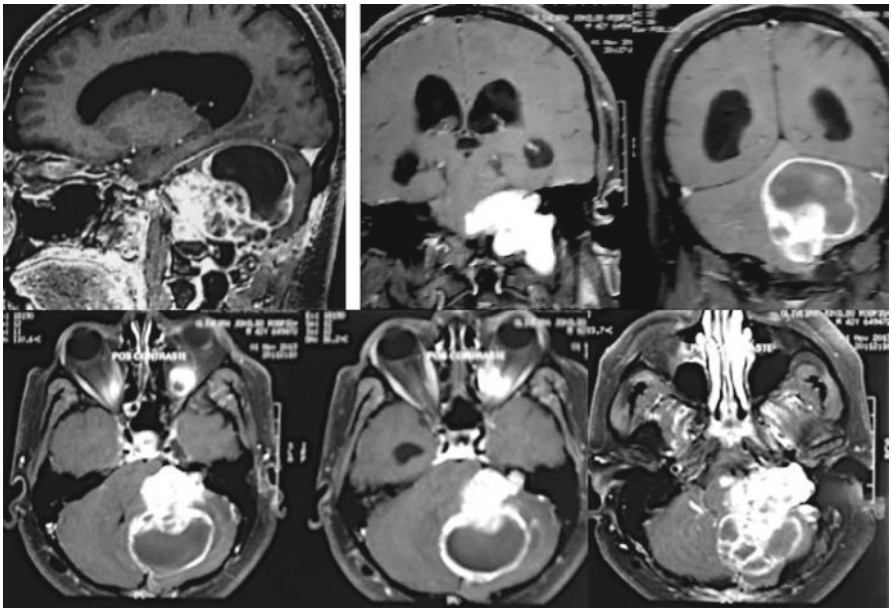

Fig. 10.15 Case 7: Preoperative MRI showing a giant cystic jugular foramen schwannoma with tumor extension to the neck and large intracranial cystic portion

right jugular foramen region with extensions to the neck and spinal canal (Fig. 10.18). Total resection of the lesion was carried out through a craniocervical approach (Fig. 10.19). The histological findings revealed the presence of a benign schwannoma.

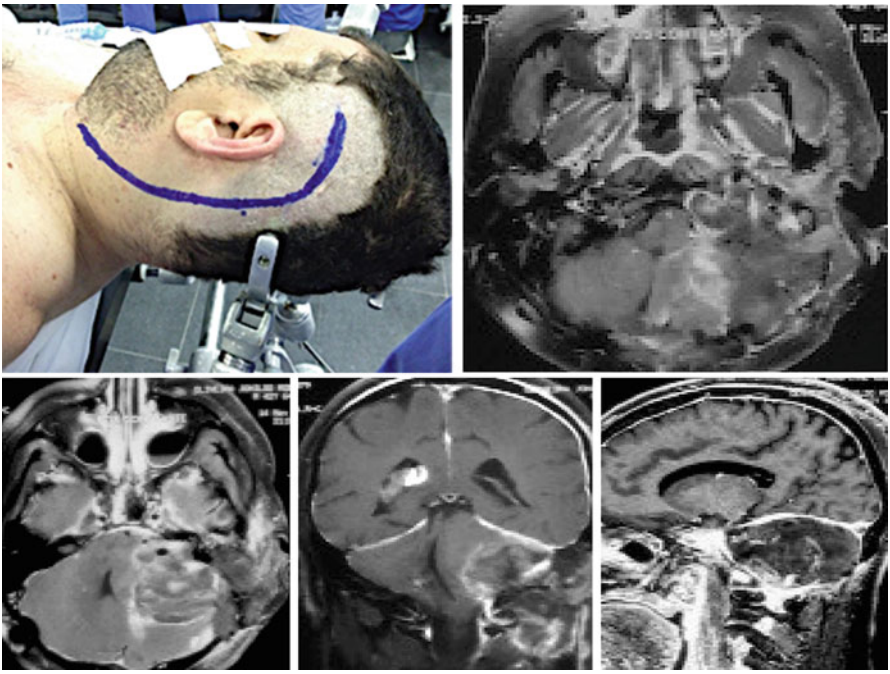

Fig. 10.16 Case 7: Patient's position and skin incision for craniocervical approach. Postoperative MRI 2 days after complete removal of the giant cystic jugular foramen schwannoma

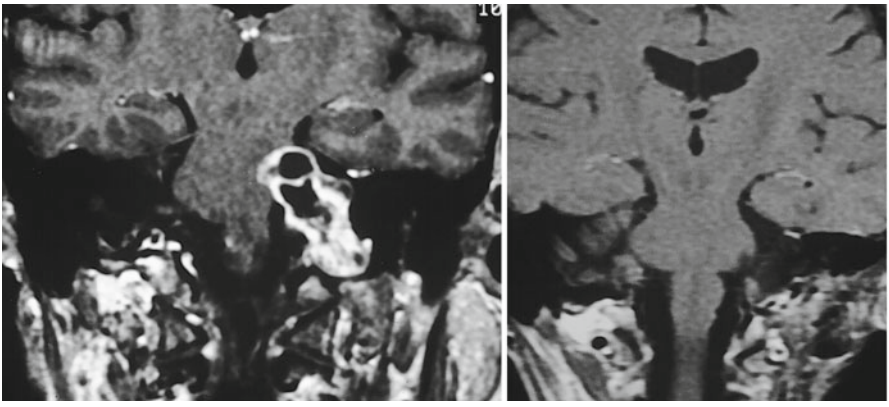

Fig. 10.17 Case 8: (**a**) Preoperative MRI showing a cystic schwannoma of the left jugular foramen with small neck extension. (**b**) MRI after total removal of the tumor through a modified retrosigmoid approach

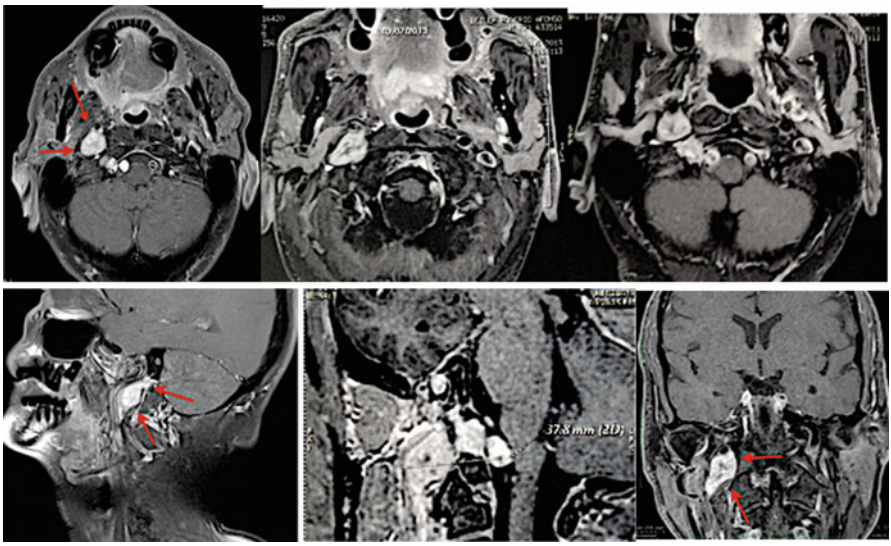

Fig. 10.18 Case 9: Preoperative MRI of a right sided hypoglossal nerve schwannoma with extensions to the jugular foramen and spinal canal (*arrows*)

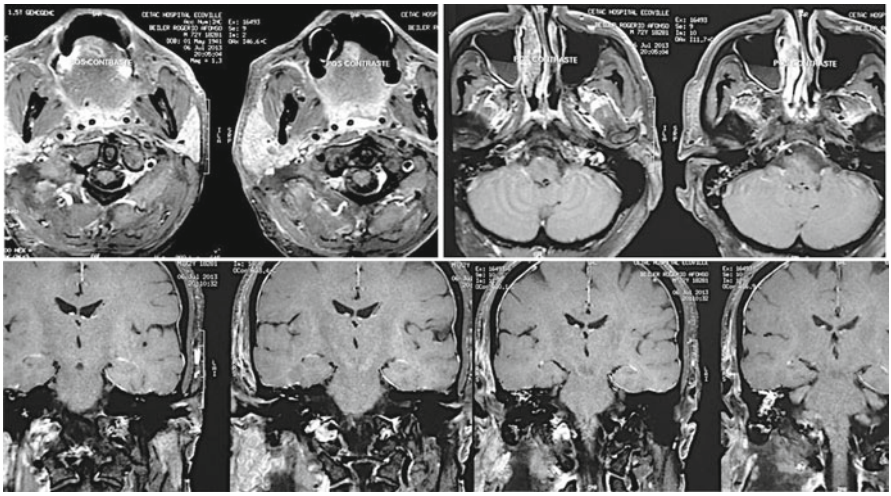

Fig. 10.19 Case 9: Postoperative MRI after total removal of a hypoglossal nerve schwannoma through a craniocervical approach

Meningiomas

Case 10

This 14-year-old girl started to present hoarse voice and underwent an MRI examination. A right sided enhancing tumor was discovered in the jugular foramen region. The lesion presented characteristic findings of a meningioma with "dural tail" (Fig. 10.20). Surgery was performed and the tumor could be totally removed through a modified retrosigmoid approach (Fig. 10.21). The jugular foramen was intradurally opened and tumor capsule could be dissected from the lower cranial nerves. With long-term follow-up of 10 years there was no recurrence and the patient neurologically intact. The histological findings were of a benign meningotheliomatous meningioma.

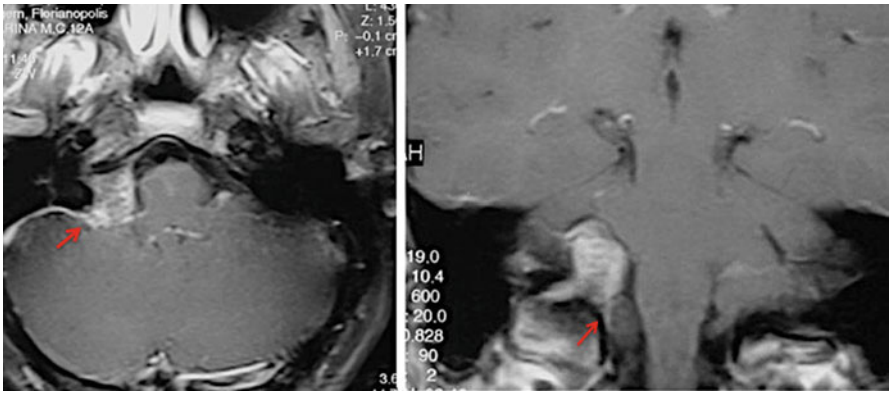

Fig. 10.20 Case 10: MRI of a jugular foramen meningioma. Dural tail is observed (*arrows*)

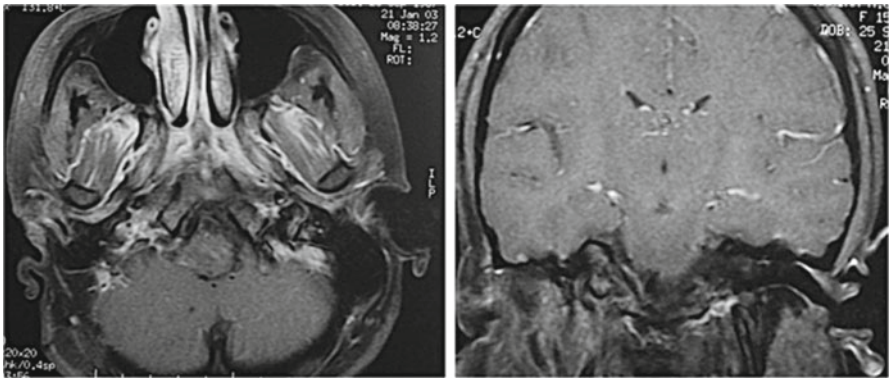

Fig. 10.21 Case 10: Postoperative MRI showing total removal of a jugular foramen meningioma through a modified retrosigmoid approach

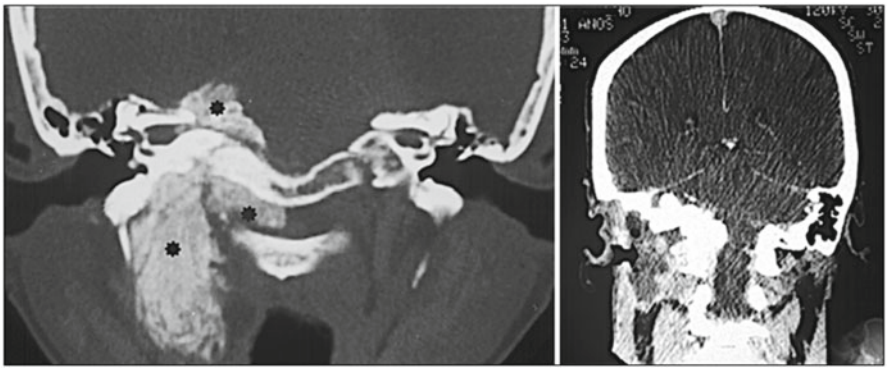

Fig. 10.22 Case 11: (**a**) Preoperative CT scan with contrast showing a large jugular foramen meningioma with tumor extension in the internal auditory canal, cervical region, and spinal canal (*). (**b**) Postoperative CT scan showing resection of the tumor. Hyperostotic bone remained in the occipital condyle

Case 11

A 42-year-old woman complained 2 years before admission of tinnitus on the right ear, hoarse voice, and swallowing difficulties. Clinical examination revealed palsy of the right cranial nerves IX, X, and XI on the right side and decreased hearing on the right ear. CT scan showed a large tumor with calcifications and extensions in the neck, spinal canal, and internal auditory canal (Fig. 10.22). The tumor was approached through a craniocervical access. The tumor was removed but the hyperostotic occipital condyle was not resected to avoid craniocervical instability (Fig. 10.22). Histologically the tumor was defined as meningotheliomatous meningioma.

Case 12

This 27-year-old woman presented 1 year before admission to our institute tinnitus, hearing loss on the right side, and progressive palsy of the lower cranial nerves. MRI disclosed a giant tumor involving the posterior fossa, cervical region, mastoid and the internal auditory canal (Fig. 10.23). A craniocervical approach was performed and the tumor was removed from the lumen of the internal jugular vein. The lesion reached the right auricle and could be totally removed (Fig. 10.24). The internal carotid artery was dissected from tumor capsule. Postoperative there was no new neurological deficit. The histological diagnosis revealed the presence of a microcytic meningioma.

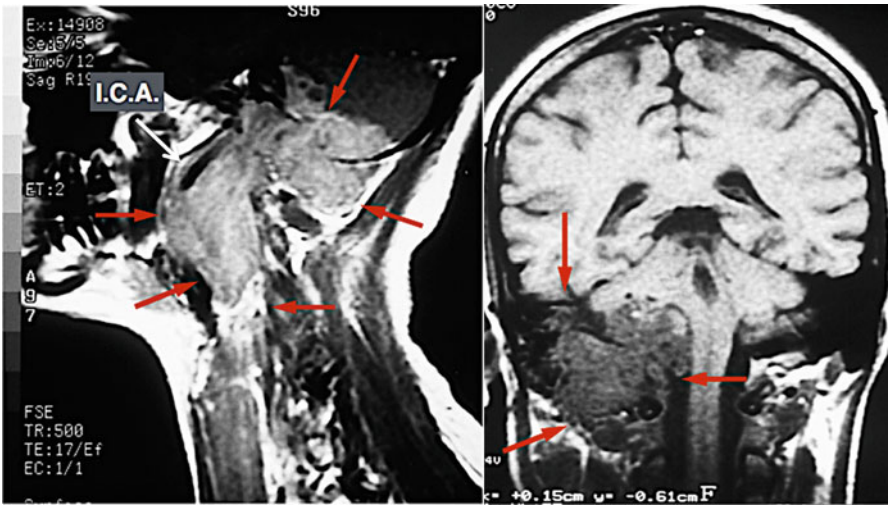

Fig. 10.23 Case 12: Preoperative MRI of a giant jugular foramen meningioma with extensions to the posterior fossa and neck (*red arrows*). The internal carotid artery (ICA) is involved by the tumor

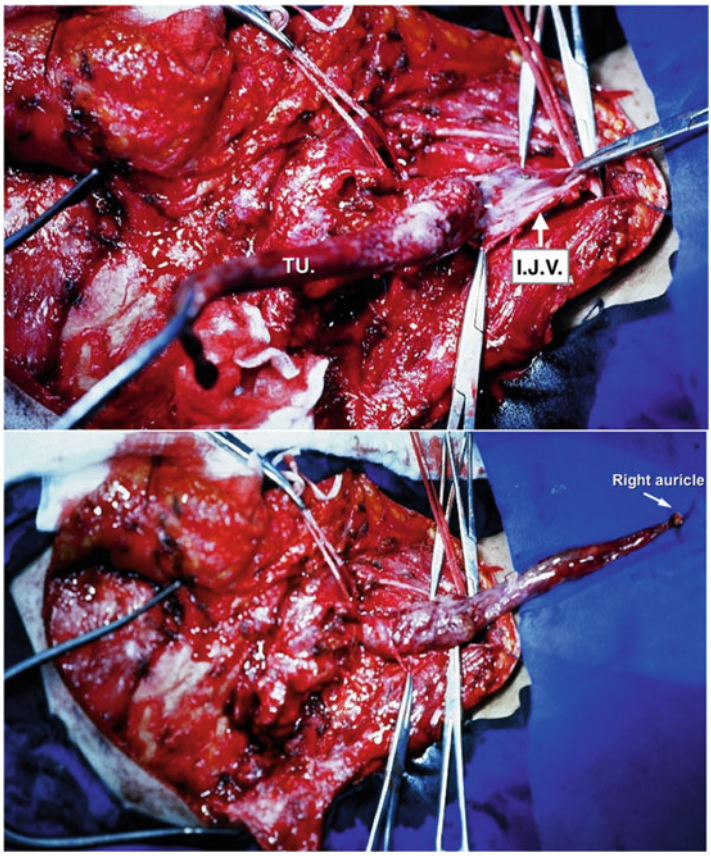

Fig. 10.24 Case 12: Intraoperative pictures showing meningioma extension within the internal jugular vein reaching the right auricle

Chondroma

Case 13

A 38-year-old man noted a tumor mass over the left occipital region. On examination this tumor was fixed, hard, and no pain upon touching. MRI showed a large extradural tumor involving the jugular foramen and the posterior fossa (Fig. 10.25). The tumor was totally removed with preservation of the lower cranial nerves (Fig. 10.25). The histological findings revealed a chondroma.

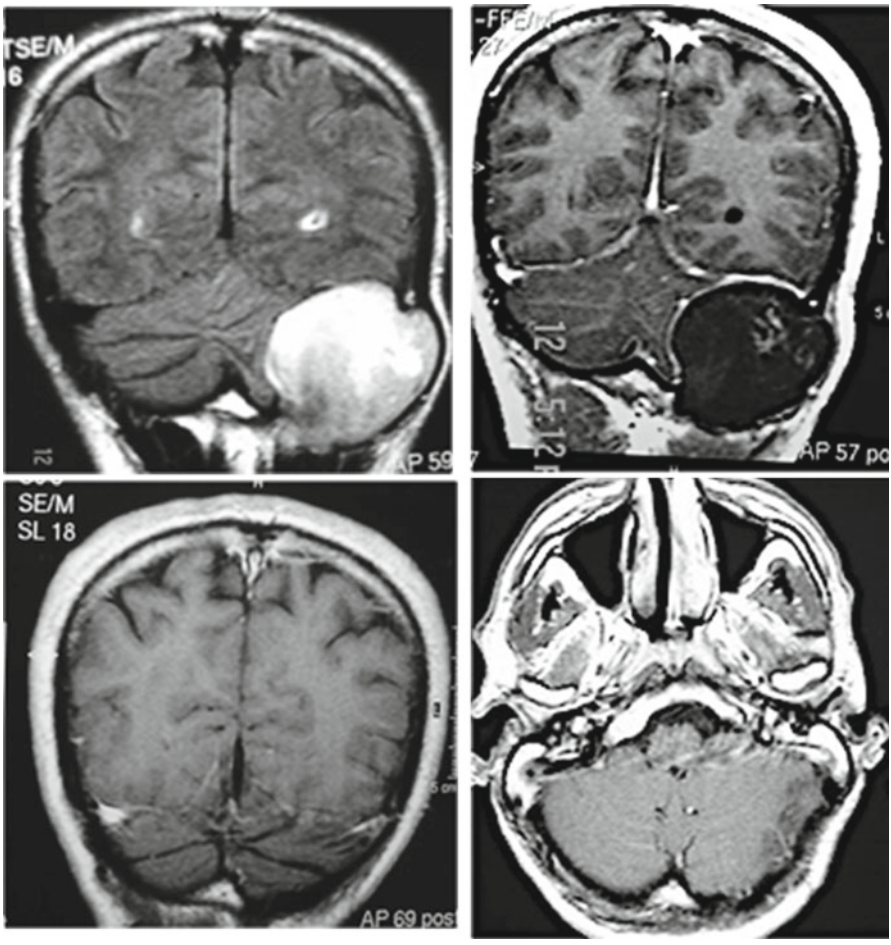

Fig. 10.25 Case 13: *Upper*: MRI showing a large extradural jugular foramen tumor compressing the cerebellum. *Lower*: Complete tumor resection was achieved through modified retrosigmoid approach

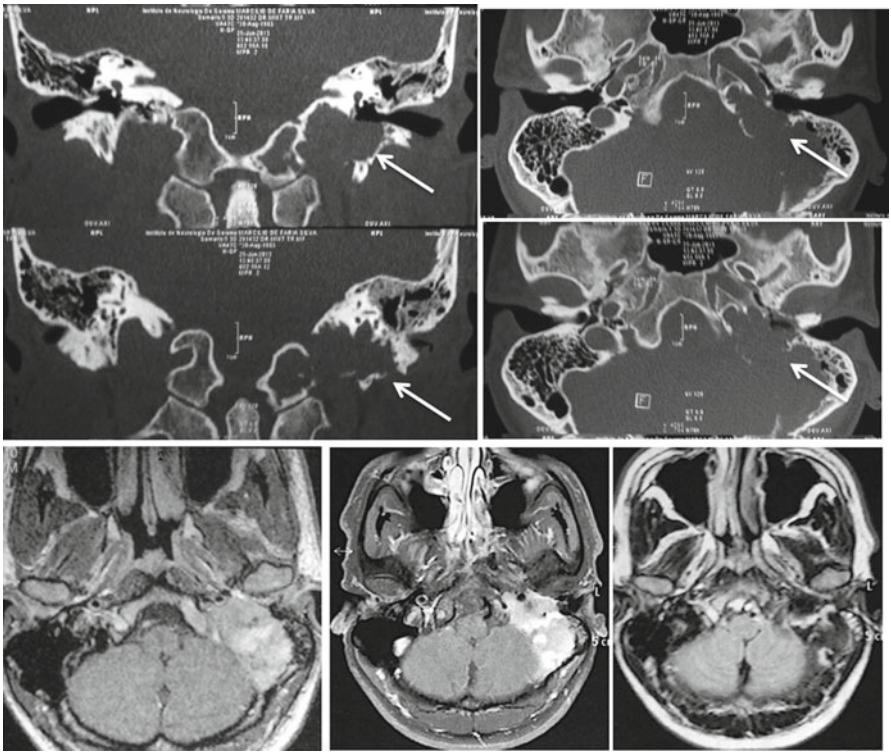

Fig. 10.26 Case 14: *Upper*: CT scan of a patient with a jugular foramen chondrosarcoma. Enlargement and destruction of the jugular foramen is observed (*arrows*). *Lower*: MRI showing heterogeneous enhancement of the tumor

Chondrosarcoma

Case 14

This 45-year-old man complained during 5 months before admission to our institute of swallowing difficulties and hoarse voice. CT scan and MRI revealed a large tumor in the left jugular foramen with extension to the posterior fossa and neck (Fig. 10.26). The tumor caused erosion and enlargement of the jugular foramen and was removed through a craniocervical approach. The histological diagnosis was chondrosarcoma. No postoperative treatment was performed and there was recurrence of the tumor in a 2-year follow-up period.

Videos 10.1, 10.2, 10.3, 10.4, 10.5, 10.6, and 10.7 show the surgical steps of craniocervical approach.

Chapter 11
Histopathological Findings

The jugular foramen tumors are rare conditions considered a challenge for the surgeon who deals with these situations. Paragangliomas, schwannomas, and meningiomas are the most frequent tumor in these regions, but others less frequent lesions can be found in this location, such as chordomas, chondrosarcomas, endolymphatic sac tumors, plasmacytomas, and giant cell tumors. Since natural history and treatment vary widely between these lesions, the precise anatomopathological diagnose must be made for the best treatment approach.

Meningiomas

Meningiomas are arachnoid derived tumors more frequent in women during perimenopause period. They are classified as grade I–III, accordingly to the World Health Organization (WHO) classification. The majority of these tumors are WHO grade I [1].

Macroscopically, lesions are white or yellowish with fibrous consistency, and calcification can be seen in some cases. In grade I, the meningothelial and transitional are the most commons. The histopathological findings in H&E are typical (Fig. 11.1).

The immunohistochemical signature of these lesions is the expression of epithelial membrane antigen (EMA) (Fig. 11.2) and the nucleus which is diffusely positive for progesterone receptor (Fig. 11.3). In more aggressive subtypes (anaplastic) we can see increased cellularity and high mitotic rate (4–10 in atypical and ≥20 in anaplastic). The cytoplasm becomes scarce and regional necrosis can be seen. In these cases, the tumor expresses moderate to high Ki-67 index with some focal areas in which antigen epithelial membrane and progesterone receptor are negative. Grade II and III, as well as higher proliferative index rate, correlate with poor prognosis and more aggressive behavior [1].

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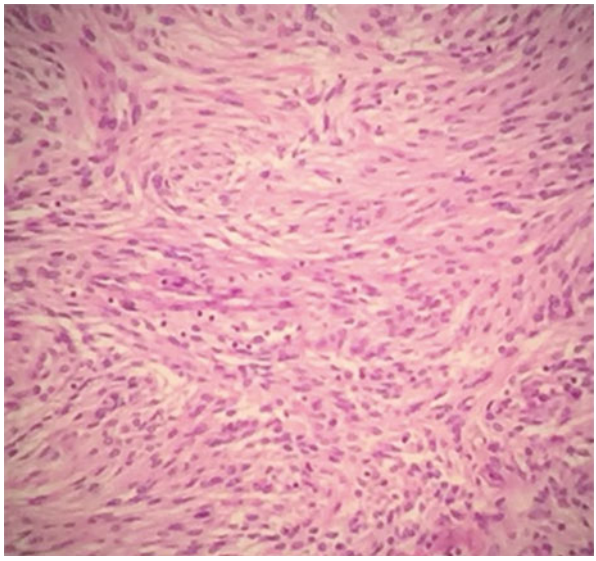

Fig. 11.1 Meningioma HE

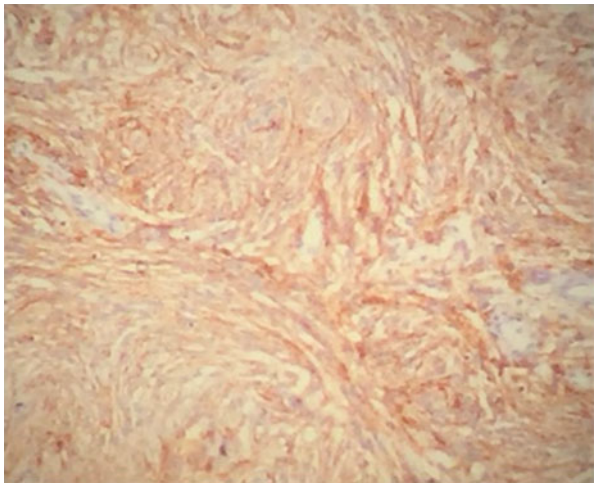

Fig. 11.2 Epithelial membrane antigen (EMA)

Paragangliomas

Paragangliomas are highly vascular tumors typically located at carotid artery and jugular bulb [2]. In general, paragangliomas have a fleshy, pink to red brown to gray appearance, due to hemorrhage or fibrosis.

The majority of these lesions seem to be sporadic. In one third, these lesions are related to some inherited syndrome. Hereditary paragangliomas have been linked to mutations in the genes encoding different subunits of the succinate dehydrogenase

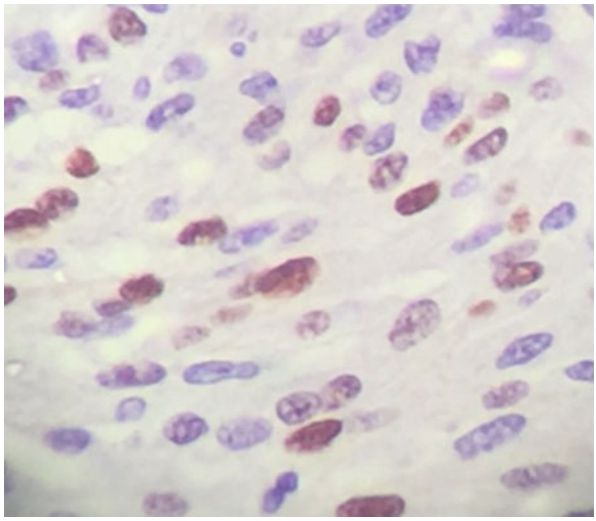

Fig. 11.3 Nucleus positively diffuse for progesterone receptors

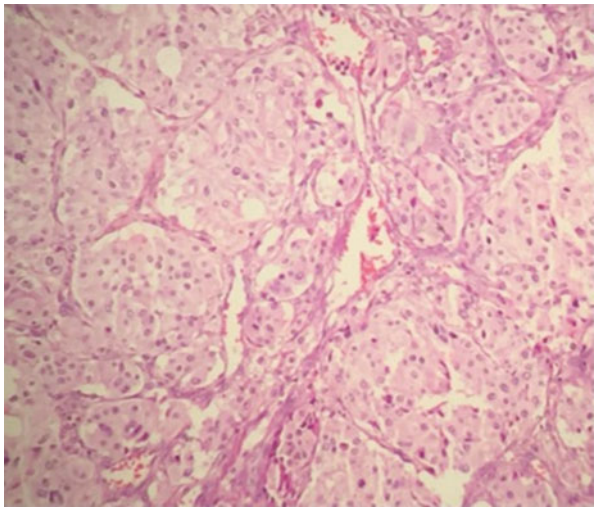

Fig. 11.4 Paraganglioma HE

enzyme complex and can be part of four genetic syndromes: multiple endocrine neoplasia types 2A and 2B (MEN2), neurofibromatosis type 1 (NF1), von Hippel–Lindau (VHL), and the Carney–Stratakis dyad [3].

Histologically, paragangliomas are composed of polygonal epithelioid cells arranged in compact cell nests or trabecular pattern which exhibit central located nuclei with fine clumped chromatin and moderate amount of eosinophilic granular nuclei. These cellular nests are usually supported by spindle-shaped cells (Fig. 11.4) [4–7].

The neuroendocrine confirmation can be achieved through positive immunohistochemical exam for neuron-specific enolase, synaptophysin, and chromogranin (Figs. 11.5 and 11.6). The sustentacular cells can express S-100 and glial fibrillary acidic protein (GFAP) [5, 6].

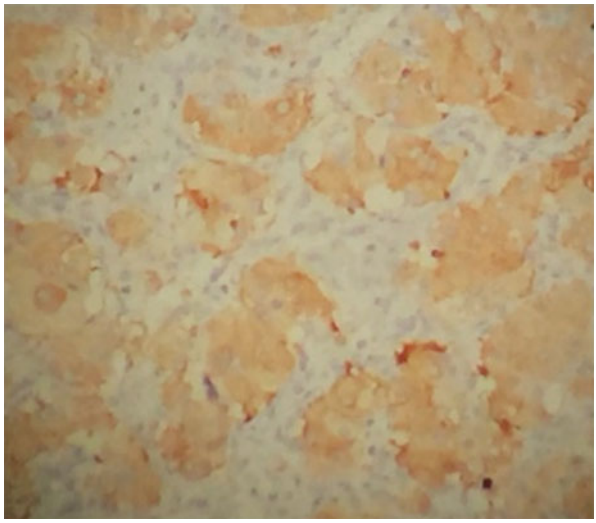

Fig. 11.5 Paraganglioma synaptophysin

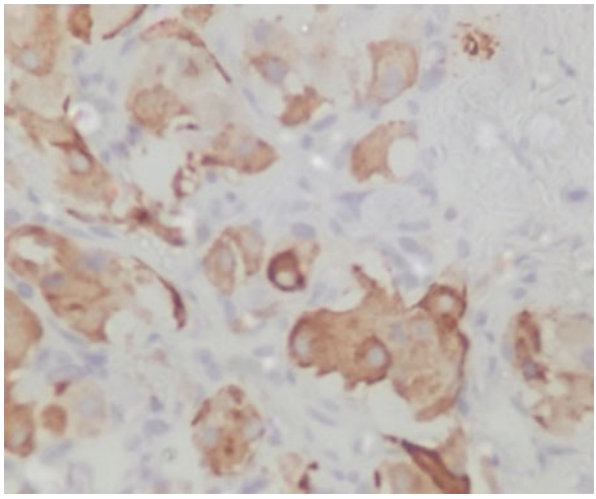

Fig. 11.6 Paraganglioma chromogranin

Histologic determination of malignancy is not easy in these cases because histologic features, such as nuclear pleomorphism, necrosis, mitotic rate, and local invasion, may be also seen in benign paragangliomas [8].

Schwannomas

Schwannomas are benign neoplasms, more common in women during 4ª to 6ª decades of life. Macroscopically they are yellow to red encapsulated lesions usually circumscribed to the nerve. They commonly present vessels with thick walls and hemorrhage is not frequent.

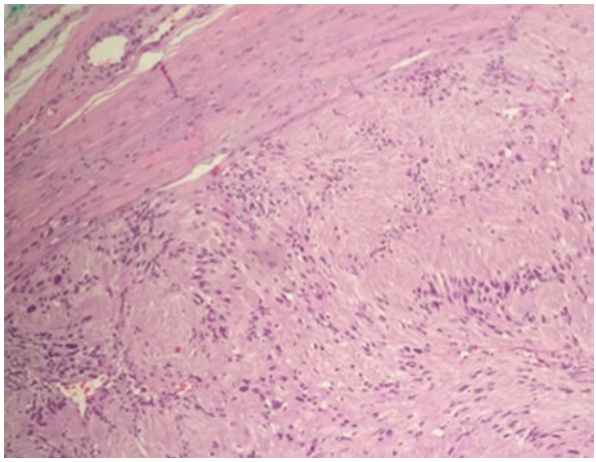

Fig. 11.7 Schwannoma. Antony A and Antony B type cells

Histologically they are divided into two patterns without prognostic implication. The Antoni A tissue type consists of compact areas of spindle cells with pink cytoplasm, while Antoni B comprises cells showing clear, vacuolated cytoplasm due to lipid accumulation (Fig. 11.7) [9]. Its immunohistochemical marker is the positiveness for S-100 protein, confirming the origin from Schwann cells [10].

Chondrosarcomas

Chondrosarcomas are a heterogeneous group of malignant bone tumors that share in common the production of chondroid (cartilaginous) matrix [11].

Commonly, they occur in patients over 50 years with slight male predominance and is classified into grade I–III depending on the cellular mitotic rate [12, 13].

Histologically, it exhibits abundant cartilage matrix production disposed in irregular shaped lobules, and often separated by fibrous band. High grade lesions can exhibit necrosis, increased cellularity, and frequent mitosis [11].

Regarding to molecular genetic, a mutation in EXT gene would lead to an accumulation of heparan sulfate proteoglycans in the cytoplasm and Golgi apparatus, instead of being transported to the cell surface where it would be important for normal chondrocyte proliferation and differentiation. Additionally, mutation in isocitrate dehydrogenase-1 and isocitrate dehydrogenase 2 gene (IDH-1 and IDH-2) has been liked to dedifferentiation in almost 50 % of chondrosarcomas [14–18].

The prognosis is close related to the grade, being grade III chondrosarcoma related to 10-year survival of 29–55 % [12].

Chordomas

Chordomas are rare, slow-growing, and locally aggressive neoplasms of bone that arise from embryonic remnants of the notochord and almost 35 %of chordomas involve the skull base [19, 20].

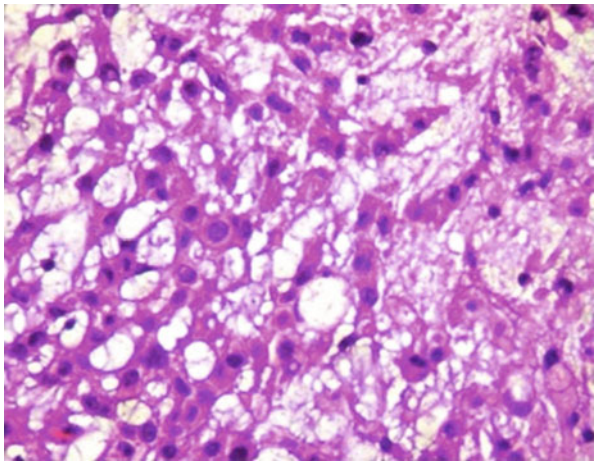

Fig. 11.8 Chordoma with physaliphorous cells

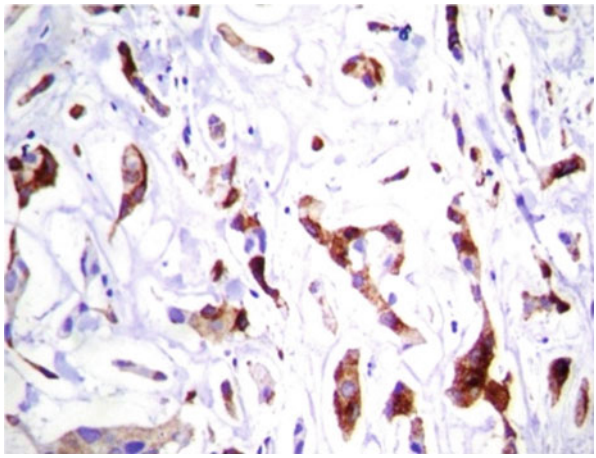

Fig. 11.9 Chordoma, immunohistochemically strong positive for cytokeratin

Histologically, these tumors are divided into three subtypes (conventional chordoma, chondroid chordoma, and chordoma with sarcomatous transformation) depending on the presence of cartilaginous or mesenquimal compounds [19, 21].

Macroscopically, these tumors exhibit a gelatinous, pink or gray appearance with solid and cystic areas. They are composed of lobes of epithelioid cells disposed in cords and separated by fibrous strands in a mucinous matrix. It presents physaliphorous cells that contain glycogen (Fig. 11.8).

Immunohistochemically is strongly positive for cytokeratin in almost all cases and is positive for EMA in up to 80 % of cases. In chondroid chordoma there is 85 % of positiveness for S-100 protein [22, 23] (Fig. 11.9).

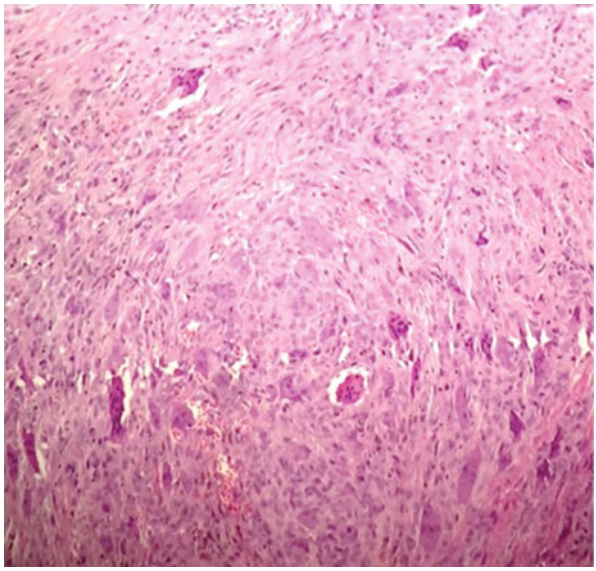

Fig. 11.10 Giant cell tumor HE

Giant Cell Tumor

Giant cell tumor is a rare, benign lesion which expresses a locally aggressive osteolytic behavior being more frequent in young adult.

Macroscopically, giant cell tumor is a reddish tumor mixed by cystic and hemorrhagic areas. Microscopically, the tumor is composed of round to oval or elongated mononuclear cells interspersed with large osteoclast giant cells. These small oval and mononuclear cells are thought to be the real neoplastic component (Fig. 11.10) [24].

In fact, the structural architecture of these cells does not express any neoplastic characteristic, but the amplification in 20q11 gene has been found and the overexpression of p53 gene has been related to increase metastasis occurrence [25].

Receptor activator of nuclear factor kappa B [NF-kB] ligand (RANKL) has also been postulated as important factor in GCT tumorigenesis. These stromal cells have a osteoblast-like structure which, in turn, exhibits a RANKL expression stimulation recruitment of osteoclasts that when activated induce bone absorption contributing to the clinical presentation of these tumors [26].

Plasmacytoma

Plasma cell neoplasms are characterized by neoplastic proliferation of a single clone of plasma cells. These lesions can be solitary or multiple (multiple myeloma).

The morphological features of plasma cells can vary accordingly to their maturity. The mature cell expresses an oval morphology with basophilic cytoplasm.

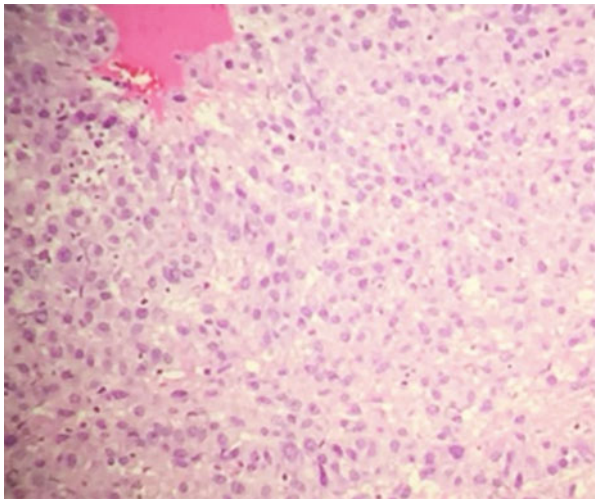

Fig. 11.11 Plasmacytoma HE

The nucleus is central located with perinuclear hof. Immature forms exhibit a high nuclear to cytoplasmic ratio (Fig. 11.11) [27].

Concerning to cytogenetics, there are several genetic abnormalities including translocations and trisomies. These translocations affect the immunoglobulin heavy chain (IgH) locus on chromosome 14q32 [28, 29].

Endolymphatic sac tumors

Endolymphatic sac tumors are rare neuroectodermal neoplasms in the petrous bone, originating from inner ear structures that can be encountered sporadically or in VHL disease.

Macroscopically, these tumors have reddish or bluish appearance and are hypervascular. The consistency is generally soft, but may contain parts of bone in the specimen.

The microscopic appearance can be divided into two major forms. The first one is composed by colloid-filled cysts with sparse stroma where the cysts are surrounded by a single-layered of cuboid epithelium and the epithelium stains with periodic acid–Schiff . The cells have relatively isomorphic nuclei with a homogeneously structured chromatin. Mitoses are very rare. The second one presents a more papillary and solid pattern. The stroma is markedly capillarized and only occasional cysts can be found. The cytoplasm is clear and the nucleus centralized.

They often have areas with hemorrhage and associated with regressive changes with siderophages and fatty degeneration [30–32].

In immunohistochemistry the most robust positivity is for cytokeratin, but it might express a variety of antigens that are characteristic for neuroectodermal tissue as neuron specific enolase. GFAP has also being reported, a protein that is normally considered to be specific for differentiated astrocytes [33, 34].

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Chapter 12
Radiation Therapy and Radiosurgery

Paragangliomas of the jugular foramen are rare, slow-growing, generally benign tumors of neuroendocrine cells. The definitive treatment for these tumors is surgical excision. However, surgery may cause injuries to the lower cranial nerves and severe postoperative neurological disabilities. The optimal treatment remains controversial. Alternative treatment options include radiotherapy (RT), stereotactic radiosurgery (SRS), and observation [1]. The effectiveness of radiation in stopping their growth must be assessed after long-term follow-up (at least 10 years) because these lesions usually display indolent behavior.

Paragangliomas

Conventional Radiotherapy

Conventional radiotherapy with fractionated external beam radiation has been used as a primary, combined, or salvage treatment in patients with jugular foramen paragangliomas [2]. This modality of treatment is indicated in most cases for malignant tumors, remnants after subtotal resection, unresectable lesions, and in patients in advanced age with comorbidity. In a recent retrospective literature reviewing articles listed in Medline, Suarez C et al. evaluated 20 published series with a total of 461 patients with jugular foramen paragangliomas treated with conventional radiotherapy (total doses ranged from 40 Gy to 65 Gy) [3]. The mean age was 53.2 years and the mean duration of follow-up was 112.6 months. In 411 patients (89.1 %) the control of disease (patient alive with tumor regression or without evidence of progression) was obtained. In 50 patients tumors progressed and 15 patients (3.2 %) died of disease progression. The neurological outcome of 351 patients was reported, on pretreatment 242 cranial nerves were affected, after radiotherapy 232. Severe complications or irradiation was observed in 57 patients causing nine deaths. The most common complications were hearing loss, osteonecrosis, and brain necrosis.

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Table 12.1 Radiosurgery for jugular foramen paragangliomas

Method	Patients (n)	Tumor volume	Dose	Follow-up	Tu. growth control	Tu reduction	Complications
Gamma-knife [4]	46	Median 3.6 cm^3	Median 20 Gy	Median 118 months	98 %	77 %	4 %
Gamma-knife [5]	58	Mean 12 cm^3, median 9.3 cm^3	Mean marginal 13.6 Gy	Mean 86.4 months	91.4 %	67.2 %	8.6 %
LINAC [6]	1 1	NA	Median 15 Gy	Median 5.3 years	81 %	NA	0 %
LINAC [7]	2 7	Median 9.5 ml	Median 15 GY	Median 9.6 years	100 %	37.5 %	3.7 %
CyberKnife [8]	3 31	10 cm^3	25GY/5 fractions	Median 24 months	100 %	49 %	19 %
CyberKnife [9]	8	NA	Mean 12.5 GY	Mean 20 months	100 %	NA	0 %

Radiosurgery

Radiosurgery (Gamma Knife, LINAC, and CyberKnife) has been reported as a useful, safe treatment option for benign jugular foramen paragangliomas (tumor diameter <3 cm) associated with minimal morbidity (Table 12.1) [5, 7]. Long-term outcome (median follow-up time was 5.3 years) after SRS for temporal bone paragangliomas has been reported. The overall survival rates ranged at 5 years from 100 % to 78 %, at 10 years from 95.2 % to 78 %, and at 20 years 79.4 % [6, 7]. Neurological deficits improved in 42 % of patients and deteriorated in 4 %. Tumor size decreased in 77 % [4]. In conclusion, radiosurgery appears to be both safe and effective in the treatment of jugular foramen paragangliomas (more favorable if tumor diameter <3 cm). Determining whether long-term tumor control and complications will arise will require further investigation.

Schwannomas

The majority of skull base schwannomas as well as jugular foramen schwannomas are benign lesions. Radiation therapy is indicated when safe resection of the tumor is not possible or when postoperatively there is proven growth of tumor remnants. Conventional radiotherapy is usually not recommended due to the risk of actinic damage of important jugular foramen neighboring structures. Fractionated stereotactic radiotherapy or single-dose radiosurgery (Gamma Knife, LINAC, and CyberKnife) are the irradiation modalities currently used to treat skull base schwannomas primarily or after partial resection.

Fractionated Stereotactic Radiotherapy

In the literature the reported number of patients treated with fractionated stereotactic radiotherapy (SRT) is very limited. SRT has been used more frequently to treat patients with vestibular schwannomas with a 5-year tumor control rate of 91.4 % [10].

Described complications of SRT are transient facial nerve palsy (4 %), trigeminal neuropathy (14 %), hydrocephalus (11 %), and balance disturbance (17 %). The risk of a benign or malignant secondary tumor development after SRT may be as high as 2 % [11]. In a study comparing treatment toxicity of SRT with radiosurgery LINAC-based to treat vestibular schwannomas, the authors found no statistically significant difference between the two groups [12].

Radiosurgery

Radical removal of jugular foramen schwannomas carries the risk of lower cranial neuropathy. Radiosurgery is not curative but is a minimally invasive alternative or adjunct to microsurgery after subtotal resection in some cases. Lower cranial nerve deficits rarely occur as adverse complication of radiosurgery. Long-term follow-up is needed for evaluation of tumor growth control and development of late cranial nerves deficits. Larger tumors require, however, surgical resection. In a series of 34 patients (35 tumors—one patient with bilateral schwannomas) with a mean follow-up of 83 months tumor regression was observed in 17 patients, remained stable in 16, and tumor progression occurred in two. Five- and 10-year control rates were 97 % and 94 %, respectively [13]. A multi-institutional study in Japan evaluated the efficacy and safety of gamma knife radiosurgery in the treatment of 117 patients with jugular foramen schwannomas. Radiosurgery was the primary treatment in 56 cases and 61 patients underwent previous surgical resection. The schwannomas were solid in 73 % of the cases and with cystic components in 27 % of patients. The median tumor volume was 4.9 cm^3, the median dose to the tumor margin was 12 Gy, and maximum and marginal doses were 42 and 21 Gy, respectively. With a median follow-up period of 52 months, 62 patients (53 %) showed partial tumor regression, 42 patients (36 %) stable tumors, and 13 (11 %) tumor progression. Pre-radiosurgery brainstem edema and dumbbell-shaped tumors significantly affected progression-free survival that was 91 % and 89 % in 3- and 5-year follow-up, respectively. Twenty patients (17 %) developed symptomatic deterioration (transient in 12 cases and permanent in eight patients). The preexisting hoarseness and swallowing deficits improved in 66 % and 63 % of the patients, respectively [14]. Planned subtotal resection followed by radiosurgery has been proposed as treatment strategy to avoid lower cranial nerves deficits [15].

Delayed development of malignant secondary tumor following radiosurgery is rare. There are many case reports after radiosurgery in the literature, but neither the incidence nor the prevalence of secondary radiation-related tumors is known [16, 17].

In a review of the literature the risk of malignancy in vestibular schwannomas patients was of 1.32–2.08 per 100,000 over 20 years in no irradiated cases. Excluding the neurofibromatoses (NF) cases this risk decreases to 1.09–1.74 per 100,000. In patients after radiation therapy the overall risk over 20 years is 25.1 per 100,000. This risk decreases to 15.6 per 100,000 if cases of NF are excluded. The authors conclude that radiation treatment increases the risk of malignancy by approximately 10 times in non-NF cases [18].

Meningiomas

WHO Grade I—benign meningiomas constitute approximately 70–85 % of intracranial meningiomas. WHO Grade II—atypical meningiomas account for 15–25 % of intracranial meningiomas. Only approximately 40–60 % of patients with Grade II meningiomas remain disease-free at 10 years [19, 20]. WHO Grade III—anaplastic meningiomas constitute 1–4 % of intracranial meningiomas [21, 22]. Radiation therapy is usually indicated for incompletely removed or inoperable benign meningiomas and for recurrent, or higher-grade meningiomas. Patients with recurrent and residual meningiomas have a less favorable prognosis and usually require further resection. Preservation of neurologic function with surgical treatment is more difficult in these cases and irradiation treatment is an option.

Fractionated Stereotactic Radiotherapy

3D conformal external beam radiation therapy can offer local tumor control in 90–95 % of cases [23]. It is usually indicated for larger tumor (>3.5 cm in diameter) and for lesion close to structures, such as the optic chiasm and brainstem. Excellent results of meningiomas treated primarily with external beam radiotherapy and fractionated stereotactic radiotherapy have been reported [24–26]. With image-based techniques the recommended doses range from 50 to 55 Gy in fractions of 1.8 to 2.0 Gy [24, 27]. Side effects of external beam radiotherapy have been described. In a series of 189 patients treated with a highly conformal stereotactic approach (median daily fractions of 1.8 Gy to a mean dose of 56.8 Gy) four patients (2.2 %) presented reduced vision, a new visual-field deficit, and trigeminal neuropathy, with a median follow-up of 3 years [28]. Brainstem necrosis has been uncommonly observed [29].

Radiosurgery

SRS is generally indicated for small meningiomas (less than 3–4 cm in diameter) with a margin doses ranging from 12 to 16 GY [30–32]. In approximately 8 % of patients new or worsened cranial nerves deficits were observed with higher margin

doses (14–16 Gy). The optic, cochlear, and trigeminal nerves were more commonly affected [33–35].

Jugular foramen meningiomas are very rare and no series reporting primarily radiosurgical treatment of these tumors has been reported in the literature. In a series of 62 posterior fossa meningiomas treated with gamma knife surgery included 26 cases of jugular foramen/petrous bone meningiomas. In a relatively short follow-up (median 28.7 months) the authors observed reduction or disappearance of the lesion in 55 % (34/62) cases of the all series, stable radiological imaging in 40 % (25/62), and progression in 5 % (3/62) [36]. Long-term results are needed to know the efficacy of radiosurgery to control tumor growth in benign skull base meningiomas. In a recent report, Chohen-Inbar O et al. evaluated long-term results in a series of 135 patients with WHO-grade I skull base meningiomas treated with a single-session gamma knife radiosurgery [37]. Median follow-up was 102.5 months, median tumor volume 4.7 cm, and median margin dose 15Gy. Tumor volume control was achieved in 88.1 %. The 5-, 10-, and 15-year actuarial progression-free survival were 100 %, 95.4 %, and 68.8 %, respectively. In a report of the North American Gamma Knife Consortium, 675 patients with posterior fossa meningiomas treated with gamma knife radiosurgery were evaluated. There was a female preponderance at a ratio of 3.8 to 1. The median patient age was 57.6 years (range 12–89 years) and 43.3 % underwent previous resection. The mean tumor volume was 6.5 cm^3 and the median margin dose was 13.6 Gy (range 8–40 Gy). At a mean follow-up of 60.1 months the control of tumor growth was achieved in 91.2 % of cases. Actuarial tumor control was 95 %, 92 %, and 81 % at 3, 5, and 10 years after gamma knife. Clival, petrous, or cerebellopontine angle location when compared with petroclival, tentorial, and foramen magnum location was predictive factor of neurological decline after radiosurgery [38]. Improvement of signs and symptoms after gamma knife radiosurgery was observed in 30 % of cases of skull bases meningiomas [39].

Chordomas

The role of routine postoperative radiation therapy in treatment of chordomas remains a debate. Surgery is the mainstay of treatment for chordomas. Chordomas are resistant to radiation and very high doses of radiation are needed. Radiation therapy can reduce the risk of recurrence and prolong survival. Jugular foramen chordomas are in close proximity to vital anatomic structures such as the brainstem, lower cranial nerves, vessels, and spinal cord. Therefore, focused irradiation treatment avoiding the surrounding structures should be used.

Different types of focused radiation are recommended. Proton beam therapy is the most often indicated radiotherapy for chordomas. This kind of irradiation delivers very high doses of radiation to the lesion with minimal doses to surrounding tissues. Another type of particle beam radiation is the carbon ion therapy that has similar effects to proton beam. These two modalities of radiotherapy are, however, available only in small number of centers. Radiosurgery with LINAC, Gamma Knife, and CyberKnife is much more accessible and can also be effective.

Intensity-modulated radiotherapy may also be an alternative. A direct comparison of these methods was not reported. Conventional photon radiation is not effective for chordomas patients [40].

Proton Beam Radiation Therapy

The role of adjuvant radiation and the type of radiation used remain a subject of discussion. Proton beam radiation is considered to offer the best long-term follow-up and efficacy [41]. In 1989, Austin-Seymour M et al. first reported the efficacy of proton beam radiation for chordomas [42]. Sixty-eight patients with chordoma or low-grade chondrosarcoma at the base of the skull received fractionated high-dose postoperative radiation delivered with a 160-MeV proton beam. With a minimum follow-up period of 17 months (median of 34 months) the 5-year actuarial local control rate was 82 % and disease-free survival rate was 76 %. In a series of 40 patients with chordomas of the skull base and cervical spine proton beam radiotherapy was performed in 75 % of the cases with a mean dose of 68.9 cobalt gray equivalents. With a median follow-up of 56.5 months, the 5-year PFS and OS rates were 70 % and 83.4 %, respectively. The authors concluded that multimodal surgery and proton therapy improved the results [43].

The emerging technology committee of the American Society of Radiation Oncology (ASTRO) found evidence for a benefit of proton beam radiation therapy over photon therapy in large chordomas [44]. Other authors, however, observed similar results with proton- and photon-based radiotherapy [45, 46]. Complications of proton beam radiotherapy for clival chordomas such as delayed optic nerve neuropathy and blindness have been described [47].

Carbon Ion Therapy

Adjuvant proton-beam, carbon ion, and modern fractionated photon radiation therapy techniques offered a similar rate of PFS and OS at 5 years [45]. Table 12.2 summarizes the relative pros and cons of each modality presented at a panel discussion on Carbon vs proton for innovative applications of particle beam therapy [48].

The long-term results with carbon ions irradiation to treat skull base chordomas were recently reported [49]. A total of 155 patients with residual macroscopic tumors were evaluated. The median total dose was 60 Gy (relative biological effectiveness) at 3 Gy (relative biological effectiveness) per fraction. The median boost planning target volume was 70 mL (range, 2 mL to 294 mL). The median follow-up was 72 months (range, 12 months to 165 months). The 3-, 5-, and 10-year local control rates were 82 %, 72 %, and 54 %, respectively. The overall survival rates at 3-, 5-, and 10-year were 95 %, 85 %, and 75 %, respectively. There was no late toxicity.

Table 12.2 Pros and cons of proton beam therapy and carbon ion therapy

	Proton beam therapy	Carbon ion therapy
Proton advantages over carbon	• Lower cost. • Able to be delivered via gantry, allowing multiple beam angles. • More narrow range of RBE (1–1.1) and greater certainty leading to smaller variations in actual delivered dose. • Decreased risk of late normal tissue damage due to lower RBE.	• Higher cost (2–3 x proton therapy). • Usually delivered via a fixed beam, not permitting multiple angles. • There are uncertainties in the RBE (1.5–3.4) which may cause large variations in the actual delivered dose. • Potential for increased risk of late normal tissue damage due to higher/variable RBE.
Carbon advantages over proton	• RBE is similar to photon radiation and increased tumor control would not be expected. • Larger lateral penumbra which can cause greater dose to normal tissue structures than carbon ion.	• Higher RBE particularly at distal edge of Bragg peak which may permit greater tumor control. • Smaller lateral penumbra which may permit a more conformal dose laterally and limit normal tissue damage.
Similarities of both therapies	• Both proton and carbon ion limit the integral dose and therefore are predicted to reduce the risk of secondary malignancies over photon therapy, particularly in the pediatric population.	• Both proton and carbon ion research is limited, largely consisting of small series of patients where definitive conclusions are difficult to make.

RBE, radiobiologic effect

Radiosurgery

Radiosurgery with gamma knife as adjuvant treatment for chordomas has been suggested by six participating centers in the North American Gamma Knife Consortium [50]. Seventy one patients with skull base chordomas were evaluated. The median radiosurgery target volume was 7.1 cm^3 (range, 0.9–109 cm^3) with median margin dose of 15.0 Gy (range, 9–25 Gy). Twenty three patients died of tumor progression at a median follow-up of 5 years (range, 0.6–14 years). The 5-year actuarial overall survival was 80 % for the entire group, 93 % for "no prior fractionated radiation therapy" group ($n = 50$), and 43 % for "prior RT" group ($n = 21$). Tumor control rate at 5 years was 66 % for the entire group, 69 % for "no prior fractionated radiation therapy" group, and 62 % for "prior fractionated radiation therapy" group.

The efficacy and toxicity of fractionated SRS with CyberKnife in skull base chordomas was reported [51]. The median tumor volume was 14.7 cc (range, 3.9–40.5 cc) and the delivered median marginal tumor dose was 30 Gy (range, 20–36 Gy) in a median 5 fractions (range, 3–5 fractions). At a median follow-up period of 42 months (range, 17–63 months), ten (91 %) patients were alive and one (9 %) had died due to tumor progression. Eight patients (73 %) had stable disease and two

(18 %) showed tumor progression. The actuarial overall survival was 91 % at 2 years. Two patients developed radiation-induced brain necrosis as a complication in the 8th and 28th months of follow-up, respectively.

Fractionated stereotactic radiotherapy

Fractionated stereotactic radiotherapy combines the precision of stereotactic planning with dose fractionation especially in larger tumors (more than 3.0–4.0 cm in diameter) that are not suitable for radiosurgery. The Heidelberg experience using a median dose at isocenter of 66.6 Gy achieved a local control rate of 82 % at 2 years and 50 % at 5 years. Survival was 97 % at 2 years and 82 % at 5 years. At a maximum follow-up of 8 years local control and survival rate of chordomas was 40 % and 82 %, respectively [52]. In another series of 12 patients treated with dynamic conformal arcs and intensity-modulated radiation therapy boost and image-guided intensity-modulated fractionated stereotactic radiotherapy a median dose of 66.6 Gy (range, 48.6–68.4 Gy) was delivered in 180 cGy fractions prescribed to the 90 % isodose line that covered the target volume to achieve a median isocenter dose of 74 Gy (range, 54–76 Gy). With a median follow-up of 42 months the overall survival was 76.4 % at 5 years, and 46.9 % and 37.5 % of patients were free of progression at 24 and 60 months, respectively [53]. In a series of 13 patients with skull base chordomas postoperative conventional local irradiation and/or SRS provided results comparable with proton beam or heavy particle therapy. The mean follow-up period was 122 months (median 108 months) and the 5-year survival rate was 82.5 %: 11 out of 13 patients survived longer than 5 years and five patients survived longer than 10 years. The authors concluded that the results of this modality of treatment have achieved a 5-year survival rate comparable to that of proton beam therapy [54]. Choy W et al. reviewed 57 patients with intracranial chordomas treated with adjuvant SRS and stereotactic radiation therapy [55]. Mean follow-up was 57.8 months and mean tumor diameter was 3.36 cm. The mean maximal dose of radiation therapy was 1783.3 cGy for adjuvant SRS (8 patients) and 6339 cGy for adjuvant stereotactic radiation therapy (34 patients). Overall rate of recurrence was 51.8 %, and 1- and 5-year progression-free survival (PFS) was 88.2 % and 35.2 %, respectively. SRS and SRT produced comparable rates of tumor control ($p = 0.28$).

Chondrosarcomas

The adjuvant radiation treatment of skull base chondrosarcoma is controversial. Surgical resection alone or followed by conventional radiotherapy, radiosurgery, or particle radiotherapy are the most frequent treatment modalities [56–59]. Skull base chondrosarcomas are rare, the majority are low-grade lesions with an indolent growth pattern.

Conventional Radiotherapy

Chondrosarcomas are considered relatively conventional radiotherapy resistant. Doses >60 Gy are needed to achieve local control and at jugular foramen region the delivering of this dose with conventional high-energy photon radiotherapy is not recommended due to the vicinity of vital structures. Stereotactic fractioned radiotherapy with a median dose at isocenter of 64.9 Gy achieved local control and recurrence-free status in 100 % of patients with a 5-year follow-up period [52].

Proton Beam Radiotherapy

Chondrosarcomas that are not resectable or recurrent, especially the mesenchymal type that are more radiosensitive should be considered for radiotherapy. Proton beam radiotherapy has been found to be beneficial to treat chordomas and chondrosarcomas of the skull base [60]. The main advantageous effect are the protons' physical feature of the Bragg peak, which provides excellent conformity of the irradiation field reducing secondary irradiation to vital structures around the irradiated target. Long-term control rates after stereotactic radiotherapy and radiosurgery for treating chondrosarcomas have been reported [61–63]. In the majority of cases, however, the tumor volume is smaller than those treated with proton beam radiotherapy.

In a recent study Weber DC et al. reviewed the long-term outcomes and prognostic factors of patients with skull base chondrosarcomas treated at the Paul Scherrer Institute in Zürich, Switzerland [64]. Seventy-seven patients were treated with median delivered dose of 70.0 GyRBE (range, 64.0–76.0 GyRBE). With a mean follow-up of 69.2 months (range, 4.6–190.8 months), six local (7.8 %) failures were observed, and five (6.5 %) patients died. The actuarial 8-year local control and overall survival were 89.7 % and 93.5 %, respectively. Tumor volume > 25 cm(3) ($p = 0.02$), brainstem/optic apparatus compression at the time of PT ($p = 0.04$) and age >30 years ($p = 0.08$) were associated with lower rates of local control. High-grade (≥3) radiation-induced toxicity was observed in six (7.8 %) patients.

Combination of photon and proton therapy for chondrosarcomas of the skull base was also reported [65]. One hundred fifty nine patients were treated with either protons alone or a combination of protons and photons. The median total dose delivered was 70.2 Gy (relative biologic effectiveness [RBE]; range 67–71). With a median follow-up of 77 months (range 2–214), 5 tumors relapsed based on the initial gross tumor volume. The 5- and 10-year local control rates were 96.4 % and 93.5 %, respectively, and the 5- and 10-year overall survival rates were 94.9 % and 87 %, respectively.

Carbon Ion Therapy

Radiotherapy with carbon ions like proton beam radiotherapy is another radiation modality that takes the physical advantages of protons with a higher radiobiological activity. A study to evaluate the effectiveness and toxicity of carbon ion radiotherapy in 54 patients with low-grade and intermediate-grade chondrosarcomas of the skull base was performed [42]. All patients had been operated on previously. The median total dose was 60 CGE (weekly fractionation 7 × 3.0 CGE). With a median follow-up of 33 months (range, 3–84 months), two patients developed local recurrences. The actuarial local control rates were 96.2 % and 89.8 % at 3 and 4 years; overall survival was 98.2 % at 5 years. In another series with 79 patients treated for skull base chondrosarcomas with carbon ion therapy the authors have applied a median total dose of 60 gray equivalent (GyE) at 3 GyE per fraction [66].

With a follow-up of 91 months (range, 3–175 months), 10 patients developed local recurrence. The 3-, 5-, and 10-year actuarial local control rates were 95.9 %, 88 %, and 88 %, respectively. With a median follow-up of 110 months the 3-, 5-, and 10-year overall survival rates were 97.5 %, 97.5 %, and 91.5 %, respectively. Improvement of cranial nerve deficits 7–10 years after treatment (range, 45.5 %–53.3 %) was observed, compared with the baseline (73.4 %) [67].

Radiosurgery

Radiosurgery is an alternative to proton beam and carbon ion radiotherapy to treat jugular foramen chondrosarcomas as adjuvant therapy. Seven centers participating of the North American Gamma Knife Consortium evaluated 46 patients who were submitted to gamma knife radiosurgery for skull base chondrosarcomas.

Previous surgical resection was performed in 36 cases and five patients underwent fractionated radiation therapy. The median tumor volume was 8.0 cm^3 (range 0.9–28.2 cm^3), and the median margin dose was 15 Gy (range 10.5–20 Gy). With a median follow-up of 75 months, eight patients died. The actuarial overall survival after radiosurgery was 89 % at 3 years, 86 % at 5 years, and 76 % at 10 years. Local tumor progression occurred in 10 patients. The rate of progression-free survival was 88 % at 3 years, 85 % at 5 years, and 70 % at 10 years. Eight patients needed further tumor removal, and three patients (7 %) developed adverse radiation effects [63].

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Chapter 13
Chemotherapy

Tumors of the jugular foramen (JF) present as special problem concerning to their diagnosis and management. Because of the great surgical challenge in these tumors, the option for effective treatment remains as especial problem. Usually the most frequent JF tumors (paragangliomas, schwannomas, and meningiomas) present poor clinical response to the chemotherapy agents.

Paragangliomas

As a rule paragangliomas are solitary slow-growing lesions with malignancy difficult to determine histologically and is usually based on the presence of metastatic disease [1].

A combination on therapeutic modalities is needed for adequate treatment of these lesions. In the setting of residual and metastatic disease, chemotherapy rises as an interesting option in the treatment. Even with this aim, currently, there is a paucity of data regarding chemotherapy for paragangliomas. The biggest series showed conflicting results. Patel (1995) published a 15-year experience with paragangliomas and reported some benefit with doxorubicin, dacarbazine, and cyclophosphamide but the same regime was considered ineffective by Massey and Wallner (1992). Since these series, only a few case reports with promising results using gemcitabine and sorafenib have been published but no prospective randomized trial is available in the literature. In conclusion, there is no effective chemotherapy agent in the treatment of benign jugular foramen paragangliomas and surgery remains the treatment of choice [2, 3].

Malignant paragangliomas presents a survival rate between 34 % and 60 %. Treatment of these tumors remains a challenge. Gillon et al. treated successfully with metronomic cyclophosphamide two patients with malignant paragangliomas. Sunitinib is a tyrosine kinase inhibitor with promising antiangiogenic effect and immune stimulation [4]. Treatment with 131l-MIBG was reported to induce tumor

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remission in a coexisting paraganglioma of the retroperitoneum and urinary bladder and combined therapy with 131I-MIBG and Sunitinib in a patient with metastatic paraganglioma (hereditary paraganglioma-pheochromocytoma syndrome) [5, 6].

Meningiomas

The jugular foramen structures have embryological and histological ability to develop extracranial meningiomas [7]. Within the jugular foramen, the cranial nerves are not covered by dura; they are involved with connective mesodermic tissue [8].

In general, meningiomas are the most common intracranial neoplasm constituting 20–30 % of all primary brain tumors. The World Health Organization (WHO) classifies meningiomas into three grades: grade 1-benign meningiomas; grade 2-atypical meningioma; and grade 3-anaplastic meningiomas. In meningiomas WHO grade 1, complete resection results in prolonged disease-free survival or cure.

In contrast, high grade meningiomas, despite initial surgical resection and multimodality radiotherapy, often recur and require re-treatment. In this scenario, systemic therapy appears as attractive option. At present, however, exists a limited number of available systemic therapy in the treatment of meningiomas.

Biochemical evidence suggests that almost 70 % of meningiomas are progesterone receptor positive and 30 % are estrogen receptor positive. This fact, added to the epidemiological female predominance, suggests that meningiomas growth may be hormone dependent [9, 10].

Other receptors have been demonstrated in meningiomas. As consequence, a variety of hormonal therapies have been utilized in the treatment of recurrent meningiomas which are not amenable to further surgery or radiotherapy. Against this first promising evidence, a great number of trials failed to demonstrate any additional benefit in these patients. Progesterone agonist (megestrol acetate) and antagonist (mifepristone) were used in some trials with no observed response when compared to placebo. Median progression-free survival was 10 months in mifepristone group and 12 months in the placebo arm [9–11]. Tamoxifen also was proved to be ineffective.

Interferon-alfa has been found to inhibit the growth of cultured human meningiomas cell line in vitro. In the largest study, 35 patients with recurrent unresectable and previously irradiated WHO grade 1 meningiomas were treated and an increased progression-free survival was seen in these patients although with no radiographic response, thus, suggesting interferon-alfa as an active agent against recurrent low grade meningioma [12].

Hydroxyurea was another biochemotherapy used in the subset of recurrent meningioma. In 1997, Schrell et al. demonstrated in vitro that hydroxyurea was a potent inhibitor of cultured meningioma cells by inducing apoptosis. After this first stimulating evidence, several clinical trials were conducted and just modest result was seen. Besides that, in many studies testing hydroxyurea, the patient had not

failed to radiotherapy leading to a potential bias. These results demonstrate that hydroxyurea, although generally well tolerated and convenient, appears to have only limited activity [13, 14].

The same occurred with the calcium block channel agent, cyclophosphamide and vincristine which failed to demonstrate any benefit in recurrent malignant meningioma [9, 15].

Currently, molecular pathogenesis of meningiomas has gained interest. Overexpression of several growth factors including platelet-derived growth factor (PDGF), epidermal growth factor (EGF), vascular endothelial growth factor (VEGF), their receptors, and signal transduction pathways have been seen and, then, implicated in meningioma growth. Many trials have been conducted trying to demonstrate any benefit with these specific inhibitors as somatostatin analog (octreotid), epidermal growth factor receptor (EGFR) inhibitors (gefitinib), platelet-derived growth factor receptor (PDGFR) inhibitors (imatinib), but anyone showed definitive evidence of benefit [16, 17].

VEGF plays a central role in tumor angiogenesis and peritumoral edema. VEGF and VEGFR are expressed in meningiomas, and the level of expression increases with tumor grade. Trials testing these agents are very limited in number and associated toxicity is not fully clarified. These drugs are only cytostatic agents and require long-term usage, and more studies are needed to support their usage [18, 19].

Schwannomas

Intracranial schwannomas represent approximately 8 % of all primary intracranial tumors [20]. Schwannomas arising from the jugular foramen are very rare and account for only 2.9 % of all intracranial schwannomas [21].

The treatment of jugular foramen schwannoma remains essentially surgical since currently there is no effective chemotherapy agent known for schwannoma in general. All trials published in literature are in the subset of neurofibromatosis patients with vestibular schwannoma. In these patients Bevacizumab have shown good results with tumor shrinkage and hearing preservation. Other drugs have been tested, as lapatinib (EGFR/ErbB2 inhibitor), but no strong evidence has been achieved. Surgery remains the only curative treatment for jugular foramen schwannomas.

Chordomas

Chordomas resist radiotherapy and cytotoxic chemotherapy is inefficient. A better understanding of the molecular biology of these tumors will help to develop more effective therapies [22]. Lebellec et al. [23] reviewed 19 articles published between 1990 and 2014 describing the activity of target therapies for chordomas. The best response with targeted therapies was disease stabilization in 52–69 % of cases.

Hindi et al. [24] have treated 48 patients with inoperable and progressive chordomas (PDGFB/PDGFRB positive) with imatinib (a platelet-derived growth factor receptor inhibitor, 800 mg/day). The median duration of treatment was 7 months. At a median follow-up of 24.5 months the median PFS was 9.9 months. EGFR inhibitors (erlotinib, gefitinib, lapatinib) have demonstrated partial and sustained response in some cases [25, 26].

Chondrosarcomas

There is no current role for chemotherapy for chondrosarcomas. Like chordomas better understanding of the molecular biology will help in the future to develop more effective drugs. Bloch et al. [27] reviewed the active signaling pathways described in human chondrosarcomas. Some functional experiments suggested that integrin activation at the cell surface results in upregulation of matrix metalloproteinases and extracellular matrix degradation, leading to increased tumor cell migration. Chondrosarcoma cell proliferation and degradation is dependent on peroxisome proliferator-activated receptor-gamma (PPAR-γ). The knowledge of these pathways may improve the development of targeted therapies.

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Chapter 14
Surgical Results, Rehabilitation, and Conclusions

Results

From 1993 to 2016, 163 patients with jugular foramen tumors were operated on (Fig. 14.1). Paragangliomas (86 patients, 52.7 %) were the most frequent tumor in this series followed by schwannomas (25 patients) and meningiomas (16 patients). The cranio-cervical approach was used in 149 cases and the modified retrosigmoid approach in 14 patients with schwannomas, meningiomas, chordomas, chondrosarcomas, endolymphatic sac tumors, and aneurysmatic bone cysts without extensions to the cervical region.

Paragangliomas

All patients with paragangliomas presented jugular foramen invasion with extensions to the ear in 78 cases (90 %), to the cervical region in 75 cases (87 %) and in 56 patients (65 %) there was some grade of intradural invasion. The internal carotid artery was involved in 22 cases and eight patients showed radiological or intraoperative signs of invasion of the internal carotid artery walls. In three cases with invasion of the ICA walls a stent was initially inserted to protect the vessel during tumor dissection. The patients received aspirin during 3 months to avoid occlusion of the stent, and the tumors could be dissected from the involved wall of the internal carotid artery without injuring the vessel. In two cases (young patients with infiltration of the carotid artery walls) a high flow by-pass between the external carotid artery and the M2 segment of the middle cerebral artery was initially performed. The ICA in its petrous portion was occluded with a balloon. The tumors were totally removed with the infiltrated internal carotid artery. There were no ischemic deficits in these five patients with internal carotid wall invasion, treated aggressively. Four patients had familial history of paragangliomas and three of these cases presented

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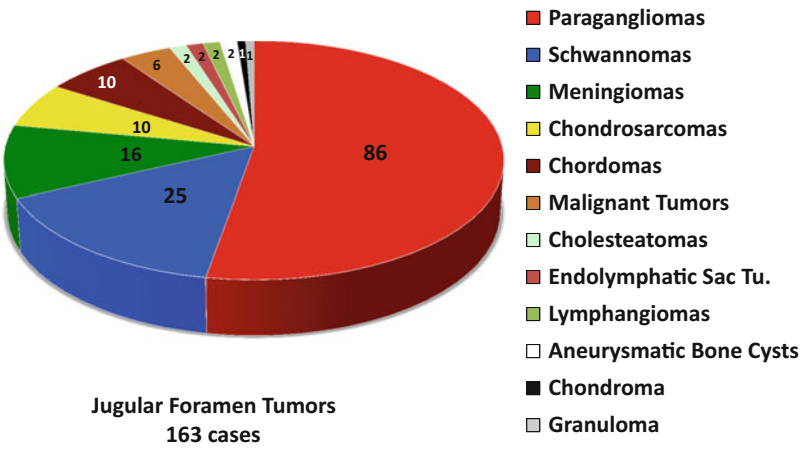

Fig. 14.1 Histology of operated jugular foramen tumors

Table 14.1 Paragangliomas—grade of resection

Paragangliomas 86 cases	Resection	
	Total	Subtotal 9 recurrent/4 malignant
No. of cases	67 (78 %)	19 (22 %)
Recurrences	7 (10 %)	9 (47 %)

multiple paragangliomas. Common carotid bifurcation paragangliomas were the most frequent associated tumors. Two patients presented tumors secreting catecholamines with hypertension, headache, arrhythmias, nausea, and palpitations. These cases were managed preoperatively with alpha adrenergic antagonists like phenoxybenzamine (one patient) and more selective α1 antagonists like prazosin (other patient). This therapy was initiate 1 week prior to surgery. Beta blockade is rarely used in tumors that only secrete norepinephrine and should not be used to control hypertension in these patients. Beta blockade before establishment of α blockade may result in myocardial infarction, organ ischemia, and death from unopposed α agonism. Grade of tumor resection in paragangliomas group is shown in Table 14.1.

Radical resection was possible in 67 patients (78 %). Seven patients (10 %) present tumor recurrence. Three of these cases underwent radiotherapy, two radiosurgery, and two reoperations. Subtotal resection was performed in 19 patients (22 %). Lower cranial nerves infiltration and involvement of the internal carotid artery were the factors precluding radical resection in these cases. Nine of these patients had recurrent tumors that had been operated on elsewhere and four patients had malignant paragangliomas with cervical lymph nodes invasion. All these patients received postoperatively radiation therapy.

Two patients died postoperatively (2 %). Causes of mortality were internal carotid artery thrombosis in one patient and large cervical hematoma due to bleeding from the internal jugular vein in the other. In this case the internal jugular vein was

Table 14.2 Meningiomas—grade of resection

Histology	No. of cases	Grade of resection	
		Total	Subtotal
Meningotheliomatous	10	8	2
Anaplastic	3	0	3
Papillary	2	1	1
Microcystic	1	0	1

ligated without double suture-ligature and the patient presented the day after surgery a cough crises. The internal jugular vein bled and a large cervical hematoma developed. It was evacuated but the patient presented ischemic/hypoxia brain damage and died 2 months later. Double suture-ligature of the internal jugular vein is recommended to avoid this complication. Patients with radical resection of the tumors were followed with a yearly MRI. For those with subtotal removal and radiation therapy MRI control is performed every 6 months. Three patients were lost of follow-up. There is no recurrence or growth of residual tumor in this series. Long-term follow-up is, however, recommended.

Meningiomas

There were 16 cases of jugular foramen meningiomas in this series. Meningiomas arising in other regions (cerebellopontine angle, petroclival, clival, or cranial cervical junction) invading the jugular foramen were excluded. Ten patients presented meningotheliomatous meningiomas, three anaplastic, two papillary, and one microcystic. Radical tumor resection was possible in nine cases (eight meningotheliomatous and one papillary). Invasion of cranial nerves, skull base bone, and malignant behavior were the causes of subtotal removal in this series (Table 14.2).

Two patients died postoperatively in this group due to pulmonary embolism and aspiration pneumonia (postoperative deficits of lower cranial nerves). One had an anaplastic meningioma and the other one a papillary meningioma with aggressive behavior. The subtotally removed tumors were treated with radiotherapy/radiosurgery. The two patients with malignant meningiomas died several months after surgery, due to tumor progression, in spite of the adjuvant radiation therapy.

Schwannomas

Twenty-five patients presented with jugular foramen schwannomas. Radical resection was possible in all cases. There was no mortality in this group of patients but 10 cases (40 %) developed or aggravated preoperative lower cranial nerves deficits. Four of these cases required transient tracheostomy. The majority of these patients

Table 14.3 Grade of resection according to the histology

Histology	No. of cases	Total	Subtotal
Paragangliomas	86	67	19
Schwannomas	25	25	00
Meningiomas	16	10	06
Aneur. bone cyst	02	02	00
Chondrosarcomas	10	01	09
Chordomas	10	00	10
Malignant tum.	06	00	06
Cholesteatomas	02	01	01
Condroma	01	01	00
Lymphangioma	01	01	00
Inflam. granulomas	02	01	01
Endolymphatic sac tu.	02	01	01
TOTAL	163	109 (68 %)	54 (32 %)

Table 14.4 Postoperative complications

Complications	No. of cases	
New cranial nerves deficits	VI	04
	VII	12 (6 Tu. infilt)
	VIII	10
	IX, X, XI	25 (15 %)
CSF fistula	10 (6 %)—3 reoperations (1.8 %)	
Hemiparesis	01	
Mortality	04 (2.4 %)	

recovered function of the affected cranial nerves within 6 months after surgery and the tracheostomy could be removed in all cases. When the sigmoid sinus and jugular bulb were not occluded these venous structures could be preserved.

Grade of tumor resection of the all series is presented in Table 14.3. Jugular foramen schwannomas were the most favorable lesions to achieve total resection.

Postoperative Complications

Postoperative complications and mortality of all cases are showed in Table 14.4. New cranial nerves deficits were the most frequent and also the most dangerous complications observed. Even transient palsy of the lower cranial nerves may cause severe morbidity and even mortality. CSF fistula occurred in 10 patients (6 %). It was conservatively managed in seven cases and in the other three patients it was surgically treated.

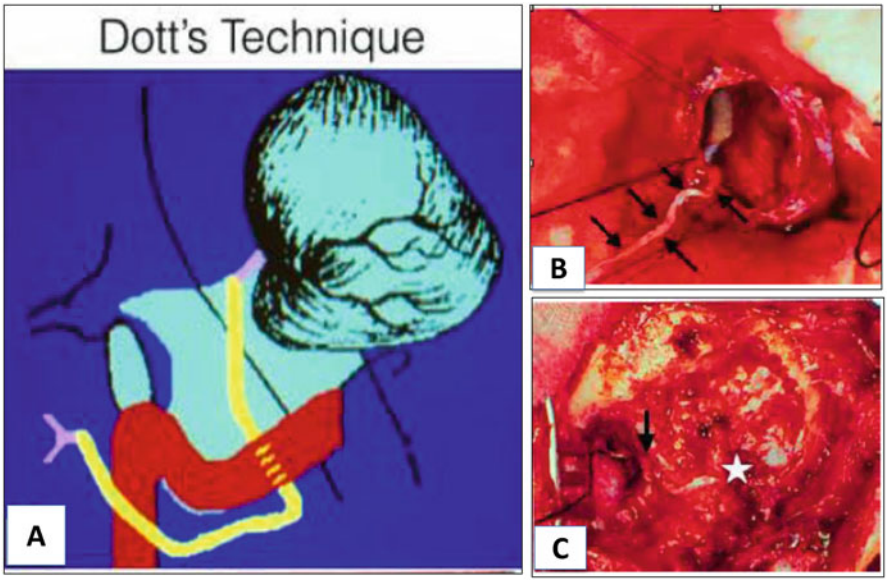

Fig. 14.2 Norman Dott's technique for reconstruction of facial nerve. (**a** and **b**) The sural graft is passed behind the sigmoid sinus. (**c**) The graft is sutured at the brain stem and at stylomastoid foramen (*arrow*)

Rehabilitation

Postoperative rehabilitation involves mainly management of cranial nerves deficits. Preservation of facial nerve during tumor removal depends on the grade of involvement or invasion of the nerve. If the facial nerve is invaded by the tumor (most frequent in cases of paragangliomas or meningiomas), the nerve is resected and grafted with sural nerve or great auricular nerve grafts. If there is a large involvement of the nerve in the infralabyrinthine and mastoid regions the techniques described by Norman Dott and Draf and Samii may be used. Norman Dott [1] described a technique of suturing a graft from sural nerve in the facial nerve at brainstem and at the stylomastoid foramen (Fig. 14.2). Draf and Samii [2] modified this technique passing the sural graft anterior to the sigmoid sinus (Fig. 14.3). If intraoperative reconstruction of facial nerve is not possible, an anastomosis of the hypoglossal nerve with the facial nerve is performed 2 weeks after surgery. Very important in these cases is to check the function of the lower cranial nerves. Palsy of the half of the tongue associated with palsy of lower cranial nerves will cause severe swallowing deficits. The techniques used to avoid half tongue palsy are: use of only the half of hypoglossal nerve as donor or performing a termino-lateral anastomosis. The facial nerve is dissected and removed from its fallopian canal and rotated down. The hypoglossal nerve is longitudinally split without severing the nerve fibers and the facial nerve is sutured in a termino-lateral pattern. When the patient presents complete

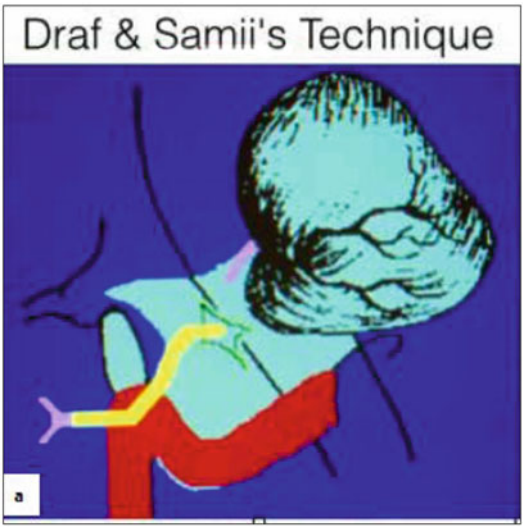

Fig. 14.3 Draf and Samii's technique for reconstruction of facial nerve. The sural graft is passed anterio to the sigmoid sinus

facial nerve palsy due to resection of the nerve, the eye is protected through a tarsorrhaphy, gold implant into the upper eyelid, or use of gas-permeable scleral contact lenses. When there is no chance to reconstruct the facial nerve, cross-face surgery or plastic surgery with free-muscle (gracilis muscle) transfer are the options.

Rehabilitation of the lower cranial nerves is of capital importance to improve postoperative quality of life. If the palsy is partial, a naso-enteral tube is inserted and close attention of a phonoaudiologist with rehabilitation exercises is mandatory. If the patient presents severe swallowing deficits or complete lesion of the nerves, a tracheostomy and eventually a percutaneous gastrostomy are required. Procedures to medicalization of paralyzed vocal cord like thyroplasty and injection of Teflon will help to improve voice deficits and even swallowing. Tracheostomy should be removed only when there is no danger of aspiration.

Conclusions

In spite of all diagnostic and surgical developments in the last decades, surgical removal of jugular foramen tumors remains a challenge for neurosurgeons and ENT-surgeons. The deep location of these tumors, the involvement of vital neurovascular structures of this region like the internal carotid artery, brainstem, and cranial nerves are the main surgical difficulties. Many of these lesions, specially the paragangliomas, are highly vascularized and excessive bleeding during surgery must be adequately managed. Preoperative embolization is very useful to reduce surgical time and blood loss in these cases. Removal of infiltrated dura mater and bone at skull base result in a large surgical defect that may be reconstructed to avoid postoperative CSF-leak.

The most frequent tumor arising in the jugular foramen region is paraganglioma. This tumor is benign in the majority of the cases, but may involve and even infiltrate cranial nerves and vessels. Therefore, the treatment strategy of each patient with jugular foramen paraganglioma requires individual consideration regarding grade of surgical removal, choice of surgical approach, and postoperative adjuvant therapy. Surgical removal of schwannomas, benign meningiomas, noninfiltrative paragangliomas, and other benign jugular foramen tumors is the treatment of choice. However, radical removal of large jugular foramen paragangliomas and meningiomas, with preservation of the involved neurovascular structures, is a difficult task to be achieved. A multidisciplinar approach involving the expertise of neurosurgeons, ENT-surgeons, interventional neuroradiologists, neuroanesiologists, and neurointensivists is the best option to help these patients. Development of postoperative neurological deficits, especially paralysis of lower cranial nerves, will impact significantly on quality of life. Morbidity and mortality of surgical treatment are related to the size, biological behavior, grade of involvement of the neurovascular structures, and histology of the lesion. Postoperative irradiation therapy, especially radiosurgery for small tumor remnants, offers long-term control of tumor growth. It may be used as primary treatment in elderly patients with small lesions. Chemotherapy is reserved for malignant tumors. Finally, experience of the surgical team remains the most important factor for postoperative outcome.

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