Surgical anatomy of the jugular foramen

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Abstract

The jugular foramen (JF) is a canal that makes communication between the posterior cranial fossa and the upper neck for one third of the cranial nerves and for the main venous channel of the brain. From a lateral view, the JF is protected by multiple layers of muscles and by the outer surface of the petrous bone. Surgical exposure of the JF is usually justified by the removal of benign tumors that grow in this region.

In the first part of the present study we describe the surgical anatomy of the JF. Then, we detail the relevant points of a stepwise surgical progression of three lateral skull base approaches with a gradual level of exposure and invasiveness. The infralabyrinthine transsigmoid transjugular-high cervical approach is a conservative procedure that associates a retrolabyrinthine approach to a lateral dissection of the upper neck, exposing the sinojugular axis without mobilization of the facial nerve. In the second step, the external auditory canal is transsected and the intrapetrous facial nerve is mobilized, giving more exposure of the carotid canal and middle ear cavity. In the third step, a total petrosectomy is achieved with sacrifice of the cochlea, giving access to the petrous apex and to the whole course of the intrapetrous carotid artery.

Using the same dissection of the soft tissues from a lateral trajectory, these three approaches bring solutions to the radical removal of distinct tumor extensions. While the first step preserves the facial nerve and intrapetrous neuro-otologic structures, the third one offers a wide but more aggressive exposure of the JF and related structures.

Keywords: Glomus tumor; jugular foramen; lower cranial nerves; meningioma; skull base surgery.

Introduction

The jugular foramen (JF) is a deeply located region that makes a communication between the posterior fossa and the superior latero-cervical area. The JF is a complex area of the skull base through which important cranial nerves and vessels course in variable anatomic patterns [2, 23, 26, 28]. The pathology that involves the JF is mainly of tumoral origin. Tumors may affect the JF primarily (e.g., schwannomas, glomus tumors, meningiomas) or secondarily (e.g., posterior fossa meningiomas, chondrosarcomas, metastasis). Surgical resection is the treatment of choice in the majority of cases. Radical resection exposes the patient to lower cranial nerves (LCNs) deficits, which is the most important source of morbidity after these operations. However, recent advances in radiation therapy techniques like radiosurgery may be proposed as first stair treatment for small tumors or by second intention for larger ones, allowing a less invasive surgical management [15, 18].

The exposure of the internal porus of the JF is well standardized, coming from a regular retrosigmoid intradural neurosurgical route. Likewise, it remains usual to control the outside aperture of the JF by exposing the upper neck. However, exposure of the whole length of the JF with preservation of the LCNs and using a single approach is challenging and necessitates an expertise in the field of skull base surgery.

The aim of this study is to provide the comprehensive anatomy of the main skull base approaches that give access within and around the JF. In the second part of the paper, a selection of these approaches will be presented in a stepwise manner.

Microanatomy of the jugular foramen region

Because of the locoregional extension of the disease that usually involve the JF and the complexity of the elements that are necessarily exposed by its surgical approaches, it is preferable to detail the regional anatomy rather than the foramen itself spoken.

General consideration

The JF is located in the cranial base in the posterior aspect of the petrooccipital fissure. It is bounded anterolaterally by the petrous bone and posteromedially by the basioccipital bone. The long axis of the foramen is directed from posterolateral to anteromedial. The right foramen is usually larger than the left (Fig. 1). Like some other foramina of the skull base, the JF does not correspond to a simple hole but is a canal that displays horizontal portion lying over the jugular process of the occipital bone and a vertical portion covered by the jugular fossa of the temporal bone. Viewed from the inside, its shape mimicks a tear drop with a narrow anteromedial part and an enlarged posterolateral margin. The structures that traverse the JF are the jugular bulb, the inferior petrosal sinus, meningeal branches of the ascending pharyngeal and occipital arteries and lower cranial nerves with their ganglia [12]. Hovelacque [11] is generally credited with classifying the JF into two compartments: an anteromedial containing the glossopharyngeal nerve (IX) and the inferior petrosal sinus (IPS) and a

Fig. 1. Endocranial view of the bony anatomy of the JF showing the general configuration of the JF in the posterior fossa and the asymmetry of the right to left JF

posterolateral compartment containing the vagus (X), the spinal accessory nerve (XI), superior aspect of the jugular bulb and posterior meningeal artery.

A more recent description based on microsurgical anatomy from Katsuta *et al.* [12], has divided the JF into three compartments: A large posterolateral venous channel which receives the flow of the sigmoid sinus, a small anteromedial venous channel which receives the drainage of the inferior petrosal sinus, and an intermediary neural compartments which is located between the sigmoid and the petrosal parts. The neural part is an intrajugular part through which course the LCNs. The IX nerve is separated from X to XI nerves by the veinous channel that connect the petrosal part to the sigmoid part.

Bony limits of the JF and dura architecture

The JF is delineated by bony boundaries that deserve a precise description.

Viewed from inside (Fig. 2), the superolateral limit of the JF is given by the inferior aspect of the posterior petrous bone. This upper border of the JF displays an anterior small excavation that is named pyramidal fossa in the apex of which opens the aperture of the cochlear acqueduct. The pyramidal fossa is an important landmark because it also houses the superior ganglion of the glossopharyngeal nerve, indicating the upper point of the LCNs. Backward, a posterior bony spine named the intrajugular process of the temporal bone is identified. This process constitutes the upper limit of the division between the petrosal and the sigmoid part of the JF. Behind this process, the petrous bone widen its circumference, and forms a large excavation that is named the jugular

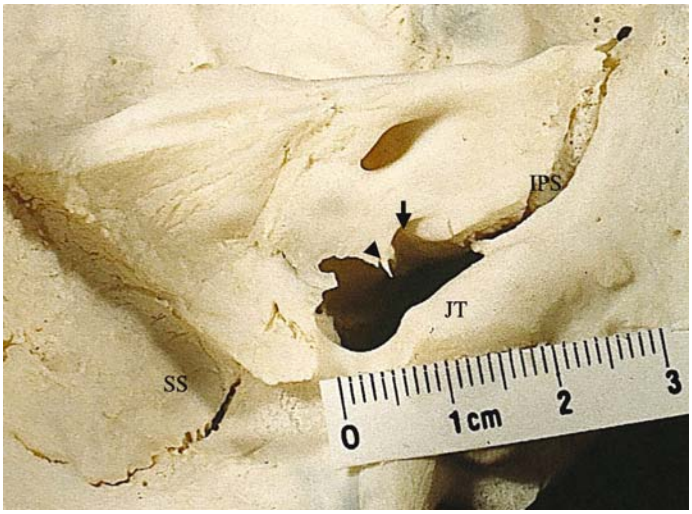

Fig. 2. Enlarged endocranial view of the left JF. Note the sharp bony boundaries of the JF. IPS indicates the groove of the inferior petrosal sinus. The black arrow shows the pyramidal fossa and the aperture of and endocochlear canal. The black arrowhead indicates the jugular spike of the temporal bone. *JT* Jugular tubercle of the occipital bone; *SS* groove of the sigmoid sinus

fossa. This excavation houses the jugular bulb (JB) and the jugular dome. The height of the dome is highly variable and a high jugular bulb (HJB) position may be an obstacle in some surgical procedures, as detailed previously [24]. At the posterior part of this excavation, lies a vertical bony ridge that is directed medially and named intrajugular ridge. This ridge makes a sharp division between the horizontal part of the sigmoid sinus and the jugular bulb. The inferomedial bony boundary of the JF is formed by the condylar part of the occipital bone and is also marked by a bony prominence that is named the intrajugular process of the occipital bone. This process constitutes the lower limit of the division between the petrosal and the sigmoid part of the JF. This bony anatomy is covered by the dura mater that completely hidden the jugular part of the JF. At the upper part of the JF, the dura thicken and makes a dural fold, which forms a roof to the glossopharyngeal meatus. The dura mater penetrates into the neural part of the JF and displays several fenestrations that give access to the LCNs; particularly there is a constant dural septum between the nerve IX and the nerve X. The dural guide plate that protects nerves IX–XI extends toward the exit of the JF where it joins to the pericranium on the inferior aspect of the outer skull base. The osteodural compartmentalization of the JF generally does not reach the outer skull base, as shown by the histological study conducted by Sen *et al.* [27].

Viewed from the outside (Fig. 3), the bony anatomy takes a circumferential shape due to the conformation of the jugular bulb and upper internal jugular

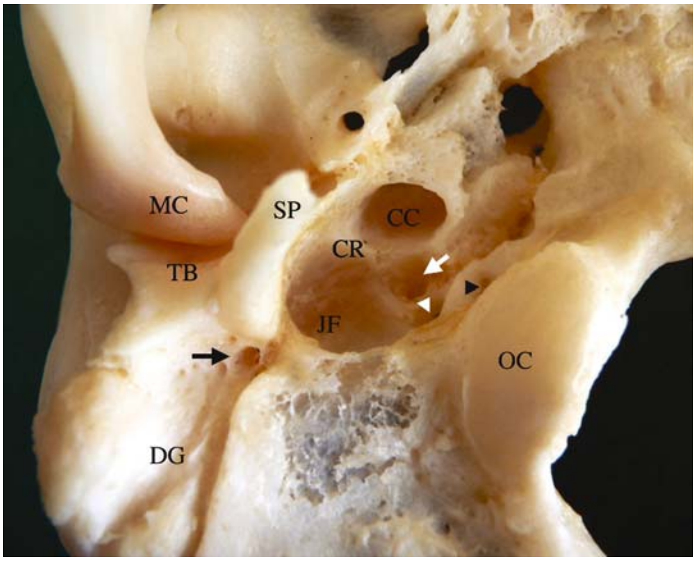

Fig. 3. Exocranial view of the right JF. *CC* Carotid canal, *CR* carotid ridge, *DG* digastric groove, *JF* jugular foramen, *MC* mandibular condyle, *OC* occipital condyle, *SP* styloid process, *TB* tympanic bone. The black arrow indicates the stylomastoid foramen, the black arrowhead indicates the external aperture of the hypoglossal canal, the white arrow shows the tympanicus canaliculus

vein. Anteriorly, the JF is limited by the carotid ridge, which is a transverse crest that separates the JF from the entry point of the carotid canal. Just anteromedial to this ridge a small hole is identified which is named the tympanic canaliculus and gives access to the tympanic nerve coursing toward the middle ear. The medial border of the JF is limited by the condylar part of the occipital bone and by the relief of the occipital condyle. The exit zone of the hypoglossal canal is identified at the anteromedial margin of the condyle. The posterior margin of the JF lies without special accident while its lateral margin is marked by several key landmarks in respect to surgical considerations: from the front to the back, just lateral to the carotid ridge is located the base of the styloid process. This process is attached to the vaginal part of the tympanic bone, which separates both the JF and the carotid canal from the glenoid fossa and temporomandibular join. The stylomastoid foramen is identified a few millimeters and lateral to the base of the styloid process. It is also located 5 mm lateral to the outer border of the JF. This foramen is just in front of the anterior edge of the digastric groove that is protected laterally by the mastoid tuberosity. These anatomic relationships clearly indicate that it is quite impossible to reach the depth of the JF and to control the LCNs inside the JF without mobilizing the third portion of the facial nerve. The same procedure is required if an access to the carotid canal is needed.

Neural contain of the jugular foramen

During their course from the brain stem to the upper neck, the glossopharyngeal, vagus and accessory nerves, named lower cranial nerves (LCNs), run from a medial and horizontal trajectory to a lateral and vertical one. They also move from a craniocaudal distribution in their cisternal course to an anteroposterior one in the neck. These changing of trajectory from the brain stem to the neck, occur at the level of the JF where the LCNs converge. The shape of the jugular tubercle that represents the floor of the JF, allows these rerouting. The course of the LCNs can be subsequently classified in 3 segments: preforaminal or cisternal, intraforaminal, and extraforaminal or cervical.

Intracisternal course (Fig. 4)

The glossopharyngeal nerve (CN IX) arises from the upper medulla dorsal to the olive. It consists of a dorsal root and most frequently of one small ventral root that is sometime difficult to identify. The nerve runs at the ventrocaudal aspect of the choroids plexus at the lateral recess of the fourth ventricule and courses anterolaterally in the cerebellomedullary cistern toward the antero-

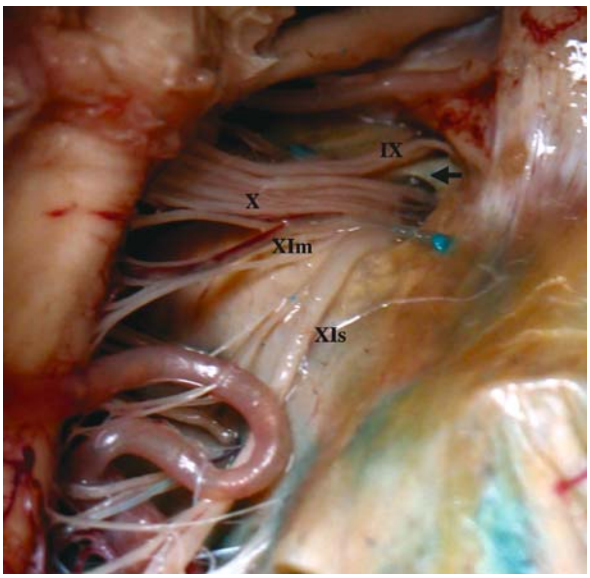

Fig. 4. Endocranial view of the right JF and lower cranial nerves after suboccipital exposure. The dura that covers the JF displays a septation (*black arrow*), which delineates two distinct apertures. The anterosuperior one contains the two bundles of the glossopharyngeal nerve (*IX*) while the posteroinferior one gives access to the vagus nerve (*X*), the medullary root of the spinal nerve (*XIm*) and the spinal root of the same nerve (*XIs*)

medial perforation of the dural covering of the jugular foramen. The nerve's intracisternal length between the brain stem and the dural porus is 15.65 mm (10–20 mm) [14]. The vagus nerve (CN X) consists of 8.6 (4–15) fiber bundles exiting from the retroolivary sulcus below the CN IX and following a cranio-caudal distribution. The intracisternal length of the fibers is equivalent to the CN IX. Both nerves are protected by the arachnoid membrane of the cerebellomedullary cistern and display close relationship with the first portion of the PICA.

The accessory nerve (CN XI) displays distinct cranial and spinal rootlets. A mean of 11 (6–16) cranial rootlets arise at the lower lever of the retroolivary sulcus while the spinal ones arise behind the first digitations of the dentate ligament, from the upper cervical cord. While approaching the inner dural orifice of the JF, cranial and spinal rootlets converge and most frequently penetrate the same dural hole then the vagus nerve.

Intraforaminal course (Fig. 5)

Some amount of arachnoid membrane enters inside the foramen around a variable length of the nerve's course. While penetrating inside the JF via its

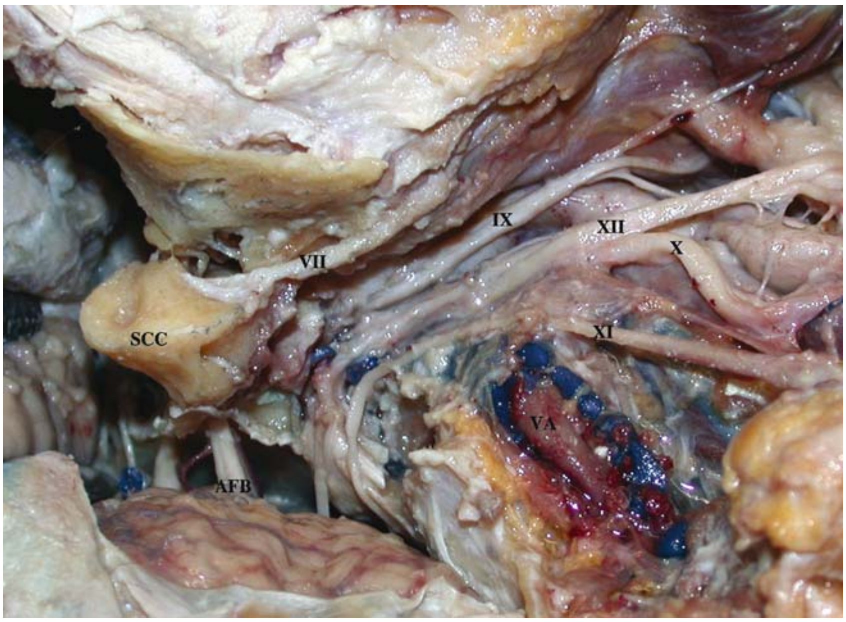

Fig. 5. Intraforaminal course of the lower cranial nerves on the right side. Note the change of direction and disposition of the nerves from their intracisternal portion to their extracranial course. *AFB* Acousticofacial bundle in the cerebellopontine angle, *SCC* superior semicircular canal, *VA* vertebral artery, *VII* facial nerve, *IX* glossopharyngeal nerve, *X* vagus nerve, *XI* spinal nerve, *XII* hypoglossal nerve

own dural porus the CN IX forms a superior and an inferior ganglion. The latter one is located just above or at the level of the external porus of the JF and gives off a branch, the tympanic branch (Jacobson's nerve) that enters the tympanic canaliculus to course in the middle ear at the surface of the promontory. The ganglion cells that belong to this nerve may give rise to glomus tumors (tympanic paragangliomas). The vagus nerve enters the JF behind the intrajugular process of the temporal bone. The dural bridge that separates the entry points of the IX and X nerves is not identified in the depth of the foramen. The rootlets of the CN X gather inside the foramen and form the superior ganglion of the vagus nerve. The average distance of the ganglion from the intracranial opening has been estimated to 2.6 mm, ranging from 2.2 to 3.0 mm [27]. This ganglion occupies the totality of the intraforaminal segment of the nerve and its average size was measured as 4.2 mm (range: 4.0–4.5 mm) in the same study [27]. At the level of the ganglion, there is a close relationship between the three LCNs which fibers establish connections. The superior vagal ganglion gives off an auricular branch (Arnold's nerve) that courses into the mastoid canaliculus toward the mastoid segment of the fallo-

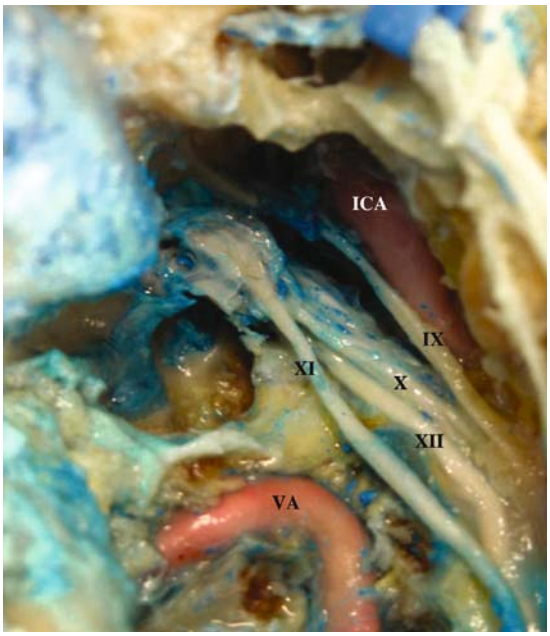

Fig. 6. Exocranial course of the lower cranial nerves on the right side. The jugular vein and jugular bulb have been resected. The internal carotid artery (*ICA*) is exposed in the carotid canal and the vertebral artery (*VA*) has been identified between the atlas and the axis. The hypoglossal nerve (*XII*) is identified just under and behind the vagus nerve (*X*)

pian canal and offers a branch to the facial nerve. This branch in its intrapetrous course may also give rise to glomus tumor. The cranial and spinal portions of the CN XI usually converge to enter the vagal meatus together. It is then difficult to separate the vagal from the accessory nerve inside the foramen because they display intimate interconnections at the level of the superior ganglion.

Extraforaminal course (Fig. 6)

The exit of LCN from the JF can be visualized only by reflection of the internal jugular vein and microscopic dissection of the inner wall of the jugular bulb. The nerves exit anteromedial to the jugular bulb, separated from it by thin layers of connective tissue. At the caudal end of the JF, CN IX is anchored to the ICA and to the junction of the JB with the internal jugular vein by a dense connective tissue. The CN IX gives off its tympanic branch (see above) and runs inferoanteriorly, crossing the lateral wall of the internal carotid artery, medial to the styloid process at the level of which it divides into several branches. The vagus nerve exists the JF vertically, behind the CN IX and often joined with the accessory nerve. It forms the inferior vagal ganglion and courses posterior to the ICA. At the level of the lower ganglion, the vagus nerve gives off several branches that communicate with CNs IX, XI and XII. Another branch is connected to the sympathetic trunk which fibers penetrate the carotid canal and forms the internal carotid nerve. The accessory nerve separates from the vagal nerve under the JF and gradually crosses the outer surface of the jugular vein while descending and coursing backward. More rarely, the CN XI courses inferoposteriorly at the medial surface of the internal jugular vein.

Hypoglossal canal and nerve

The hypoglossal canal does not belong to the JF, but takes place in its close vicinity. The CN XII leaves the medulla oblongata at the level of the preolivary sulcus and anterolaterally to enter the hypoglossal foramen. Then it courses through dense connective tissue in the hypoglossal canal, which is approximately 7.5 mm inferior to the FJ, under the jugular tubercle and at the top of the medial part of the occipital condyle. The exit point of the hypoglossal canal is just medial and under the outer margin of the JF. At this point, the CN XII passes adjacent to the vagus nerve at the level of the inferior ganglion of the vagus nerve and connects with it by several thin branches. Then the nerve runs anteromedial to the CN XI and crosses the posterior and lateral wall of the ICA under the nerve IX toward the tongue (Fig. 7). In the upper neck, the nerve is protected by the posterior belly of the digastric muscle.

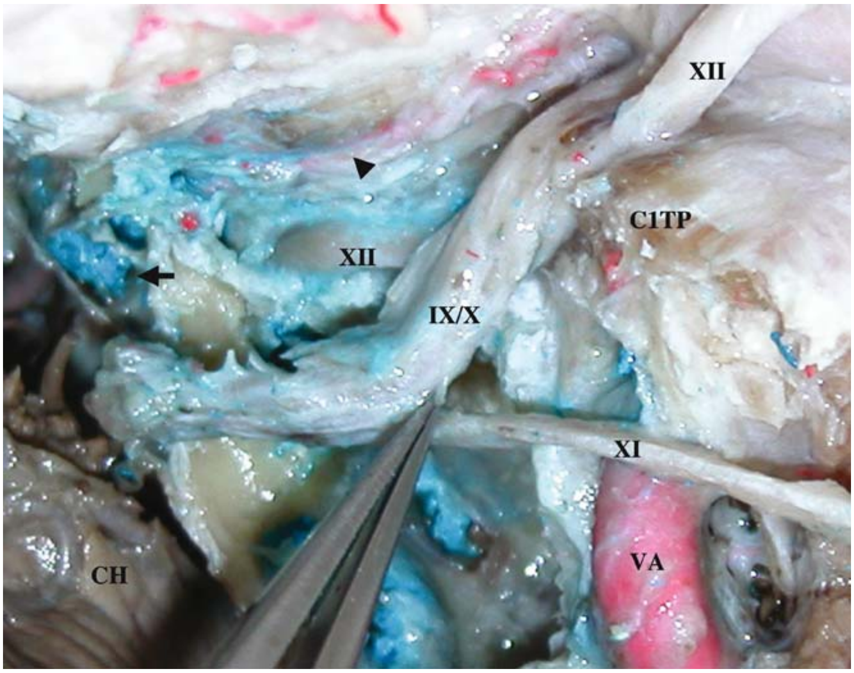

Fig. 7. Exocranial view of the lower cranial nerves (*IX*, *X* and *XI*) and hypoglossal nerve (*XII*) on the right side. The jugular vein and jugular bulb have been resected. The black arrowhead shows a branch of the ascending pharyngeal artery that feed the JF. Note the close relationship of the LCN in the upper neck with the transverse process of C1 (*C1TP*). The black arrow shows the opening of the inferior petrosal sinus. *CH* Cerebellar hemisphere

Venous relationships

The sigmoid sinus drains into the posterior aspect of the jugular bulb (JB). The JB varies considerably in size and shape as described above. The dome of the JB can extend as high as the internal auditory canal or protrude in the mesotympanum. The JB lies beneath the floor of the middle ear cavity. This floor, which is usually formed by a compact bone, may be thin or dehiscent in cases with a HJB. The lateral wall of the JB is separated from the vertical segment (mastoid segment) of the facial nerve (Third portion) by the retrofacial and infralabyrinthine air cells. It is important to note that the wall of the jugular bulb is very thin and fragile because devoid of adventitia [13]. At its outside aperture, the JF is reinforced by a periosteal ring and acquires a normal venous structure while becoming the internal jugular vein.

The IPS (Fig. 8) is the major site of drainage for the cavernous sinus. There is usually one main sinus orifice located most frequently between the exit of IX and X. The IPS which has a variable course and drainage pattern, usually enters

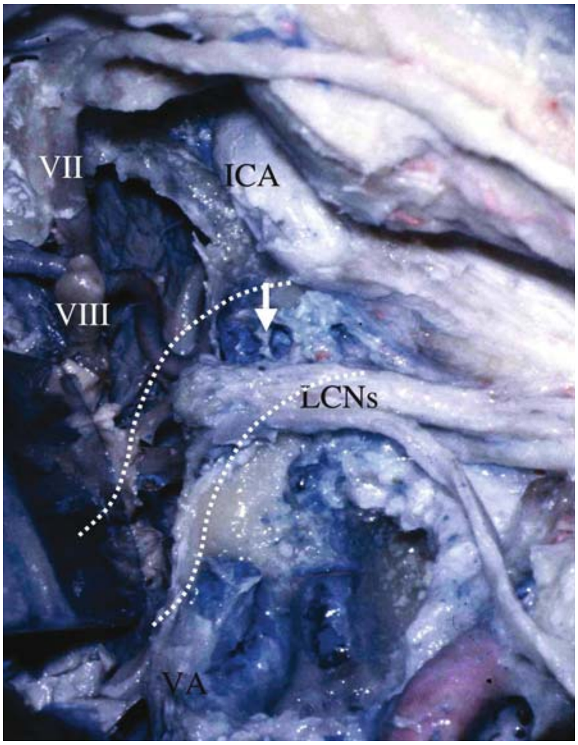

Fig. 8. Venous relationship of the jugular foramen region (*right side*). The sigmoid sinus, jugular bulb and internal jugular vein have been resected in order to expose the apertures of the inferior petrosal sinus. In this case, there are two channels that are divided by a fibrous septum (*white arrow*). Note that in this case, the CN IX is not separated from the CN X by the opening of the IPS. The double white dotted line indicates the position of the jugular bulb before transaction and removal

the anterior aspect of the jugular bulb in around 90% of cases; in other cases, the IPS shares its drainage into the JB and the internal jugular veins and more rarely exclusively into the internal jugular vein (10%). In other circumstances of poorly developed IPS, it drains into a deep cervical plexus of veins. In such cases, the IPS makes a plexiform confluens with the venous plexus of the hypoglossal canal, the inferior petroclival vein, and tributaries from the posterior condylar emissary vein. The posterior condylar emissary vein courses into the posterior condylar canal and enters the thicker inferior wall of the JF below the sigmoid sinus. This vein puts into communication the vertebral venous plexus to the jugular bulb. It usually opens into the posteromedial aspect of the junction between the SS and the JB. The venous plexus of the hypoglossal canal is also named anterior condylar vein. It communicates the marginal sinus of the foramen magnum with the jugular bulb (in 11.53% of cases [14]). It may do so directly or by the intermediary of a plexiform chamber located at the lower end of the IPS.

Arteries

The region of the JF is mainly supplied by the occipital artery and the ascending pharyngeal artery. The occipital artery (OA) arises either the posterior or the lateral aspect of the external carotid artery (ECA), at a variable distance from the carotid bifurcation [1]. These authors have described three segments, the digastric segment, the suboccipital segment and the terminal segment. The digastric segment extends from the origin of the OA to the exit of the occipital groove. In its distal digastric segment, the OA runs medially to the posterior belly of the digastric muscle and the emergence of the facial nerve from the stylomastoid foramen. The OA gives off several muscular branches to the SCM, DM, and the group of muscles inserted on the transverse process of C1. The OA gives off meningeal branches from a "stylomastoid" trunk that enters the JF to reach the dura of the posterior fossa. The ascending pharyngeal artery (APA) belongs to the posterior group of the occipital artery's branches. In all specimens the APA gives off a posterior meningeal branch to the JF. This artery courses upward ventral to the ICA and IJV and enters the JF most often between CN X and XI. Several others meningeal branches from the APA pass through the foramen lacerum, JF and hypoglossal canal, to supply the surrounding dura of the posterior cranial fossa. The APA also gives rise to the inferior tympanic artery, which reaches the tympanic cavity by way of the tympanic canaliculus also shared by the Jacobson's nerve. An accessory supply is given by the posterior auricular artery, which arises above the posterior belly of the DM and courses between the parotid gland and the styloid process. It gives off a branch dedicated to the stylomastoid foramen that supply the facial nerve, and branches that may connect with the occipital artery to supply the JF. Muscular branches that come from the extracranial part of the vertebral artery (VA) may rarely feed the outside of the JF. While penetrating the dura mater in C1, the dural branches of the VA give supply to the dura of the craniocervical junction. In some cases, it can also provide feeders to the posterior part of the JF.

At the level of the skull base, the ICA courses just anterior to the jugular vein, being separated from it by the carotid ridge. At this level, both artery and vein are surrounded by the thick fibrous attachment of the carotid sheath to the periosteum of the skull base (Fig. 9). This periosteum is also in the continuum of the styloid ligaments. The ICA enters the carotid canal and describes a short vertical portion before turning at right angle and taking a horizontal course. While it changes of direction, the ICA is located just below the promontory that corresponds to the basal turn of the cochlea at the inner surface of the middle ear. Into the carotid canal, the ICA is surrounded by a loose venous plexus and by the carotid sympathetic nerves. It gives rise to a small branch

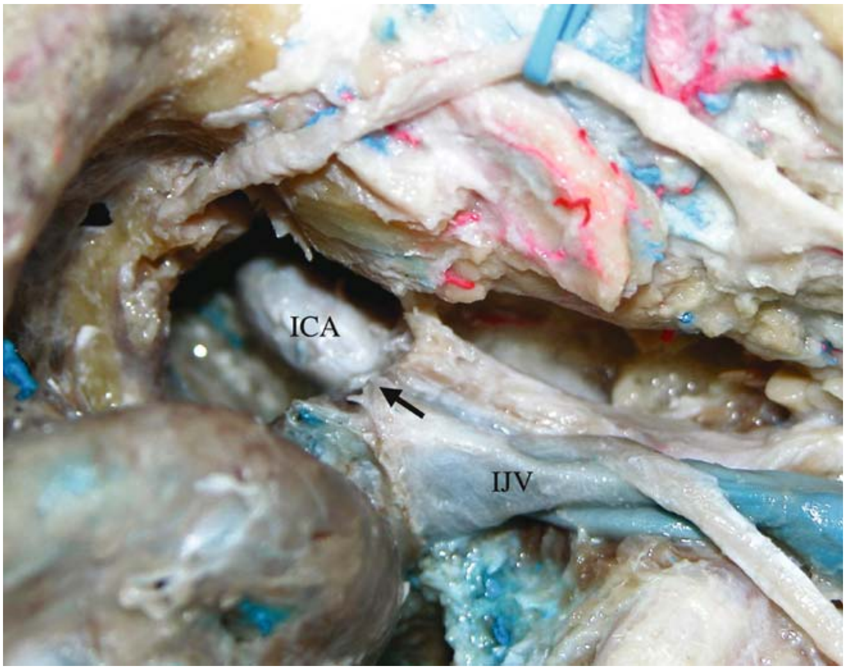

Fig. 9. General anatomy of the outer surface of the JF (*right side*). The bone has been resected and the upper neck has been dissected following a widened transcochlear technique. The close relationship between the carotid artery and the internal jugular vein are shown. The *black arrow* indicates the periosteal ring that ensheath both vessels at inferior margin of the JF. *ICA* Ascending portion of the intrapetrous internal carotid artery, *IJV* Internal jugular vein

named the caroticotympanic artery that reaches the tympanic cavity laterally through a small aperture.

Muscular environment

We focus here on the muscles that cover the lateral area of the JF and that are exposed during the lateral approaches (Fig. 10).

The first group of muscles are inserted in the proximity of the mastoid process. The most superficial is the sternocleidomastoid muscle (SCM). It attaches above the mastoid process and the lateral border of the superior nuchal line. It runs obliquely downward and forward. Just under the SCM, the splenius capitus attaches at the mastoid tip and runs downward and backward. Deeper and medial to the mastoid tip, the posterior belly of the digastric muscle arises in the digastric groove and runs anteroinferiorly to reach the hyoid bone. This muscle is innervated by the facial nerve.

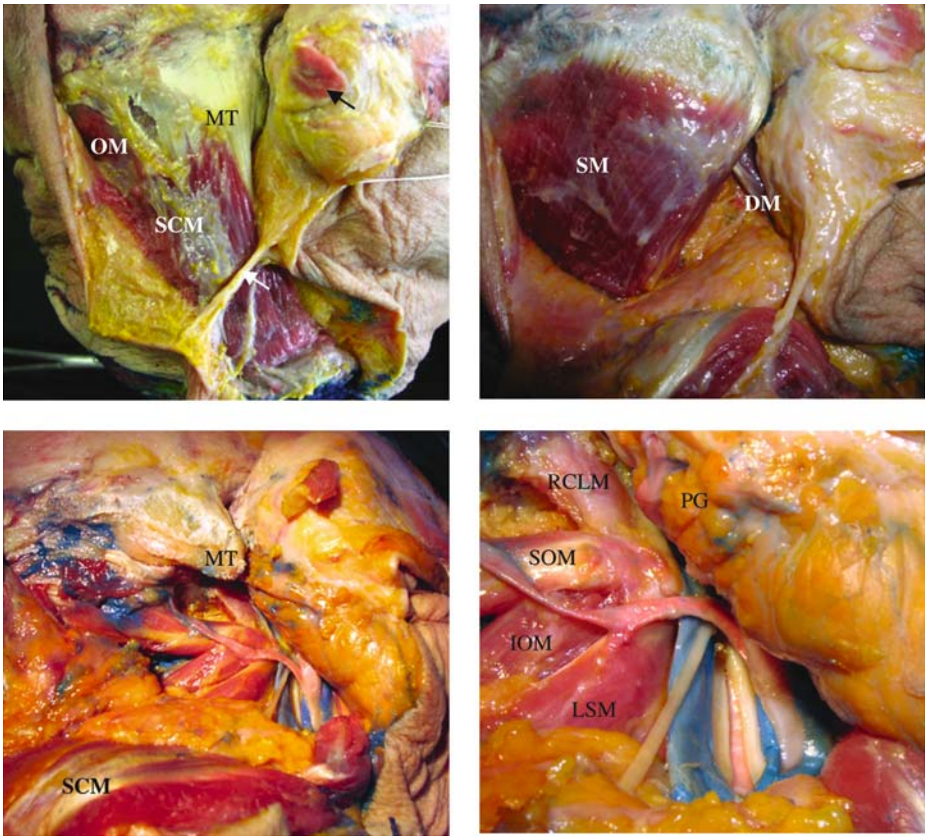

Fig. 10. Lateral view of the muscles that cover the region of the JF. The skin and galea have been elevated forward. The external auditory meatus has been preserved. The black arrow indicates the posterior auricular muscle. The white arrow indicates a branch of the superficial cervical plexus. The mastoid tip (*MT*) and the parotid gland (*PG*) are important landmarks. The superficial layers are shown at the top right and left of the figure. *OM* Occipital muscles, *SCM* sternocleidomastoid muscle, *DM* digastric muscle, *SM* splenius capitis muscle. The muscles that are inserted on the lateral process of C1 constitute the deep layer. *IOM* Inferior oblique muscle, *LSM* levator scapulae muscle, *RCLM* rectus capitis lateral muscle, *SOM* superior oblique muscle

The second group consists in the muscles that are attached to the styloid process. They are deeply seated just lateral and anterior to the JF. The styloglossus muscle is attached anteriorly, the stylohyoid laterally and the stylopharyngeal posteromedially.

The third group of muscle are mainly attached to the transverse process of the atlas. In this group, two muscles run upward: The rectus capitis lateral muscle is short and vertical, running toward the medial and anterior border of the digastric groove. The superior oblique muscle runs upward and backward toward the condylar part of the occipital bone. Two other muscles run posteroinferiorly, the inferior oblique muscle and the levator scapulae muscle.

The approaches to the region of the jugular foramen

Classification and selection of the approach (Fig. 11)

The number and complexity of the approaches that have been proposed for the control of the lesions involving the JF illustrates the lack of ideal procedure. As mentioned above, the inner portion of the JF is usually properly reached using a suboccipital retrosigmoid approach [25]. All neurosurgeons are familiar and confident with this approach but the corridor that is offered to the inside of the JF is limited and blind. It is generally reserved to control the cisternal extension of the disease (case illustration 1). Excepting this regular cisternal route, the other ones belong to the field of skull base procedures and can be classified following the target that is aimed.

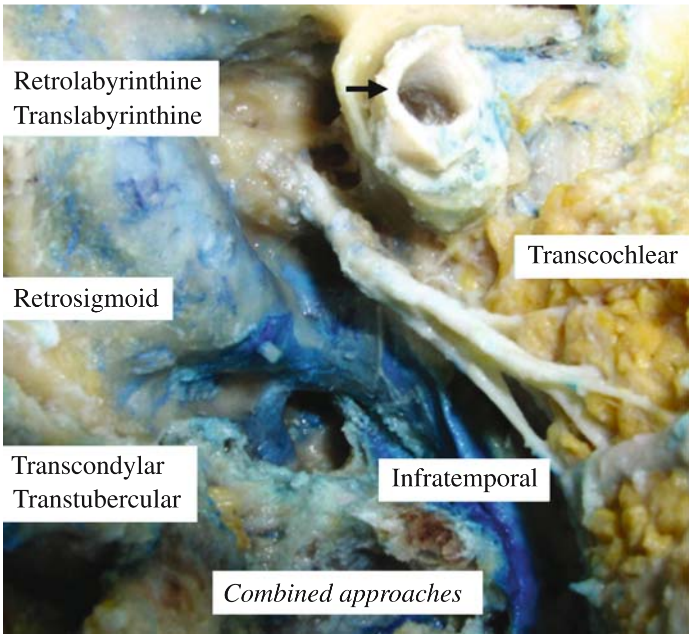

Fig. 11. Summary of the main surgical approaches to the region of the JF. The present dissection represents the final step of the infralabyrinthine transigmoid transjugular-high cervical approach. Several of these approaches can be used in a combined manner (*combined approaches*), depending on the extension of the disease and clinical condition. The black arrow indicates the cartilaginous wall of the outer meatus that has been cut

The inferolateral approaches are represented by transcondylar [3], juxta condylar [8], far lateral or extreme lateral approaches [29]. They target the posterolateral part of the JF and craniocervical junction.

The posterolateral approach is illustrated by the infralabyrinthine transigmoid transjugular-high cervical approach, as described below.

The superolateral approaches are the retrolabyrinthine and the translabyrinthine approaches. Both of them expose the jugular dome and bulb from above and do not control the lower cranial nerves in their intra and extraforaminal portion.

The anterolateral approaches associate a transpetrous and an upper neck exposure: The Fisch infratemporal fossa [4] approach and the widened transcochlear approach [19] belong to this group. In an attempt to obtain a similar exposure with a less invasive technique, it is possible to combine a retrolabyrinthine exposure with an upper neck dissection as we will detail below.

Selection of the approach depends on the tumor characteristics, patient examination, and expertise of the team.

The nature, the origin and the extension of the tumor are crucial points, obtained from high-resolution preoperative imaging. As stated by Lustig and Jackler [16], tumors located lateral to the cranial nerves are favourable for cranial nerve preservation during surgical excision. Recently, Ramina *et al.* [22], reviewed their experience about 106 consecutive tumors of the jugular foramen. Most of them were paragangliomas (57%) while schwannomas and meningiomas represented respectively 16 and 10% of cases. Excepting rare cases of primary cervical location [17], meningiomas usually grow up from the intradural compartment of the JF and shift the nerves that remain protected by arachnoid at the early stage of tumor development. They modify the adjacent petrooccipital bone and secondarily involve the inside of the foramen. Schwannomas are relatively uncommon in this location, representing less than 3% of intracranial schwannomas. They involve one or several rootlets of the LCNs from the beginning [25]. The early symptoms of presentation depend on the nerve of origin; however, this may not be true in cases of jugular foramen tumors, because the compartment is so narrow that all LCNs may be involved at the same time. Although these tumors can adopt various location in the foramen as described in published classifications [7], the dumbbell shape configuration also named Type D [19], is the most typical one. Bone window CT scan may show considerable widening of the JF and high-resolution MR images show significant enhancement of the tumor mass after gadolinium administration. The tumor mass may also display cystic features. Paragangliomas may develop from various points in the petrous bone or along the LCNs in the region of the JF [9]. The venous axis is usually invaded and occluded because the most frequent location of paraganglioma is the jugular bulb region. As stated by Fisch and Mattox [5], the medial wall of the sigmoid sinus is usually spared by the tumor. The full extension of the tumor along the carotid canal may be difficult to identify but this involvement may influence the selection of the approach. Paraganglioma are richly vascularized by feeders coming from the external carotid artery and particularly from the ascending pharyngeal artery. Preoperative embolization of the tumor's feeders may be useful to decrease the blood loss during removal. The preoperative work-up of the patients must include a complete otological and neurological examination, audiological testing, CT, MRI, MR angiogram and digital subtraction angiography.

From the patient's perspective, hearing level, facial nerve status and function of the LCNs are crucial point to select the approach and the therapeutic planning. However, several authors had underlined [27] that cranial nerve impairment may not be present despite microscopic infiltration of tumor among the nerve's fascicles. Hopefully, large tumors are generally associated to LCN deficits that have already been compensated before surgery. In this situation, surgical damage or sacrifice of nerves is well tolerated. However, it may be necessary to leave some tumor against the nerves and discuss adjunctive treatment or careful follow-up. For extensive paragangliomas, it may be scheduled that the IX nerve is difficult to preserve and that the epinerium of the facial nerve may be invaded [5]. General condition, previous treatments like radiation therapy and own opinion of a well-informed patient are essential in the decision-making process.

The team needs to be prepared to this kind of surgery. The collaboration between an ear-head and neck surgeon and a neurosurgeon is requested. They need both to have a perfect knowledge of the anatomy of the normal and pathological skull base. It is also strongly advised to have the whole panel of approaches available in order to provide a tailored surgery. It is also recommended to be able to monitor the electrophysiology of facial nerve and LCNs during the operative time and to offer a postoperative observation in an intensive care unit.

The infralabyrinthine transsigmoid transjugular-high cervical approach

This approach combines several techniques in order to expose the JF and related structures in an extensive manner while preserving the neuro-otologic structures of the petrous bone.

Dissection of the superficial layers

The patient is positioned supine and the head is turned 70° toward the opposite side. The skin incision is C shaped around the external ear from the temporal fossa to the upper neck, ending in front of the SCM under the angle of mandibula. Skin is elevated and reclined frontward. The external auditory canal is not necessarily divided; It may be the case if there is a need to work in the middle ear cavity in front of the vertical segment of the facial nerve. Temporal muscle is desinserted. Anterior chief of the SCM is desinserted from the mastoid process, showing the splenius capitis. This muscle is also desinserted from the mastoid process. In the depth, the posterior belly of the digastric muscle is identified. During the dissection of the upper neck, under this muscle, the internal jugular vein and the XI nerve are shown. In 80% of cases the XI nerve courses over the IJV posteroinferiorly while it courses under the vein in 20% of cases in the same direction. In front of the IJV, the internal carotid artery runs vertically. At the early step of the operation, there is no need to dissect the vagus nerve in the depth between the IJV and the ICA. Under the mastoid tip, the IJV courses just in front of the lateral process of C1. This process is not directly seen because covered by a group of four muscles as detailed previously and shown in Fig. 10. This is a key landmark for the identification of the inferior part of the operative field and for identification of the vertebral artery before its penetration point in the dura.

Exposure of the upper pole of the JF

In order to approach the sigmoid sinus and the junction with the jugular bulb, a retrolabyrinthine step is undertaken. This step has been extensively described in previous papers [20]. Briefly, the drilling is conducted gradually toward the depth in front of the sigmoid sinus, exposing the mastoid air cells. Backward it is essential to expose the sinodural angle between the superior petrosal sinus and the sigmoid sinus. The mastoid antrum is identified while the loop of the lateral SCC is approached medially in a more compact yellowish bone. Just under this loop, the facial nerve courses in the Fallopian canal, describing an angle that varies from 95 to 125° between the tympanic and the vertical segment (13 mm). The anatomy and variation of the facial nerve into the petrous bone has been nicely described in the Proctor's textbook [21]. It is not necessary to skeletonize extensively the canal at this time but the nerve is followed as far as the stylomastoid foramen. This foramen is identified in front of the anterior margin of the digastric groove. While drilling the infralabyrinthine air cells, the jugular dome is unroofed using a diamond drill, and cautiously detached from the jugular fossa. At this place and as mentioned above, the wall of the bulb is extremely thin and care should be taken to leave a thin eggshell bone over the dome to protect it.

Exposure the lateral circumference of the jugular bulb

The occipital bone is also exposed behind the sigmoid sinus and the lateral part of the condyle is drilled under and behind the jugular bulb. It is important to keep in mind the trajectory of the sigmoido-jugular complex and realize that

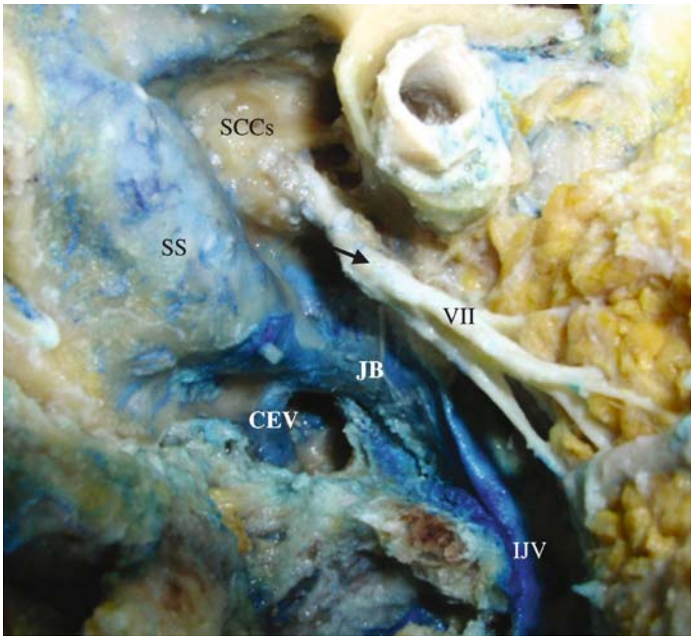

Fig. 12. The infralabyrinthine transsigmoid transjugular-high cervical approach is achieved. The approach preserves the intrapetrous neuro-otologic structures. The semicircular canals (*SCCs*) are exposed at the top of the field. The facial nerve (*VII*) is exposed in its vertical segment and can be mobilized along a very short segment in the area of the stylomastoid foramen (*black arrow*). This maneuver allows an optimized exposure of the jugular bulb (*JB*). The venous axis is extensively exposed, from the sinodural angle to the internal jugular vein (*IJV*). *CEV* Condylar emissary vein

this step is conducted in the depth under magnification. The mastoid tip is removed, the digastric muscle is divided and the styloid process identified. It is of importance to note that the facial nerve leave the stylomastoid foramen just laterally to the "pars venosa" of the JF. Thus, in order to control the elements of the JF, particularly the LCNs, the stylomastoid foramen should be opened and the facial nerve identified in its course before entering the parotid gland (Fig. 12). This procedure allows a safe mobilisation of the facial nerve along a restricted segment of its course. Care should be taken to preserve the vascularization of the nerve (see above). In this way, a normal postoperative motor facial function may be expected. Usually, the periosteum of the stylomastoid foramen is tightly attached to the facial nerve; thus the nerve should be elevated with this surrounding tissue, as recommended by Fisch and Mattox [5].

Exposure of the LCNs inside the jugular foramen

Since the LCNs course anteromedially to the jugular bulb, their intraforaminal segment cannot be exposed if the venous axis is not mobilized. The sigmoid

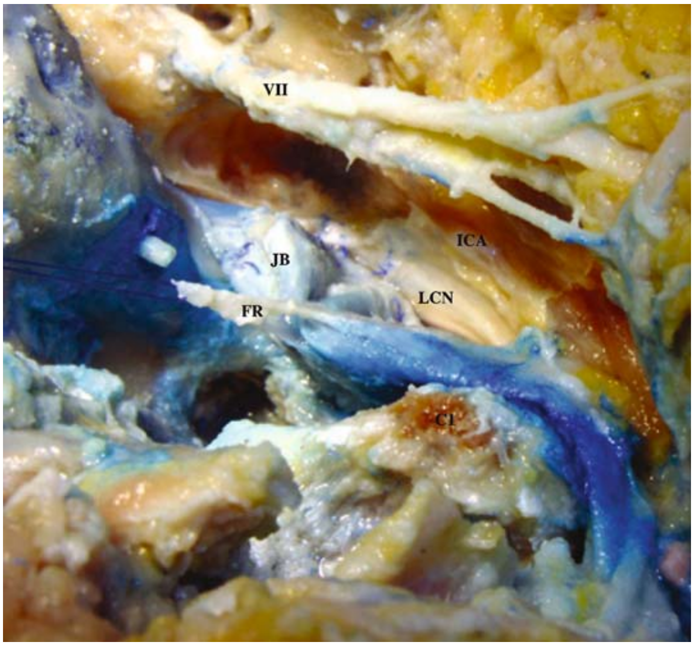

Fig. 13. Once the exposure has been achieved, it can be necessary to expose the lower cranial nerves (*LCN*) inside the JF. The IJV is ligated and elevated in a retrograd way. Note the close relationship of the IJV with the lateral mass of the atlas (*C1*). *FR* Fibrous ring, *ICA* Internal carotid artery, *JB* jugular bulb, *LCN* lower cranial nerves

sinus is ligated and divided in its vertical portion after making an incision of the pre- and retrosigmoid dura and put two threads for the ligation. The IJV is also ligated and divided in the neck, under the level of C1, and elevated in a retrograde way as far as it joins the jugular bulb. The jugular bulb is now freed from the jugular fossa (Fig. 13) but achievement of the venous exclusion needs the identification and the occlusion of the aperture of the IPS in the bulb. This venous occlusion is achieved by plugging its aperture with pieces of Surgicel. The permeability of the venous axis and the anatomical variation of the IPS drainage should be adequately assessed by a venous angiogram or MR angiogram before undertaking surgery. The LCNs are now identified and can be dissected in their intraforaminal course depending on the individual pathological anatomy. Since the pre- and retrosigmoid dura has been opened, it is possible to control the intracisternal segment of the LCNs.

Tumor resection and closure steps

The procedure of tumor resection depends on the insertion and extension of the lesion; it is also greatly influenced by the pathology of the lesion. Careful hemostasis is required because drainage is generally avoided. The posterior tympanotomy is closed using the bone dust that has been harvested in the operative field during drilling, and that is mixed with biological glue. Large strips of abdominal fat cover the cavity of petrectomy and the dura defect in order to avoid cerebrospinal fluid leak.

Commentaries

This approach has been developed and used by previous authors [6, 22] and is a minimal invasive skull base procedure. The approach is conducted using reliable permanent landmarks and may be routinely performed by any neuro-otologic team. This approach offers multiple corridors to the intra- and extra-dural portions of the JF region, which allows an ideal control of dumbbell shaped tumors. The mobilization of the facial nerve is limited to the region of the stylomastoid foramen and in the distal part of the vertical portion of the facial canal. Thereby, a good facial motor function may be expected after operation. The neuro-otologic structures are preserved inside the petrous bone. The major limitation of this approach is the insufficient exposure of the carotid canal, protympanum and petrous apex.

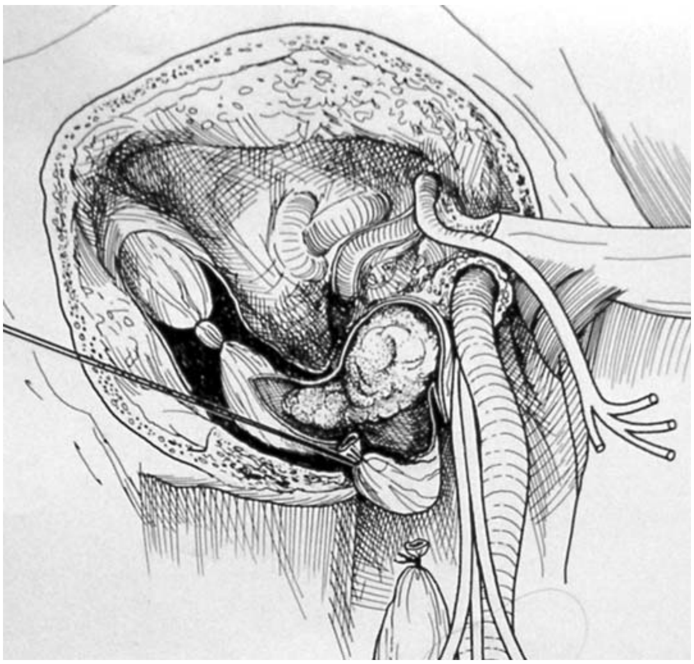

Fig. 14. Illustration of an infratemporal Type A approach on the right side. The internal jugular vein and the sigmoid sinus have been ligated and the lumen of the venous channel has been opened, exposing the tumor. Observe the anterior mobilisation of the second and third portion of the facial nerve

The Fisch infratemporal fossa approach Type A

The first steps of this approach are similar to those of the previous approach regarding the skin incision and elevation of fascia and muscles. Blind sac closure of the external auditory canal and total removal of the skin from the external auditory canal are achieved. The facial nerve is identified in the parotid gland and major vessels are exposed in the upper neck. A subtotal petrosectomy is conducted with total mastoidectomy in the way of a retrolabyrinthine approach (Fig. 14). Tympanic and mastoid segment of the facial nerve are identified from the geniculate ganglion to the stylomastoid foramen. The chorda tympani is sectioned and the hypotympanum is exposed. The facial nerve is transposed anteriorly and protected in a new canal that is drilled in the remaining petrous and tympanic bone. These consecutive procedures allow the exposure of the entire carotid canal from the tympanic ostium of the Eustachian tube down to the carotid foramen.

Commentaries

In order to control the disease that extends into the middle ear and the carotid canal, it is needed to proceed forward sectioning the external auditory canal, opening the middle ear and mobilizing the facial nerve. This approach preserves the cochlea and posterior labyrinth. Moreover, the mobilization of the facial nerve gives more space available in front of the jugular foramen. In case of additional extension toward the petrous apex, the petroclival area and the parapharyngeal space, it is possible to modify the Type A approach; this modification requires the resection of the superficial lobe of the parotid gland, resection of the TMJ, removal of the styloid muscles and ligaments (Fisch B). Section of the mandibular branch of the trigeminal nerve as described in the Fisch type C approach, should be avoided as possible.

The widened transcochlear approach

Infiltration of the carotid canal, petroclival region and infratemporal fossa justify an extensive approach, which associate at the same time a total petrosectomy as described in the original transcochlear approach described by House and Hitselberger [10] and the dissection of the upper neck. Such combined exposure can be achieved by the widened transcochlear approach as described by Pellet *et al.* [19]. Actually, this approach offers a wider corridor than the Fisch infratemporal Type B approach, but avoids the section of the maxillary branch of the trigeminal nerve.

From an infratemporal fossa Type A, it is possible to proceed toward a widened transcochlear approach (WTCA) because both approaches share the same initial steps. Skin incision, retrolabyrinthine exposure and upper neck dissection are similar. At that time, and before mobilizing the facial nerve,

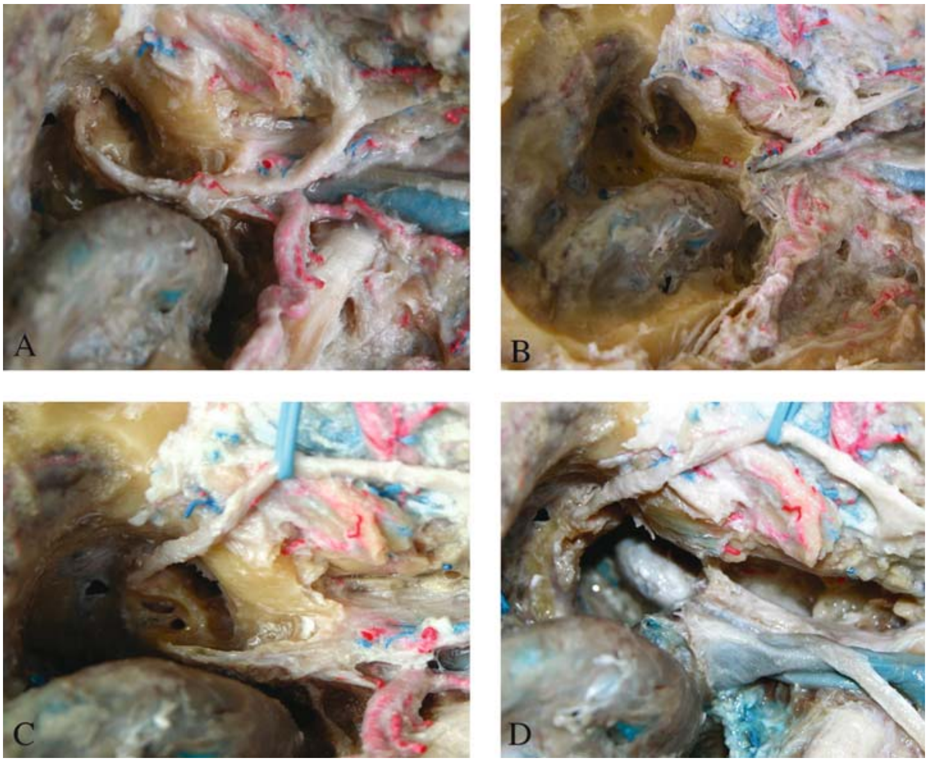

Fig. 15. Widened transcochlear approach performed on the right side of an injected specimen. (A) The first steps are equivalent to those that are conducted during an infratemporal Type B approach. (B) The posterior labyrinth (semicircular canals and vestibule) and the cochlea are drilled, in order to expose the first and second portion of the Faloppian canal. (C) The facial nerve has been mobilized from its bony canal and dissected from the stylomastoid foramen. (D) The widened transcochlear approach is now achieved. Note the completeness of the petrosectomy and the wide exposure of the jugular bulb and intrapetrous carotid artery

the semicircular canals are drilled and the vestibule is opened in order to reach the fundus of the IAC. The upper and the lower border of the IAC are then drilled and the surgeon is now in the situation of a translabyrinthine approach. Then, it is time to skeletonize the fallopian canal and mobilize the facial nerve forward, from the geniculate ganglion to the extracranial segment of the nerve (Fig. 15). In some cases it may be useful to mobilize the nerve backward but this step requires the exposure of the geniculate ganglion and section of the superficial petrosal nerve. Once the mobilization of the nerve and the removal of the ossicles have been achieved, the promontory is exposed and the cochlea is entirely drilled. Resection of the cochlea offers significant space above the genu and the horizontal portion of the carotid canal, toward the petrous apex

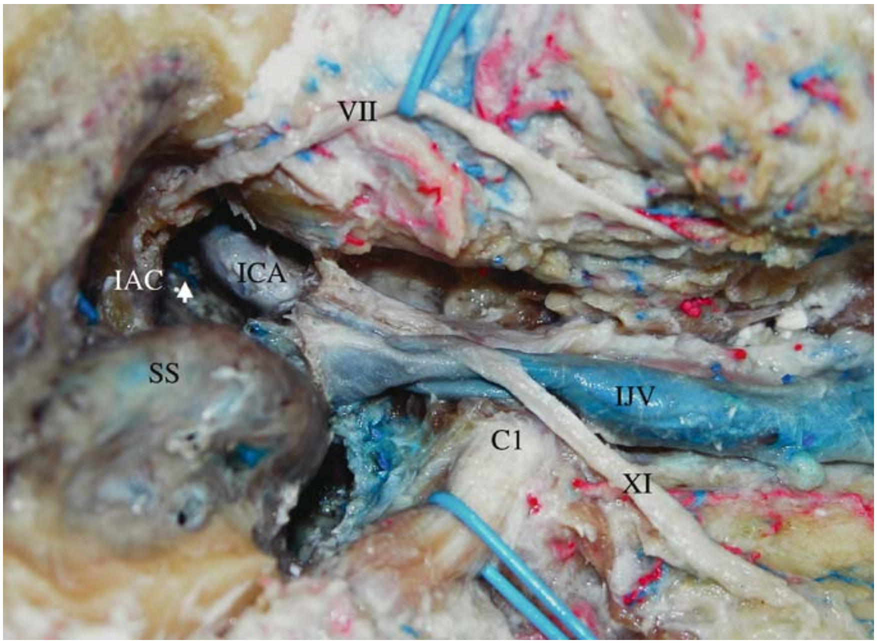

Fig. 16. Enlarged view of the Fig. 15. D. *IAC* Internal auditory canal. The white arrow indicates the course of the inferior petrosal sinus after drilling of the petroclival groove

(Fig. 16). The premeatal dura is widely exposed in the triangle delineated by the superior and the inferior petrosal sinuses. The tympanal bone is removed and the ascending branch of the mandibula is pushed forward to widen the corridor in front of the intrapetrous carotid artery.

Due to the wide field that has been exposed and the importance of the bony and dura defect, the closure step needs to be meticulous. As mentioned previously, abdominal fat is a precious material to occlude the cavity but it can be useful to cover the fat with a flap of temporalis muscle that is folded and sutured to the sternocleidomastoid muscle.

Commentaries

The step of total translocation of the facial nerve implies a postoperative facial deficit that never recovers better than House and Brackman grade III. If the nerve is mobilized backward, it necessitates a section of the superficial petrosal nerves, which compromise permanently the function of the VII bis nerve. Additionally, the intrapetrous neuro-otologic structures are sacrificed by the approach, which implies a hearing loss. The extratime that is needed to achieve the procedure is really significant and justifies a two-surgeons procedure.

Case illustration

Case illustration 1

The case of a primarily intracranial lesion with minimal extension into the jugular foramen.

A 30-year-old woman presented with a 6-month history of swallowing disorders and voice modification. She was admitted in neurosurgery following an acute pulmonary infection. She complained of cervical pain, dysphagia, hoarseness and shoulder weakness on the left side. Enhanced MR images (Fig. 17A and B) showed a cystic schwannoma involving the jugular fossa, the cerebellomedullary cistern and cerebellopontine angle on the left side without extension through the jugular foramen. Resection was carried out using a

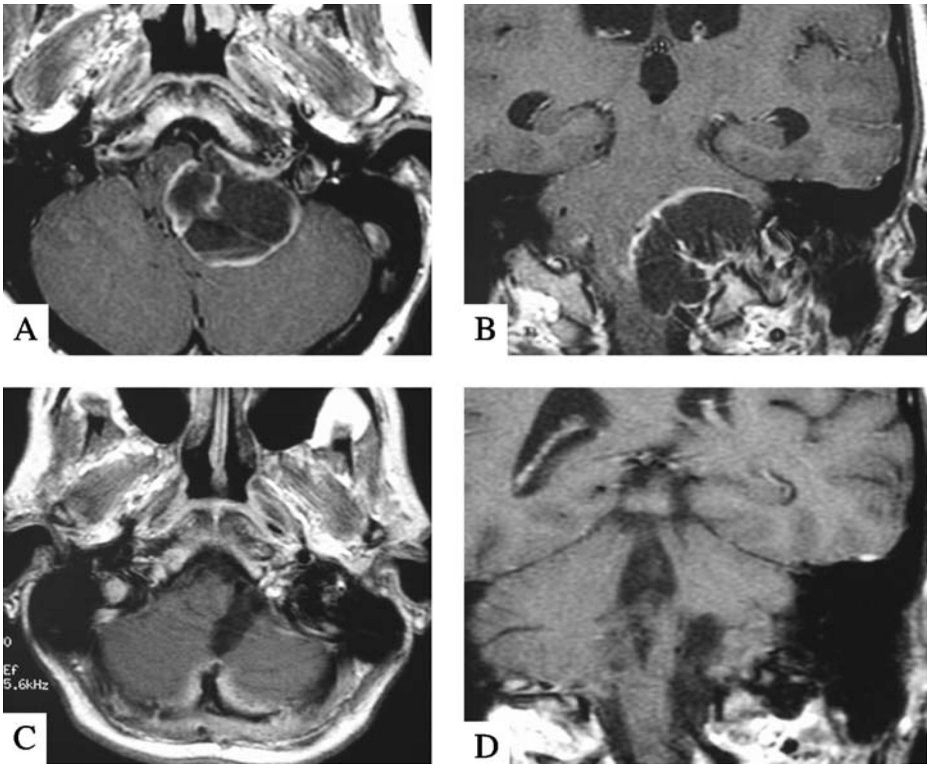

Fig. 17. Pre- and postoperative neuroimaging of the case illustration 1. (A) Post-gadolinium T1 image (*axial*) showing a large cystic tumor involving the left cerebello-medullary cistern with mass effect over the medulla. (B) Coronal view using the same sequence. Considering the reduced amount of intraforaminal infiltration, it was decided to operate this patient via a suboccipital retrosigmoid approach. (C and D) post-operative MR images showing the lack of residual tumor

lateral retrosigmoid route. Post-operative MR images (Fig. 17C and D) showed complete resection of the tumor. At the 6-month follow-up examination, the lower cranial nerve dysfunction had significantly improved.

Case illustration 2

The case of a lesion involving the jugular foramen with minimal intracranial extension.

This 40-year-old male was admitted to our institution for recent onset of hoarseness. He was operated on elsewhere 15-year ago for "partial removal of a posterior fossa schwannoma". Since that time, he complained of some swallowing disorders. The clinical examination showed a laryngeal palsy and a

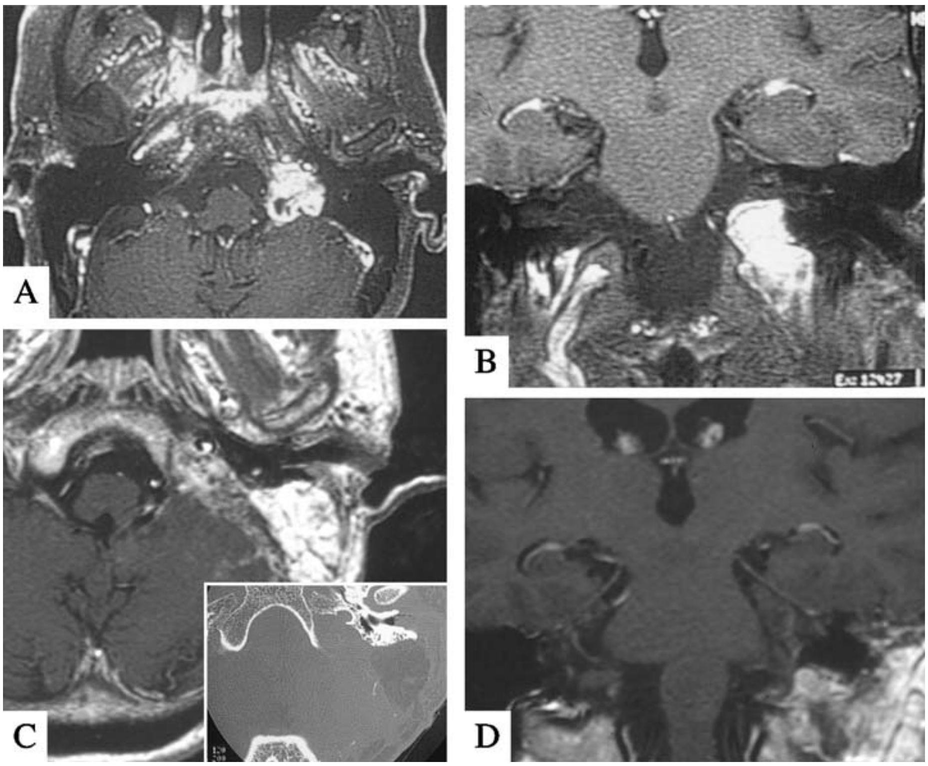

Fig. 18. Pre- and postoperative neuroimaging of the case illustration 2. (A) Post-gadolinium T1 image (*axial*) showing an intraforaminal tumor mass on the left side. Note that the intracisternal extension of the lesion is reduced, as confirmed in coronal view (B). This extension justified an infralabyrinthine transigmoid transjugular-high cervical approach. (C and D) Postop imaging confirmed the lack of residual tumor. Post-operative bone window CT scan (*white small screen*) showed the large opening of the jugular foramen

shoulder weakness on the left side. Enhanced MR images showed a jugular foramen schwannoma with minimal intracranial extension and with a small component involving the superior aspect of the posterior parapharyngeal space (Fig. 18A and B). The bony CT scan showed enlargement of the jugular foramen. An infralabyrinthine transigmoid transjugular-high cervical approach was performed and allowed a complete removal of the lesion as shown on MR images (Fig. 18C and D). The cranial nerve dysfunction remained unchanged.

Case illustration 3

This illustration is about two patients presenting with a very similar clinical history of hypacousia and tinnitus on the right side. In both cases, preoperative examination and neuroradiological work-up concluded to a jugulotympanic paraganglioma (illustration not shown). In both cases it was decided to operate via an infralabyrinthine transigmoid transjugular-high cervical approach. The main difference between the two cases is the distinct course of the eleven

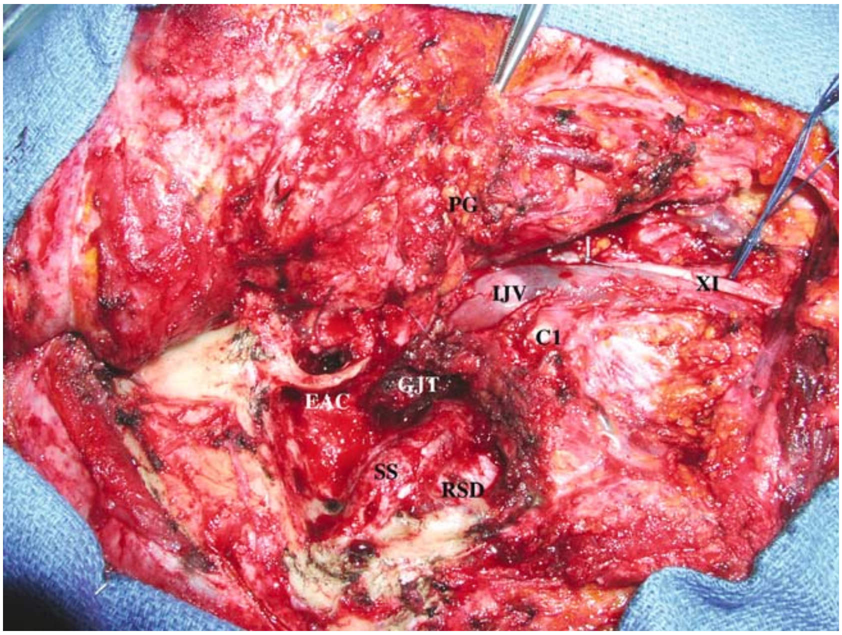

Fig. 19. Peroperative view of the case illustration 3. An infralabyrinthine transigmoid transjugular-high cervical approach has been achieved on the right side The glomus jugulare tumor (*GJT*) has been exposed below the posterior labyrinth in the hypotympanum, inside the lumen of the jugular bulb and occluding the internal jugular vein (*IJV*). The external auditory canal (*EAC*) has been cut, the parotid gland (*PG*) has been exposed with the division of the facial nerve. The retrosigmoid dura (*RSD*) has been exposed in order to ligate and divide the sigmoid sinus (*SS*)

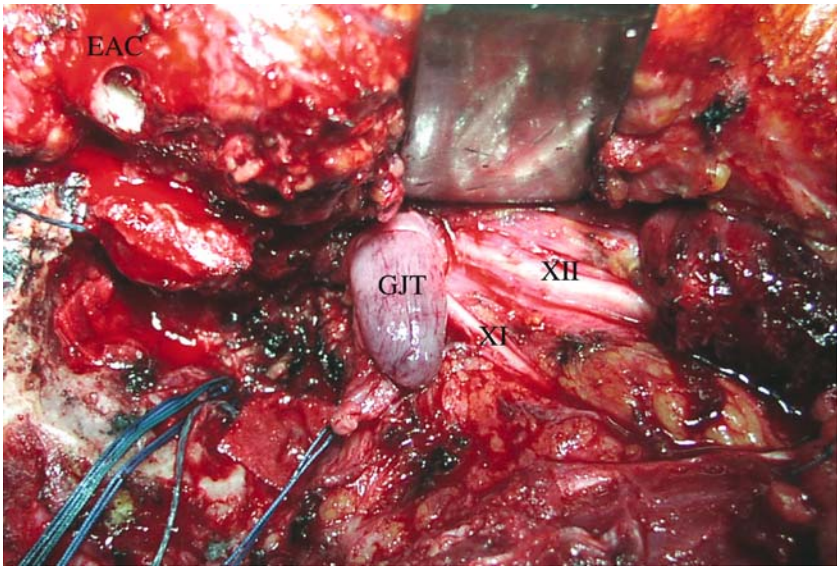

Fig. 20. Peroperative view of a right sided jugulotympanic paraganglioma. The tumor origin and tumor extension are similar to what has been observed in the previous case (Fig. 19). At this step, the internal jugular vein has been ligated and opened in order to expose and remove the tumor (*GJT*). Note the position of the eleventh nerve (*XI*) which courses medially to the IJV

nerve; in the first case (Fig. 19), the CN XI courses laterally to the internal jugular vein while it courses medially in the other one (Fig. 20).

Conclusions

One third of the cranial nerves as well as the major vascular supply and drainage of the brain course through the jugular foramen region. This region may be involved by various diseases which are dominated by the tumors. In order to treat these affections, there is a need to understand the locoregional surgical anatomy of the JF. Surgical approaches are not only influenced by the origin and extensions of the tumor, but also by the clinical condition of the patient, justifying an extensive work-up before treatment. In this paper we have described successively three skull base approaches with a gradual level of exposure and invasiveness. We have shown that the facial nerve and lower cranial nerves are in the close proximity of the operative field and may be jeopardized during exposure or resection of the disease. Thereby, the skull base neurosurgeon needs to be able to master this panel of approaches and to propose an individual tailored surgery. In cases of benign tumors in patients presenting with few symptoms, which is a common situation, we particularly recommend the use of this tailored surgery. The role of radiosurgery in the treatment of residual tumors that infiltrate the LCNs remains to determine but looks promising.

References

1. Alverina JE, Fraser K, Lanzino G (2006) The occipital artery: a microanatomical study. Neurosurgery 58 Suppl 1: 114–122
2. Ayeni SA, Ohata K, Tanaka K, Hakuba A (1995) The microsurgical anatomy of the jugular foramen. J Neurosurg 83: 903–909
3. Bertalanffy H, Seeger W (1991) The dorsolateral, suboccipital, transcondylar approach to the lower clivus and anterior portion of the craniocervical junction. Neurosurgery 29: 815–821
4. Fisch U (1978) Infratemporal fossa approach to tumours of the temporal bone and base of the skull. J Laryngol Otol 92: 949–967
5. Fisch U, Mattox D (1988) Microsurgery of the skull base. Thieme, Stuttgart, pp 136–173
6. Fournier HD, Laccoureye L, Mercier P (1998) La voie rétroauriculaire transmastoidienne infralabyrinthique. Neurochirurgie 44: 111–116
7. Franklin DJ, Moore GF, Fisch U (1989) Jugular foramen peripheral nerve sheath tumors. Laryngoscope 99: 1081–1087
8. George B, Lot G, Tran Ba Huy P (1995) The juxta condylar approach to the jugular foramen (without petrous bone drilling). Surg Neurol 44: 279–284
9. Glasscock ME, Jackson C, Dickins J, Wiet R (1979) The surgical management of glomus tumors. Laryngoscope 89: 1640–1651
10. House WF, Hitselberger WE (1976) The transcochlear approach to the skull base. Arch Otolaryngol 102: 334–342
11. Hovelacque A (1934) Ostéologie. Doin, Paris 2: 155–156
12. Katsuta T, Rhoton AL, Matsushima T (1997) The jugular foramen: microsurgical anatomy and operative approaches. Neurosurgery 41: 149–202
13. Kawano H, Tono T, Schachern PA, Paparella MM, Komune S (2000) Petrous high jugular bulb: a histological study. Am J Otolaryngol 21: 161–168
14. Lang J (1993) Anatomy of the posterior cranial fossa. In: Sekhar LN, Janecka IP (eds) Surgery of the cranial base. Raven Press, New York, pp 131–146
15. Liscak R, Vladyka V, Wowra B, Kemeny A, Forster D, Burzaco JA, Martinez R, Eustacchio S, Pendl G, Régis J, Pellet W (1999) Gammaknife radiosurgery of the glomus jugulare tumour – early multicentre experience. Acta Neurochir (Wien) 141: 1141–1146
16. Lustig LR, Jackler RK (1996) The variable relationships between the lower cranial nerves and jugular foramen tumors: implications for neural preservation. Am J Otol 17: 658–668
17. Malca SA, Roche PH, Thomassin JMT, Pellet W (1994) An unsual cervical mass tumor: meningioma. A propos of a case of petrous origin. Review of the literature of meningioma presenting as cervical mass. Neurochirurgie 40: 96–108
18. Muthukumar N, Kondziolka D, Lunsford AD, Flickinger JC (1999) Stereotactic radiosurgery for jugular foramen schwannomas. Surg Neurol 52: 172–179
19. Pellet W, Cannoni M, Pech A (1988) The widened trancochlear approach to jugular foramen tumors. J Neurosurg 69: 887–894
20. Pellet W, Cannoni M, Pech A (1989) Otoneurosurgery. Springer, Berlin Heidelberg New York
21. Proctor B (1989) Surgical anatomy of the ear and temporal bone. Thieme, New York

22. Ramina R, Maniglia JJ, Fernandes YB, Paschoal JR, Pfeilsticker LN, Neto MC (2005) Tumors of the jugular foramen: diagnosis and management. Neurosurgery ONS 1 Suppl 57: 59–68
23. Rhoton AL, Buza R (1975) Microsurgical anatomy of the jugular foramen. J Neurosurg 42: 541–550
24. Roche PH, Moriyama T, Thomassin JM, Pellet W (2006) High jugular bulb in the translabyrinthine approach to the cerebellopontine angle: anatomical considerations and surgical management. Acta Neurochir (Wien) 148: 415–420
25. Samii M, Babu RP, Tatagiba M, Sepehrnia A (1995) Sugical treatment of jugular foramen schwannomas. J Neurosurg 82: 924–932
26. Sanna M (1995) Atlas of temporal bone and lateral skull base surgery. Thieme, New York
27. Sen C, Hague K, Kacchara R, Jenkins A, Das S, Catalano P (2001) Jugular foramen: Microscopic anatomic features and implications for neural preservation with reference to glomus tumors involving the temporal bone. Neurosurgery 48: 838–848
28. Van Loveren HR, Sing Liu S, Pensak ML, Keller JT (1996) Anatomy of the jugular foramen: The neurosurgical perspective. Operative technique in otolaryngology head and neck surgery, vol 7, pp 90–94
29. Wen HT, Rhoton AL, Katsuta T de Oliveira E (1997) Microsurgical anatomy of the transcondylar, supracondylar, and paracondylar extensions of the far-lateral approach. J Neurosurg 87: 555–585