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Lower Four Cranial Nerves in the Management of Glomus Jugulare: Anatomical Study

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Abstract

Introduction The surgical management that achieves minimal morbidity and mortality for patients with glomus and non-glomus tumors involving the jugular foramen (JF) region requires a comprehensive understanding of the complex anatomy, anatomic variability, and pathological anatomy of this region.
Objective The aim of this study is to propose a rational guideline to expose and preserve the lower cranial nerves (CNs) in the lateral approach of the JF.
Methods The technique utilized is the gross and microdissection of 4 fixed cadaveric heads to revise the JF's surgical anatomy and high part of the carotid sheath compared with surgical cases to understand and preserve the integrity of lower CNs. The method involves radical mastoidectomy, microdissection of the JF, facial nerve, and high neck just below the carotid canal and the JF. The CNs IX, X, XI, and XII are microscopically dissected and kept in sight up to the JF.
Results This study realized well the surgical and applied anatomy of the lower CNs with relation to the facial nerve and JF.
Conclusions The JF anatomy is complicated, and the key to safely operate on it and preserving the lower CNs is to find the posterior belly of the digastric muscle, to skeletonize the facial nerve, to remove the mastoid tip preserving the stylomastoid foramen, to skeletonize the sigmoid sinus and posterior fossa dura not only anterior but also posteroinferior to reach and drill the jugular tubercle.

Keywords
- cadaveric study
- facial nerve
- jugular foramen
- lower cranial nerves
- surgical anatomy

Introduction

Despite numerous studies regarding the jugular foramen (JF) anatomy, achieving wide exposure of the JF while minimizing neurovascular injury remains a challenge. Visualization of the disease in the JF region is often compromised, with a greater risk for injury to local neurovascular structures or incomplete tumor removal.[1]

With the introduction of the infratemporal fossa approach by Fisch,[2] the right management of the facial nerve became the key for successful access to JF lesions.[3] Regarding the lower cranial nerves (CNs), the standardization to respect

We conducted our work in the otology laboratory of the Faculty of Medicine from the Mediterranean University, and the Department of Otorhinolaryngology and Head and Neck Surgery of Marseille, France.

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such neural structures is unclear, despite being useful to the surgeon. There are excellent anatomic descriptions, but the surgical recognition of the lower CNs in their pars nervosa course is still problematic, even in the absence of neural invasion by the disorder.

The bipolar coagulation of the surrounding tumoral process or packing of the adjacent venous sinus are the main causes of postoperative lower cranial injury, except when the tumor's extent requires their sacrifice, which is uncommon without preoperative paralysis.

Basically, approaches to the JF can be considered as lateral approaches involving the various transmastoid and infratemporal fossa corridors, including the Fisch A approach. The lateral approaches are more applicable to tumors of the JF region. They include various degrees of mastoid removal, preservation of the ear canal, and different facial nerve mobilization degrees.[4]

Due to the large surgical involvement of the surrounding structures, this type of surgery has been associated with morbidity, especially the lower CN injury, which may occur without their courses' appropriate orientation. The lateral dissection described here may be a simple modification of prevailing surgical techniques, either for access to the JF or the high part of the internal carotid artery (ICA). After transmastoid dissection of the facial nerve and the jugular bulb, the dissection is carried from the neck to the skull base, and medially to the internal jugular vein to reach the JF following the lower CNs.[5]

This study aims to propose a rational guideline to expose and preserve the lower CNs in the lateral approach of the JF. The lateral dissection described in our study may be a simple modification of prevailing surgical techniques, either for access to the JF or the high part of the ICA. This report outlines a step-by-step procedure for studying cadaveric dissections to safely expose the lower CNs at the junction of the high cervical region and lower skull base.

Material and Methods

We conducted our work in the otology laboratory of the faculty of medicine and the Department of Otorhinolaryngology (ORL) and Head and Neck Surgery. All procedures performed in this study involving human participants were in accordance with the ethical standards of the Institutional Research Editorial Board (33–5-021). We used the operating microscope Leica (Leica Microsystems, Wetzlar, Germany) and drill system Bien-Air (Bien-Air Surgery SA., Le Noirmont, Switzerland). Four human cadaver specimens (8 sides), consisting of the whole head and neck prepared above the C4 vertebral body, were investigated. The specimens were fixed in formalin and injected with red silicone for the carotid and vertebral arteries, and blue silicone for the internal jugular vein. All four specimens were males with an average age of 66.3 years at the time of death. Dissections were performed on both sides of the head on all cadaver specimens. Each specimen was put in a three-pin holder system, with the aim of simulating the conditions of positioning a real patient in the actual surgical setup. In two out of the four heads, we completely removed the brain along with the brain stem to expose the whole skull foramina from the intracranial aspect, aiming to orientate ourselves, compare, and estimate the anatomy.

The technique utilized in our work aimed to make different extents of dissection on the cadavers as a sort of serial leveling of dissection, thus, precisely estimating the anatomical details in a layer by layer manner so that all the specimens complement each other.

- A large, post-auricular, C-shaped incision is extended into the neck, two fingerbreadths below the angle of the mandible and almost to the midline at the level of the thyroid cartilage. The platysma muscle is divided along the skin incision. The wide undermining of the anterior edge creates an anteriorly based musculoperiosteal flap, which was elevated to expose the underlying sternocleidomastoid muscle (SCM).
- In the neck, the SCM is detached from the mastoid tip. Beneath the posterior belly of the digastric muscle, the very prominent transverse process of the atlas (TPA) represents a sure landmark to find the CN XI. The posterior belly of the digastric muscle is divided near its origin in the digastric groove of the mastoid. This is a key point to expose the upper part of the internal jugular vein (IJV). The occipital artery and the CN XII were identified under the posterior belly of the digastric muscle; then, the occipital artery was transected. The JF and carotid canal can be reached by tracing the carotid sheath upward, and the exposure is limited by the mastoid process, parotid gland, facial nerve, and styloid process.
- In the temporal bone, a radical mastoidectomy, including resection of the mastoid tip, is performed, with preservation of the tympanic membrane in position as a landmark. In this process, the transverse sinus and sigmoid sinus are skeletonized with a diamond bur. Bone is removed anterior and posteriorly to the sigmoid sinus, and the posterior and middle fossa dura are exposed completely. The fallopian canal is also skeletonized from the geniculate ganglion to the stylomastoid foramen.
- In the neck, the CN VII is identified distally to the stylomastoid foramen within the parotid gland. The styloid process must be freed from the stylohyoid, styloglossus, and stylopharyngeus muscles, then fractured and resected with a rongeur. This maneuver exposes the fibrous tissue covering the carotid canal. Resection of the dense fibrous tissue, with the drilling of the residual anterior wall of the external auditory canal, exposes the vertical petrous part of the ICA. A retrograde dissection (from below upwards) of the soft tissue in the neck, beginning at the level of the second cervical vertebrae, isolating the IJV and the succeeding CNs XI, XII, and X to the skull base, followed by dissection of the IX along the upper part of the ICA.
- In the temporal bone, an anterior transposition of the facial nerve is performed, and the drilling of the inferior and anterior part of the tympanic bone exposes the vertical part of the petrous carotid canal. The fascia

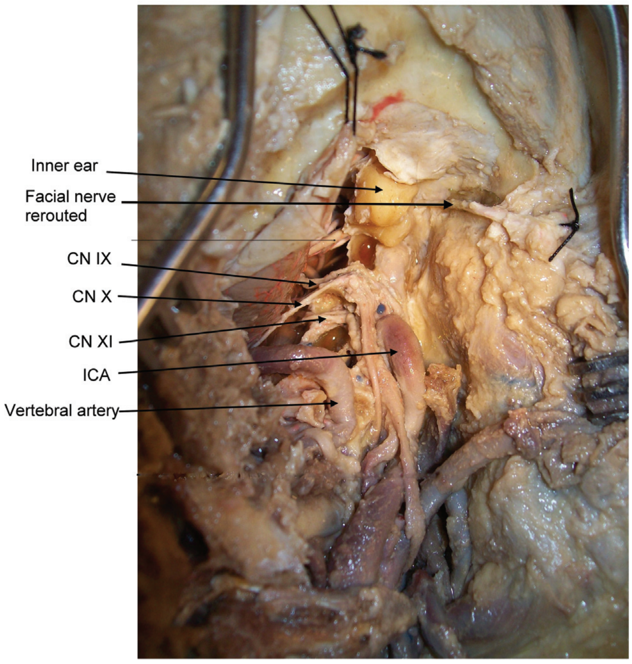

Fig. 1 Anatomy of the right cerebello-pontine angle through combined infratemporal and far lateral approaches, which shows the relationship between the lower cranial nerves (CNs), the internal carotid artery (ICA), and the vertebral artery.

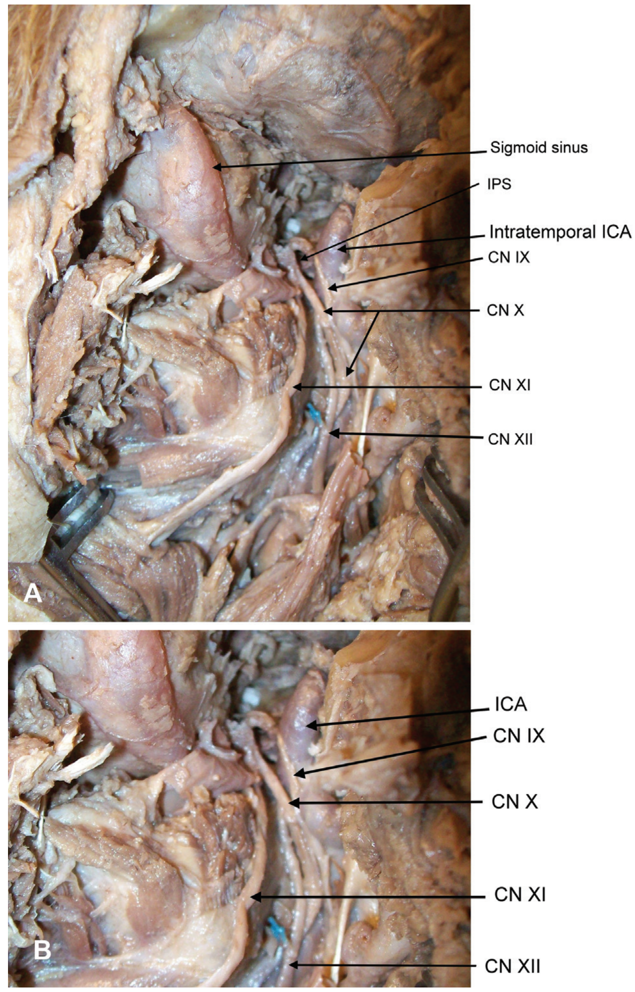

Fig. 2 (**A**) Right infratemporal approach. (**B**) High magnification relationship of the lower cranial nerves (CNs) at the level of the jugular foramen (JF) region.

between the IJV and the ICA must be sharply dissected, to open this area widely and expose, inferiorly, the JF and petrous ICA. After that, the IJV is dissected from below upwards and reflected to expose the contents of the JF, especially the CN IX, X, XI, and XII.

- The infratemporal approach can be extended medially by combining it with the far lateral approach, which consists of the drilling of the occipital condyle and transverse process of the atlas to expose the vertebral artery. The cerebello-pontine angle (CPA) is entered by incising the posterior fossa dura and sacrificing the sigmoid sinus and jugular bulb to expose the entire course of the lower CNs (►**Fig. 1**).

Results

Anatomy

Using the previously mentioned technique of skull base and JF dissection, we were able to identify and control the vital neurovascular structures occupying this area (the sigmoid sinus–jugular bulb–jugular vein system, the ICA, and the lower CNs). The lower CNs start their journey from the bottom of the cerebellopontine angle by exiting the medulla and running forward and downwards toward the JF. They are arranged, in order, from above downwards as CN IX, X XI, and XII more transversely, respectively, exiting the intracranium and entering the neck. Following the course of each CN at the level of the JF, important landmarks were evidenced. As regards the CN XI, it courses over the lateral process of the atlas, then behind the jugular vein in 2 cases, and lateral to the jugular vein in 6 cases (►**Fig. 2**).

In the upper part of the neck, CN X and XII were found emerging between the IJV and the ICA. At the foramen jugular, the CN X and XI are more related and run posteromedially, and are very difficult to separate from each other within this area. Furthermore, CN IX is slender and separates from the others when approaching the JF to become anterolaterally oriented in the foramen, then runs along the lateral aspect of the ICA and crosses it anteriorly.

This level of exposure is reached after removal of the mastoid tip, posterior belly of the digastric muscle, styloid process, rerouting of the facial nerve, and extensive drilling of the tympanic bone. This technique does not require dislocation of the mandible to improve the exposure.

After removal of the jugular vein, and with higher magnification, the relationship between the different CNs becomes more obvious. The XI from the TPA is ascending underneath the other CNs. The XII is easy to be exposed in the neck, then becomes too close to the CN X, before reaching its bony canal. The CN X follows an ascending course toward the JF and reaches the intracranial portion below the inferior petrosal sinus. So, in the neck, the CN X is behind the CN XII, and crosses over it before entering the JF. The CN IX has a completely separate course following the ICA, and crosses

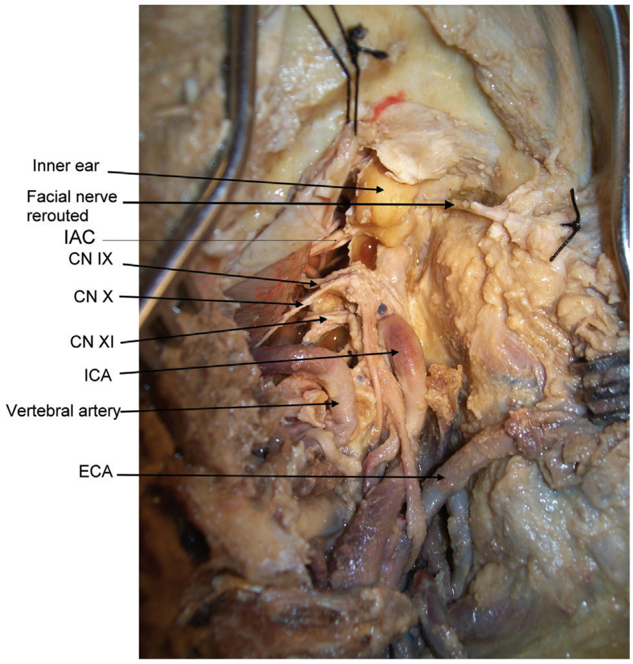

Fig. 3 Detailed dissection of the jugular foramen area, with the sigmoid sinus and jugular bulb-vein sacrificed to expose the vertebral artery, internal carotid artery (ICA), and the external carotid artery (ECA).

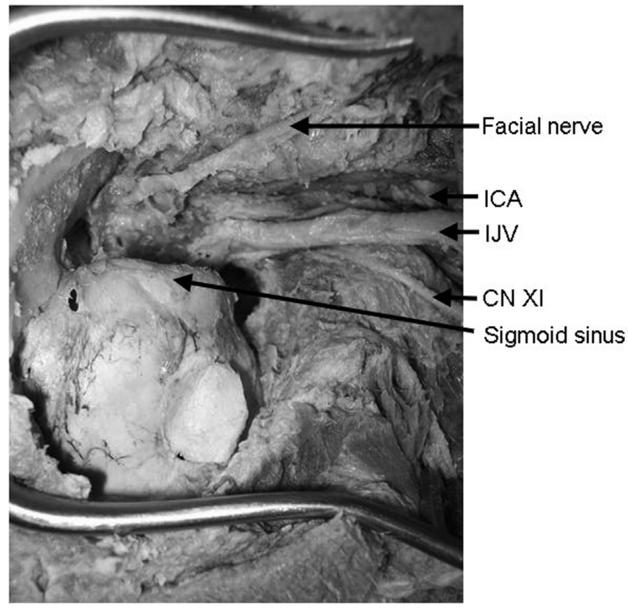

Fig. 4 Jugular foramen exposure with anterior transposition of the facial nerve, without dislocation of the mandible. **Abbreviations:** IJV, internal jugular vein; ICA, internal carotid artery.

the inferior petrosal sinus anterolaterally. The far lateral approach, combined with extra- and intracranial dissection, could provide exposure as deep as the vertebral artery and all the components of the CPA (►**Fig. 3**).

Step by Step Surgical Consequences

Tip of the Mastoid

After radical mastoidectomy, the dura of the middle and posterior cranial fossae is visible along with the middle ear, the semi-circular canals, and the facial nerve in its tympanic and mastoid parts. In the neck, the extracranial part of the facial nerve entering the parotid gland, part of the IJV, and the CN XI can be identified. The tip of the mastoid process hides the upper part of the IJV, and the JF with all its contents.

Following Removal of the Mastoid Tip

The upper part of the IJV and the CN XI could be controlled. Also, the exit of the CN VII from the stylomastoid foramen and the base of the styloid process are now visible. The lower part of the CN XII and the occipital artery can be seen crossing the ICA. However, the ICA and the contents of the JF are still obscured.

Inferolateral Approach without Facial Nerve Rerouting

Resection of the styloid process with retro- and infrafacial drilling, then retro- and infrasigmoid sinus drilling through the jugular tubercle, giving sufficient exposure of the junction of the sigmoid sinus and the jugular bulb, and allowing control of the venous system without the need to drill the occipital condyle. The hypoglossal canal between the jugular tubercle and the occipital condyle is exposed for anatomic descriptive purposes. However, proper control of the lower CNs could not be achieved at this stage.

The lateral wall of the jugular bulb is separated from the vertical segment of the facial nerve by the retrofacial and infralabyrinthine air cells; we also discovered that the average distance between the jugular bulb and the medial wall of the vertical segment of the facial nerve is 1 cm, and from the jugular bulb to the hypoglossal canal is 1 cm. Consequently, the exposure of all the venous complex carries no risk of injury to the lower CNs.

Anterior Transposition of the Facial Nerve (Infratemporal Approach A)

With the opening of the stylomastoid foramen, the CN VII is now able to be freed and anteriorly rerouted to expose the underneath of the jugular vein and foramen, as well as the removal of the styloid process, as mentioned before. This allows drilling of all of the tympanic bone remnants to skeletonize the vertical petrous ICA. So, in addition to the exposure of the venous complex, there is also the exposure of the upper part of the ICA and the upper course of lower CNs in the neck, but we could not yet control the CNs at the level of the JF. (►**Fig. 4**)

Exposure of the Lower Cranial Nerves

The CN IX exits the JF and is the most lateral and anterior nerve in its exit position. The rootlets of the vagus nerve run caudally to the glossopharyngeal nerve, coursing ventrally to the choroid plexus of the foramen of Luschka, and entering the JF posteriorly to the glossopharyngeal nerve in conjunction with the cranial component of the spinal accessory nerve. The vagus and spinal accessory nerves course anteromedially to the jugular bulb, exiting the foramen between the ICA and internal jugular vein. We found anastomotic

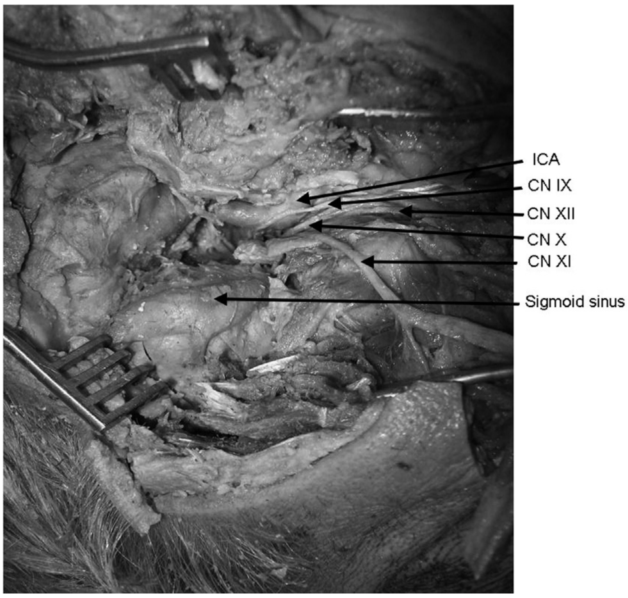

Fig. 5 Exposure of the lower cranial nerves (CNs) in the jugular foramen and the high neck area, after removal of the internal jugular vein (IJV).

connections of CN X with the cranial component of CN XI, as well as with CN XII and IX. (►**Fig. 5**)

The CN XI is easily identified, coursing laterally over the internal jugular vein below the foramen. Following CN XI retrogradely, the exits of XI and X are more medial and slightly posterior to IX. The close proximity of IX to the ICA, as well as the more medial orientation of X and XI—with X lying most medially among the three—should be noted at the base of the skull. In our specimens, no bony partition dividing the JF into two sections was found.

As a result, the glossopharyngeal nerve emerges from the cranial cavity through the foramen's medial part (pars nervosa). The lateral part of the cranial cavity is where the internal jugular vein, vagus nerve, and spinal accessory nerve exit the cranial cavity (pars venosa). The hypoglossal nerve exits the cranial cavity via the hypoglossal canal, which is usually located anteroinferiorly to the JF. The carotid canal opens anteromedially to the JF.

Discussion

Tumors are the main pathological lesions arising in the JF. They may arise in the adventitia of the dome of the internal jugular vein.[6] Consequently, the standard management of these lesions is their surgical removal. They were considered to be unresectable in the past due to limited surgical equipment and techniques. Even now, surgical access to the JF is difficult.

We aimed to review the three-dimensional anatomy of the JF and the relationships of its internal structures on four cadaver specimens and 41 surgical cases.

Catalano and David[1] addressed that the anatomic "bottleneck" is encountered during dissection between the transverse process of C1, the descending portion of the facial nerve, and the anteromedial vascular structures, namely the jugular bulb and ICA.

Ayeni et al.[7] reported that in 20 (100%) specimens studied; the JF was divided into two separate dural compartments by either a fibrous or bony septum. The septum was a complete bony bridge in 15%; in 5%, the bony bridge was incomplete, extending from the jugular spine of the petrous temporal bone to the middle of the JF.

We found that in 4 (50%) out of the eight sides dissected there was a bony septum dividing the JF and the remainder were dense fibrous. However, this compartmentalization was not present at the exocranial portion of the JF.

Saleh et al.[8] identified that the glossopharyngeal nerve traversed the anterior compartment, whereas the vagus and spinal accessory nerves traversed the posterior compartment in 27 (96%) of the 28 specimens that had a bipartite foramen. In the remaining specimen, all three nerves were confined to the anterior compartment, and the jugular bulb alone was located in the posterior compartment. In our work, the glossopharyngeal nerve was always anterior and laterally positioned, while the vagus and accessory CNs were medial and posterior to the internal jugular vein. Consequently, they delineated the boundaries of the entrance of the inferior petrosal sinus.

Van Loveren et al.[9] stated that in the infratemporal fossa, CNs IX through XI is located in loose connective tissue, anteromedial to the jugular bulb and separated from it by fibrous tissue of variable thickness or a bony septum. Identification of CNs IX to XI in the infratemporal fossa is difficult during surgery, because a discrete division of the contents of the exocranial JF into pars nervosa and pars venosa is absent at this level. In all dissections we did, the right jugular vein was found to be larger than the left jugular vein, and it was the motivation for showing the right side in our study.

We tracked the CNs IX through XI from below in the upper neck upwards to the JF to orientate ourselves with the anatomic relations of these structures in a retrograde manner. The easiest was the CN IX, as it is in a separate compartment in most of the cases, and in a very high and anterior direction in the foramen jugular area.

Tekdemir et al.[6] reported that the glossopharyngeal nerve entered the JF from the anterosuperomedial aspect in all cadavers. After entering the foramen, the nerve made a curve with an angle of 90° near the external opening of the Cochlear canaliculus and descended vertically in the JF.

We confirmed this, as well as the presence of a bony septum in all cases separating the jugular vein from the ICA, and when this septum is drilled, it leads to a wide opening of the bottleneck area and identification of the glossopharyngeal nerve lying on the lateral aspect of the ICA, which is impossible to find before this.

Van Loveren et al.[9] stated that in the cervical region, the glossopharyngeal nerve is difficult to preserve because of its lateral position and its adherence to the fibrous sheath that anchors it to the ICA. But during surgery, we could be able to identify the nerve by retrograde positioning and opening of the bony septum between the JV and the ICA, and in most cases we preserved the CN IX.

The vagus nerve was located between the accessory and the glossopharyngeal nerves. The vagus and accessory nerves ran together in the JF and were encased in the same fibrous sheath, with nervous connections to each other, so their nerve fibers intermingled, making microdissection impossible. We also found that the vagus and the hypoglossal, and the accessory CNs are intimately related in the foramen area, and the CN X and XII are very close and show anastomosis with each other in the area and could be separated practically by tracking from the neck upwards. The CN XI is more posterior and obvious, and it is a key point to start the dissection to separate pars venosa from pars nervosa.

Sheen et al.[10] said that 70% of the spinal accessory nerve sits lateral to the jugular vein, 27% sits medial to the jugular vein, and 3% passes through the vein in this area. We confirmed that this nerve has a constant course. It was medial to the vein in 25% of the specimens, and it was posteriorly positioned and lateral to the vein inside the foramen, but such an anatomic variability has no practical incidence in the management of the tumoral process.

As regards the facial nerve, we could preserve the stylomastoid foramen in most of the surgical cases and avoid anterior rerouting of the facial nerve until class C1 tumors, following the Fisch classification. But this requires complete drilling of both the tympanic bone inferolaterally and the jugular tubercle posteriorly.

Aslan et al.[11] said that the IX nerve made a genu within the JF in all specimens. We found this glossopharyngeal genu to be lodged at the external opening of the carotid canal in 91% of the specimens. This intimate relationship should also be kept in mind while performing enlarged translabyrinthine surgery so as to avoid a possible injury to the glossopharyngeal genu. We also evidenced that the CN IX is vulnerable to injury during deep dissection in the area of the hypotympanum and, more anteriorly, near the carotid artery.

Another structure that runs through the JF is the posterior meningeal artery. According to Ayeni et al.,[7] this artery is frequently found to rise from the ascending pharyngeal artery. Rhoton and Buza[12] reported an 8% incidence of the posterior meningeal artery emerging from the anterior-inferior cerebellar artery. The meningeal artery emerged from the ascending pharyngeal artery, in our dissection, and is located between the CNs X and XI, and occasionally between the CNs X and XII just below the JF in the high neck.

Conclusion

The JF anatomy is complicated, and the key to safely operate on it and preserve the lower CNs is to find the posterior belly of the digastric muscle, skeletonize the facial nerve, remove the mastoid tip preserving the stylomastoid foramen, skeletonize the sigmoid sinus and posterior fossa dura not only anterior but also posteroinferiorly, and, finally, reach and drill the jugular tubercle. At that time, retrograde identification of the lower CNs and upward reflection of the jugular vein are crucial points to preserve the pars nervosa, regardless of the tumor size and surgical management of the facial nerve. The reflection of the styloid process, with its muscular attachments downwards, and sharp dissection of the septum between the ICA and the internal jugular vein, will widely open the bottleneck area of the JF and the access to the ICA.

Ethical Approval

All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional research editorial boards and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional research editorial board (33–5-021).

Availability of Data and Materials

The datasets used and/or analyzed during the current study are available from the corresponding authors upon reasonable request.

Authors' Contributions

A.F, methodology and idea; M.D, review writing and editing the final draft; J.M, data collection; R.M, data collection and revision; A.D, data collection, and revision; S.Z, review writing and reference collection.

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Conflict of interests

The authors have no conflict of interests to declare.

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