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Technique

Middle fossa approach: microsurgical anatomy and surgical technique from the neurosurgical perspective

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Abstract

Background: The purpose of this study was to call attention to the subtemporal approach directed through the petrous apex to the IAM. We studied the microsurgical anatomy of the middle floor to delineate a reliable angle between the GSPN and the IAM to precisely localize and expose the IAM from above. A new technique for the elevation of middle fossa floor in an anterior-to-posterior direction has also been examined in cadaveric dissections and performed in surgery.

Methods: The microsurgical anatomy of the middle fossa floor was studied in 10 adult cadaveric heads (20 sides) after meatal drilling on the middle fossa. Five latex-injected specimens were dissected in a stepwise manner to further define the microsurgical anatomy of the middle fossa approach. The middle fossa approach is illustrated in a patient for the decompression of the facial nerve to demonstrate the surgical technique and limitations of bone removal.

Results: Elevation of middle fossa dura in an anterior-to-posterior direction leads to early identification of the GSPN, where the nerve passes under V3. The most reliable and easily appreciated angle to be used in localizing the IAM is between the IAM and the long axis of the GSPN, which is approximately 61°. Beginning drilling the meatus medially at the petrous ridge is safer than beginning laterally, where the facial and vestibulocochlear nerves become more superficial. The cochlea anteromedially, vestibule posterolaterally, and superior semicircular canal posteriorly significantly limit the bone removal at the lateral part of the IAM.

Conclusions: The surgical technique for the middle fossa approach which includes an anterior-to-posterior elevation of middle fossa dura starting from the foramen ovale and uses the angle between the IAM and the long axis of the GSPN to localize the meatus from above may be an alternative to previously proposed surgical methods.

Keywords: Acoustic neuroma; Facial nerve; Microsurgical anatomy; Middle fossa approach

1. Introduction

Since the initial description of the IAM exposure through the petrous apex for the division of the vestibulocochlear nerve in a case of tinnitus and vertigo by Parry [29] in 1904, the middle fossa approach has been an important part of an otolaryngologist's, and less frequently a neurosurgeon's, armamentarium. In 1961, William House [18], an ear-nose-throat surgeon, redefined the approach with the aid of the operating microscope for decompression of the IAM in the management of otosclerosis.

The middle fossa approach has undergone several modifications to expand its exposure along the cerebellopontine angle, petrous apex, tentorial incisura, upper clivus, and posterior cavernous sinus [2,14,15,20,22-25]. The modifications of the middle fossa approach can be classified

Abbreviations: GSPN, greater superficial petrosal nerve; IAM, internal acoustic meatus; MMA, middle meningeal artery; SCC, semicircular canal; V3, mandibular division of the trigeminal nerve.

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according to their extensions into various anatomical regions: the middle fossa approach to the internal auditory canal, the extended middle fossa approach with a wider opening of the posterior part of the petrous pyramid for the removal of larger acoustic neuromas, and the middle fossa anterior transpetrosal approach, so-called the Kawase's approach, which is designed for the anterior cerebellopontine angle, the ventral surface of pons, and the upper clivus. This article focuses on the subtemporal approach to the IAM (middle fossa and its extended modification), which provides exceptional exposure to the cisternal, meatal, labyrinthine, and tympanic segments of the facial nerve, the vestibulocochlear nerve, and the geniculate ganglion [9,10,12,13,17,18].

The middle fossa approach to the IAM and its extensions have been used for the removal of small acoustic tumors with the potential for hearing preservation, facial nerve exploration, and vestibular nerve section [16,17,21,35,36]. As hearing preservation is the hallmark of the middle fossa approach, a detailed knowledge of the anatomy of the middle fossa floor to define the surgical limitations, such as the inner ear structures and the ossicular chain, is mandatory for neurosurgeons [27,38]. Our purpose was to describe the microsurgical anatomy of the middle fossa approach to the IAM and to delineate the angle between the GSPN and the IAM, which can be used as a guide to accurately locate the meatus from above. We also intended to define the technical details of a modified technique, which includes the anteroposterior elevation of middle fossa dura, starting from the mandibular division of the trigeminal nerve (V3), and uses the angle between the GSPN and IAM to precisely localize the meatus on the middle fossa floor.

2. Materials and methods

The microsurgical anatomy of the middle fossa floor was studied and the measurements were taken in 10 formalin-fixed adult cadaveric heads (20 sides) after meatal drilling on the middle fossa. The angle between the GSPN and the IAM has been measured in 10 formalin-fixed adult cadaveric heads (20 sides), using 3 to 40 magnification, after the meatal drilling on the middle fossa. The distance between the geniculate ganglion and the point, where the GSPN passes under the mandibular nerve, has also been measured in these dissections. In addition, an extradural subtemporal middle fossa approach to the IAM was performed in 5 formalin-fixed adult cadaveric heads and the petrosal part of the temporal bone above the IAM was removed by using microsurgical techniques to demonstrate the limiting anatomical structures for the bone removal at the lateral part of the IAM. The surgical technique to elevate the middle fossa dura and to locate the IAM on the middle fossa floor was described in a case with traumatic delayed facial nerve palsy without temporal bone fracture where the hearing was preserved.

3. Results

3.1. Basic anatomical relationships

3.1.1. Facial nerve anatomy

The segments of the facial nerve and its relation with the temporal bone should be thoroughly understood to clarify the microsurgical anatomy of the middle fossa floor, as the course of the nerve and its ganglion are the key landmarks during exposure of the IAM from above [3,38,40]. The facial nerve, the seventh cranial nerve of the second brachial arch, extends from the pontomedullary junction to the parotid gland and has 6 segments: cisternal, meatal, labyrinthine, tympanic, mastoid, and extracranial or intraparotid. The middle fossa approach is closely related with proximal 4 segments and the geniculate ganglion, so the microsurgical anatomy will be discussed in this regard.

3.1.2. Cisternal and meatal segments

The facial nerve leaves the brain stem at the pontomedullary junction anteromedial and below the vestibulocochlear nerve (Fig. 1A). The initial cisternal segment of the facial nerve, approximately 24 mm in length, is closely related to the vestibulocochlear nerve and the nervus intermedius, or the sensory root. The meatal segment, about 8 mm in length, follows a shallow gutter in an anterosuperior aspect of the IAM (Fig. 1B and C). The positions of the facial and the vestibulocochlear nerves are most constant in the lateral portion of the IAM, which is divided into a superior and an inferior portion by a horizontal ridge, called the transverse crest. The superior compartment is further divided by a vertical crest into an anterior smaller facial and a posterior larger superior vestibular compartments. The vertical crest, also called “Bill's bar” in recognition of William House, is made up of variably ossified arachnoid tissue and usually cannot be visualized with current computed tomography technology.

3.1.3. Labyrinthine-tympanic segments

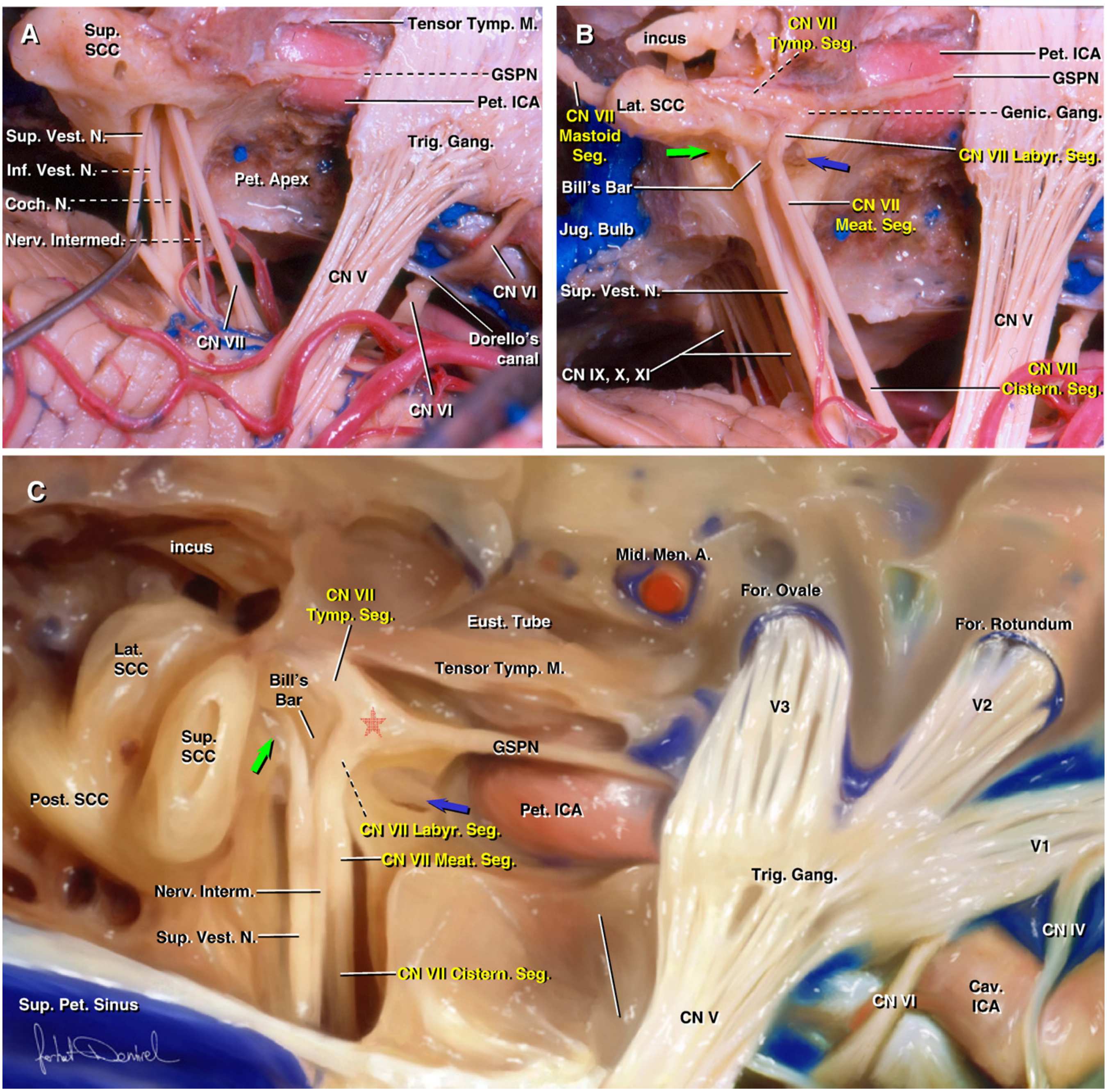
The orifice of the facial canal in the IAM measures 0.68 mm in diameter [31]. The labyrinthine segment of the facial nerve, so named because of its intimate relationship to the cochlea and the superior SCC, is the narrowest (<0.7 mm) and shortest (3-5 mm) segment (Fig. 1B and C). This segment is related to the apical turn of the cochlea medially and the ampullae of the lateral and superior SCCs posterolaterally, and terminates in the geniculate ganglion.

The geniculate ganglion, a bulbous enlargement of the facial canal, contains the terminal part of the nervus intermedius, which emerges from the ganglion as the GSPN (Fig. 1). The GSPN can be identified medial to the arcuate eminence as it leaves the geniculate ganglion by passing through the sphenopetrosal groove along the middle fossa floor, immediately superior and anterolateral to the horizontal segment of the petrous carotid. In our dissections, the GSPN traveled an average of 17 mm anteriorly from the geniculate ganglion to the level of V3, where it passed under the nerve (Figs. 1 and 2). The GSPN, from this point, passes forward under the gasserian ganglion to reach the vidian canal, eventually to supply the lacrimal gland via the pterygopalatine ganglion [29].

The tympanic segment of the facial nerve begins at the geniculate ganglion, pursues a straight course measuring 7 to 12 mm in length, and ends at the level of the stapes, where the nerve turns downward below the lateral SCC (Fig. 1B and C). The initial part of the tympanic segment of the facial nerve is densely concealed by bone; however, the bony wall adjacent to the middle ear is very thin [31]. Only a few millimeters of bone separate the tympanic segment of the facial nerve from the vestibule medially. The distal tympanic segment courses immediately beneath the short process of the incus, where the mastoid segment of the facial nerve begins.

3.2. Middle fossa approach

We performed the middle fossa approach in 5 cadavers (10 sides) to define the microsurgical anatomy and delineate the efficacy of a modified technique to precisely localize the IAM (Figs. 1-3). The technique is a modification of the work of Garcia-Ibañez and Garcia-Ibañez [11], who proposed to



locate the IAM by relying on the angle between GSPN and the superior SCC. In our study, the angle between the IAM and the long axis of the GSPN was pretty constant and measured 61° (range, 55°-64°). The use of this angle has been proposed to precisely localize the IAM on the middle fossa floor [32] (Figs. 2C and 3A). The distance between the geniculate ganglion and the point where the GSPN passes under V3 was also fairly constant, approximately 17 mm (range, 13-21 mm). In those cases where the geniculate ganglion could not be identified on the middle fossa floor or an additional drilling was needed, locating the line of drilling at this point and using the 61° angle provided satisfactory exposure of the IAM. In all of our dissections, we were able to accurately locate the IAM using the angle between the GSPN and the IAM, and drilled it from medial to posterolateral beginning from the petrous ridge. The cisternal, meatal, labyrinthine, and the tympanic segments of the facial nerve were exposed along with the geniculate ganglion (Fig. 2).

3.2.1. Surgical technique

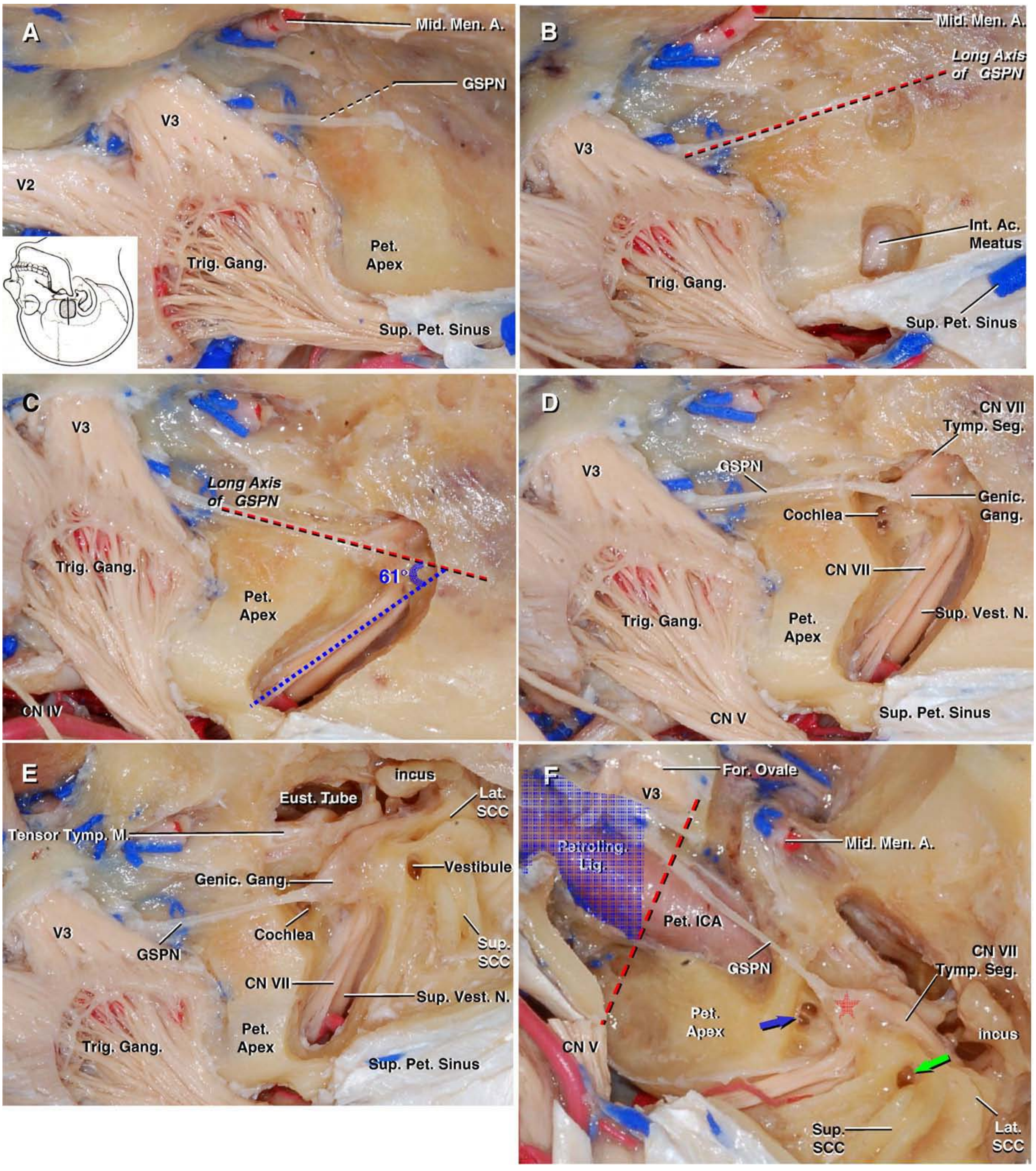
We performed the approach in the supine position with the patient under general anesthesia and with the head turned less than 90° to the contralateral side, which allowed us for more extension of the head on the operating table (Fig. 3). If needed, the operating table can be mobilized to the contralateral side during the peeling of the dura or temporal bone drilling. We also used a lumbar spinal catheter for cerebrospinal fluid drainage to minimize the amount of temporal lobe retraction.

The incision begins from the tragus, extends perpendicular to the zygomatic arch, turns a little anterior on the upper edge of the pinna, and continues approximately to the level of the superior temporal line (Fig. 3C). Fascia and temporal muscle are exposed, split, and then retracted with fishhooks. A craniotomy with a diameter of 4 cm, two thirds of which extending anterior to the external auditory canal, is performed. A high-speed drill (Midas Rex Legend EHS, Medtronic, Fort Worth, Tex) is used for the removal of the edge of the temporal bone to gain an unobstructed exposure and to minimize the retraction of the temporal lobe. Cerebrospinal fluid drainage through the lumbar catheter is started at this point of the operation to decrease the amount of retraction on the temporal lobe. The operative microscope is introduced into the operative field, and elevation of the middle fossa dura is started at the region of the posterior root of the zygomatic arch. The foramen spinosum is identified initially and the MMA is sectioned about a centimeter distal to its exit from the foramen, to preserve the proximal perforating branches to the facial nerve and geniculate ganglion. The separation of the middle fossa dura is continued anteriorly and medially from the foramen spinosum, to expose the foramen ovale and the mandibular division of the trigeminal nerve (V_3) (Fig. 3C). Once the V_3 is identified, the peeling is continued medially about 6 mm until the GSPN becomes visible as it passes under the mandibular division. The dural elevation is continued up to the level of the superior petrosal sinus (Fig. 3C). The Leyla retractor, a self-retaining retractor, is placed, and extending the elevation of the middle fossa dura posteriorly and medially allows the superior petrosal sinus along the petrous ridge and the arcuate eminence to become visible.

The angle between the long axis of the GSPN and the IAM, 61°, is used for appropriate localization of the IAM on the middle fossa floor. We begin drilling the IAM medially on the petrous ridge with a 4-mm round cutting drill (Midas

Fig. 1. A and B: Superior view of the left temporal bone in a cadaveric specimen, stepwise dissection. A: The superior vestibular nerve has been retracted to show the cranial nerves approaching to the IAM. The petrous apex has been partly removed and the horizontal segment of the internal carotid artery has been exposed. The facial nerve arises at the pontomedullary junction anteromedial and below the vestibulocochlear nerve. The nervus intermedius initially attaches to the vestibulocochlear nerve and joins the facial nerve near the IAM. The trigeminal nerve passes the Meckel's cave toward its ganglion. The abducens nerve traverses through the Dorello's canal. B: Part of the labyrinth has been further removed and 5 segments of the facial nerve have been exposed to demonstrate the surgical limitations of bone removal at the lateral part of the IAM. The positions of the facial and the vestibulocochlear nerves are constant in the lateral portion of the IAM, and the Bill's bar divides the superior compartment of the meatus into an anterior smaller facial and a posterior larger superior vestibular compartments. The labyrinthine segment, the narrowest and shortest segment, courses anterolaterally and makes an abrupt angulation forward toward the geniculate ganglion and is related to the apical turn of the cochlea (blue arrow) medially and the superior SCC posterolaterally. The tympanic segment extends from the geniculate ganglion to the level of the stapes, where the nerve turns downward below the lateral SCC and the mastoid segment of the facial nerve begins inferior to the short process of the incus. The cochlea (blue arrow) lies in the angle between the labyrinthine segment and the GSPN. The vestibule (green arrow), a small cavity at the confluence of the SCCs, is located posterolateral to the fundus of the IAM. C: A drawing of the middle fossa floor based on a cadaveric dissection to demonstrate the middle fossa floor in relation to the middle fossa approach (left side). The bone over the petrous carotid and the IAM has been removed, and the SCCs have been unroofed to expose the facial and vestibulocochlear nerves, geniculate ganglion, cochlea, and vestibule. The surface of the floor of the middle fossa, as exposed through the middle fossa approach to the IAM, can be divided into 2 regions anteroposteriorly separated by a vertical plane passing through the anterior border of the cochlea. The anterior part contains the eustachian tube, tensor tympani muscle and horizontal segment of the petrous carotid artery, all of which lie side by side parallel to the GSPN in the space between the V3 anteriorly and the cochlea posteriorly. The posterior part of the middle fossa floor, the bony labyrinth, contains the cochlea, the vestibule, and the SCCs, which are all closely related to the meatal, labyrinthine, and tympanic segments of the facial nerve and the geniculate ganglion. The posterior border of the cochlea (blue arrow) is the fundus of the IAM, and, posterolaterally, it is related to the geniculate ganglion. The vestibule (green arrow), a small cavity at the confluence of the SCCs, communicates below the fundus with the cochlea. The superior, lateral, and posterior SCCs are situated posterosuperior to the vestibule. The superior SCC, the one that is most closely related to the middle fossa approach, projects toward the middle fossa floor. A indicates artery; Ac, acoustic; Cav, cavernous; Cistern, cisternal; Coch, Cochlear, CN, cranial nerve; Eust, eustachian; For, foramen; For, foramen; Gang, ganglion; Genic, geniculate; ICA; internal carotid artery; Inf, inferior; Int, internal; Interm, intermedius; Jug, jugular; Labyr, labyrinthine; Lat, lateral; M, muscle; Meat, meatal; Men, meningeal; Mid, middle; N, nerve; Nerv, nervus; Pet, petrous/petrosal; Post, posterior; Seg, segment; Subarc, subarcuate; Sup, superior; Trig, trigeminal; Tymp, tympani; Vest, vestibular.

Rex Legend EHS, Medtronic) and extend it posterolaterally toward the geniculate ganglion with a 3-mm diamond drill and constant suction and irrigation. The posterior fossa dura is exposed at the medial part of the operative view and then followed toward the lateral edge of the IAM. Opening the posterior fossa dura medially to laterally exposes the cisternal, meatal, and labyrinthine segments of the facial nerve anteriorly and the superior vestibular nerve posteriorly. The most difficult part of the drilling begins on the lateral part of the IAM toward the Bill's bar at the junction of the meatal and labyrinthine segments of the facial nerve (Figs. 2 and 3). The Bill's bar separates the anteriorly located facial canal from the posteriorly located superior vestibular area and should be identified for a complete exposure of the IAM



(Fig. 3C). The cochlea and the SCCs should be avoided to preserve the hearing when drilling the lateral part of the meatus (Fig. 4). The tympanic segment of the facial nerve is exposed distal to the geniculate ganglion when needed. At the end of the operation, the posterior fossa dura is closed with a small piece of temporalis muscle and fibrin glue. After careful hemostasis, the retractor is removed and the dura over the temporal lobe is sutured to the corners of the craniotomy. The bone flap is positioned back into its original site and a suction drain is secured in the subgaleal space.

4. Discussion

The microsurgical anatomy of the temporal bone offers the opportunity for 3 basic approaches to the region of IAM and cerebellopontine angle. The most popular one is directed through the posterior cranial fossa and posterior meatal lip, followed by an approach through the labyrinth and posterior surface of the temporal bone. A less used way of accessing the IAM, the middle fossa approach, is directed through the middle fossa floor and the roof of the meatus. The popularity of the middle fossa approach appears to have declined within the last decades, partly because of alternate more invasive approaches, and partly for reasons associated with its complications [1]. Nevertheless, the approach is unique in that it allows for direct exposure of the IAM; the cisternal, labyrinthine, and tympanic segments of the facial nerve; the vestibulocochlear nerve; and the perigeniculate area with total hearing preservation and gives the best opportunity for access to the IAM in some occasions [16,17]. The microsurgical anatomy of the middle fossa floor is complex and should be thoroughly studied to safely access the IAM from above.

4.1. Middle cranial fossa floor

The surface of the floor of the middle fossa, as exposed through the middle fossa approach to the IAM, can be divided into 2 regions separated by a vertical plane passing through the anterior border of the cochlea: an anterior part that contains the eustachian tube, tensor tympani muscle, and horizontal segment of petrous carotid artery; and a more vulnerable posterior part for the middle fossa approach, which contains the bony labyrinth (Fig. 1C).

In the anterior part of the middle fossa, the eustachian tube, the tensor tympani muscle, and the petrous carotid artery lie side by side parallel to the GSPN in the space between the V3 anteriorly and the cochlea posteriorly. The eustachian tube, the most lateral of the 3 anatomical structures, communicates the nasopharynx with the tympanic cavity. The cartilaginous part of the eustachian tube, which is attached to the lower margin of the sphenopetrosal groove, is closely related to the roof of the IAM (Figs. 1C and 2). The tensor tympani muscle is a long slender muscle which occupies a bony canal adjacent to the eustachian tube, from which it is separated by a thin bony septum (Fig. 1C). The canals for the tensor tympani superiorly and the eustachian tube inferiorly open into the upper part of the anterior wall of the tympanic cavity. The most medial of the 3 parallel structures in the anterior part of the middle fossa is the horizontal segment of the petrous carotid [6,7] (Figs. 1C and 2). The thickness of the bony covering over these structures, which is important in approaches directed to the middle fossa, shows great variability. The tensor tympani muscle, located above and lateral to the eustachian tube, is almost always covered by bone. The horizontal segment of the petrous carotid has been reported to be apparent without a dense bony covering just inferior to the posterior border of V3 in approximately 65% of the cases [26,30].

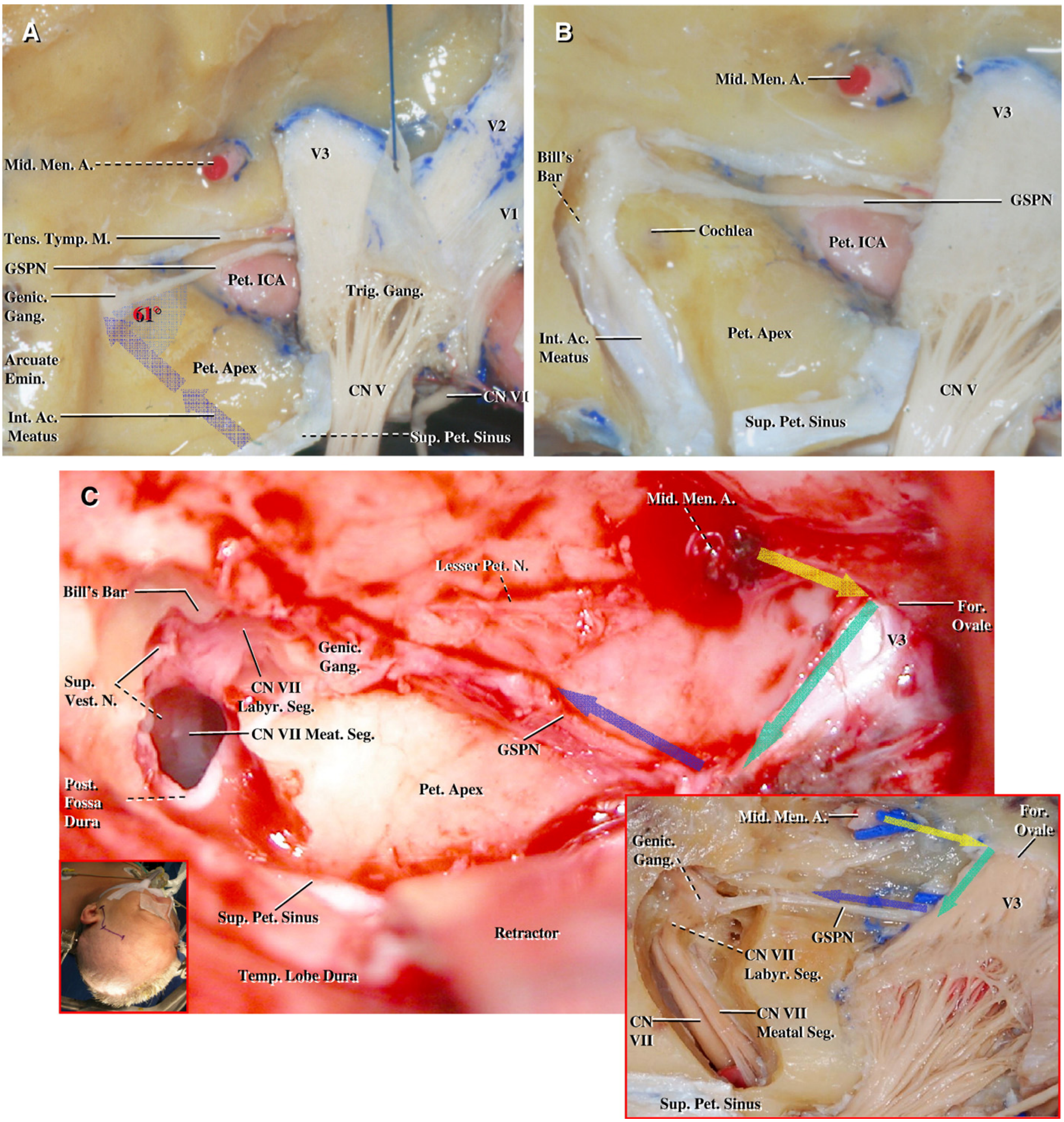
The bony labyrinth, which occupies the posterior part of the middle fossa, consists of 3 structures, the cochlea, the vestibule, and the SCCs (Figs. 1 and 2). These anatomical structures are closely related to the meatal, labyrinthine, and tympanic segments of the facial nerve and the geniculate ganglion, and all of them can be easily injured during middle fossa approach to the IAM.

Fig. 2. Stepwise dissection of the right middle fossa approach on a cadaveric specimen. A: The inset shows the skin incision and the craniotomy needed to expose the middle fossa floor. The middle fossa floor has been elevated and the MMA, GSPN, trigeminal nerve, superior petrosal sinus, and the petrous apex have been identified. B: The long axis of the GSPN has been marked with an interrupted red line. The IAM is located at a distance of approximately 1.7 cm from the lateral limit of V3, with an angle of 61° to the long axis of GSPN. Beginning drilling the IAM medially is safer than beginning laterally near the level of the geniculate ganglion, where the nerves are more superficial. C: The IAM has been opened and the nerves have been exposed from above by relying on its angle with the long axis of GSPN. The angle between the long axis of GSPN (red interrupted line) and the IAM (blue interrupted line) is 61°. D: The superior vestibular and the facial nerves have been exposed within the IAM along with the geniculate ganglion and the cochlea. The cochlea lies below the floor of the middle fossa in the angle between the labyrinthine segment of the facial nerve and the GSPN. The posterior border of the cochlea is the fundus of the IAM, and, posterolaterally, it is related to the geniculate ganglion. The cochlea should not be violated during the exposure of the lateral part of the IAM to preserve the hearing during a middle fossa approach. The bone over the tympanic segment of the facial nerve distal to the geniculate ganglion has been removed. E: The bone on the middle fossa floor has further been removed laterally to show the eustachian tube, the tensor tympani muscle, bony labyrinth, and the middle ear structures. The eustachian tube and the tensor tympani muscle lie side by side parallel to the GSPN in the space between the V3 anteriorly and the cochlea posteriorly. The bony labyrinth consists of 3 structures: the cochlea, the vestibule, and the SCCs. The vestibule, a small cavity at the confluence of the SCCs, is located in the central part of the bony labyrinth and situated posterolateral to the fundus of the IAM. The superior, lateral, and posterior SCCs are situated posterosuperior to the vestibule. The superior SCC, the one that is most intimately related to the middle fossa, projects toward the floor at the region of the arcuate eminence. F: The trigeminal nerve has been sectioned to expose the full course of the GSPN and the petrous ICA. The interrupted red line corresponds to the posterolateral limit of the V3 and the GSPN passes 1.7 cm from this point to the geniculate ganglion (marked with a red star). The cochlea (marked with a blue arrow) and the vestibule (marked with a green arrow) are the main structures to be preserved during the middle fossa approach. The petrous segment of the ICA passes under the petrolingual ligament to enter the cavernous sinus. The petrolingual ligament has been removed; however, the approximate position has been shown in the blue area. (See abbreviations in Fig. 1.)

The cochlea lies below the floor of the middle fossa in the angle between the labyrinthine segment of the facial nerve and the GSPN (Figs. 1-2). The posterior border of the cochlea is the fundus of the IAM, and, posterolaterally, it is related to the geniculate ganglion. The horizontal portion of the petrous carotid lies anteroinferior to the cochlea, which is separated from the artery only by a 2.1-mm thickness of bone. The vestibule, a small cavity at the confluence of the SCCs, is located in the central part of the bony labyrinth and situated posterolateral to the fundus of the IAM (Fig. 2E and F). The superior, lateral, and posterior SCCs are situated posterosuperior to the vestibule. The superior SCC, the one that is most intimately related to the middle fossa, projects toward the floor at the region of the arcuate eminence.

4.2. Elevation of the middle fossa dura

One of the critical surgical steps of the middle fossa approach is the elevation of the middle fossa dura. Ear-nose-



throat surgeons usually do not sacrifice the MMA at the foramen spinosum in the middle fossa approach to the IAM, unless the lesion is large and warrants an extended approach. However, from a neurosurgical standpoint, it is often necessary to sacrifice the MMA to gain a satisfactory exposure of the petrous apex region [4,37,39]. The branches to the facial nerve near the geniculate ganglion usually arise from the initial centimeter of the MMA as the vessel passes through the foramen spinosum, and the artery can be safely sacrificed distal to this point without any consequences [7]. Therefore, it is important to preserve a centimeter of the stem of the MMA at its exit from the foramen spinosum to preserve the branches that supply the facial nerve.

It has been advised that the separation of the middle fossa floor is easier from posterior to anterior [19]. Instead, we perform the peeling of the middle fossa floor in 3 steps, most of which involves an anterior-to-posterior peeling (Fig. 3C). Initially, we move anteriorly as soon as we coagulate and cut the MMA to identify the foramen ovale to begin elevating the dura over the V3 medially. The GSPN can be identified within a distance of approximately 5 mm from the foramen ovale at the point where the nerve intersects and passes under the V3. This point is easy and safe for an early identification of the GSPN, which may be injured iatrogenically on the sphenopetrosal groove during elevation of the middle fossa dura. In fact, it has been reported that there was no bone over the GSPN along its course on the sphenopetrosal groove in 30% of the cases, and in another 15%, a piece of bone covered the geniculate ganglion but not the GSPN [7,19,33]. Early identification of the GSPN as it passes under V3 permits an anterior-to-posterior peeling on the sphenopetrosal groove under direct vision, which will eventually result in safe identification of the geniculate area. The peeling of the middle fossa dura is easier medial to GSPN and should always extend to the superior petrosal sinus.

4.3. Exposure of IAM from above

The approach to the IAM through a subtemporal craniotomy needs a precise localization of the meatus on the floor of the middle fossa; however, variable relationships exist between the IAM and the nearby anatomical structures. Parisier [28] published the distances between anatomical landmarks in the middle fossa approach to help the surgeon avoid critical structures, such as the middle ear, cochlea, and carotid artery. In a detailed anatomical study, Day et al [5] expanded this work and described the middle fossa floor in terms of a rhomboid-shaped complex of landmarks, mainly focusing on the petrous apex removal. The IAM makes different angles with a variety of anatomical structures: 52° (range, 34°-75°) with the superior SCC, 44° (range, 35°-55°) with the superior petrosal sinus, and 158.5° (range, 150°-170°) with the external auditory canal [34]. The most constant angle is reported to be between the IAM and the superior petrosal sinus [34].

Three surgical techniques have been described to access the IAM during the middle fossa approach after the exposure of the GSPN, arcuate eminence, and the petrous ridge. House and Shelton [16] proposed that once the GSPN has been identified, it is possible to drill the floor of the middle fossa (2-3 mm), to identify the geniculate ganglion, and to follow the labyrinthine segment of the facial nerve medially until the IAM is reached. The House technique requires great care and meticulous technique and puts the facial nerve at risk more than that of the other 2 methods. As the labyrinthine segment is narrowest, the surgeon begins to open the IAM through a small corridor, where the facial and vestibulocochlear nerves are most superficial and most vulnerable to iatrogenic injury.

Fisch et al [8,9] described an imaginary line drawn 60° to a line over the long axis of the arcuate eminence, specifically

Fig. 3. A and B: Middle fossa approach to the IAM on the left side of a different cadaveric head. A: The dura has been removed from the middle fossa floor and cavernous sinus wall to expose the greater petrosal nerve, middle menigeal artery, and the nerves in the sinus wall. The tentorium has been removed preserving the edge adjacent to the superior petrosal sinus. The arachnoid over the Meckel's cave has been elevated with a stitch to show the trigeminal ganglion. We used the angle between the IAM and the long axis of the GSPN, approximately 60°, to precisely localize the IAM on the middle fossa floor (shown in blue). The distance between the geniculate ganglion and the point where the GSPN passes under V3 is approximately 15 mm, and locating the line of medial to posterolateral drilling at this point provides satisfactory exposure of the IAM (blue arrows). B: The bone over the IAM has been removed medially to posterolaterally, and the posterior fossa dura has been exposed to the level of the Bill's bar. The bone at the angle between the greater petrosal nerve and the IAM has been drilled to show the cochlea. The petrous apex has been preserved. As the MMA, V3, greater petrosal nerve, and arcuate eminence are the main anatomical landmarks exposed through the middle fossa approach, once the dura has been elevated, the most easily appreciated and reliable angle to be used in localizing the internal auditory canal seems to be between the IAM and the long axis of the GSPN. C: Intraoperative photograph of the middle fossa approach to the IAM. The insert on the lower left shows the position of the head and the skin incision and the insert on the lower right demonstrates the anatomical structures in a similar view. After a low temporal craniotomy, the middle fossa dura has been elevated. We perform the peeling of the middle fossa floor in 3 steps, most of which involves an anterior-to-posterior peeling. Initially, we move anteriorly as soon as we coagulate and cut the MMA to identify the foramen ovale (route of dissection is marked with a yellow arrow) to begin elevating the dura over the V3 medially (marked with a green arrow). The GSPN can be identified within a distance of approximately 5 mm from the foramen ovale, where the nerve passes under the V3. Early identification of the GSPN as it passes under V3 permits an anterior-to-posterior peeling on the sphenopetrosal groove under direct vision, which will eventually result in safe identification of the geniculate area (marked with a blue arrow). The peeling of the middle fossa dura is easier medial to the GSPN and should extend to the superior petrosal sinus. The angle between the IAM and the long axis of the GSPN has been used for localization, and the bone over the IAM has been drilled medially to posterolaterally. The bone removal has been extended laterally to the Bill's bar. The posterior fossa dura has been opened and the superior vestibular nerve and the cisternal, meatal, and labyrinthine segments of the facial nerve have been exposed. The lesser petrosal has been preserved by using the anterior-to-posterior peeling of the middle fossa dura. The lesser petrosal nerve arises from the geniculate a few millimeters lateral to the greater petrosal nerve and traverses in a small canal below that for tensor tympani toward the foramen ovale. Emin indicates eminence; Temp, temporal; V1, ophtalmic division of trigeminal nerve; V2, maxillary division of trigeminal nerve; V3, mandibular division of trigeminal nerve. For the rest of the abbreviations, see Fig. 1.

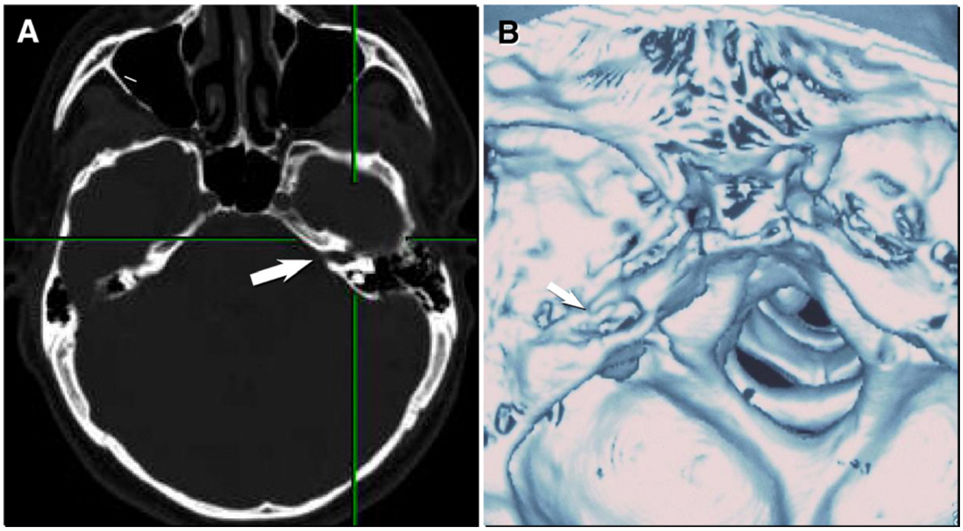


Fig. 4. A. and B: Postoperative computed tomography imaging after the middle fossa approach to the IAM. Computed tomography scan and its 3-dimensional reconstruction show the amount of bone removal (white arrows) during the middle fossa approach to the IAM.

to the superior SCC. The imaginary line provides the location of the IAM. This method requires the drilling of the arcuate eminence to locate the superior SCC, with the risk of opening it. When the blue reflection of the superior SCC is obtained, the IAM is found on 60° angle anteromedially. Great care must be given to avoid damage to the SCC in this technique.

In 1980, Garcia-Ibañez and Garcia-Ibañez [11] published one of the largest middle fossa approach series in cases of vestibular neurectomies and proposed to locate the IAM by relying on a constant angle of 120° between the GSPN and the superior SCC. The authors suggested that bisecting this angle provides the site at which to start drilling the temporal bone to expose the IAC, which may be performed laterally to medially [11]. The MMA, V3, the GSPN, and the arcuate eminence are the only anatomical landmarks exposed through the middle fossa approach, once the dura has been elevated. One of the most reliable and easily appreciated angles to be used in localizing the internal auditory canal is between the IAM and the long axis of the GSPN, which is approximately 61°. It is easier to locate the IAM approximately 37° medial to the long axis of the arcuate eminence at an angle of about 60° medial from the long axis of the GSPN. The distance between the geniculate ganglion and the point where the GSPN intersects with V3 is approximately 15 mm and placing the angle at this point provides the definitive position of the IAM along the middle fossa floor. We were able to locate the IAM accurately with this technique in all of our anatomical dissections and in surgery.

Contrary to most of the literature, we begin drilling the IAM medially at the petrous ridge and follow the posterior fossa dura laterally for several reasons. In contrast to the medial part, the lateral edge of the IAM is intimately related to important anatomical structures, such as the cochlea, vestibule, superior SCC, and the geniculate ganglion. Furthermore, the distal part of the meatal and the labyrinthine segment of the facial nerve disclose a different course and angulation, and the nerve is narrower than the more proximal parts of the facial nerve at the lateral edge of the IAM. Finally, the facial and vestibulocochlear nerves are deep at the petrous apex region, but become more superficial as they approach to the lateral part of the meatus.

4.4. Limitations of bone removal at the lateral part of IAM

One of the most difficult surgical steps of the middle fossa approach is drilling of the bone at the lateral part of the IAM. As the drilling advances nearer to the lateral part, the facial canal becomes slightly constricted by the vertical crest or the Bill's bar creating an unsafe zone for drilling. Three anatomical structures limit the bone removal at the lateral part of the meatus: anteromedially the cochlea, posterolaterally the vestibule, and posteriorly the superior SCC. The cochlea lies anteromedial to the IAM in the angle between the labyrinthine segment of the facial nerve and the GSPN. The bone removal just behind the cochlea can be drilled with a 2-mm diamond drill, as the periosteum of the IAM is thicker at this point than any part along the facial canal [31]. The horizontal portion of the petrous carotid lies anteroinferior to the cochlea, separated only by a 2.1-mm thickness of bone. The vestibule is situated posterolateral to the fundus of the IAM and the superior SCC is located posteriorly at the region of the arcuate eminence. The labyrinthine segment of the facial nerve at the lateral edge of the meatus is not only related to the apical turn of the cochlea anteromedially, but also to the ampullae of the lateral and superior SCCs posteriorly and laterally creating a dangerous zone for drilling. The vestibule and the cochlea can be easily injured during drilling of the bone above the labyrinthine segment of the facial nerve at the lateral part of the IAM.

5. Conclusions

As hearing preservation is the hallmark of the middle fossa approach, a detailed knowledge of the microsurgical anatomy of the middle fossa floor is mandatory to define the surgical limitations and to avoid any complications. Elevation of the dura on the middle fossa floor in an anterior-to-posterior direction may lead to early and safe identification of not only GSPN, where the nerve passes under V3, but also the lesser petrosal nerve and the geniculate ganglion. A reliable angle to be used in localizing the IAM is between the IAM and the long axis of the GSPN and is approximately 61°. It is safe to begin drilling the IAM medially at the petrous ridge, as the lateral part of the IAM is closely related to the bony labyrinth. The technique to localize and expose the IAM through the middle fossa floor, using the angle between the IAM and the long axis of the GSPN, may be an alternative to previously proposed surgical methods.

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Commentary

The authors performed a study of the microsurgical anatomy of the structures relevant for the middle fossa approach to the internal auditory canal. They described a new technique for the elevation of the middle fossa floor in an anterior-to-posterior direction that has also been examined in cadaveric dissections and performed in surgery. This technique allows early identification of the GSPN, where the nerve passes under V3. They introduce a new angle and propose its application for localizing the IAM: the angle between the IAM and the long axis of the GSPN, which is approximately 61°.

The real strength of the manuscript lies in the description of the microsurgical anatomy of the middle cranial fossa and the clear illustrations provided by the authors. Each step of the middle fossa approach has been illustrated and presented in detail. Furthermore, the anatomical details with surgical significance are underlined (eg, to preserve the proximal perforating branches to the facial nerve and geniculate ganglion, the MMA should be sectioned about 1 cm distal to its exit from the foramen). Although we do not perform and recommend this approach in case of vestibular schwannomas, it might be a useful route to the petrous segment of the facial nerve in patients with preserved hearing (eg, in posttraumatic facial nerve palsy). An important consideration that should be always kept in mind, however, is that the microanatomy of cadaver heads differs from the ones seen at surgery, which might be additionally distorted by the pathologic process.

The clinical reliability of the newly described angle remains to be proven in real surgeries.

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