The internal acoustic meatus and its meningeal layers: a microanatomical study

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Object. The authors studied the cadaveric heads of 22 adults to describe the internal acoustic meatus (IAM) and its contents. Special attention was paid to the length of the arachnoidal and dural sheaths surrounding the neural structures, including the vestibular ganglion. An additional goal of this study was to verify anatomically the concept of arachnoidal duplication, which is reputedly induced by medial growth of vestibular neuromas and helpful in atraumatic dissection.

Methods. Twelve cadaveric heads (24 IAMs) were injected with colored latex and fixed in formalin. Cautious removal of the skull vault and the brain or the skull base allowed superior and anteroinferior views of the IAM, respectively. Photographs were obtained after removal of the bone canal and dissection of the meninges with the aid of optic magnification. Ten IAMs were prepared for histological study and the osteological anatomy of the fundus was endoscopically described for the remaining 10.

The dura mater covered the bone structures of the IAM, and the arachnoidal membrane of the cerebellopontine cistern invaginated into this dural cul-de-sac as a “muff.” The entire neurovascular content of the IAM, including the vestibular ganglion, was surrounded by this arachnoidal sheath in which cerebrospinal fluid circulated. The length of this arachnoidal sheath was the same ventrally and dorsally and, in all specimens, the entrance of the cochleovestibulofacial complex into the subarachnoid space was located at the fundus level.

Conclusions. In this study the authors demonstrated the existence of an acoustico-facial cistern containing every nerve of the vestibulocochlear complex, including the vestibular ganglion from which acoustic neuromas develop. These findings clearly contradict the theory of the duplication of arachnoidal layers during medial growth of vestibular neuromas and may explain some of the intraoperative difficulties encountered in the atraumatic dissection of these tumors.

KEY WORDS • acoustic neuroma • facial nerve • vestibulocochlear nerve • meninges • internal acoustic meatus

Since the first description by Yaşargil and colleagues, it has been widely accepted that the origin of an acoustic neuroma is located outside the subarachnoid space. The results of their in vivo study, performed in the 1970s, demonstrated that acoustic neuromas originate from the intracanalicular segment of the vestibular division of the eighth cranial nerve located outside the subarachnoid space, whereas the intracanalicular portions of the facial and cochlear nerves are located inside the subarachnoid space (Fig. 1A). According to their theory, growth of an acoustic neuroma pushes the arachnoid wall of the cerebellopontine cistern medially and induces an apparent duplication of the arachnoidal layers. If the tumor reaches the boundaries of the different cisterns, a triplication of the arachnoidal layers may even occur.

Also according to this theory, to avoid injury to the pia mater or pontine vascularization during the extirpation of neuromas, an arachnoidal layer should be left on both the tumor and the pons. This idealistic concept of atraumatic dissection is not consistently observed, however, because the facial nerve (or the cochlear nerve) is sometimes closely adherent to the neuroma without any arachnoid interface between the nerve and the tumor.

We hypothesized that anatomical variations in the length of the arachnoidal sheath within the IAM (Fig. 1) may create a more or less clear neuroma/nerve interface that could explain some of the intraoperative difficulties encountered. The purpose of this study was to review the anatomical relationships of the vestibulocochleofacial complex and its meningeal layers within the IAM. Special attention was given both to the length of arachnoidal and dural sheaths around the neural structures and to their relationships with the vestibular ganglion.

Materials and Methods

Cadaveric heads from 22 adults (44 IAMs) were studied by performing microdissection and histological and endoscopic examinations.

For the microanatomical study, vessels in 12 cadaveric heads were injected with colored neoprene latex: red for the internal carotid and vertebral arteries and blue for the jugular veins. The specimens were fixed with a 20%-formalin solution and bleached with a...
20%—hydrogen peroxide solution. After several weeks, this procedure induced softening of the bone without modifying the fixed soft tissues, thus allowing the bone to be cut with an ordinary scalpel. Cautious removal of the skull vault and brain or of the skull base allowed superior and inferior views of the IAM, respectively. After removal of the bone canal, dissections were performed with the aid of optic magnification (250-, 300-, and 400-mm focal distances). The meningeal layers were progressively dissected to describe the contents of the IAM. The arachnoid was emphasized with a toluidine blue solution by using two techniques: in the first, a drop of this solution was spontaneously spread over the surface of the arachnoid and stained it blue and, in the second, the blue solution was also injected into the cerebellopontine cistern to observe its lateral diffusion into subarachnoid spaces within the IAM.

For the histological studies, five fresh cadaveric heads (10 IAMs) were used. The contents of three IAMs—nerves and leptomeninges—were removed en bloc via a middle cerebral fossa approach.15 After fixing with 10% formalin, the specimens were embedded in paraffin and transversally cut. The 10-μm-thick sections were stained with HES and Masson green trichrome. The seven other temporal bones were removed en bloc, with a special effort to avoid traction on the nerves and the arachnoidal sheath inside the IAM. These specimens were fixed in 10% formalin, decalcified, and embedded in a mixture of 95% paraffin/5% resin. Successive 10-μm sections were obtained in the horizontal plane for three temporal bones, in the vertical plane parallel to the IAM for two specimens, and following the vertical plane perpendicular to the IAM for the remaining two. These sections were also stained with HES and Masson green trichrome and subsequently studied using light microscopy.

Five dry skulls (10 IAMs) were studied using direct endoscopy to describe the fundus of the IAM and to confirm the morphology of the transverse crest.

**Sources of Supplies and Equipment**

The surgical microscope (model OPMI 9FC) was manufactured by Zeiss (Oberkochen, Germany). The Nikon camera (FE) and Kodak film (Ektachrom 160T) were purchased from Nikon (Tokyo, Japan) and Eastman Kodak (Rochester, NY), respectively. The teleoscopy with a Hopkins straight forward-viewing lens (0’, 4-mm diameter, 6-cm length) and the video camera (model Endo- vision Telecom SL-IPM) were purchased from Karl Storz (Tuttlingen, Germany), and the digital image capture system (model DKR-700-P) was manufactured by Sony (Tokyo, Japan). The Hasselblad camera and lenses were purchased from Victor Hasselblad AB (Göteborg, Sweden). The RSX100 120 roll–film was manufactured by Agfa-Gevaert S.A. (Rueil-Malmaison Cédex, France). The Rapide Décalcifiant Osseux used to decalcify the temporal bones was manufactured by Laboratoires Eurobio (Les Ulis, France). The neoprene latex (#671) injected into the vessels of the cadaveric heads was manufactured by El DuPont de Nemours–Dow Elastomers (Wilmington, DE).

**Results**

**The IAM Bone Canal**

The IAM was a cylindrical bone canal grooved into the medial aspect of the pars petrosa of the temporal bone. The porus was the medial opening of the IAM that faced the cerebellopontine cistern. The IAM was directed ventrolaterally toward its fundus, which faced the medial part of the vestibule and the tractus spiral of the cochlear area.

The transverse crest, located at the fundus of the IAM, was a ventrodorsally directed bone structure. It was triangularly shaped, with its ventral portion always larger than its dorsal segment. Endoscopy of the IAM demonstrated that usually this crest clearly divided the fundus into an upper and a lower compartment (Fig. 2A). When this was not the case, it was truncated or thinned and perforated by several small foramina to allow passage of the saccular nerve (Fig. 2B).
The area below the transverse crest was divided by a vertical crest separating the cochlear area (ventral) from the inferior vestibular area (dorsal). The cochlear area extended toward the anterior wall of the IAM and was riddled with two rows of foramina for the fibers constituting the cochlear nerve. The inferior vestibular area was dorsal to the cochlear area and extended onto the dorsal aspect of the IAM (dorsocaudal quadrant). It served as the exit for the saccular nerve. The posterior ampullar nerve ran through the singular foramen, located caudal and dorsal to the inferior vestibular area, close to the floor of the dorsal wall of the IAM.

The superior compartment, located above the transverse crest, was smaller than the inferior compartment. This area was divided by the vertical crest, which was obliquely directed in a dorsosuperior direction and separated the superior vestibular area (dorsally) from the facial canal (ventrally). The superior vestibular area contained several openings for the three nerves that give rise to the superior vestibular nerve: ampullar anterior, ampullar lateral, and utricular nerves. The vertical crest formed the posterior wall of the origin of the facial canal and, because of the direction of this crest and that of the transverse crest, the facial nerve was located more superior than the superior vestibular nerve at the fundus.

Neurovascular Content of the IAM

The facial nerve and the intermediate nerve entered the porus to exit at the fundus, whereas the cochlear nerve and the vestibular nerve ran from the fundus to the porus and coursed through the cerebellopontine cistern before penetrating the pontomedullary sulcus.

The Facial Nerve

Before it entered the facial canal, the facial nerve was located ventral and superior to the IAM. It was easily identifiable as a rounded nerve on macroscopic examination (Fig. 3) and as a multifasciculated nerve on histological sections (Fig. 4A and B). From the porus to the fundus, the intermediate nerve twisted around the facial nerve from a dorsocaudal position to a superior one before merging with it. At this intrameatal point of fusion, ganglion cells were histologically identifiable. These findings are consistent with Gacek’s recent observations3 and correspond to the intrameatal contingent of sensory fibers of the intermediate nerve. Within the first portion of its canal, the facial nerve was ventrally and superiorly directed and ran into the petrous bone just below the floor of the middle cranial fossa. This first portion of the facial canal was more superior than the second portion, which it subsequently joined at the fossa of the geniculate ganglion.

The Vestibulocochlear Nerve

Inside the IAM, the vestibulocochlear nerve consisted of the vestibular nerve and the cochlear nerve and modified its shape during its course.

Three nerves emerged from the superior vestibular area of the fundus (Fig. 2A and B) and merged to form the superior vestibular nerve: the utricular, ampullar anterior, and ampullar lateral nerves, which originated from the utricle and the anterior and lateral ampullar crests of the semicircular canals, respectively. The superior vestibular nerve was dorsal to the facial nerve (Fig. 3A–C).

The inferior vestibular nerve and the saccular nerve were located caudal to the superior vestibular nerve (Fig. 3C). The superior vestibular ganglion and the inferior vestibular ganglion merged into the vestibular ganglion, close to the level of the fundus. This vestibular ganglion, particularly easy to identify on superior views, was a superficially streaked swelling of the vestibular nerve (Fig. 3A and B). It contained the cellular bodies of the vestibular neurons stained red following application of HES or brown Masson green trichrome. Thus, the vestibular ganglion, which was the merging point of the superior and inferior vestibular nerves, was the true origin of the vestibular nerve.

The cochlear nerve consisted of fibers emerging from the tractus spiral, in the cochlear area. It was the largest portion of the vestibulocochlear nerve and lay ventrally.
Fig. 3. Superior and anteroinferior views of a right-sided IAM after removing its bone roof and opening the sheath made of dura mater (DM). A and B: Superior views. The external layer of the cerebellopontine cistern invaginated into the porus and sheathed the facial nerve intermediate nerve, superior vestibular nerve, and AICA in a single arachnoidal muff. Close to the fundus, the arachnoidal membrane covered a swollen zone corresponding to the vestibular ganglion (VG). A bone bridge was preserved at the porus. The toluidine blue injected into the CSF (B) of the cerebellopontine cistern (CPC) was also visible inside the IAM. This acousticofacial cistern (AFC) extended from the porus to the lateral part of the fundus and embedded the entire vestibulocochleofacial complex, including the vestibular ganglion. C: Anteroinferior view of the arachnoid of the fundus. The arachnoid covered the cochlear nerve (CN), saccular nerve (SN), and posterior ampullar nerve (PAN), which merged to constitute the inferior vestibular nerve. Fig. 3 (continued)
and caudally in the fundus, below the facial nerve (Figs. 3C and E and 4B).

The vestibular and cochlear nerves had multifasciculated aspects and were distinct only at the fundus. As the nerves coursed medially and merged, there was actually no external limit between the cochlear and vestibular fibers. At histological examination, however, the dense and compact cochlear fibers had a ventral location, and the less dense vestibular fibers were grouped in caudal and dorsal locations (Fig. 4B). Despite the fact that incomplete septa indicated separation of the vestibular and cochlear nerves, these nerves became indistinct at the porus. At that point, the vestibulocochlear complex was C-shaped, with a ventrocaudal concavity in which the facial nerve and the intermediate nerve ran (Figs. 3E and 4B).

**Vestibulofacial and Vestibulocochlear Anastomoses**

Anastomosis between the different nerves of the IAM was observed.

Vestibulofacial anastomoses were located at the porus or the fundus. In the former case, they were made of ten- tuous fibers (Fig. 3E), whereas in the latter case they were organized as a dense network.

Vestibulocochlear anastomoses were thin and ran from the utricular nerve to the origin of the cochlear nerve (Fig. 3C).

**Vascular Content of the IAM**

During its course from the vertebrobasilar complex to the cerebellum, the AICA looped close to the porus of the internal acoustic meatus and its meningeal layers.
Meningeal Layers Within the IAM

The dura mater of the medial part of the petrous bone invaginated into the IAM at the level of the porus. Within the IAM, the dural sheath closely covered the bone walls like periosteum. These close relationships between the bone of the IAM and the dura mater were observed during microdissections. On histological specimens, an artifactual space between these structures was induced by prolonged decalcification. The dura gradually became thinner toward the fundus, where it covered the different crests and areas. It invaginated into the facial canal to drape the genicularganglion and became the perineurium.

The arachnoidal layer bordering the cerebellopontine cistern also entered the porus as an arachnoidal muff for the IAM. This arachnoidal sheet was continued in the arachnoid covering the cerebellum superodorsally, the preoptine arachnoid ventrally, and the premedullar arachnoid ventrocaudally. Our staining method left the arachnoidal membrane transparent and the superficial layer was stained with toluidine blue to follow the sheath beyond the porus (Fig. 3A and C–E). Because of a shrinkage artifact, this muff appeared to join the dura mater (Fig. 3A) or the vestibulocochleofacial complex. Perforating vessels arising from the middle meningeal artery were discernible when the injection was optimal. After crossing the arachnoidal layer, these rami contributed to the vascularization of the vestibulocochleofacial complex and created an anastomotic network between the meningeal and the cerebellolabyrinthine vascular system. Near the fundus, the arachnoidal muff continued ventrally to drape over the facial nerve and the emergence of the cochlear nerve, and then it continued dorsally over the transverse swelling of the vestibular ganglion. After blue staining of either the superficial arachnoidal layer or the CSF of the cistern, the arachnoidal sheath clearly appeared to follow the dura to surround the vestibulocochleofacial complex and its vascularization (Fig. 3A–D). After opening the arachnoidal sheath, we observed that it was a single uninterrupted layer without any arachnoidal trabeculations inside the meatus that could have separated the different nerves (Fig. 3E). The arachnoidal membrane covered the entire fundus (Fig. 3C), including the singular foramen, and was perforated by nervous fibers at the level of the cochlear and vestibular areas.

Histological data confirmed this organization of the meningeal layers. For example, close to the fundus of the IAM (Fig. 4C), bodies of cellular neurons of the vestibular root were easily recognizable because of their tinctorial affinity (large ganglion cells). The vestibular ganglion was lined by a thin conjunctive layer made of collagen and cells with fusiform nuclei, which was identified as the arachnoid. This demonstrated that the vestibular ganglion was located inside the subarachnoid space and confirmed that the entire vestibulocochleofacial complex penetrated the arachnoid membrane as soon as the different nerves originated from the fundus.

Discussion

The microanatomy of the IAM is of interest to many surgeons and has been the subject of numerous studies. Even if its neurovascular content is now well described, we lack precise knowledge on the anatomy of its meninges. Better knowledge of the meninges of the IAM is not only an academic or aesthetic concern, but is also very important from a practical point of view because the presence of an arachnoidal layer may help in the atraumatic dissection of benign tumors. Yaşargil and colleagues were the first to emphasize the importance of this arachnoidal layer. Note that during surgery for acoustic neuromas, technical problems related to surrounding structures are more important than the size of the tumor itself, especially within the IAM and near the porus. Thus, the presence of an arachnoidal membrane may improve the results of atraumatic dissection. Yaşargil and colleagues’ theory of arachnoidal duplication around the tumor was attractive because it helped to explain some of the technical problems encountered during surgical procedures and proposed a solution for avoiding them. Despite an excellent description based on in vivo observations confirmed by DiTullio, et al., and duplicated in numerous textbooks, the theory posited by Yaşargil, et al., has never been clearly demonstrated anatomically, probably for technical reasons; that is, the thinness and fragility of the arachnoidal membrane makes its postmortem description difficult because it rarely remains intact after removal of the brain.

Intraoperatively, this theory seems to be inaccurate since the facial nerve is sometimes closely adherent to the neuroma, without any arachnoid between the nerve and the tumor. After microscopically observing solitary schwannomas removed en bloc, Neely emphasized the absence of real cleavage between the cochlear nerve and the tumor. Luetje, et al., demonstrated the elusive appearance of the surgical plane of cleavage between the facial nerve and the tumor, especially at the porus where the arachnoid enclosed both the tumor and the facial nerve.

These inconsistent surgical and pathological findings and the presence of CSF around the different nerves of the vestibulocochleofacial complex, as shown with the aid of magnetic resonance imaging studies, suggest that Yaşargil and colleagues’ theory may not always be accurate. To explain these findings and considering the known variability of penetration of the cranial nerves into the meninges, we hypothesize that the vestibular ganglion is located outside the subarachnoid space, as proposed by Yaşargil and colleagues, but we suggest that the length of the arachnoidal sheath may be variable in its ventral aspect.

The results of our anatomical study, however, failed to demonstrate any variation in the length of the arachnoidal
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sheath. Conversely, in our study material, the relationships of the arachnoid with the vestibulocochleofacial complex were constant: the arachnoid underlined the dura mater of the IAM from the porus to the fundus. It bordered a single subarachnoid space that may be called the acousticofacial cistern (Fig. 1C) by analogy with the trigeminal cistern, and referring to the “dural acousticofacial recess.”16 Consequently, the vestibular ganglion was located within the subarachnoid space, and schwannomas developing from the vestibular nerve will consequently be contained in the acousticofacial cistern.

Our microanatomical observations fail to confirm the widely admitted theory of arachnoidal duplication around the tumor.1,9–11,14,17,19,20 Because all the vasculonervous structures—and neuromas—are located in the same subarachnoid space, it is probably important to pay particular attention to the arachnoidal membrane during surgical procedures. Its preservation during drilling may prevent bone dust from entering the subarachnoid space,12 but cannot be considered a perfectly safe guideline for atraumatic dissection.

Conclusions

The dura mater and the arachnoidal membrane invaginated into the IAM from the porus to the fundus, creating a lateral extension of the cerebellopontine cistern, the acousticofacial cistern. This cistern contained the entire vestibulocochleofacial complex including the vestibular ganglion, from which acoustic neuromas originate. These findings clearly contradict the theory of arachnoidal layer duplication during medial growth of vestibular schwannomas and suggest that arachnoid preservation during surgical procedures cannot ensure safe surgery.

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References


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