Beyond the Middle Ear

Endoscopic Surgical Anatomy and Approaches to Inner Ear and Lateral Skull Base

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KEYWORDS

• Transcanal endoscopic approach • Petrous bone pathologic condition
• Lateral skull base • Surgical anatomy • Inner ear

KEY POINTS

- The endoscopic approach to lateral skull base can be classified as a transcanal exclusively endoscopic approach or as combined approaches (microscopic endoscope-assisted): transotic, infralabyrinthine, and suprameatal translabyrinthine.
- The transcanal exclusive endoscopic approach allows eradication of pathologic conditions involving the petrous apex, internal ear canal fundus, with extension limited to the intracochlear, intravestibular, and pericartoid regions. If the pathologic state involves the mastoid, an exclusive approach is not feasible.
- The transotic endoscope-assisted approach allows the removal of big lesions, which completely involve the petrous bone, with hearing loss compromised (ie, cholesterol granulomas). In particular, endoscope introduction is indicated for the control of the paraclival region and for the control of the carotid artery at the level of the clivus and the petrous apex.
- The infralabyrinthine endoscope-assisted approach is indicated for lesions extending inferiorly to the labyrinth. This approach allows removal of pathologic matter without loss of hearing.
- The suprameatal translabirinthine endoscope-assisted approach is indicated for pathologic conditions (mainly cholesteatomas) involving the labyrinthine tract of the facial nerve with or without internal auditory canal extension facial nerve tract with or without internal auditory canal extension.

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INTRODUCTION

Endoscopic instrumentation, techniques, and knowledge have improved during the last few years and the authors believe that, in the future, endoscopic surgical techniques will gain increasing importance in otologic surgery. The authors' experience in endoscopic ear surgery leads to the belief that most of the spaces considered to be difficult to access with the microscopic technique could be easily visualized by endoscope-assisted surgery or by exclusively endoscopic approaches.[1,2] Moreover, the authors think that new anatomic,[1] physiologic,[3,4] and surgical concepts[1,5–8] should be introduced for this purpose.

A gradual introduction of endoscopic techniques to treatment of pathologic conditions of the middle ear began in the 1990s.[9] Endoscopies were primarily used for the visualization of hidden areas such as the posterior epitympanum during classic microscopic tympanoplasty.[10] Gradually, endoscopies were used also in an operative fashion, to substitute for the microscope as a main tool during middle ear operations.[2,7,8] At present, the main application of endoscopic surgery is in middle ear cholesteatoma surgery but, in the natural evolution of the technique, there are the steps forward of lateral skull base surgery. In recent years, the authors began to notice that the internal ear and the whole temporal bone could be accessed in an endoscopic-assisted fashion or by an exclusive endoscopic approach. The only problem would be codifying, as much as possible, the landmarks and the procedures, and integrating them to classic microscopic approaches. At present some experiences of endoscopic ear surgery of the lateral skull base have already been made, both on cadaver dissection and in living patients. The codification of the initial exclusively endoscopic approaches was based on cadavers. The first steps of the procedures were attempted for cholesteatoma treatment or for exploration and study of middle ear. The codification of the endoscopic approaches in combination with microscopic approaches come, on the other hand, from clinical experiences in which endoscopes were used as an aid for microscopic-based approaches to internal ear or petrous treatment of pathologic conditions of bone.

Summarizing these concepts, the approaches can be classified as follows:

A. Transcanal exclusively endoscopic approach
B. Combined approaches: microscopic endoscope-assisted
  - Intralabyrinthine (**Fig. 1**A)
  - Suprameatal translabyrinthine (see **Fig. 1**B)
  - Transotic (see **Fig. 1**C).

The aim of this article is to analyze the morphology and surgical and anatomic findings of the approach to lateral skull base surgery, petrous apex, internal ear, and internal auditory canal by using exclusive or combined endoscopic techniques.

TRANSCANAL EXCLUSIVE ENDOSCOPIC APPROACH

This endoscopic approach allows eradication of pathologic matter involving petrous apex, internal ear canal fundus, with extension limited to the intracochlear, intravestibular, and pericartoid regions. If the pathologic condition involves the mastoid, an exclusive approach is not feasible.

Possible indications are

- Mesotympanic cholesteatomas with medial extension toward inner ear structures
- Cholesterol granulomas of the petrous apex

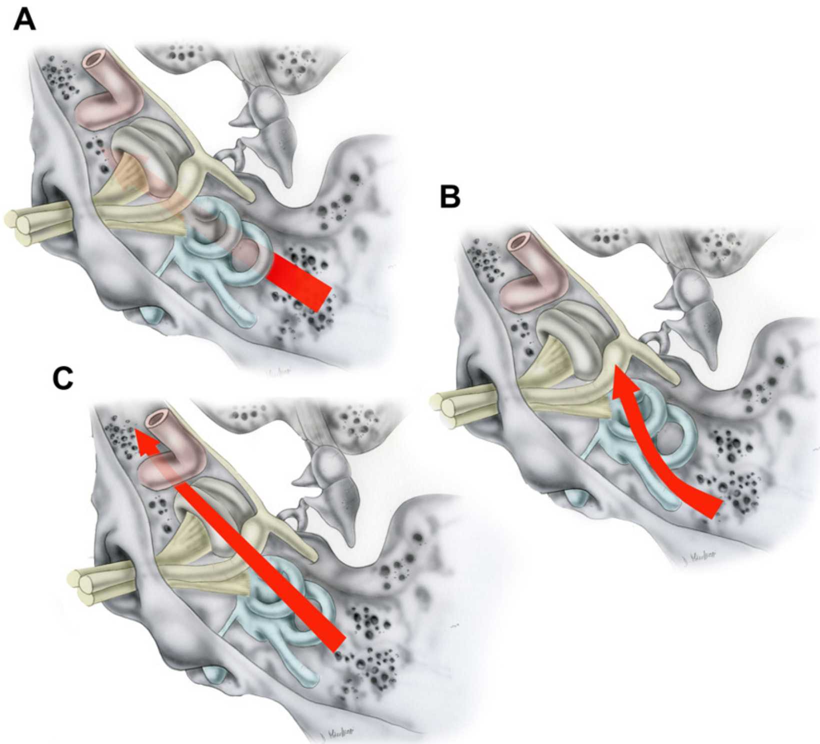

Fig. 1. (*Left ear*) The combined approaches to the inner ear. Arrows indicate direction of procedures. (*A*) Infralabyrinthine. (*B*) Suprameatal translabyrinthine. (*C*) Transotic.

- Small symptomatic or growing acoustic neuromas with exclusive extension to internal ear canal fundus
- Cochlear schwannomas with or without internal ear canal fundus extension
- Facial nerve schwannomas involving timpani tract and geniculate ganglion.

Clinical application of this approach is currently limited, although preliminary experiences and results following initial attempts are promising. Even indications for surgery in some of the pathologic conditions treated by these approaches could change in the future as a result of these minimally invasive operations, compared with the extensive bony tissue removal that microscopic techniques require.

Preliminary Surgical Steps

Using a transcanal endoscopic approach, a circumferential incision of the external ear canal skin is made approximately 3 cm from the annulus by a 0° degree endoscope.

Tympanic membrane and external ear canal skin are then removed en bloc to obtain the widest exposition of the middle ear. Using a 0° degree endoscope, a circumferential drilling is made to further increase the view and to facilitate maneuvering of surgical instruments.

Next, it is fundamental to identify the great vessels that have close relationships to the middle ear (ie, the jugular bulb and carotid artery). The first is found at the level of hypotympanum and the second at the level of protympanum, close to the eustachian tube. In some cases, an extensive drilling at those levels are required, in other cases the vessels are clearly identified without drilling any bony tissue.

Next, the incus and the malleus are removed. This allows the surgeon better access to the tympani tract of the facial nerve, to the geniculate ganglion region, and to the greater petrosal nerve, which is located anteriorly.[6]

The tympanic tract of the facial nerve and the greater petrosal nerve are then skeletonized. The cochleariform process should be removed, uncovering the underlying tensor tympani muscle. This step could be performed in a posterior to anterior direction using a microcurette because the bone at this level is very thin. In some cases the muscle need to be cauterized due to the bleeding that these procedures might provoke. When cauterizing, pay attention to the proximity of the geniculate ganglion at this level.

Once the tensor tympani canal has been removed, dissection of the muscle itself is done, displacing it anteriorly. In this way an adequate space is achieved to enable surgery directed to the geniculate ganglion and greater petrosal nerve. The relationship between the superior and lateral border of the tensor tympani canal and the facial nerve (in particular the geniculate ganglion in its posterior and inferior aspect) is apparent.

If the pathologic matter extends anteriorly to the pericartoid region, an increased skeletonization of the greater petrosal nerve should be made in a posterior to anterior direction, by also identifying the dura of the middle cranial fossa, which at this level is situated very close to the geniculate ganglion. The greater petrosal nerve represents a fundamental landmark for this procedure because it has an almost parallel course to the horizontal tract of the carotid artery.

If the lesion has an intracochlear or intravestibular extension with or without extension to the fundus of internal ear canal, the identification of the labyrinthine tract of the facial nerve should be performed. The nerve should be followed from geniculate ganglion to its entry into the internal auditory canal with either a transvestibular or a transcochlear approach.

The choice of the approach will depend on which lesion is being removed and, in particular, will depend on the internal auditory canal involvement and the bone erosion provoked by the pathologic state.

TRANSVESTIBULAR APPROACH

A transvestibular approach is indicated in cases of lesions from the tympanic cavity that cause a wide erosion of the cochlea and vestibule, creating communication with the internal ear canal fundus, and lesions coming from the internal auditory canal fundus with or without cochlear involvement (eg, small acoustic neuromas from the fundus or cochlear schwannomas). The stapes is removed from the oval window to expose the internal ear spaces at this level. The oval window is enlarged in a anterior and inferior direction to obtain a good exposition of the medial aspect of the bony labyrinth. The saccular fossa is identified, with the spherical recess, which is the site of medial termination of the inferior vestibular nerve. The spherical recess is a thin cribriform plate which separates vestibule from internal auditory canal fundus and this bony layer is removed by a microcurette. This step allows access to the internal auditory canal, with possible consequent cerebrospinal fluid (CSF) outflow.

Next, the facial nerve can be identified at the level of internal auditory canal, which lays close to the spherical recess, approximately 1 mm anteriorly and medially. The cochlear nerve lays inferiorly compared with the facial nerve, which terminates in the modiolus (**Fig. 2**). Once the intrameatal portion of the nerve have been identified, the identification of the intralabyrinthine tract of the nerve must be completed, and dissection of it is made in a anterior and superior direction following the facial nerve into the internal auditory canal to the geniculate ganglion.

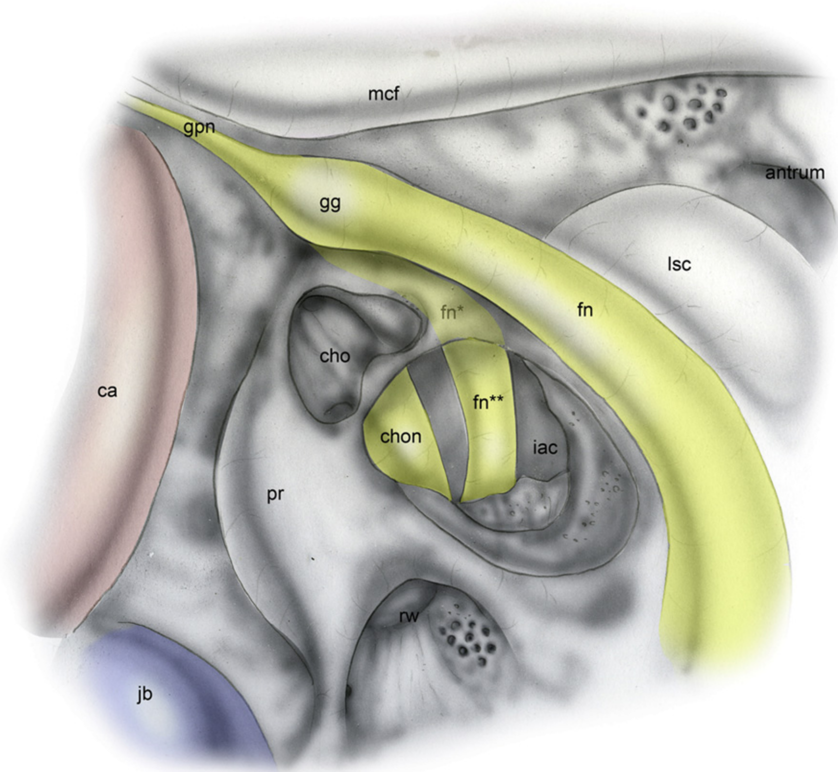

Fig. 2. (*Left ear*) The surgical cavity after transcanal exclusive endoscopic approach. ca, carotid artery; cho, cochlea; chon, cochlear nerve; fn, facial nerve; fn*, intralabyrinthine facial nerve; fn**, facial nerve on the internal auditory canal; gg, geniculate ganglion; gpn, greater petrosal nerve; iac, internal auditory canal; Jb, jugular bulb; lsc, lateral semicircular canal; mcf, middle cranial fossa; pr, promontory; rw, round window.

Before this step, identification of the middle turn of the cochlea is suggested. Because it lies close to the vestibule anteriorly, it could represent an important landmark for the identification of the intralabyrinthine tract of facial nerve, which runs just above this structure (**Fig. 2**). Another important consideration is the characteristics of the intralabyrinthine portion of the facial nerve: this tract is thin and more fragile than the other tracts of the same nerve and it is covered by a thick bony layer. For these reasons, the authors prefer to use Piezosurgery (S.R.L. medical; Mectron) dissection during those steps. The dissection substantiates following the nerve toward the internal auditory canal in an anterior and superior direction, removing the bone over the basal turn of the cochlea where the intralabyrinthine tract reaches the geniculate ganglion. Finally, the whole facial nerve can be visualized and the possible pathologic tissue can be removed while preserving the facial nerve structure.

TRANSCOCHLEAR APPROACH

The transcochlear approach has the advantage of the absence of internal auditory canal opening, avoiding CSF outflow. This approach is preferred in cases of lesions originating from the tympanic cavity, with a medial extension to the cochlea and/or vestibule without internal auditory canal fundus involvement, or of lesions originating from the timpani cavity with intracochlear and pericartoid extension, or even in cases of facial nerve schwannomas.

Nerve dissection is verified by an anatomic triangle identification between the middle turn of the cochlea, geniculate ganglion, and vestibule. The stapes is removed, followed by identification of the vestibule through the oval window. Then, a promontory drilling is made anteriorly to the vestibule and inferiorly to the geniculate ganglion. This step allows the access to the middle turn of the cochlea, which represents a landmark for the intralabyrinthine tract of the facial nerve. As mentioned above, this part of the facial nerve runs just above the cochlea, with a transverse direction from lateral to medial from geniculate ganglion to the internal auditory canal fundus. This is followed by removal, using Piezosurgery instruments, of the bony tissue laying between cochlea anteriorly and inferiorly, the geniculate ganglion anteriorly and superiorly, and the vestibule posteriorly and inferiorly (the latter representing the base of the triangle). Bone removal should be done very gently to avoid damaging to the nerve itself, which at this level is very fragile and thin. Dissection should be done carefully, to where the nerve penetrates into the internal auditory canal, trying to avoid dural tearing at this level and/or creating communications with the internal auditory canal fundus.

This approach allows the complete control of the facial nerve in its tympanic tract, geniculate ganglion, greater petrosal nerve, and labyrinthine tract of the nerve. The pathologic tissue can be removed safely and further bone removal is made based on the pathologic condition.

At the end of the surgical procedure, in case a communication with intradural spaces was created, some adipose tissue should be placed in the region of CSF leak. It is necessary to obliterate the eustachian tube and to obliterate the external auditory canal, similar to classic translabirinthine approaches. Otherwise, a reconstruction with cartilage or fascia of the can be considered.

TRANSOTIC ENDOSCOPE-ASSISTED APPROACH

This approach allows the removal of big lesions that completely involve the petrous bone and provoke hearing loss (ie, cholesterol granulomas). In particular, endoscope introduction is indicated for the control of the paraclival region and for the control of the carotid artery at the level of the clivus and the petrous apex, allowing a good control of the petrous bone medially and anteriorly to the vertical tract of the carotid artery and to the inferior and medial tract of the horizontal part of the artery.

Microscopic Surgical Steps

An incision is made approximately 2 to 3 cm from the retroauricular groove and tissues covering the mastoid are raised. Mastoidectomy is done by the canal wall-down technique. During this phase it is important to identify the classic landmarks, such as middle cranial fossa dura, which is skeletonized posteriorly up to the sinodural angle, and the sigmoid sinus, lying posteriorly and inferiorly. Skeletonization of the sigmoid sinus proceeds in an inferior and medial direction, until the identification and skeletonization of the posterior cranial fossa dura, close to the bony labyrinth and endolymphatic sac. The sigmoid sinus is skeletonized inferiorly until a good exposition of the jugular bulb is obtained. Tympanic membrane with ossicular chain and skin of the external auditory canal is removed. The next step is the identification and skeletonization of the mastoid and tympanic tract of the facial nerve, until the geniculate ganglion is visualized above the cochleariform process, maintaining a thin bony layer to protect the nerve. Based on the extent of the pathologic condition, a drilling of the intersinus facial air cells, then a labyrinthectomy is performed, until the dura of the internal auditory canal is identified. Drilling is also extended at the retrofacial recess, creating a communication with the cochlear region and tympanic cavity. Next, a wide skeletonization of the vertical tract of the carotid artery is performed. If the lesion or pathologic matter is very extended, it is advisable to drill anteriorly to the carotid itself toward tubaric region to isolate that vessel completely. Then the stapes is removed and the vestibule is identified, the promontory is drilled until the cochlea is identified and opened. If necessary, a wide drilling of the cochlea is performed until the internal auditory canal fundus is visualized.

Endoscopic Surgical Steps

The advantage of endoscopic approach after the previous microscopic time is that it allows a precise and extended drilling at the pericartoid level, reaching anteriorly and medially to vertical tract of the carotid artery, and inferiorly to the horizontal carotid artery without extensive manipulation of the vessel itself. This procedure is indicated when the pathologic state involves the petrous apex, going toward the most medial and anterior part of the carotid artery.

Before the endoscopic procedure is started under endoscopic view, the surgical field is evaluated to obtain a good orientation. The main surgical landmarks to consider are: cochlea, vertical tract of carotid artery, tensor tympani muscle, geniculate ganglion, and jugular bulb (if it extends to the tympanic cavity) (**Fig. 3**).

Cochleariform process with tensor tympani muscle are removed to obtain a wide access to the sovratubaric region, the greater petrosal nerve is identified following the geniculate ganglion anteriorly: this latter structure is often adherent to the middle cranial fossa, which at this level becomes lower. The greater petrosal nerve is the superior limit of the dissection, representing an important landmark for internal carotid artery in its horizontal portion. The greater petrosal nerve indicates where the horizontal tract of the carotid artery can be found. When the greater petrosal nerve is followed, it can be damaged due to its fragility.

Next, drilling of the area included by vertical tract of carotid artery anteriorly, cochlea posteriorly, greater petrosal nerve superiorly, and jugular bulb inferiorly is performed.

Using 45° optics by a diamond burr the vertical tract of the carotid artery is further skeletonized, removing bone medially to the vessel. This procedure allows opening of the paraclival air cells close to the clivus. Drilling is made inferiorly and superiorly until the horizontal tract is identified, and is followed medially and anteriorly just to the anterior carotid foramen.

Drilling under endoscopic view is performed at the level of cochlear pericarotic area until a good access is obtained for instruments and optics. Drilling is continued medially to the internal carotid artery until the air cells of the petrous apex and clivus are reached. Once the air cells lying intracarotid and pericartoid have been drilled, the pathologic matter is removed by curved dissectors and suction. Neuronavigator-guided surgery can be extremely useful during these steps. Moreover, the endoscopic-assisted transotic approach 45° optic allows the best control of the retrofacial area after posterior retrofacial tympanotomy, guaranteeing the complete removal of the pathologic matter without the necessity of facial rerouting, such as happens during classic exclusively microscopic transcochlear approaches (**Fig. 3**).

Once the endoscopic procedure is ended, and after further explorative endoscopy to identify possible residuals, an obliteration of the eustachian tube is made by a temporalis muscle fragment and by obliterating the surgical cavity with abdominal fat, as

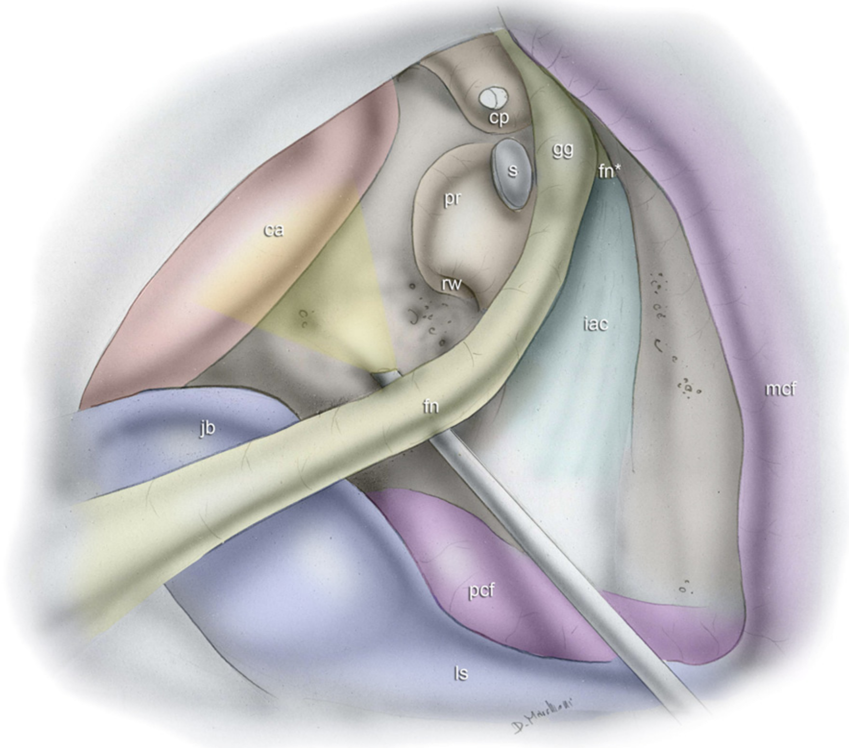

Fig. 3. (*Left ear*) The surgical cavity after transotic endoscope-assisted approach. ca, carotid artery; cp, cochleariform process; fn, facial nerve; fn*, intralabyrinthine facial nerve; gg, geniculate ganglion; iac, internal auditory canal; Jb, jugular bulb; ls, lateral sinus; lsc, lateral semicircular canal; mcf, middle cranial fossa; pcf, posterior cranial fossa; pr, promontory; rw, round window; s, stapes.

in transcochlear microscopic approaches. The procedure concludes by cul-de-sac closure of the external ear canal skin.

INFRALABYRINTHINE ENDOSCOPE-ASSISTED APPROACH

This approach is indicated for lesions extending inferiorly to the labyrinth. This approach allows removal of pathological matter without loss of hearing.

Microscopic Surgical Steps

An incision is made approximately 2 to 3 cm from the retroarticular groove and tissues covering mastoid are raised. A classic cortical mastoidectomy to underline conventional surgical landmarks, middle cranial fossa dura, and sigmoid sinus is performed. Also, the jugular bulb must be found. The mastoid tract of the facial nerve is identified anteriorly to the digastric ridge. If necessary, an antrotomy is performed and, after individuation of otic capsule and fossa incudis, the mastoidectomy is completed by removing bone more medially, toward posterior semicircular canal, which represents the superior limit of the dissection.

The purpose of these steps is to create room for the optics introduction and the following anatomic limits are eventually identified for the endoscopic dissection: superiorly the labyrinth, anteriorly and laterally the facial nerve (mastoid tract), posteriorly and inferiorly the posterior cranial fossa dura and sigmoid sinus with jugular bulb (**Fig. 4**). The next steps are endoscopic, allowing optimal pathologic tissue removal.

Endoscopic Surgical Steps

Endoscopic access is performed initially by inserting the endoscope under the retrofacial recess; bent surgical instruments (ie, dissectors) and curved suction instruments allow removal of the pathology under direct visualization by endoscopic view.

A preliminary endoscopic exploration is performed to identify landmarks. Special attention should be paid to internal auditory canal dura, which can be found at the most superior part of the field. The identification of the carotid artery is necessary in cases in which that vessel is in close relationship to the pathologic matter. Endoscopic dissection proceeds in a lateral to medial direction without damaging the labyrinth.

Initially the use of 0° optics is suggested, then 45° to explore the least accessible areas. Cleansing of the surgical filed is suggested to obtain best visualization, avoiding

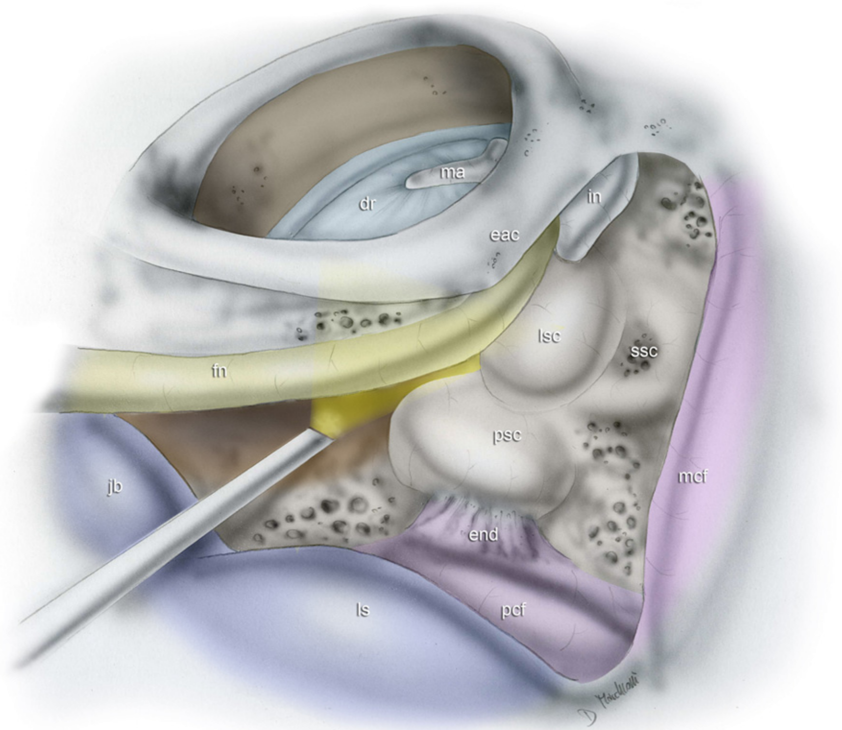

Fig. 4. (*Left ear*) The surgical cavity after infralabyrinthine endoscope-assisted approach. dr, eardrum; eac, external auditory canal; end, endolymphatic sac; fn, facial nerve; in, incus; jb, jugular bulb; ls, lateral sinus; lsc, lateral semicircular canal; ma, malleus; mcf, middle cranial fossa; pcf, posterior cranial fossa; psc, posterior semicircular canal; ssc, superior semicircular canal.

dirtying of the optic tip. Once the pathologic matter is removed, a final exploration of the surgical cavity is performed by 45° to possibly identify residuals.

At the end of the procedure, the internal ear is filled by adipose tissue and isolated from the middle ear. A middle ear obliteration by fat tissue is required only in cases of an intradural operation with extensive communication with arachnoidal spaces. This is done by eustachian tube orifice closure with muscle fragments and cul-de-sac closure of the external ear canal skin.

A contraindication to this approach can be a high jugular bulb extending superiorly and in close relationship with the labyrinth. This condition may prevent the retrofacial tympanotomy and room for endoscopic maneuvering could be reduced. Also, pathologic matter with wide intradural extension is a contraindication to this approach.

SUPRAMEATAL TRANSLABYRINTHINE ENDOSCOPE-ASSISTED APPROACH

This approach is indicated for pathologic conditions (mainly cholesteatomas) with supralabyrinthine and labyrinthine extension, with or without internal auditory canal involvement.

Microscopic Surgical Steps

An incision is made approximately 2 to 3 cm from retroarticular groove and tissues covering mastoid are raised. Mastoidectomy is performed using a canal wall down technique to identify conventional landmarks. The lateral sinus is skeletonized and followed inferiorly till the jugular bulb is identified. The middle cranial fossa is skeletonized. A good visualization of the mastoid tract of facial nerve is obtained, and the nerve is followed from mastoid tract to geniculate ganglion. The labyrinth is identified and dura of the posterior cranial fossa is skeletonized posteriorly. The endolymphatic sac is identified. The cochleariform process is removed and the tensor tympani muscle is elevated and transposed anteriorly, paying attention to not damage during procedures facial nerve. Next, a labyrinthectomy is performed until the vestibule is identified; then, the internal auditory canal dura is identified. At this level the labyrinthine tract of the facial nerve is carefully identified; the apparent direction of the nerve at this level is superiorly to inferiorly, laying superiorly to the middle turn of the cochlea until it enters into the internal auditory canal. Due to the position and orientation of the nerve at this level, the procedure is done endoscopically, identifying the geniculate ganglion with the labyrinthine tract of the facial nerve, until it enters into internal auditory canal; the close relationship between the vestibule and the labyrinthine tract of the facial nerve is also endoscopically investigated (**Fig. 5**).

Endoscopic Surgical Steps

The purpose of the endoscopic step is to remove pathologic tissue from the geniculate ganglion region and from labyrinthine tract of the facial nerve, when involved by pathologic tissue. The labyrinthine tract of the facial nerve is identified and followed anteriorly and posteriorly, lateral to medial direction, to the internal auditory canal (**Fig. 5**). The use of 45° optic allows control of the intralabyrinthine tract of the nerve and of anatomic areas laying medially and anteriorly to it, allowing matrix removal possibly without rerouting the facial nerve, which is otherwise necessary in case of a exclusive microscopic approach. This advantage includes a reduced manipulation of the nerve with a better outcome in terms of facial nerve postoperative function.

If cholesteatoma does not involve the internal auditory canal dura, the dura layer is preserved, avoiding CSF leak. On the other hand, in case of dural involvement by

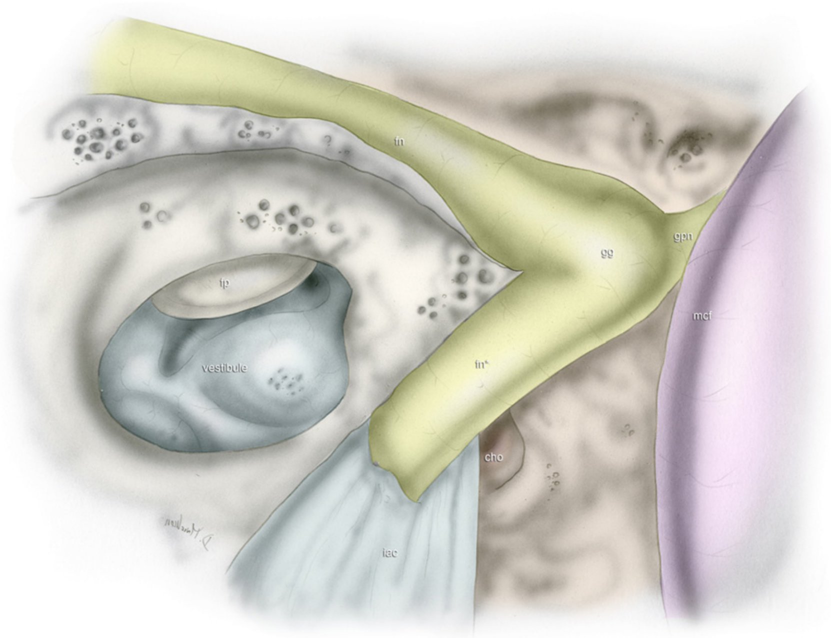

Fig. 5. (*Right ear*) The surgical cavity after suprameatal translabyrinthine endoscope-assisted approach. cho, cochlear nerve; fn, facial nerve; fn*, intralabyrinthine facial nerve; fp, stapes from behind; gg, geniculate ganglion; gpn, greater petrosal nerve; iac, internal auditory canal; mcf, middle cranial fossa.

pathologic matter, the lesion could be closed by a muscular fragment put on the surgical cavity.

The tympanic cavity and mastoid are obliterated by abdominal fat and the eustachian tube is closed by a muscle fragment. External auditory canal is closed by cul-de-sac.

SUMMARY

Use of the endoscope may benefit the surgeon in several ways for lateral skull base approaches. Its use is exclusive or in combination with microscope. Introduction of the endoscope, in the authors' opinion, can help in tissue preservation and removal of the pathologic matter, particularly in hidden areas or inaccessible spaces of the petrous bone.

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