The endoscopic anatomy of the middle ear approach to the fundus of the internal acoustic canal

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OBJECTIVE The application of the endoscope in the lateral skull base increases the importance of the middle ear cavity as the corridor to the skull base. The aim of this study was to define the middle ear as a route to the fundus (lateral end) of the internal acoustic canal and to propose feasible landmarks to the fundus.

METHODS This was a cadaveric study; 34 adult cadaveric temporal bones and 2 dry bones were dissected with the aid of the endoscope and microscope to show the anatomy of the transcanal approach to the middle ear and fundus of the internal acoustic canal.

RESULTS In the middle ear cavity, the cochleariform process is one of the key landmarks for accessing the fundus of the internal acoustic canal. The triangle formed by the anterior and posterior edges of the overhang of the round window and the cochleariform process provides a landmark to start drilling the bone to access the fundus of the internal acoustic canal.

CONCLUSIONS The external acoustic canal and middle ear cavity combined, using endoscopic guidance, can provide a route to the fundus of the internal acoustic canal. A triangular landmark crossing the promontory has been described for reaching the meatal fundus. This transcanal approach requires an understanding of the relationship between the middle ear cavity and the fundus of the internal acoustic canal and provides a potential new area of cooperation between otology and neurosurgery for accessing pathology in this and the bordering skull base.

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KEY WORDS acoustic neuroma; cochlea; endoscopic anatomy; external acoustic canal; internal acoustic canal; middle ear

The endoscope is commonly used in endonasal anterior skull base surgery, and its use is being extended to lateral skull base approaches.4–8,11,22 The advantages of the endoscope over the microscope are that it allows for more highly magnified focal exposures in small and difficult-to-access areas such as in middle ear cholesteatoma and in the recently reported removal of a cochlear nerve schwannoma at the fundus of the internal acoustic canal through the middle ear, as described by Presutti and colleagues.12,20,21,26,27,31 The middle ear is surrounded by the labyrinth, petrous carotid, facial nerve, internal and external acoustic canal, eustachian tube, jugular bulb, and the middle and posterior cranial bases. This study was designed to define the landmarks for the endoscopic middle ear approach to the internal acoustic canal, and to provide the detail essential to the approach based on cadaveric and dry bone dissections. Completing endoscopic approaches to this area requires a profound understanding of the middle and inner ear and the lateral skull base anatomy, because the endoscope provides only a narrow access viewed directly ahead and sideways.

Methods

Cadaveric Dissection

Thirty-four formalin-perfused cadaveric temporal bones and 2 dry bones were dissected to define the anatomy of the middle ear and adjacent structures and to identify the landmarks for accessing the fundus of the internal acoustic canal through the middle ear. The arteries and veins were
injected with red or blue silicone rubber, respectively, and the specimens were dissected with the surgical microscope using ×3 to ×40 magnifications and a high-speed surgical drill.

Results

This study began with the examination of cadaveric (Fig. 1) and dry temporal bones (Fig. 2) to reveal the relationship between the middle ear and the skull base. As our dissections show, the middle ear cavity has a close relationship to the skull base. Several recent studies have described the transcanal endoscopic technique, but when performing the transcanal approach, it is not easy to imagine where the internal acoustic meatus courses behind the medial wall of the middle ear cavity. To access the internal acoustic meatus precisely, feasible landmarks are necessary. Based on our cadaveric and dry bone dissections, we found that the cochleariform process, overhang of the round window and the cochleariform process, are readily identifiable in the middle ear, and the triangular area formed by the anterior and posterior elevated edges of the overhang of the round window and the cochleariform process provide landmarks for drilling the bone to access the fundus of the internal acoustic canal safely (Fig. 2F).

The approach was begun by making the tympanomeatal flap on the external acoustic canal 2 cm external to the tympanic membrane (Fig. 3A). During the degloving of the canal in continuity with the tympanic membrane, care should be taken to avoid breaking the skin off, because the skin of the ear canal is attached firmly along the fissures between the parts of the temporal bone and is used in the closure (Fig. 3B). The tympanic membrane is also attached to the anterior and posterior malleolar ligaments. Removing this flap exposes the petrotympanic and tympanomastoid fissures and the contents of the middle ear cavity. The tympanic part of the temporal bone articulates with the petrous bone and mastoid parts at the petrotympanic fissure and tympanomastoid fissure, respectively (Figs. 2A, 2B, and 3B). Branches of the auriculotemporal and Arnold’s nerves can be identified passing along the tympano mastoid area, and Arnold’s nerves can be identified passing along the tympanomastoid fissures and the contents of the middle ear cavity.

To gain sufficient exposure, the tympanic sulcus, the site of attachment of the tympanic membrane, is drilled to expose the middle ear cavity and its medial and inferior wall. The chorda tympani passes between the long process of the incus and the handle of the malleus and just below the cochleariform process to reach the petrotympanic fissure (Figs. 1B, 1D, and 3C). Jacobson’s nerve, forming the tympanic plexus, crosses the promontory with a branch of the internal carotid sympathetic plexus and a branch of the facial nerve (Figs. IC, ID, and 3C). This plexus gives off the lesser petrosal nerve, the deep branch to the greater petrosal nerve, and branches to the tympanic cavity. The opening of the bony eustachian tube is identified in the protympanum. The roof of this opening is composed of the semicanal for the tensor tympani muscle, which passes posterolaterally where the tensor tendon leaves the bony wall and hooks around the cochleariform process to run laterally and insert into the medial side of the manubrium of the malleus (Figs. 1A, 2E, and 3D).

Drilling the scutum, the sharp upper edge of the lateral attic wall, exposes the joint between the body of the incus and the head of the malleus, which are located just below the middle fossa floor (Figs. 1D and 4A). Several tympanic diaphragms are observed around the ossicular chain and the tensor tympani muscle and its semicanal. Mucosal septa are identified bridging the bony structures between the malleus handle and tendon of the tensor tympani muscle, the semicanal of the tensor tympani muscle and bony eustachian tube, the body of the incus and the middle cranial base, the pyramidal eminence and the tendon of the stapedius muscle, and the head of the malleus and the long process of the incus (Fig. 4B and 4C). The genu of the facial nerve passes just above the oval window in which the footplate of the stapes bone sits. Along the fallopian canal, the bony canal for the facial nerve, there is often a dehiscence of bony canal around the tympanic segment close to the genu. In our dissections, this defect was identified in 25 of 34 sides (74%).

After disconnection of the tensor tympani muscle tendon, the malleus can be removed. Removing the malleus exposes the chorda tympani, which courses just below the attachment of the tensor tympani tendon to the neck of the malleus to enter its anterior canalculus, which is located just above the opening of the bony eustachian tube (Figs. 1B, 1D, and 4D). Removing the ossicles and chorda tympani exposes the medial wall of the middle ear cavity (Fig. 4E). The spherical recess of the vestibule is identified inside the oval window. The cribrosa area in the wall of the vestibule is a multiperforated area through which branches of the inferior vestibular nerve pass. The cochleariform process, located anterior and superior to the oval window, projects laterally from the inferolateral edge of the facial canal (Figs. 1E, 1F, and 4E). The cochleariform process is also positioned superior to the promontory and just inferolateral to the geniculate ganglion. The tympanic nerve passes over the promontory, where it splits into tiny bundles that form the tympanic plexus. Another bulging bony area is the promontory, where the tympanic and bony eustachian tube overlies the carotid canal and it is often dehiscent, exposing the petrous carotid artery (Figs. 1A, 4E, and 4F).

The cribrosa of the vestibule and cochleariform process are reliable landmarks to reach the internal acoustic canal while avoiding damage to the facial nerve. Removing the bone forming the promontory exposes the basal turn of the cochlea, which is divided into 3 cavities: the scala vestibule above, the cochlear duct in the middle, and the scala tympani below (Fig. 5A). The scala tympani and vestibule are connected by a small opening, the helicotrema, at the apex of the cochlea. Extending the drilling through the medial wall below the cochleariform process opens the middle and apical turn of the cochlea (Figs. 1F and 5B). The upper portion of the middle turn of the cochlea serves as a landmark for the labyrinthine sector of the facial nerve because it is located just superior to the middle turn of the cochlea (Figs. 1A and 5B). The modiolus of the cochlea, its conical and central axis, contains the spiral ganglion and cochlear nerve (Fig. 5C). Drilling the bone between the spherical recess of the vestibule and the middle turn of
the cochlea exposes the dura mater of the internal acoustic canal (Fig. 5C). This opening is within the triangle formed by the cochleariform process and the anterior and posterior edges of the overhang of the round window (Figs. 2F, 4E, 4F, and 5C). Opening the dura exposes the 4 main nerves in the internal acoustic canal: facial, cochlear, and superior and inferior vestibular nerves (Fig. 5D and 5E). This dissection exposes the fundus of the internal acoustic canal and is located below the lower edge of the junction of the vertical and transverse crests at the fundus of the...
internal acoustic canal; this avoids damage to the facial nerve (Fig. 5F).

We found that the triangle formed by the cochleariform process and anterior and posterior edges of the round window, called the anterior and posterior pillars, provides satisfactory orientation for drilling to access the internal acoustic canal (Figs. 2F, 4E, and 4F). The anterior and posterior sides of this triangle correspond to the deeper positions of the cochlea and vestibule, respectively. The lengths of the 3 sides were measured in 34 cadavers. The
anterior, posterior, and inferior sides measured 5.54 ± 0.90 mm, 5.10 ± 0.90 mm, and 2.52 ± 0.69 mm, respectively (mean ± SD). The area of the triangle measured 6.40 ± 2.44 mm$^2$, which is similar to the area of the tip of the 1.5-mm diamond bur. Drilling this triangle opened and exposed the internal acoustic canal in all specimens without damaging the facial nerve.

**Discussion**

The application of the endoscope to the middle ear and lateral skull base exposure has become common.$^{11,20,26,27,31}$ In 2013, Presutti et al. described the endoscopic approach through the external acoustic canal for cochlear schwannomas.$^{20}$ This report examined the anatomy of the endoscopic transcanal route for accessing the internal acoustic canal, and it identified several useful landmarks.

The triangular area that we defined in this study is formed by 3 points: 1) the cochleariform process; 2) the posterior edge (pillar) of the overhang of the round window; and 3) the anterior edge (pillar) of the overhang of the round window. The area is 6.40 ± 2.44 mm$^2$ (mean ±
FIG. 4. A: Removal of the scutum exposes the epitympanum containing the incudomalleal joint. 
B: Enlarged view of panel A. 
C: Structures around the stapes footplate. The stapes sits in the oval window niche, the depression in which the oval window is positioned. 
D: Removing the incus and malleus exposes the cochleariform process and the tensor tympani tendon. The anterior canalculus of the chorda tympani is exposed (yellow star). 
E: Removing the stapes and chorda tympani nerve exposes the triangular landmark formed by the anterior and posterior edges (pillars) of the round window and the cochleariform process (green triangle). The spherical recess is exposed through the oval window. 
F: Enlarged view of panel E. The triangular landmark for promontory drilling is outlined (green triangle). 

Car. = carotid; Cochlear. = cochleariform; Eust. = eustachian; Inc. = incudo; Mall. = malleolar; Plex. = plexus; Proc. = process; Rec. = recess; Spher. = spherical; Staped. = stapedius; Tend. = tendon; Tens. = tensor; Tymp. = tympani, tympanic.
FIG. 5. A: Removal of the bone covering the triangular landmark exposes the membranous basal turn of the cochlea and vestibule. B: Extending the bone removal inferior to the cochleariform process opens the middle and apical turn of the cochlea. C: Removing the bone laterally through the triangular landmark exposes the dura lining the internal acoustic canal. D and E: Opening the dura of the internal acoustic canal exposes the facial, cochlear, and superior and inferior vestibular nerves. The green square in panel D outlines the area exposed in panel E. F: View of the fundus of the right internal acoustic canal after drilling the posterior meatal wall from medially. The endoscope has been advanced along the anterior surface of the nerves to show the opening through the middle ear into the fundus of the meatus. The opening from the middle ear cavity is located just below the vertical crest (red arrow at the meatal fundus) separating the facial and cochlear nerves. The superior and inferior vestibular nerves are located behind the facial and cochlear nerves. Ac. = acoustic; Car. = carotid; Coch. = cochlea; Cochlear. = cochleariform; Intermed. = intermedius; Mid. = middle; Proc. = process; Tens. = tensor; Transv. = transverse; Tymp. = tympani, tympanic; Vest. = vestibular.
SD). This shape approximates an isosceles triangle. Drilling the bone within this triangle opens the fundus of the internal acoustic canal while avoiding injury to the facial nerve. The anterior edge corresponds to the position of the cochlea deep to the medial wall of the middle ear. If the cochlea is intact, the internal acoustic canal can be accessed by following the modiolus, the conical central axis of the cochlea where the spiral ganglion, which blends into the cochlear nerve, is located. The posterior side is located superficial to the vestibule and anterior to the genu of the facial nerve. Opening the vestibule exposes 2 distinct depressions: the elliptical recess posterosuperiorly and the spherical recess anteroinferiorly. The utricle is firmly adherent to the wall of the elliptical recess, and the sacculus is adherent to the wall of the spherical recess. The opening of the vestibular aqueduct is situated below the elliptical recess. The spherical and elliptical recesses are separated by the vestibular crest, which inferiorly encloses a small space called the cochlear recess, through which some cochlear nerve filaments pass. The scala tympani of the cochlea is adherent to the round window and is continuous with the scala vestibule at the helicotrema. The superior vestibular nerve innervates the superior and lateral semicircular canal and gives off the utricular branch. The inferior vestibular nerve gives off the saccular branch to the spherical recess. The singular nerve, the posterior semicircular canal and gives off the utricular branch. The inferior vestibular nerve gives off the saccular branch to the spherical recess. The singular nerve, the posterior semicircular canal and gives off the utricular branch.

Closure in Presutti et al.’s patient was by abdominal fat graft in the internal acoustic canal without obliteration of the middle ear, a tragal cartilage graft to separate the cochlea and middle ear, and replacement of the external canal skin with another cartilage graft to support the tympanic membrane.

Disadvantages of the endoscopic procedures include the following: 1) the loss of backward or sideways surgical vision; 2) difficult hemostasis; and 3) the narrow surgical space compared with conventional microsurgical approaches. Moving the endoscope in the operative field requires that extreme care be taken to avoid injury of the anatomical structures hidden from view along the side of the tube.

Vascular anomalies of the temporal bone are rare, and should be avoided. The access corridor is extremely small compared with that provided by the conventional approaches, thus making arterial bleeding difficult to control. Presutti et al. state that bleeding from the anterior inferior cerebellar artery branches and internal auditory artery bleeding would be unmanageable, especially in inexperienced hands. If the vascular anatomy is found pre- or intraoperatively, a transcanal procedure should be avoided or stopped.

Vascular anomalies include a high jugular bulb, aberrant internal carotid artery, persistent stapedial artery, dehiscence of bone surrounding the carotid artery canal, and abnormality of the anterior inferior cerebellar artery. The meatal loop of the anterior inferior cerebellar artery may course in the internal acoustic canal, reaching the fundus in 10.1%–40.0% of cases. The majority of meatal loops coursed in a horizontal plane above or below the nerves, but some, mostly those passing between the facial and vestibular cochlear nerves, are oriented in a vertical or oblique plane. Mazzoni reported that the meatal segment reached the porus in 27%, and entered the canal in 40% of canals, but rarely went beyond the medial half of the canal. The internal auditory artery also enters the internal acoustic canal. In examining 50 cerebellopontine angles, Martin et al. found 94 internal auditory arteries, of which 77% originated from the premeatal segment, 21% from the meatal segment, and 2% from the postmeatal segment. There was 1 internal auditory artery in 30%, 2 in 54%, 3 in 14%, and 4 in 2%. An aberrant internal carotid artery, an anomaly affecting less than 1% of arteries, is presumed to be due to regression or underdevelopment of the cervical portion of the internal carotid artery, which leads to an anastomosis between an enlarged inferior tympanic artery and an enlarged caroticotympanic artery. A high jugular bulb, commonly identified in temporal bone surgery, occurs in 24%–50% of cerebellopontine angles. Preoperative radiological examination with CT and MRI is important in case selection.

The transcanacl endoscopic technique has become widely practiced in surgery for middle ear pathology, mainly cholesteatoma. Recently this technique has been extended into lateral skull base surgery. The transcanacl approach to the fundus of the internal acoustic canal is less invasive and reduces the skin incision and temporal bone drilling required for other approaches to the area. However, the application of this approach to the internal acoustic canal will be extremely limited. This approach will sacrifice inner ear function. Thus, the patient who already has severe hearing loss and canal paresis may be preferentially selected; appropriate patients for this approach should be carefully selected. Presutti’s group shows that this approach is a promising technique in appropriately selected cases with low mobility to the facial nerve for Koos Grade I or II vestibular schwannomas. For tumor resection, this approach may be selected if the pathology involves the cochlea, vestibule, and the most lateral part of the internal acoustic canal. For a diagnosis of tumor filling the internal acoustic canal, a biopsy performed with this approach may be useful and less invasive than alternatives. It may be combined with the retrosigmoid approach to complete the total resection of a large vestibular schwannoma extending medial to the fundus. For preservation of cochlear function for the possibility of a cochlear implant on the ipsilateral ear, the infracochlear (retrocochlear) route, which may be used for petrous apex cholesterol granuloma drainage, has been proposed, but the exposure of the internal acoustic canal will be extremely limited. Thus the application of this route for the resection of pathology occupying the internal acoustic canal is still controversial.

Considerable training and knowledge of endoscopic anatomy are required to complete this endoscopic approach. The indications for the transcanacl approach are very limited and should be preceded by careful preoperative studies. As currently designed it would be considered only for a small cochlear nerve tumor in the fundus of the internal acoustic canal in which cochlear function
has been lost. It could be considered as an alternative to a more invasive translabyrinthine approach for a small tumor in which there is no chance of preserving hearing. Alternatives to consider are the middle fossa or retrosigmoid approaches if there is some possibility of preserving hearing.

Conclusions
This study defined an endoscopic route to the meatal fundus directed through a triangular area formed by the inferior edge of the cochleariform process and anterior and posterior edges of the overhang of the round window. Completing this endoscopic approach requires a profound knowledge of the anatomy of the middle ear and training with the endoscope. The endoscopic route along the external canal and middle ear offers a potentially new area of cooperation between otology and neurosurgery for accessing pathologies in this and the bordering skull base.

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References
28. Wadin K, Wilbrant H: The topographic relations of the high
jugular fossa to the inner ear. A radioanatomic investigation. 
*Acta Radiol Diagn (Stockh)* **27:**315–324, 1986


**Disclosures**
The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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Conception and design: Komune, Miki, Rhoton. Acquisition of data: Komune, Matsuo, Rhoton. Analysis and interpretation of data: Komune, Matsuo, Rhoton. Drafting the article: Komune, Miki, Rhoton. Critically revising the article: Komune, Rhoton. Reviewed submitted version of manuscript: all authors. Administrative/technical/material support: Rhoton. Study supervision: Rhoton.

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