The Journal of International Advanced Otology

J Int Adv Otol 2016; 12(3): 298-302 • DOI: 10.5152/iao.2016.2998

Original Article

Defining the Limits of Endoscopic Access to Internal Auditory Canal

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OBJECTIVE: To quantify surgical access to the internal auditory canal (IAC) using an exclusively endoscopic transcanal approach (EETA) and investigate surgically relevant relationships with neurovascular and osseous landmarks of the temporal bone.

MATERIALS and METHODS: Anatomical dissection of two paired temporal bones and 15 unpaired temporal bones was performed using an exclusively endoscopic approach to IAC. The dissection proceeded until the cerebellopontine angle (CPA) could be accessed. Following dissection, all the specimens were subjected to computed tomography (CT) imaging. Anatomage InVivo5 software was used to analyze the CT scans and record measurements.

RESULTS: CPA access and visualization of the labyrinthine segment of the facial nerve were achieved in all specimens. The mean distances from the carotid artery, jugular bulb, and middle fossa to the surgical opening (or fundostomy) of IAC were 4.1±1.5, 6.4±2.5, and 5.5±1.9 mm, respectively. The mean cross-sectional areas of the fundostomy and tympanic ring were 30.8±10.4 and 67.7±11.3 mm2. The mean distances from the osteo–cartilaginous junction and tympanic ring to the porus acusticus were 29±2.6 and 21±2.3 mm, respectively.

CONCLUSION: Transcanal access to the entire IAC can be safely achieved using an exclusively endoscopic approach. Generous removal of the cochlear promontory can be accomplished while a safe distance is maintained from key neurovascular structures. EETA to IAC offers a minimally invasive alternative to patients without serviceable hearing for intrameatal and medial IAC tumors. Increased knowledge of crucial anatomical relationships involved in this approach will facilitate acceptance and utilization.

KEYWORDS: Endoscopic ear surgery, exclusively endoscopic transcanal approach, endoscopic skull base surgery, cadaveric study

INTRODUCTION

The introduction of endoscopes to otologic surgery has opened a new avenue of access to the temporal bone. The utility of endoscopes was first recognized as a means of visualizing the sinus tympani, a region of the retrotympanum common for harboring residual cholesteatoma [1]. In the last decade, the utilization of endoscopes for middle ear surgery has been steadily increasing. Compared with microsurgery, endoscopic surgery offers a wider operative view, superior magnification, and the ability to seamlessly change the operative view during dissection [1-3].

Traditionally, access to the internal auditory canal (IAC) and cerebellopontine angle (CPA) was achieved through translabyrinthine, retrosigmoid, or middle fossa (MF) approaches. While each provides adequate exposure for the removal of variable pathologies from the lateral skull base, all have inherent disadvantages [4]. Translabyrinthine and other transpetrous approaches often require large-volume bone removal, with an increased risk of postoperative cerebrospinal fluid leak. MF approaches are technically challenging, particularly for gaining access to the lateral portion of IAC, and they require some degree of retraction on the temporal lobe. Retrosigmoid approaches offer limited medial exposure of IAC and require cerebellar retraction [5].

Recently, Marchioni et al. [6-9] have described an exclusively endoscopic transcanal approach (EETA) to IAC. It differs from traditional approaches as it offers a direct route through the ear canal, a natural orifice of the temporal bone. Compared with a posterior or medial approach, EETA does not require any external incisions, soft-tissue dissection, or mastoidectomy. Recent reports have demonstrated that this approach has been used successfully in a limited number of patients [7, 9]. Initial data suggest that EETA is applicable to pathologies involving the IAC fundus, petrous apex, pericarotid, and intravestibular areas. At present, it is not appropriate for pathologies with a large CPA component or the involvement of the mastoid.

The aim of this study was to quantify the size of the surgical corridor and the anatomical relationships of EETA to IAC using a cadaveric model. Specifics of fundostomy size, access to CPA, and the relationships between surgically relevant landmarks were analyzed

Presented in: This study was presented at the American Neurotology Society in Chicago, 20-22 May 2016, Illionis, USA.
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Submitted: 19.08.2016 **Accepted:** 21.11.2016

using 3D CT modeling software (Anatomage InVivo5). Increased knowledge of the anatomical limitations of the EETA approach to IAC will enable a greater understanding of the potential applications of this technique.

MATERIALS and METHODS

Study Materials

This study was submitted for ethical approval by the institutional review board and was deemed exempt on the basis of the cadaveric study design. This study followed Louisiana State Health Sciences Center guidelines governing anatomic, cadaveric research. All specimens were acquired from the affiliated institution's department of anatomy and were anonymous. Two paired whole heads and 15 unpaired temporal bones were used in this study. Rigid endoscopes (3 mm, 0° and 30°, 11.8 cm long, Karl Storz) connected to a high-definition video tower (Karl Storz) were used to perform all dissections. High-resolution computed tomography (CT) was postoperatively performed on all specimens using the standard university protocol for IAC imaging, including coronal, sagittal, and axial images. Each CT scan was analyzed using InVivo 5 software (Anatomage, San Jose, CA).

Surgical Technique

Under endoscopic guidance, a round knife was used to make a circumferential incision at 1 cm from the annulus. The flap was elevated to the annulus, and the fibrous annulus was elevated from its bony ring. The flap and tympanic membrane were then removed en bloc using microscissors. The incudostapedial joint was disarticulated, the tensor tendon was cut, and the malleus and incus were removed. The tympanic ring was circumferentially widened using a 3-mm diamond burr attached to a microdrill (Stryker, Kalamazoo, MI) until the jugular bulb (JB), epitympanum, and internal carotid artery (ICA) were well visualized. The stapes was removed, exposing the oval window. The tensor canal and cochleariform process were fractured with manual pressure using a blunt instrument, and the bone was carefully removed. The tensor tympani muscle was then elevated from the tensor canal and anteriorly transposed to expose the geniculate ganglion (The geniculate ganglion and intratympanic portion of the facial nerve mark the superior limit of the fundostomy). Drilling was performed anterior to the oval window with a 1.5-mm diamond burr to expose the basal turn of the cochlea. Next, the oval window was anteriorly widened with a microcurrette or drill to expose the medial wall of the vestibule. The spherical recess of the saccule was identified and carefully curetted, creating a window into IAC. This was carefully done to avoid injuring the labyrinthine segment of the facial nerve, which lies directly anteromedial to the spherical recess. Once the facial nerve was identified, the fundus of IAC was entered and widened to provide a wider view of IAC and its contents (Figure 1). Attempts were made to keep the fundostomy size constant and at the minimal diameter necessary for access to CPA. IAC was explored until CPA could be accessed. Damage to the facial nerve, JB, MF, and carotid artery was recorded in all the specimens. Access to CPA was also recorded.

Measurements and Data Analysis

After the surgical dissection, each cadaveric specimen underwent high-resolution CT following the university's standard protocol for CT imaging of the temporal bone. The radiologic images were imported

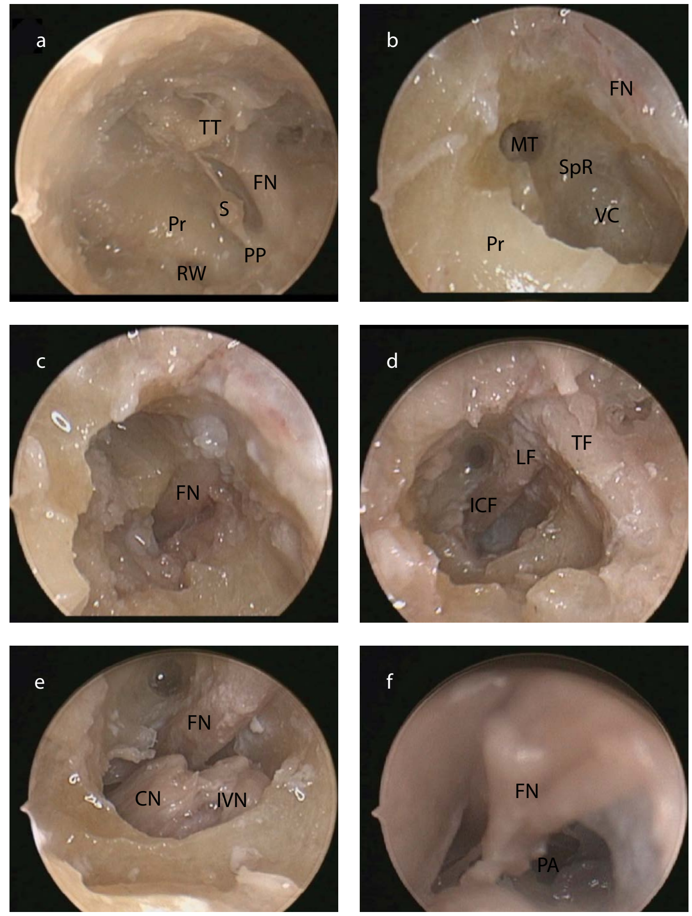

Figure 1. a-f. Surgical dissection of left ear. (a) View of middle ear cavity. Tympanic membrane, malleus, and incus removed. Tensor tympani anteriorly transposed. (b) Stapes removed. Oval window enlarged. (c) Internal auditory canal (IAC) entered. Labyrinthine segment of facial nerve exposed. (d) First genu of facial nerve completely exposed, showing exit from IAC. (e) Further enlargement of fundostomy inferiorly. (f) Endoscopic view of lateral IAC.
CN: cochlear nerve; FN: facial nerve; ICF: intracanalicular facial nerve; IV: inferior vestibular nerve; LF: Labyrinthine segment facial nerve; MT: medial turn of cochlea; PA: porus acusticus; PP: pyramidal process; Pr: promontory; RW: round window; S: stapes; SpR: spherical recess; TF: tympanic segment facial nerve; TT: tensor tympani; VC: vestibular crest

into Invivo 5 software, and 3D reconstructions were made combining axial, coronal, and sagittal views. Using either the axial or coronal images, measurements (mm) were performed from the fundostomy to several surgically pertinent anatomical landmarks: the petrous ICA, JB, and MF floor. Measurements were performed from edge to edge and not from the middle portions of structures and were confirmed in multiple planes. All data were recorded at the hundredth millimeter and then rounded to the nearest millimeter.

The cross-sectional areas of both the tympanic ring and fundostomy were calculated using sagittal images and reconstructions in Anatomage software (Figure 2). The distances from the tympanic bone, at the osseo-cartilaginous junction and at the tympanic ring (proximal and distal ends), to the porus acusticus were measured using 3D models (Figure 3).

All the measurements were performed on all the specimens, except for specimen 12, which was harvested posterior to the carotid artery, making this measurement unattainable. All the other measurements from specimen 12 were included in the analysis.

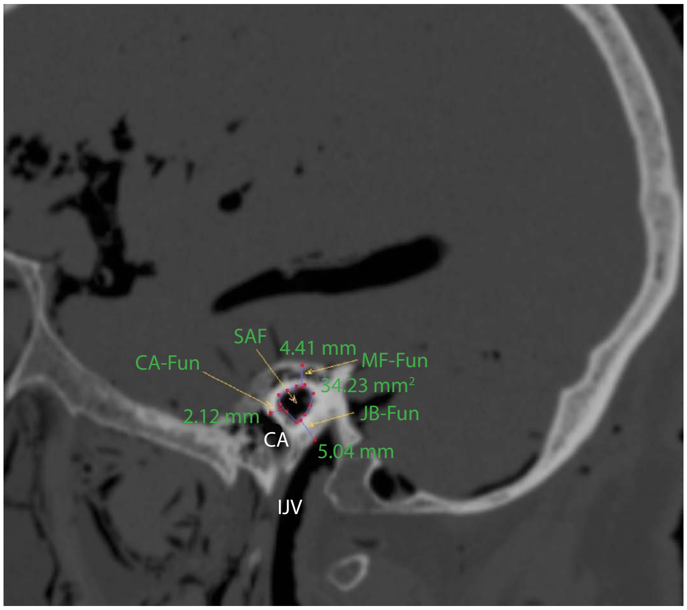

Figure 2. Recorded measurements of fundostomy. Sagittal image in plane of fundostomy of internal auditory canal (IAC), demonstrating representative view of how measurements were performed.
CA-Fun: carotid artery to fundostomy edge; CA: carotid artery; IJV: internal jugular vein; JB-Fun: jugular bulb to fundostomy edge; MF-Fun: middle fossa floor to fundostomy edge; SAF: surface area of fundostomy

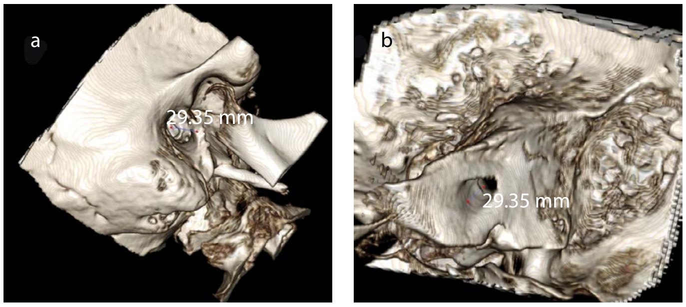

Figure 3. a,b. Measurements of osseo-cartilaginous junction to porus acusticus. 3D reconstructions were used to measure these. (a) Lateral view of temporal bone specimen. (b) Medial view of temporal bone specimen.

Measurements were separately performed by two independent observers and averaged. The mean, standard deviation (SD), and confidence interval (CI) were computed for each specimen. The coefficient of variance (CV) was calculated to determine the amount of variability among the measures. All analyses were performed using StatPlus 6.0 (Analystsoft Inc. Walnut, CA USA, 2016).

RESULTS

Preservation of the labyrinthine segment of the facial nerve and access to the porus acusticus were achieved in all the specimens. No violation of surgically vital structures (specifically the ICA, JB, facial nerve, and MF) was required to attain this view.

The mean distance from the fundostomy to the carotid artery was 4.1 mm [SD=1.5, 95% CI (3.2–4.9), CV=0.37]. The mean distance from the inferior limit of the fundostomy to the dome of JB was 6.4 mm [SD=2.5, 95% CI (5.0–7.7), CV=0.39] and that from the superior aspect of the fundostomy to the floor of MF was 5.5 mm [SD=1.9, 95% CI (4.5–6.5), CV=0.34].

The minimal mean cross-sectional area of the fundal opening to enable access to the porus acusticus was 30.8 mm^2 [SD=10.4, 95% CI (25.2–36.9), CV=0.34], whereas the mean cross-sectional area of the tympanic ring was 67.7 mm^2 [SD=11.32, 95% CI (61.7–73.7), CV=0.17].

The mean distance from the osseo-cartilaginous junction of the tympanic bone to the porus acusticus was 29 mm [SD=2.6, 95% CI (27.6–30.4), CV=0.09]. The mean distance from the medial aspect of the tympanic bone, i.e., the tympanic ring, to the porus acusticus was 21.1 mm [SD=2.3, 95% CI (19.9–22.3), CV=0.11].

DISCUSSION

Exclusively endoscopic transcanal approaches to the middle ear are becoming increasingly accepted as a viable alternative to middle ear microsurgery [10-12]. The expansion of this technique to IAC and the lateral skull base, however, remains a relatively novel concept with limited published data. The present study supports prior data and suggests that EETA is a viable and safe route of access to the lateral skull base in select cases [5-7, 9].

The facial nerve was structurally preserved in this study despite the fact that the labyrinthine segment of the facial nerve lies adjacent to the fundostomy created into IAC. Removing the bone of the tensor canal and elevating the tensor tympani muscle anteriorly enabled the identification of the facial nerve at the first genu. Recent clinical reports of EETA to IAC suggest that the identification of the facial nerve is important for maximizing the postoperative function. Exposure of the first genu using this maneuver does not take much time and may enable the identification of the facial nerve distal to tumor involvement in lateral IAC.

Our results suggest an intimate relationship between the surgical approach and ICA: this was the closest measured structure in the dissection, and in two specimens, the distance was less than 2 mm from the fundostomy. This distance indicates that caution should be taken when widening the entry point to IAC anteriorly. Our results underscore those of Marchioni et al. and others who suggest that visualization of the carotid canal in the protympanum is recommended to maximize safety when using this approach [6-9, 14].

The JB dome may have a variable position [13]. The average distance from the JB dome to fundostomy was 6.4 mm in this study. Although CV was fairly low (0.39), the minimum and maximum values were 3 and 11 mm, respectively. With a low JB, additional hypotympanic bone can be removed to create a wider opening to IAC. It may be helpful in surgical planning to assess the distance in the sagittal and coronal views to determine how much exposure to IAC can be achieved through EETA. Other studies have shown that ample hypotympanic space may permit a corridor to IAC that preserves the cochlea, possibly for drug delivery or brachytherapy [14]. Access can be gained to the petrous apex in the same manner to drain cholesterol granuloma [6].

The MF floor was not violated during the dissections. The mean distance was 5.5 mm at the fundostomy. This distance was mainly determined by the size of the epitympanum and pneumatization above IAC. By keeping our dissection inferior to the tympanic segment of the facial nerve, we avoided violation of MF at the fundostomy without difficulty. It is important to understand that as IAC is traversed medially, the distance from the roof of IAC to the MF floor can change. Unfortunately, this was not reflected in our measurements; however, it could be examined in future studies.

A distinct advantage of endoscopic ear surgery is superior magnification, potentially providing details not visible through a microscope. In addition, the proximity of the endoscope to the dissection offers a wider viewing angle, enabling greater visualization of the surgical field [3, 4]. Enlargement of the tympanic ring is an important surgical step that may improve safety and efficiency. Our data suggest that the cross-sectional area of the tympanic ring is often more than twice that of the fundostomy. Widening the proximal access point (i.e., the tympanic ring) enables greater maneuverability and minimization of risk to key structures in the fundal portion of IAC. Maximization of the tympanic ring is also important for clear visualization of the carotid canal and JB dome.

This study provides additional data on the development of minimally invasive endoscopic approaches to IAC. Although EETA has not been widely applied to the lateral skull base, it has certain distinct advantages over traditional techniques, particular in terms of its natural orifice access to IAC, minimal bone removal, and minimal soft-tissue dissection. Anatomically, the external auditory canal is a natural corridor to IAC and a potentially viable route for minimally invasive approaches to the lateral skull base. Our results suggest that the distance between the proximal and distal ends of the tympanic bone ranges from 21 to 29 mm, which is a relatively small working distance compared with those of traditional craniotomy approaches. The anatomical data provided in this study can aid future applications of this technique (including the use of surgical navigation) and the development of procedure-specific instrumentation.

Recently, Marchioni et al. [9] published the first case series (n=10) of an exclusively endoscopic transcanal resection of Koos Grade I (within IAC) or II (IAC and limited CPA involvement) tumors. All the patients in this cohort had American Academy of Otolaryngology–Head and Neck Surgery (AAO-HNS) Class D hearing status (from severe to profound hearing loss) preoperatively. Gross total resection was achieved in all the patients, with an average operative time of 192 min. There were no intraoperative complications. Postoperatively, no patient experienced permanent facial nerve paresis/paralysis or CSF leak. Although preliminary, this report underscores the potential clinical applicability of this approach in select patients and suggests that postoperative complications may be similar, or improved, compared with those for traditional methods. More widespread utilization and acceptance of endoscopic techniques will depend on increased familiarity and knowledge of the anatomical relationships involved in this approach.

Limitations of the present study include its sample size of 17 specimens that were randomly chosen; this may not provide a true representation of the population. Preoperative CT scans were not obtained but may have been helpful for examining accessibility prior to dissection and predicting whether any anatomical features contribute to more difficult dissections. Endoscopic surgery of the middle ear has several widely cited disadvantages, namely the necessity of operating with one hand (while the other holds the endoscope), the challenges of hemostasis, the need for specialized equipment, and an increase in the operative time because of a lack of familiarity with the surgical procedure. The cadaveric design of this study did not enable the simulation of many of these challenges.

CONCLUSION

The exclusively endoscopic transcanal approach is a safe and feasible approach to IAC and CPA and may be appropriate for certain patients with a lateral skull base pathology. Our data suggest that inherent anatomic variability in the position of ICA and JB can affect surgical access and underscore the importance of preoperative imaging to assess the position of these structures and to predict the fundostomy size. The success of this technique requires intimate knowledge of the facial nerve anatomy and emphasis on the utility of early identification at the geniculate ganglion. Although current indications for this approach are rare, further research and development should be encouraged. The current management of CPA tumors includes surgery, radiotherapy, and observation. Minimally invasive transcanal approaches offer another element in the algorithm for the management of select tumors of the lateral skull base. Increased knowledge and familiarity with the crucial anatomic relationships involved in this approach will facilitate acceptance and utilization.

Ethics Committee Approval: Ethics committee approval was received for this study from the ethics committee of Louisiana State University Health Sciences Center – Shreveport according to the guidelines governing anatomic, cadaveric research.

Informed Consent: This study followed Louisiana State Health Sciences Center guidelines governing anatomic, cadaveric research. Written consent for cadaveric donation was obtained in all cases and followed strict institutional and state rules for educational use.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept - A.M., M.C.; Design - A.M., M.C.; Supervision - M.C.; Resources - A.M., M.H., M.C.; Materials - A.M., M.C.; Data Collection and/or Processing - A.M., M.H., M.H.; Analysis and/or Interpretation - A.M., M.H., M.C.; Literature Search - A.M., M.H., M.C.; Writing Manuscript - A.M., M.C.; Critical Review - A.M., M.H., M.C.

Conflict of Interest: No conflict of interest was declared by the authors.

Financial Disclosure: The authors declared that this study has received no financial support.

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