Surgical Anatomy of the Infralabyrinthine Approach

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Abstract

Objective. The objective of this study is to demonstrate the surgical anatomy of the infralabyrinthine approach (ILA) and ways to prevent complications based on the complex anatomy.

Study Design. Cadaveric study.

Setting. Ankara University Faculty of Medicine, Department of Anatomy.

Subjects and Methods. Temporal bones were selected from 30 sides of 20 fixed human cadaver heads. Computed tomography (CT) scans of the heads were performed and, afterward, the cadavers were dissected using a surgical microscope and electric drill.

Results. An appropriate tract could be achieved in 73.3% of the dissections by applying slight pressure to the jugular bulb (JB). The narrowest portion of the ILA was defined as the inner window, which was located superior-inferiorly between the inferior border of the cochlea and the inferior wall of the petrous apex and anterior-posteriorly between the posterior wall of the carotid canal and the cochlear opening of the cochlear aqueduct. The ILA could not be performed when the distances between the facial nerve-JB and JB-cochlea were less than 2.9 mm and 2.6 mm, respectively, on CT scan.

Conclusion. Close attention should be paid to the access and inner window during preoperative temporal bone imaging to assess for ILA. The detailed anatomy of the route, measurements of the topography of the cochlea from the mastoid view, and angles of the route are defined to prevent complications.

Keywords

anatomy, cholesterol granuloma, infralabyrinthine approach, radiology, skull base surgery

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Introduction

The petrous apex is the most difficult part of the ear to approach surgically when preservation of inner ear and facial nerve (FN) functions is desired. Petrous apex lesions have distinct management requirements, including periodic reimaging, medical treatment, surgical drainage, and total resection.

Cholesterol granuloma is the most common benign pathological lesion of the petrous apex.1 Direct exposure of these lesions is difficult because of the risk of injury to overlying structures. The goal in management of cholesterol granuloma is to achieve adequate and permanent drainage while preserving adjacent critical structures.2 One of the most commonly used surgical treatments for cholesterol granuloma is by way of ventilation tubes through the infralabyrinthine approach (ILA).3,4 This approach provides an appropriate route from the mastoid cavity to the anterior petrous apex in close proximity to all structures located in the petrous bone.

The objective of this study is to demonstrate the surgical anatomy of the ILA and ways to prevent potential complications based on the complex anatomy of petrous bone.

Methods

Thirty sides of 20 fixed human cadaver heads, 10 paired and 10 nonpaired, were dissected using a binocular surgical microscope (Zeiss OPMI PRIMO; Carl Zeiss, Göttingen, Germany) and an electric drill. There were 17 left and 13 right temporal bones. All the bones contained an adequate portion of petrous apex. Before dissection, temporal computed tomography (CT) (bone window setting) scans of the heads were performed using a Toshiba Aquilion 64 CT

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Scanner. Multiplanar reconstruction images were obtained from axial sections with a slice thickness of 0.5 mm and without an interslice gap.

The head of the cadaver was placed in the correct surgical position for transmastoid ILA. After postauricular incision and removal of the periosteal flap, the mastoid cortex was exposed, and a complete mastoidectomy was performed. By using the lateral semicircular canal (LSC) as the initial landmark, exposure of the posterior semicircular canal (PSC) was accomplished and the inferior extent of the PSC was skeletonized. The sigmoid sinus (SS) was skeletonized and the jugular bulb (JB) was identified. The mastoid segment of the FN was located, and then the skin of the external auditory canal was elevated until the middle ear was entered. The posterior wall of the external auditory canal was removed and the rest of the canal and tympanic annulus was enlarged circumferentially. The cochlea (Coc), the tympanic part of the JB, and the horizontal and vertical portions of the internal carotid artery (ICA) and cochlear aqueduct (AC) were skeletonized. An access window was drilled in the bone bounded laterally by the mastoid segment of the FN, medially by the dura of the posterior cranial fossa or JB, superiorly by the vestibule and inferiorly by the JB. If required, the JB was slightly compressed to gain access. By additional removal of the posteroinferior part of the mastoid cortex down to the digastric ridge (DR), a straight tract could be achieved from the infralabyrinthine air cells through the anterior petrous apex (Figure 1). The dissection was then converted to a middle fossa approach in order to check the position of the tract by drilling the superficial surface of the petrous apex posterior to the ICA and inserting a guide wire into the pathway. The length of the course of the ILA was defined as the distance between the access window and the most medial part of the petrous apex and measured by inserting a guide wire into the pathway and by measuring its length between the access window and the petrous apex. The horizontal line (HL) was defined as the line passing from the most inferior portion of the PSC parallel to the line of the zygomatic arch and used to describe the topography of the Coc.

In some cases, a high and laterally located JB hindered removal of the bone from the infralabyrinthine and subcochlear regions. In these cases, exposure was achieved by totally removing the bone from the JB and slightly compressing it. The ILA was considered to be unachievable when occlusion of the JB and/or drilling of the bony otic capsule or FN were required.

Direct measurements of the shortest distances between the structures described below were taken with the measuring probe and read with a digital caliper. The angles were measured with a goniometer (error 0.5°).

All data were measured independently by 2 authors (E.C., A.C.) and repeated twice, and their average values were calculated. Angles and some measurements about the route were recorded by inserting a guide wire into the tract. The angular measurements and measurements related to the route and topography of the Coc were obtained only on dissected specimens. The rest of the measurements were consistent across radiological and dissection modes.

The data were collected using an Excel (Microsoft, Redmond, Washington, USA) spreadsheet. Paired t test was used to compare the radiological and anatomical measurements. The kappa statistic was used to analyze the agreement between 2 raters. The statistical package used for the analysis was SPSS for Windows, release 15.0 (SPSS Inc, Chicago, Illinois, USA).

Measurements between the Coc and the anatomical structures were as follows:

1. Coc-JB: distance between the inferior aspect of the cochlea and the summit of bone covering the jugular bulb
2. Coc-ICA: shortest distance between the cochlea and the internal carotid artery

Measurements of the topography of the Coc were as follows:

1. FN-HL-P (depth): distance between the intersection of the facial nerve and the horizontal line and the lateral surface of the promontorium in the lateral-medial plane
2. FN-HL-Coc ab (length): distance between the intersection of the facial nerve and the horizontal line and the anterior border of the cochlea in the anterior-posterior plane
3. P-Coc mb (depth): distance between the promontorium and the medial border of the cochlea in the lateral-medial plane

Figure 1. View of the left mastoid cavity after dissection showing the route of the infralabyrinthine approach by inserting a guide wire into the tract. *, oval window; **, round window; Coc, cochlea; d, dura of the posterior fossa; DR, digastric ridge; FN, facial nerve; ICA, internal carotid artery; LSC, lateral semicircular canal; PSC, posterior semicircular canal; SS, sigmoid sinus; SSC, superior semicircular canal.
Measurements of the route were as follows:

1. Access window width: distance between the vestibule and the jugular bulb
2. Access window depth: distance between the facial nerve and the dura of the posterior cranial fossa or jugular bulb
3. Inner window width: distance between the inferior border of the cochlea and the inferior wall of the petrous bone
4. Inner window depth: distance between the posterior wall of the carotid canal and the cochlear opening of the cochlear aqueduct

Our study was exempt from review by the Institutional Review Board of the Ankara University Faculty of Medicine.

Results

An appropriate tract could be attained in 73.3% (n = 22) of the dissections by applying slight pressure to the SS and the JB. There was 96.6% agreement on the applicability of ILA with a kappa value of 0.918 between 2 raters (P < .001). The posteroinferior mastoid cortex had to be removed to the level of the DR from the inferior third of the SS down to the posterior half of the DR in all the dissections. The length of the course of the ILA was measured as 24.96 mm (range, 19.12-31.15 mm).

Results for measurements between the Coc and the anatomical structures are included in Table 1, whereas measurements of the topography of the Coc and the route are included in Tables 2 and 3, respectively.

Route-JB

The anatomy of the JB mainly determined the applicability of the ILA. Both the medial-lateral and superior-inferior position of the JB were of great importance. In a laterally localized JB, if no air cells were present between the JB and the FN, the ILA was considered to be inappropriate (Figure 2A). This relationship was observed in 5 (16.6%) sides (all nonpaired) of the cadavers. A medially located JB, even extending above the PSC, did not rule out the ILA (Figure 2B). But when considering the tympanic portion of the JB, the superior extension of the JB determined the applicability of the ILA. If the JB extended up to the Coc, the ILA was considered to be inapplicable as drilling over the otic capsule was required. This relationship was seen in 3 (10%) sides (1 paired and 2 nonpaired) of the cadavers.

Table 1. Measurements between Anatomical Structures.

<table>
<thead>
<tr>
<th></th>
<th>Temporal Bone Dissection</th>
<th>Radiology</th>
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<tr>
<td></td>
<td>Average, mm</td>
<td>Standard Deviation, mm</td>
</tr>
<tr>
<td>Coc-ICA</td>
<td>1.75</td>
<td>1.0</td>
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<tr>
<td>Coc-JB</td>
<td>5.27</td>
<td>1.88</td>
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Table 2. Measurements about Topography of Cochlea.

<table>
<thead>
<tr>
<th></th>
<th>Standard Deviation, mm</th>
<th>Minimum, mm</th>
<th>Maximum, mm</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Average, mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FN-HL-P (depth)</td>
<td>5.39</td>
<td>0.85</td>
<td>3.83</td>
</tr>
<tr>
<td>FN-HL-Coc ab (length)</td>
<td>7.38</td>
<td>1.33</td>
<td>5.14</td>
</tr>
<tr>
<td>P-Coc mb (depth)</td>
<td>7.43</td>
<td>1.06</td>
<td>6.82</td>
</tr>
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</table>

Table 3. Measurements Related to the Track of the Infralabyrinthine Approach.

<table>
<thead>
<tr>
<th></th>
<th>Average, mm</th>
<th>Standard Deviation, mm</th>
<th>Minimum, mm</th>
<th>Maximum, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access window width</td>
<td>5.67 mm</td>
<td>1.49 mm</td>
<td>3.5 mm</td>
<td>8.64 mm</td>
</tr>
<tr>
<td>Access window depth</td>
<td>5.79 mm</td>
<td>2.11 mm</td>
<td>2.96 mm</td>
<td>11.17 mm</td>
</tr>
<tr>
<td>Inner window width</td>
<td>4.32 mm</td>
<td>1.14 mm</td>
<td>3.82 mm</td>
<td>4.95 mm</td>
</tr>
<tr>
<td>Inner window depth</td>
<td>3.51 mm</td>
<td>0.32 mm</td>
<td>2.85 mm</td>
<td>4.02 mm</td>
</tr>
<tr>
<td>Guide-coronal plane</td>
<td>42°</td>
<td>35°</td>
<td>50°</td>
<td></td>
</tr>
<tr>
<td>Guide-axial plane</td>
<td>30°</td>
<td>25°</td>
<td>38°</td>
<td></td>
</tr>
<tr>
<td>Guide-sagittal plane</td>
<td>50°</td>
<td>42°</td>
<td>55°</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: Coc-ICA, cochlea to internal carotid artery; Coc-JB, cochlea to jugular bulb.
The ILA could not be performed when the distances between FN-JB and JB-Coc were less than 2.9 mm and 2.6 mm, respectively, on CT scan.

**Access Window**

During our dissections, we saw that the distance between the FN and the JB in the lateral-medial plane was one of the narrowest places of the route that determined the applicability of the ILA. The vestibule was the nearest part of the labyrinth to this plane. Different from the recent literature, we described a more reliable access window that was bounded superiorly by the vestibule, inferiorly by the JB, laterally by the FN, and medially by the dura of the posterior cranial fossa or JB (Figure 3). The average dimensions of the access window were 5.67 × 5.79 mm (Table 3).

**Route-Coc**

The route mainly passed below the PSC, vestibule, and Coc to reach the petrous apex. Without entering the middle ear cavity, only the PSC could be clearly identified from the mastoid cavity. To define the position of the most inferior portion of the Coc, the most inferior portion of the PSC was chosen as the reference point. The HL was drawn passing from the most inferior portion of the PSC parallel to the line of the zygomatic arch (Figure 4). In the surgical position, the most inferior portion of the Coc was always located above this line. The PSC, FN, and HL were used as landmarks to describe the 3-dimensional topography of the Coc from the transmastoid view. The distances from the intersection between the FN and HL (FN-HL) to the most anterior border of the Coc in the anterior-posterior plane (x) and the promontorium (P) in the lateral-medial plane were measured (Figure 5). In addition, the distance between the P and the most medial border of the Coc in the lateral-medial plane (y) was measured (Figure 5). According to our results, the most anterior border of the Coc was located 7.38 mm (x) anterior to the FN-HL and the most medial border of the Coc was located 12.82 mm medial to the FN-HL. The results are included in Table 2.

The internal auditory canal was always located medial to the Coc, at a level above the HL. Dissection on or under the HL should lead to preservation of the Coc, cochlear nerve, and internal auditory canal.

**Inner Window**

The cochlear opening of the AC was at risk of injury during the ILA. It was located 8.21 mm (range, 7.36-9.02 mm) away from the access window. With preservation of the AC, we defined the narrowest portion of the route, which was located 9.52-12.24 mm) away from the access window and which we called the “inner window.” The inner window was bounded anteriorly by the posterior wall of the carotid canal, posteriorly by the cochlear opening of the AC, superiorly by the inferior border of the Coc,
and inferiorly by the inferior wall of the petrous bone (Figure 6). The average dimensions of the inner window were $4.32 \times 3.51$ mm (Table 3).

**Route-ICA**

The posterior wall of the vertical segment of the carotid canal represented the anterior border of the medial part of the route. Preservation of the Coch resulted in preservation of the ICA because of the close relationship between them (average distance, 1.75 mm; range, 0-3.75 mm).

**Discussion**

The ILA is a transmastoid approach that has been presented as one of the best treatment options for cholesterol granuloma. During our dissections, we used a canal wall down approach to demonstrate and measure the distances between the anatomical structures that could not be identified during the ILA. Our results demonstrated the close relation of the course of the ILA with important structures and explained the reasons for its complications. Reported complications include cerebrospinal fluid leakage, sensorineural hearing loss, and FN injury.

The main problem with regard to the ILA was reported to be the presence of a high JB. The JB is a highly variable structure with respect to its size, location, and configuration. The incidence of JB abnormalities was reported as 10% to 15%. It has been demonstrated that the high riding JB may be in extremely close apposition to the inner ear structures with a very thin layer of bone separating them.

Previous studies advocated that the ILA could not be performed in almost 50% of the cases because of a high JB. Those studies were based on temporal bone dissections, rather than cadaver heads. In addition, clinical studies supported the view that a high JB should not be considered to be a contraindication for the ILA and it could be lowered using bone wax and Surgicel. In our cadaveric study, we totally skeletonized, fractured, and slightly compressed the bulb but we did not perform a total occlusion. With these procedures, we demonstrate that the applicability of the ILA gradually increases from 50% to 73%. We note that the ILA cannot be performed in 2 situations: with absence of air cells between the FN and the JB or between the Coch and the JB. The ILA can be applied by removal of the bone of the JB and slightly compressing it under the distal third of the mastoid segment of the FN unless it is located laterally, close to the FN. The ILA cannot be performed when the distance between the JB and Coch is less than 2.6 mm on CT scan.

In previous studies, the access window for the ILA has been described as the window bounded anteriorly by the FN, posteriorly by the SS, superiorly by the PSC, and inferiorly by the JB. Haberkamp also compared the dimensions of this access window with those created by the...
supracochlear and subcochlear approaches and advocated that the ILA provided the widest access. This window represents the lateral walls of the most lateral infralabyrinthine air cells but does not provide any information about the course through the petrous apex. For this reason, we describe a more reliable access window that is bounded superiorly by the vestibule, inferiorly by the JB, laterally by the FN, and medially by the dura of the posterior cranial fossa or JB. It represents an opening from the mastoid cavity through the petrous apex under the FN and especially its lateral-medial dimension (depth) determines the applicability of the ILA. This window is \( 5.67 \times 5.79 \) mm and it can be enlarged up to \( 8.64 \times 11.17 \) mm by compressing the bulb. The ILA cannot be performed if the depth of the access window is less than 2.9 mm on CT scan. Close attention should be paid to this anatomic area during preoperative imaging to assess for ILA.

Without compression of the JB, the level of the FN was determined to be the narrowest point of the ILA.9 With compression of the JB, we demonstrate that the narrowest portion of the ILA, which we call the inner window, is located between the inferior border of the Coc, the inferior wall of the petrous apex, the posterior wall of the carotid canal, and the cochlear opening of the AC. The inner window is the entrance to the petrous apex air cells, which are located inferior to the Coc. Most of the complications of the ILA, including cerebrospinal fluid leakage and hearing loss, are the results of penetration of the walls of the inner window. Our dissections revealed that the dimensions of the inner window had less variability. The inner window forms a rigid ring 10.02 mm away from the access window and it mainly determines the low range of the angles of the route. We recommend using the topography of the Coc, adequate compression of the bulb, dissection under the HL, and removal of the posteroinferior mastoid cortex to achieve the right angles to gain access to the inner window.

One of the most important disadvantages of the ILA is the lack of identification of the Coc and ICA intraoperatively. Although the extended facial recess approach manifests these structures, it increases the risk of FN injury. To determine the location of the Coc from the mastoid cavity, we describe the position of the Coc with regard to the PSC and the FN. In the surgical position, the most inferior portion of the Coc was always located just above the HL, in a box approximately 7.38 mm in width and 12.82 mm in depth medial to the FN. For a safe dissection, the tract should pass inferior and medial to the Coc. Expecting the location of the inferior and medial border of the Coc and the angles of the route that are presented in our study can help the surgeon for a safer surgery.

Accidental opening of the AC has been reported as one of the complications of the ILA only in a few studies in the literature.3 It has been demonstrated that the rate of the presence of a patent lumen throughout the AC is 34%.12 In other words, cerebrospinal fluid leakage occurs only in 1 of 3 injuries to the AC, and most surgeons do not even realize it. Despite all the details that we recommend for a safe approach, in our opinion, the AC is still at risk in each case.

Compatible with previous reports, the basal turn of the Coc was always in close proximity to the vertical portion of the ICA.9,13 Carotid injury has never been reported as a complication in the ILA.3 Preservation of the Coc prevents carotid injury.

Detailed knowledge of petrous anatomy is a fundamental requirement for surgical treatment of pathologies involving the petrous apex. An in-depth knowledge of petrous anatomy improves the sense of depth in identifying the location of anatomic structures and thus can reduce complications.

**Conclusion**

The applicability of ILA increases to 73% with the compression of the JB. A new access window is described and the narrowest portion of the ILA is defined as the inner window. The topography of the Coc and angles of the route are defined to prevent complications.

**Author Contributions**

Ela Co¨mert, data collection, data analysis, manuscript author, study design; Ayhan Co¨mert, data collection, data analysis, manuscript author, study design; Nurdan C¨ay, data analysis, manuscript

![Figure 6. View of the right tympanic cavity after dissection showing the inner window. AC, cochlear aqueduct; Coc, cochlea; FN, facial nerve; ICA, internal carotid artery; iw, inner window; JB, jugular bulb.](image-url)
AUTHORS

Umit Tunçel, data collection, data analysis, manuscript revision; Ibrahim Tekdemir, data collection, study design, manuscript revision.

DISCLOSURES

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