A study of middle cranial fossa anatomy and anatomic variations

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Abstract
We conducted a study to establish standardized measurements of the common anatomic landmarks used during surgery via the middle cranial fossa approach. Results were based on high-resolution computed tomography (CT) images of 98 temporal bones in 54 consecutively presenting patients. Measurements were obtained with the assistance of the standard PACS (picture archiving and communication system) software. We found that the superior semicircular canal (SSC) dome was not the highest point on the temporal bone (i.e., the arcuate eminence) in 78 of the temporal bone images (79.6%). Pneumatization above the SSC and above the internal auditory canal (IAC) was found in 27 (27.6%) and 39 (39.8%) temporal bone images, respectively. The anterior wall of the external auditory canal was always anterior to the anterior wall of the IAC. The mean angles between the SSC and the posterior and anterior walls of the IAC were 42.3° and 60.8°, respectively. We also measured other distances, and we compared our findings with those published by others. We hope that the results of our study will help surgeons safely and rapidly locate anatomic landmarks when performing surgery via the middle cranial fossa approach.

Introduction
The first reported use of the middle cranial fossa approach occurred in 1904; a hammer and chisel were used then to access the vestibular nerve for sectioning. Routine use of the middle cranial fossa approach did not gain widespread acceptance until the early 1960s when it was refined by House, who incorporated the use of the operating microscope. At that time, it was thought that decompression of the internal auditory canal (IAC) might alleviate symptoms of otosclerosis. Although this treatment ultimately proved to be unsuccessful, experience with the middle cranial fossa approach showed that it had some potential for use in the removal of acoustic neuromas.

Indications for the use of the middle cranial fossa approach are now clearly understood. Indeed, today it is the primary route of access for the surgical treatment of small, intracanalicular acoustic neuromas. However, the lack of definitive landmarks on the superior surface of the temporal bone makes this approach technically difficult. Vital structures such as the cochlea, labyrinth, and labyrinthine facial nerve are vulnerable as the surgeon searches for the IAC. Several methods have been devised to avoid these vital structures, all of them relying heavily on anatomic landmarks. Surgeons need to be familiar with all of these concepts because anatomic variations are common and standardized measurements are not available.

In 2003, Sennaroglu and Slattery reported a high correlation between anatomic and computed tomography (CT) measurements in the middle cranial fossa anatomy in 10 temporal bones. In this article, we describe the results of our study in which we used high-resolution CT to develop standardized measurements (including ranges of normal) for common anatomic landmarks in this area. These measurements provided the basis for a discussion of the strengths and limitations of the various systems used to locate the IAC. Our measurements also allowed us to determine a preferable approach to dissecting the middle cranial fossa. We propose that knowledge of these measurements will help the surgeon safely, reliably, and expeditiously locate the IAC and therefore avoid surgical complications.

Patients and methods
Our study population was made up of 54 consecutively presenting patients—20 men and 34 women, aged 18 years and older. Each underwent high-resolution axial and coronal CT of both temporal bones. The 1.25-mm images were...
obtained with a General Electric LightSpeed CT scanner.

We endeavored to ensure that the position of each head was identical during imaging by using fixed landmarks. Axial images were obtained on a plane parallel to the floor of the anterior cranial fossa, and coronal images were obtained on a plane perpendicular to the hard palate. No reconstructed images were used.

Films were read by a neurotologist and a neuroradiologist, both of whom looked for evidence of abnormalities. As a result of this search, they identified 10 temporal bones that exhibited evidence of chronic otitis media, and these 10 were excluded from our study, leaving us with a total of 98 temporal bones.

Measurements were made with the assistance of the standard PACS (picture archiving and communication system) software, which is accurate to 0.1 mm. Measurements made by this method have been found to be more accurate than those based on hard-copy film. In an effort to eliminate observer error and bias, all measurements were made twice—once each by two different physicians. The mean of the two values was used to calculate the final measurement. If there was a difference of more than 10% in any two measurements, the measurement was repeated in the presence of both evaluators, and agreement was reached. Values were recorded as means, standard deviations, ranges, and frequencies.

Measurements made from axial images. Six measurements were made in the axial plane (figure 1):

Measurement 1: The distance by which the incudomalleolar (IM) joint was anterior to the IAC. All IM joints were located anterior to the lateral-most extent of the IAC. This measurement was made from the medial aspect of the IM joint to Bill’s bar along a horizontal plane.

Measurement 2: The distance by which the IM joint was lateral to the IAC.

Measurement 3: The distance by which the external auditory canal (EAC) was anterior to the IAC. The anterior wall of the bony EAC was located laterally. PACS tools were used to draw a line (line E) beginning at the lateral-most point of the anterior wall of the bony EAC and running perpendicular to the anteroposterior axis of the head. Then...
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Measurement 4: The length of the IAC. The length of the IAC was measured at the level of the horizontal semicircular canal. First, the medial extent of the IAC was determined. Then a line was drawn from the anterior edge to the posterior edge of the porus acusticus internus. A line bisecting this line was extended to the lateral extent of the IAC at Bill’s bar, and its length was recorded.

Measurement 5: The angle between a line drawn through the membranous superior semicircular canal (SSC) and the posterior border of the IAC. A line (line S) was drawn between the SSC crura at a level 1.25 mm below the dome, as would be seen in a bluelined SSC. Then the angle between line S and a line drawn along the posterior edge of the IAC was measured. The apex of the angle was set at the lateral crus of the SSC.

Measurement 6: The angle between line S and the anterior border of the IAC.

Measurements made from coronal images. Measurements were also made in the coronal plane:

Location of the arcuate eminence. The dome of the SSC was identified, and PACS tools were used to measure the distance by which the highest point on the temporal bone (i.e., the arcuate eminence) was superior, lateral, and posterior to the SSC dome (figure 2).

The distance between the SSC dome and the outer table. The midpoint of the SSC was determined, then the distance from this point to the lateral portion of the skull was measured (figure 3).

The distance between the IAC and the zygomatic root. The distance from the lateral-most extent of the IAC to the outer portion of the zygomatic root was measured (figure 3).

Other determinations made on coronal imaging. We also examined coronal CTs for the presence or absence of pneumatization, which can obscure commonly used landmarks:

Pneumatization above the SSC. For each temporal bone, we identified the highest point of the SSC. We then recorded whether any air cells were present directly above this structure (figure 4).

Pneumatization above the IAC. We also identified the roof of the IAC and recorded whether any air cells were present directly above it.

Results
The results of all measurements are shown in tables 1 and 2. The SSC dome was located directly under the arcuate eminence in only 20 temporal bone images (20.4%); in the remaining 78 temporal bone images (79.6%), the arcuate eminence was superior to the SSC dome by a mean of 4.2 mm, lateral to the SSC dome by a mean of 5.3 mm, and posterior to the SSC dome by a mean of 6.3 mm (table 2).

Pneumatization above the SSC and above the IAC was found in 27 (27.6%) and 39 (39.8%) temporal bone images, respectively (table 3).

The mean angles between the SSC and the posterior and anterior walls of the IAC were 42.3° and 60.8°, respectively (table 1).
Discussion

**Literature review.** Using the middle cranial fossa approach to access the IAC requires in-depth knowledge of the anatomy of the temporal bone, petrous apex and, of course, the middle cranial fossa. Multiple methods have been devised to locate the IAC. In House’s report in 1961, he described a method of using the facial hiatus and greater superficial petrosal nerve as landmarks. First, the greater superficial petrosal nerve is located. Then a retrograde dissection to the geniculate ganglion, the labyrinthine portion of the facial nerve, and the IAC is performed. Dissection around the geniculate ganglion can compromise the vascularity of the facial nerve or damage the labyrinthine facial nerve; in either case, poor postoperative facial nerve function may ensue. At the geniculate ganglion, the cochlea is approximately 0.4 mm from the facial nerve and is vulnerable with this approach. Because the greater petrosal nerve is rarely discernible on CT and magnetic resonance imaging (MRI), these imaging modalities confer no benefit for the purpose of preoperative planning.

In 1970, Fisch described an alternate method of locating the IAC. He contended that the arcuate eminence closely corresponds to the location of the SSC. According to Fisch, once the arcuate eminence is identified, a 60° angle can be imagined anterior to the line along the SSC (with the apex of the angle at the lateral limb of the SSC). Drilling on the medial side of that angle would reveal the IAC. However, Kartush et al argued that the anatomic relationship between the arcuate eminence and the SSC is not constant and therefore not completely reliable. Our study confirmed their assertion.

With respect to pneumatization, the findings of our study indicate that surgeons should be prepared to drill through an air cell in order to locate the SSC in roughly one-quarter of patients. With this in mind, we propose that the safest way to approach an air cell that is superior to the SSC is to start posteriorly. No vital structures will be encountered in this area of the mastoid, and the likelihood of causing damage

<table>
<thead>
<tr>
<th>Measurement*</th>
<th>Mean (SD)</th>
<th>Range</th>
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<tbody>
<tr>
<td>1. IM–IAC anterior</td>
<td>3.3 mm (±0.9)</td>
<td>1.0 to 6.5 mm</td>
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<tr>
<td>2. IM–IAC lateral</td>
<td>8.3 mm (±0.9)</td>
<td>5.6 to 11.4 mm</td>
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<tr>
<td>3. EAC–IAC</td>
<td>5.0 mm (±1.6)</td>
<td>1.6 to 8.4 mm</td>
</tr>
<tr>
<td>4. IAC length</td>
<td>11.6 mm (±1.8)</td>
<td>8.5 to 16.5 mm</td>
</tr>
<tr>
<td>5. SSC–posterior IAC</td>
<td>42.3° (±6.6)</td>
<td>24.0 to 56.9°</td>
</tr>
<tr>
<td>6. SSC–anterior IAC</td>
<td>60.8° (±6.2)</td>
<td>40.2 to 73.2°</td>
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* Key:
1. IM–IAC anterior: The distance by which the incudomalleolar (IM) joint was anterior to the internal auditory canal (IAC).
2. IM–IAC lateral: The distance by which the IM joint was lateral to the IAC.
3. EAC–IAC: The distance by which the external auditory canal (EAC) was anterior to the IAC.
4. IAC length: The length of the IAC.
5. SSC–posterior IAC: The angle between the line (line S) drawn through the membranous superior semicircular canal (SSC) and the posterior border of the IAC.
6. SSC–anterior IAC: The angle between line S and the anterior border of the IAC.
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The area of drilling over the mastoid can then be expanded anteriorly to locate the SSC. The SSC can be recognized by the more yellow color of the bone and the solid nature of the otic capsule compared with the air cells. The air cells can be obliterated with bone wax to prevent postoperative CSF leakage through this route. Gelfoam and fibrin glue can be applied at the conclusion of the operation to further reduce this risk.

Based on our data, we believe that Fisch’s concept of drilling at a 60° angle anterior to the line along the SSC to find the IAC is reliable once the SSC is located (with the apex of the angle at the lateral limb of the SSC). In our study, the mean angle from the SSC to the posterior edge of the IAC was 42.3°, and the mean angle from the SSC to the anterior edge of the IAC was 60.8°.

In 1980, Garcia-Ibanez and Garcia-Ibanez described a method of locating the IAC that combined elements of the methods described by House and Fisch. According to their system, imaginary lines are drawn through the

<table>
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<tr>
<th>Measurement*</th>
<th>Mean (SD)</th>
<th>Range</th>
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<tr>
<td>1. AE superior</td>
<td>4.2 mm (±1.6)</td>
<td>1.6 to 7.8 mm</td>
</tr>
<tr>
<td>2. AE lateral</td>
<td>5.3 mm (±2.6)</td>
<td>0.0 to 13.1 mm</td>
</tr>
<tr>
<td>3. AE posterior</td>
<td>6.3 mm (±2.1)</td>
<td>2.5 to 11.6 mm</td>
</tr>
<tr>
<td>4. SSC–OT</td>
<td>21.1 mm (±2.4)</td>
<td>17.5 to 27.9 mm</td>
</tr>
<tr>
<td>5. IAC–ZR</td>
<td>25.7 mm (±2.6)</td>
<td>20.4 to 35.0 mm</td>
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* Key:
1. AE superior: The distance by which the arcuate eminence (AE) was superior to the superior semicircular canal (SSC) dome.
2. AE lateral: The distance by which the AE was lateral to the SSC dome.
3. AE posterior: The distance by which the AE was posterior to the SSC dome.
4. SSC–OT: The distance between the SSC dome and the outer table (OT).
5. IAC–ZR: The distance between the internal auditory canal (IAC) and the zygomatic root (ZR).

<table>
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<th>Presence</th>
<th>Absent</th>
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<td>n (%)</td>
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<td>Above the superior semicircular canal</td>
<td>27 (27.6)</td>
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<tr>
<td>Above the internal auditory canal</td>
<td>39 (39.8)</td>
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Table 2. Temporal bone measurements obtained from coronal CTs

Table 3. Presence and absence of pneumatization on coronal CT of 98 temporal bones
SSC and the greater superficial petrosal nerve. The IAC is located at the point where these lines bisect. As previously noted, however, the greater superficial petrosal nerve is rarely discernible on CT, so we were unable to make any assessment of this method of IAC localization. Other localizing procedures were described by Cohadon and Castel in 1968 and Pialoux et al in 1973; their methods rely on the use of the arcuate eminence or other superficial landmarks.

In 1993, Catalano and Eden described a method based on the location of the malleus head. They reported that the mean distance between the zygomatic root and the malleus head was 18 mm, and the mean distance between the malleus head and the edge of the vertical crest was 7.6 mm; therefore, the mean total distance from the zygomatic root to the IAC was 25.6 mm. In our study, the mean distance from the zygomatic root to the IAC was similar—25.7 mm (±2.6; range: 20.4 to 35.0). However, in our study, the mean distance between the zygomatic root and the IM joint was 17.4 mm and the mean distance between the IM joint and the IAC was 8.3 mm (±0.9; range: 5.6 to 11.4).

An interesting aspect of our findings is that our measurements refute the concept that the anterior edge of the IAC is in the same plane as the anterior edge of the EAC. In all of our measurements, the anterior wall of the EAC was always anterior to the anterior wall of the IAC (mean distance: 5.0 ± 1.6 mm; range: 1.6 to 8.4).

The high degree of correlation between our data and those of Catalano and Eden indicates that the IM joint is a reliable surgical landmark. However, in order to identify the IM joint, the surgeon must create a tegmen defect, which increases the patient’s risk of postoperative meningitis and CSF leakage. Unlike a mastoid defect, a tegmen defect cannot be easily obliterated with bone wax because the tegmen tympani is not supported by underlying bone, and the pressure required to apply the wax can fracture it. Other means of obliteration—such as the use of fascia—may lead to the formation of adhesions on the malleus or incus and the subsequent development of conductive hearing loss. Therefore, we reserve this method as a second-line option for IAC localization.

As previously mentioned, Sennaroglu and Slattery studied the correlation between anatomic and CT measurements in the middle cranial fossa anatomy in 10 temporal bones. Although their study was limited by the small number of samples, they were able to draw several important conclusions:

• First, their study demonstrated the variability of the arcuate eminence (as did the study by Kartush et al). An arcuate eminence was not identifiable in 3 of the 10 temporal bones, and therefore it was not a reliable landmark for the SSC.
• Second, 4 of their 10 temporal bones had air cells above the IAC. When the air cells superior to the IAC were large, the IAC was easy to identify. When the air cells were small, identifying the IAC was a significant challenge. Our study demonstrated the presence of air cells above the IAC in an almost identical number of cases—39.8%.
• Third, and most pertinent to our study, Sennaroglu and Slattery found a high correlation between anatomic and CT measurements. The small differences that they did observe might have been avoided if they had used PACS software to obtain their measurements.

Our technique. The approach to the IAC used by the senior author (H.R.D.) begins with the identification of the SSC. If the SSC is not clearly identifiable (e.g., if air cells are present above the SSC or if the SSC dome is not the highest point on the temporal bone), superficial drilling is commenced posteriorly. A few mastoid air cells are opened posteriorly, and superficial drilling is continued anteriorly until the SSC is visualized. Once the SSC is identified, it is slowly bluelined. The purpose of the blueline is to clearly identify the canal so that the IAC can be drilled to its most lateral point. The bluelining is done with feather-touch diamond drilling so as to avoid entering the membranous SSC.

After the bluelining of the canal is complete, lines are drawn to demarcate 40° and 60° angles from the lateral aspect of the SSC. The IAC is identified in the space between these two lines. Drilling with a 3-mm diamond or coarse diamond bur is performed posterior to the 60° line. The IAC is bluelined, and once the bone overlying the dura is removed, all bone posterior to the IAC and anterior to the SSC blueline is removed down to the floor of the IAC. The lateral limit of drilling is the point where a blunt hook inserted between the superolateral IAC dura and the overlying bone reaches the lateral-most aspect of the superior vestibular nerve. Inserting the hook at the lateral extent of the IAC at a slight anterior angle (anterior to Bill’s bar) identifies the course of the labyrinthine segment of the facial nerve. Posteriorly, the drilling is not continued as far laterally in order to avoid the SSC ampulla.

We advocate routinely obtaining a preoperative CT scan for all patients who are scheduled to undergo surgery via a middle cranial fossa approach. The CT will identify any air cells above the SSC, the location of the arcuate eminence and its relationship to the SSC, and any unusual anatomic variations, such as an IAC located more posteriorly than usual. Knowledge of anatomic variations preoperatively will significantly reduce intraoperative temporal lobe retraction and the drilling time required to locate the IAC.

Study strengths and limitations. The strength of our study is the large number of temporal bones that we examined. Most previous efforts to delineate the anatomy of the middle cranial fossa have involved only a small number of temporal bones. The fact that we studied 98...
temporal bones suggests that our data on means, standard deviations, and ranges can be more reliably extrapolated to the population as a whole.

Our study has two limitations. First, the thickness of our CT images was 1.25 mm, which limited their resolution somewhat. CT images can be as thin as 0.3 mm. However, obtaining 0.3-mm images would have meant that our patients would have been exposed to four times the amount of radiation. Second, despite our efforts to eliminate observer error and bias, it is possible that such did occur.

In conclusion, neurotologic surgeons should be familiar with the concepts devised by House, House, Fisch, and others. However, our study clearly demonstrated that the measurements and angles they reported are not exact and therefore not always reliable. We believe that our findings provide surgeons with reliable ranges in which the various anatomic structures commonly lie. When data from our study and those of others are used together, surgeons can safely and rapidly locate the IAC and other vital structures when performing surgery via the middle cranial fossa approach.

References