Classification of Temporal Bone Pneumatization on High-Resolution Computed Tomography: Prevalence Patterns and Implications

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No sponsorships or competing interests have been disclosed for this article.

Abstract
Objective. The degree of pneumatization of the temporal bone has implications in the pathophysiology and surgical considerations of many temporal bone disorders. This study aims to identify common pneumatization patterns in the petrous apex, mastoid, and infralabyrinthine compartments of the temporal bone. Variables associated with temporal bone pneumatization were also identified.

Study Design. Case series with chart review.

Setting. Single tertiary hospital.

Subjects and Methods. In total, 299 high-resolution computed tomography scans of the temporal bone performed on patients between 2013 and 2016 were reviewed. Only normal temporal bone scans in patients aged 13 years and older were included. Previously published grading systems were used to classify pneumatization patterns in the petrous apex, mastoid, and infralabyrinthine compartments of the temporal bone. Variables associated with temporal bone pneumatization were also identified.

Results. The most common pneumatization pattern in the petrous apex was group 2 (less than half of the petrous apex medial to the labyrinth is pneumatized), that in the mastoid was group 4 (hyperpneumatization), and that in the infralabyrinthine region was type B (limited pneumatization), at 54.8%, 55.4%, and 76.0% of patients, respectively. Patients with increased pneumatization of 1 temporal bone compartment tended to have increased pneumatization of the same compartment on the contralateral side and the other compartments on the ipsilateral side (P < .05). Younger age (P < .001) and male sex (P = .001) were associated with increased pneumatization in the petrous apex and infralabyrinthine compartments.

Conclusion. The degree of temporal bone pneumatization varies among the different compartments. Age and sex have a significant association with the degree of pneumatization of the petrous apex and infralabyrinthine compartment.

Temporal bone, pneumatization, high resolution, computed tomography, petrous apex, mastoid, infralabyrinthine

Received January 17, 2018; revised March 29, 2018; accepted May 1, 2018.

The varying degree of pneumatization of the temporal bone has implications on the pathogenesis of temporal bone diseases, including cholesterol granuloma, otitis media, and cholesteatoma.1-3 Pneumatized areas of the temporal bone represent areas of minimal resistance that allow the spread of these pathologies within the temporal bone.4 Increased pneumatization of the temporal bone has also been linked to increased incidence of cerebrospinal fluid fistula after skull base surgery in the area.5-7 Recognition of any deviation from common pneumatization patterns of the temporal bone is therefore critical before undertaking surgery to extirpate various pathologies of the temporal bone.

Previous studies8,9 have attempted to quantify the degree of pneumatization of the temporal bone. There are otherwise limited data in the published literature on the prevalence of various pneumatization patterns of the temporal bone. Using these classification systems and high-resolution computed tomography (HRCT) scans, this study aims to quantify the various pneumatization patterns of the temporal bone, specifically the petrous apex, infralabyrinthine, and mastoid.

Keywords

Temporal bone, pneumatization, high resolution, computed tomography, petrous apex, mastoid, infralabyrinthine

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compartments. This study also aims to identify variables associated with the degree of pneumatization of the temporal bone.

Method

This study is a retrospective review of HRCT temporal bone scans performed between 2013 and 2015 at a single tertiary institution. A total of 798 patients who presented with otologic symptoms underwent HRCT scanning of their temporal bones during this period. All patients older than 13 years with normal temporal bone HRCT scans were included in this study. A normal scan can be defined as the presence of normal external, middle, and inner ear anatomy with the absence of any mass lesions, opacification, or bony destruction. In total, 299 patients meeting the inclusion criteria were included in this study. These patients had no clinical evidence of otologic diseases. SingHealth centralized institutional ethics review board exemption was obtained for this study.

Temporal Bone Pneumatization Classification System

The degree of pneumatization of the petrous apex, infralabyrinthine, and mastoid compartments of the temporal bone on HRCT scans was evaluated using the following classification systems proposed by Han et al.8 and Marchioni et al.9 To minimize inter- and intraobserver variation, 1 author (ADT) reviewed all the temporal bone HRCT scans in this study and classified the temporal bone pneumatization patterns using standard methods described in the classification systems by Han et al8 and Marchioni et al,9 detailed below.

Petrous apex pneumatization: evaluated with reference to the labyrinth in axial view.8 The classification is described as such (Figure 1):

- Group 1: No air cells are present in the vicinity of the inner ear.
- Group 2: Less than half of the petrous apex medial to the labyrinth is pneumatized.
- Group 3: More than half of the petrous apex medial to the labyrinth is pneumatized.
- Group 4: Most of the petrous apex area medial to the labyrinth is composed of air cells.

Mastoid pneumatization: evaluated with reference to the sigmoid sinus in axial view.8 On the section where the malleoincudal complex appears as an ice-cream cone shape, 3 parallel lines angled at 45 degrees in the anterolateral direction are applied at positions in which each line crossed the most anterior point of the sigmoid sinus at the junction with the petrous bone, the most lateral aspect along the transverse plane of the sigmoid groove and the most posterior point of the sigmoid sinus, respectively.

The classification is described as such (Figure 2):

- Group 1 (hypopneumatization group): Pneumatization remains anteromedial to the line drawn at the most anterior point of the sigmoid sinus.
- Group 2 (moderate pneumatization group): Pneumatization extends to the space between the 2 arbitrary lines drawn at the most anterior point of the sigmoid sinus and the most lateral aspect of the sigmoid sinus.
- Group 3 (Good pneumatization): Pneumatization extends to the space between the 2 arbitrary lines drawn between the most lateral aspect of the sigmoid sinus and the most posterior point of the sigmoid sinus.
Group 4 (hyperpneumatization group): Pneumatization extends beyond the arbitrary line drawn at the most posterior point of the sigmoid sinus.

Infralabyrinthine pneumatization: evaluated with reference to the labyrinth, petrous apex, and internal auditory meatus in sagittal view. The classification is described as such (Figure 3):

Type A: Computed tomography (CT) sagittal view shows the presence of well-pneumatized temporal bone at the most inferior and medial portion of the petrous apex below the internal auditory meatus.

Type B: CT sagittal view shows the presence of limited pneumatized bone below the labyrinth.

Type C: CT sagittal view shows the absence of air cells at the most inferior and medial portion of the petrous apex.

In total, 299 patients meeting inclusion criteria had their HRCT scans evaluated for petrous apex, mastoid, and infralabyrinthine pneumatization pattern using the classification systems detailed above. The \( \chi^2 \) test was used to analyze for association between pneumatization group classification, sex, and racial group. The presence of association between pneumatization group classification of the various ipsilateral and contralateral temporal bone compartments was also analyzed using the \( \chi^2 \) test. The distribution of patients from different races reflects the inherent demographic pattern in Singapore. Due to a lack of normality in the distribution of age in our patient population, the nonparametric Kruskal-Wallis test was used to compare median age of patients between the pneumatization groups in the 3 studied compartments of the temporal bone. SPSS version 21 (SPSS, Inc, an IBM Company, Chicago, Illinois) was used for all statistical analyses in this study.

Results

A total of 299 patients with 299 HRCT temporal bone scans were included in this study. The median age of the patients was 50 years (interquartile range, 33-63). Of the patients, 166 (55.5%) were male and 133 (44.5%) were female. With regards to race, 73.9% (221 patients) were Chinese, 15.7% (47 patients) were Malay, and 10.4% (31 patients) were Indian.

Overall Patterns of Temporal Bone Pneumatization

The degree of pneumatization in the petrous apex, mastoid, and infralabyrinthine compartments of the temporal bone in the study subjects was classified based on the system described in the Method section. The most common pneumatization pattern of the petrous apex is group 2 (less than half of the petrous apex medial to the labyrinth is pneumatized). The most common pneumatization pattern of the mastoid is group 4 (hyperpneumatization), where pneumatization extends beyond the arbitrary line drawn at the most posterior point of the sigmoid sinus. The most common pneumatization pattern of the infralabyrinthine compartment is type B, where there is a presence of limited pneumatized bone below the cochlea. These results are detailed in Table 1.

Patients who had increased pneumatization on one side of their temporal bone also tended to have increased pneumatization on the other side and vice versa. This association is significant at \( P < .001 \) for the petrous apex, mastoid, and infralabyrinth compartments. Between their left and right temporal bones, 71.6% of patients had the same pneumatization group classification for the petrous apex compartment. This is 62.0% and 84.2% for the mastoid and infralabyrinth compartments, respectively.

Similarly, patients with increased pneumatization of 1 compartment of the temporal bone also tended to have increased pneumatization of the other compartments on that same side and vice versa. The association between the pneumatization groupings of the petrous apex and mastoid compartments, petrous apex and infralabyrinthine compartments, and mastoid and infralabyrinthine compartments is significant at \( P < .001, P < .001, \) and \( P = .03 \) respectively.

Association between Age and Temporal Bone Pneumatization

In the petrous apex, there was a significant difference in age distribution between the pneumatization groups \( (P < .001) \). In patients with group 1 type (least pneumatized) petrous apex, median age was 56.0 years. Median age was


Table 1. Overall Pattern of Temporal Bone Pneumatization.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Group 1, %</th>
<th>Group 2, %</th>
<th>Group 3, %</th>
<th>Group 4, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petrous apex</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>23.4</td>
<td>54.8</td>
<td>14.4</td>
<td>7.4</td>
</tr>
<tr>
<td>Left</td>
<td>20.1</td>
<td>54.8</td>
<td>18.1</td>
<td>7.0</td>
</tr>
<tr>
<td>Mastoid</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>3.0</td>
<td>26.9</td>
<td>20.5</td>
<td>49.5</td>
</tr>
<tr>
<td>Left</td>
<td>1.0</td>
<td>19.2</td>
<td>18.5</td>
<td>61.3</td>
</tr>
<tr>
<td>Infralabyrinthine</td>
<td>Type A, %</td>
<td>Type B, %</td>
<td>Type C, %</td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>16.8</td>
<td>77.2</td>
<td>6.0</td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>20.5</td>
<td>74.8</td>
<td>4.7</td>
<td></td>
</tr>
</tbody>
</table>

progressively younger with increasing pneumatization of the petrous apex—in patients with group 4 type (most pneumatized) petrous apex, median age was only 30.0 years. This difference in age distribution was also present between the different infralabyrinth pneumatization types ($P < .001$). Patients with a type A (most pneumatized) infralabyrinth compartment had a median age of 38.5 years compared to patients with a type C (least pneumatized) infralabyrinth compartment, who had a median age of 56.0 years. However, there was no significant difference in age distribution between the various mastoid pneumatization groups ($P > .05$). These results are summarized in Table 2.

Association between Sex and Temporal Bone Pneumatization

The most common group of pneumatization in the petrous apex for both sexes was group 2. However, males were more likely to have more pneumatized petrous apex (PA), with 27.9% of patients represented in groups 3 and 4 compared to 18.0% in females. There was a significant association between sex and pneumatization of the petrous apex ($P < .001$). In both males and females, type B was the most common infralabyrinth pneumatization pattern. Again, males were more likely to have increased pneumatization of the infralabyrinth compartment, with 23.7% exhibiting type A pneumatization compared to 12.1% in females. The association between sex and pneumatization of the infralabyrinth compartment is significant ($P = .001$).

There was no association between mastoid pneumatization groups and sex ($P > .05$). These results are presented in Table 3.

Association between Racial Group and Temporal Bone Pneumatization

No significant association between racial groups and degree of pneumatization in all 3 temporal bone compartments (petrous apex, mastoid, infralabyrinth) was found.

Discussion

This study is the largest one performed to evaluate the patterns of pneumatization in individual parts of the temporal bone based on established classification systems. It is also the first study that attempts to find links between pneumatization patterns and variables such as age, sex, and race.

In the current literature, various studies have been published to classify temporal bone pneumatization patterns. Han et al$^8$ studied 116 temporal bone CT scans and measured the volume of temporal bone air cells using volume-rendering techniques. They then proposed a system of classification based on various reference structures such as the labyrinth and the malleoincudal complex. This was the system used in our study to classify petrous apex and mastoid pneumatization. Marchioni et al$^9$, in turn, described a method of classifying the anatomy observed at the subcochlear canaliculus, which we used in our study to evaluate infralabyrinthine pneumatization.

Few other studies in the literature have attempted to study temporal bone pneumatization. Jadhav et al$^{10}$ evaluated 125 temporal bone cone beam CT scans and found a statistically significant correlation between volume measurement of temporal bone air cells by cone beam CT and the classification system proposed by Han et al.$^8$ Bronnoosh et al$^{11}$ used the same classification system by Han et al$^8$ to evaluate the relationship between temporal bone pneumatization and the presence of a pneumatized articular tubercle. The rest of the studies on this subject focused only on pneumatization of the articular tubercle part of the temporal bone alone in the context of maxillofacial surgery.$^4,12,13$

Comparing between relevant studies, a wide range in the patterns of temporal bone pneumatization is noted. In this study, the most common pneumatization pattern in the petrous apex was group 2 (less than half of the petrous apex medial to the labyrinth is pneumatized), found in 54.8% of patients. However, other studies found the most common pattern to be group 1 (no air cells are present in the vicinity of the inner ear), present in 40.0% to 72.4% of patients.$^8,10,11$ In the mastoid, the most common pattern of pneumatization in this study was type 4 (hyperpneumatization), found in 55.4% of our patients. The study by Bronnoosh et al$^{11}$ also found this to be the most common pattern, occurring in 30.9% of their study patients. On the other hand, Han et al$^8$ found the most common pattern in the mastoid to be type 2 pneumatization (moderate pneumatization). In the

Table 2. Age and Temporal Bone Pneumatization.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Group 1, y</th>
<th>Group 2, y</th>
<th>Group 3, y</th>
<th>Group 4, y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petrous apex</td>
<td>56.0</td>
<td>51.0</td>
<td>49.0</td>
<td>30.0</td>
</tr>
<tr>
<td>Mastoid</td>
<td>60.5</td>
<td>51.0</td>
<td>51.0</td>
<td>50.0</td>
</tr>
<tr>
<td>Infralabyrinthine</td>
<td>Type A, y</td>
<td>Type B, y</td>
<td>Type C, y</td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>38.5</td>
<td>51.0</td>
<td>56.0</td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>38.5</td>
<td>51.0</td>
<td>56.0</td>
<td></td>
</tr>
</tbody>
</table>
Infralabyrinthine compartment, the most common pattern in this study was type B pneumatization (limited pneumatization), found in 76.0% of our patients. In contrast, Marchioni et al. found the most common pattern to be type A pneumatization (well pneumatized), found in 40.0% of their study group.

In our study, younger age was associated with more extensive pneumatization in the petrous apex and infralabyrinthine compartments and vice versa ($P < .001$). However, no association was found between age and pneumatization of the mastoid compartment. To the authors’ knowledge, this is the first study to establish an association between patient age and extent of temporal bone pneumatization. However, as our study did not collect information on the patients’ lifetime exposure to other risk factors such as otitis media, we are unable to determine if age has a direct impact on temporal bone pneumatization or whether it is confounded by the fact that patients of different ages may have different exposures to risk factors. A previous study by Hug and Pfaltz found that the presence of chronic secretory or recurrent suppurative otitis media caused an inhibition in temporal bone pneumatization. With the improvement in access to health care in recent years, as well as the introduction of nationwide hearing screening in newborns and before elementary school, it is now unusual for the younger population in our country to be less than promptly treated for otitis media. It is possible that the association we observed between age and temporal bone pneumatization represents different exposures to risk factors between patients of different ages.

This study found that the extent of pneumatization on one side of a patient’s temporal bone is positively associated with pneumatization on the contralateral side ($P < .001$). In addition, 71.6%, 62.0%, and 84.2% of patients had the same pneumatization group classification bilaterally for the petrous apex, mastoid, and infralabyrinthine compartments, respectively. This is supported by cadaveric studies showing symmetrical pneumatization of the temporal bone in 72% to 99% of specimens.

In addition, this study found that patients with increased pneumatization of one compartment of the temporal bone also tended to have increased pneumatization of the other compartments on that same side and vice versa. This is similar to the findings in other studies. Hindi et al. found that the probability of petrous apex and perilabyrinthine pneumatization corresponds directly with the degree of mastoid pneumatization. Yamakami et al. found that the extent of mastoid cells significantly correlated with pneumatization of the petrous apex ($P < .01$).

This study also shows that there are positive associations of pneumatization patterns whereby the degree of pneumatization of one part of the temporal bone affects the degree of pneumatization of other parts in the temporal bone, as in other studies. Yamakami et al. found that the extent of mastoid cells significantly correlated with pneumatization of the petrous apex ($P < .01$).

The degree of pneumatization of the petrous temporal bone has important surgical implications. A study by Stieglitz et al. found that in patients undergoing retrosigmoid surgical removal of vestibular schwannoma, patients with higher mean air cell volume in the petrous temporal bone had a significantly higher rate of postoperative cerebrospinal fluid (CSF) fistula. Yamakami et al. similarly found that air cells in the petrous bone provide the route for CSF rhinorrhea after skull base surgery for cerebellopontine angle tumors and recommended routine CT assessment of the petrous air cells to prevent this complication. Stieglitz et al. also found that males had more pneumatization of the petrous temporal bones, which may account for a CSF fistula rate of 5.2%, almost twice that in females. This is in concordance to our study, which also found that males tended to have more pneumatization of the petrous apex and infralabyrinthine compartments of the temporal bone. This poses an important surgical consideration, as Valtonen et al. found that failure to recognize and adequately pack patent air cells after suboccipital vestibular schwannoma surgery is a major cause of postoperative CSF leaks.

### Table 3. Sex and Temporal Bone Pneumatization.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Group 1, No. (%)</th>
<th>Group 2, No. (%)</th>
<th>Group 3, No. (%)</th>
<th>Group 4, No. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pneumatization of the petrous apex</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>79 (29.5)</td>
<td>141 (52.6)</td>
<td>35 (13.1)</td>
<td>13 (4.9)</td>
</tr>
<tr>
<td>Male</td>
<td>51 (15.5)</td>
<td>187 (56.7)</td>
<td>62 (18.8)</td>
<td>30 (9.1)</td>
</tr>
<tr>
<td>Pneumatization of the mastoid</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>6 (2.2)</td>
<td>53 (19.8)</td>
<td>50 (18.7)</td>
<td>159 (59.3)</td>
</tr>
<tr>
<td>Male</td>
<td>6 (1.8)</td>
<td>84 (25.5)</td>
<td>67 (20.3)</td>
<td>173 (59.3)</td>
</tr>
<tr>
<td>Pneumatization of the infralabyrinth</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>32 (12.1)</td>
<td>219 (82.6)</td>
<td>14 (5.3)</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>78 (23.7)</td>
<td>233 (70.8)</td>
<td>18 (5.5)</td>
<td></td>
</tr>
</tbody>
</table>

In addition, this study found that patients with increased pneumatization of one compartment of the temporal bone also tended to have increased pneumatization of the other compartments on that same side and vice versa. This is similar to the findings in other studies. Hindi et al. found that the probability of petrous apex and perilabyrinthine pneumatization corresponds directly with the degree of mastoid pneumatization. Yamakami et al. found that the extent of mastoid cells significantly correlated with pneumatization of the petrous apex ($P < .01$).

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The infralabyrinthine approach has been described in the literature as an option to access and treat various benign and malignant neoplasms of the petrous apex, jugular foramen, internal acoustic meatus, and even the carotid foramen. However, it has to be considered that access via this approach would be limited by anatomical factors, including a high-riding jugular bulb and poor pneumatization of the infralabyrinthine compartment. In our study, only 18.7% of patients had well-pneumatized infralabyrinthine compartments. This is again an important surgical consideration prior to undertaking infralabyrinthine approaches.

Marchioni et al also highlighted the importance of infralabyrinthine pneumatization in cholesteatoma surgery. The authors noted that type A (well-pneumatized) infralabyrinthine compartments could be infiltrated by cholesteatoma involving the medial wall of the tympanic cavity. As the area may be difficult to visualize microscopically, the authors recommended endoscopic examination and an infralabyrinthine approach for complete disease clearance if deemed necessary.

Temporal bone pneumatization is also linked to the pathogenesis of various temporal bone diseases. Thedinger et al noted that up to 83.3% of patients with cholesterol granuloma of the petrous apex tended to have pneumatization of the contralateral petrous apex. This finding is similarly noted by Bruchhage et al who found that 88.9% of patients in their series had pneumatization of the contralateral petrous apex. This is likely related to the pathogenesis of cholesterol granulomas—some of the theories proposed involve the obstruction of a pneumatized cell, leading to mucosal damage, hemorrhage, and a subsequent inflammatory granulomatous reaction. In our patient population, 76.6% of patients had minimal or no pneumatization of their petrous apex. This may account for the low rates of cholesterol granulomas observed in our population.

While this study does not set out to examine the correlation between the degree of mastoid pneumatization and the development of middle ear or temporal bone disease, previous studies have shown mastoid pneumatization to be variably linked to the development of chronic otitis and middle ear cholesteatoma. A study by Wang et al noted that 88% of patients with middle ear cholesteatomas had diploic mastoids, compared to 22% in patients with external auditory canal cholesteatomas. Sadé and Fuchs found that cholesteatomas associated with poorly pneumatized mastoids showed mainly an attic and mastoid distribution communicating with a pars tensa or pars flaccida retraction or marginal perforation, whereas cholesteatomas associated with pneumatized mastoids appeared most often behind an intact drum. Further to that, another study by Shinnabe et al found that mastoid pneumatization was significantly better in ears with pars tensa than pars flaccida cholesteatoma.

**Conclusion**

There is a wide variation in the most commonly observed pattern of temporal bone pneumatization between studies. Age and sex were identified as significant variables associated with the degree of pneumatization of the petrous apex and infralabyrinthine compartments of the temporal bone. As discussed above, temporal bone pneumatization has important surgical implications that should be considered prior to undertaking surgery to extirpate diseases of the temporal bone.

**Author Contributions**

Arthur Dexian Tan, acquisition and interpretation of data, drafting the manuscript, final approval of version to be published, ensuring accuracy and integrity of the study; Jia Hui Ng, data analysis and interpretation, drafting of manuscript and critical revision for intellectual content, final approval of version to be published, ensuring accuracy and integrity of the study; Su Ann Lim, acquisition and interpretation of data, drafting the manuscript, final approval of version to be published, ensuring accuracy and integrity of the study; David Yong-Ming Low, conception and study design, data interpretation, critical revision of manuscript for intellectual content, final approval of version to be published, ensuring accuracy and integrity of the study.

**Disclosures**

**Competing interests:** None.

**Sponsorships:** None.

**Funding source:** None.

**References**