Analysis of various tracts of mastoid air cells related to CSF leak after the anterior transpetrosal approach

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OBJECTIVE The anterior transpetrosal approach (ATPA) was established in 1984 and has been particularly effective for petroclival tumors. Although some complications associated with this approach, such as venous hemorrhage in the temporal lobe and nervous disturbances, have been resolved over the years, the incidence rate of CSF leaks has not greatly improved. In this study, some varieties of air cell tracts that are strongly related to CSF leaks are demonstrated. In addition, other pre- and postoperative risk factors for CSF leakage after ATPA are discussed.

METHODS Preoperative and postoperative target imaging of the temporal bone was performed in a total of 117 patients who underwent ATPA, and various surgery-related parameters were analyzed.

RESULTS The existence of air cells at the petrous apex, as well as fluid collection in the mastoid antrum detected by a postoperative CT scan, were possible risk factors for CSF leakage. Tracts that directly connected to the antrum from the squamous part of the temporal bone and petrous apex, rather than through numerous air cells, were significantly related to CSF leak and were defined as “direct tract.” All patients with a refractory CSF leak possessed “unusual tracts” that connected to the attic, tympanic cavity, or eustachian tube, rather than through the mastoid antrum.

CONCLUSIONS Preoperative assessment of petrous pneumatization types is necessary to prevent CSF leaks. Direct and unusual tracts are particularly strong risk factors for CSF leaks.

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KEY WORDS anterior transpetrosal approach; skull base; CSF leak; petrous apex; mastoid air cell

Development of the surgical technique, monitoring devices, and preoperative radiographic technologies was helpful to resolve complications, such as venous hemorrhage in the temporal lobe and nervous disturbances.26,32 However, the incidence rate of postoperative CSF leakage at our hospital was still not low—12.9% in the first 15 years and 13.2% in the last 15 years. In most cases, the ATPA cannot be performed without opening the air cells, because it requires drilling of the squamous part of the temporal bone and petrous apex, as described above. In general, the large dural defect is covered by a flap of vascularized temporalis fascia, and the opened air cells are replaced by autologous tissues (e.g., fat or muscle tissue) and fibrin glue to prevent a CSF leak.10,36 However, in large series of patients who underwent skull base surgery, including the ATPA, up to 15% suffered from a postoper-
ative CSF leak. Although other modified methods (e.g., multilayer sealing techniques using fat, fascia, and inlay techniques) have been developed, CSF leaks have not been completely resolved.

In recent years, skull base surgery via the endonasal endoscopic approach has demonstrated outstanding progress. The risk of CSF leak after the endonasal endoscopic approach has been decreased by using fat, fascia, or muscle to plug the surgical defects. Therefore, more efficient ways to prevent and predict CSF leaks following an ATPA should be developed.

In this study, we revealed different tracts that are related to CSF leaks after an ATPA. Determination of the pre- and postoperative risk factors in this study may lead to meticulous packing of the opened air cells and decrease the incidence ratio of CSF leaks.

Methods

The current retrospective study, performed at the Keio University Hospital (Tokyo, Japan), was approved by the institutional review board. For this retrospective analysis, we collected all CT images obtained in 168 patients who underwent surgery via the petrosal approach at our hospital between January 2005 and March 2017. The CT examinations were performed on a 64–detector row CT scanner (LightSpeed VCT; GE Healthcare), a 320–detector row CT scanner (Aquilion ONE; Toshiba Medical Systems), or a 256–multidetector row CT scanner (Revolution CT; GE Healthcare).

Exclusion criteria of this study were as follows: 1) patients who underwent a combined petrosal approach (n = 31), and 2) patients for whom there were no retained records (n = 20). Thus, data in 117 patients (45 males and 72 females, 6–76 years of age) who underwent the ATPA were analyzed in this study. The anatomy of the petrous bone air cells was evaluated by pre- and postoperative bone window CT using direct axial imaging with 1.0- or 5.0-mm collimation parallel to the orbitomeatal line or target imaging of the petrous bone. To avoid the possibility of biasing the results, this retrospective review of CT scans obtained in 117 patients was performed blindly by 2 authors (R. Tamura and R. Tomio), who studied the scans independently. Surgical data were retrieved from operative reports, information on tumor histology was obtained from pathology reports, and all other perioperative information was collected from hospital medical records.

Parameters analyzed to assess their relationship to CSF leaks were as follows: 1) preoperative factors—pneumatization in the petrous apex (Fig. 1A) or squamous part of the temporal bone (Fig. 1B), bone erosion by tumor, the tegmen tympani (Fig. 1C), and the anatomical features of air cell tracts around the mastoid antrum; 2) intraoperative factors—the size of craniotomy and drilled petrous apex, the surgeon’s intraoperative awareness of the opened air cells, replacement air cells of the petrous apex by fat or muscle tissue, and the insertion of a spinal drain during the perioperative period; and 3) postoperative factors—fluid collection in the mastoid air cells or antrum detected by CT scan 1 day postoperatively (Fig. 1D).

The chi-square test was used to compare the incidence rates of CSF leak in the presence and absence of the parameters listed above. Analyses were performed with IBM SPSS Statistics (IBM Corp.).

Results

The results are summarized in Table 1. Of 117 patients, 17 (14.5%) suffered a CSF leak. One hundred fifteen patients had a tumor, and the remaining 2 patients had neuralgia.

Preoperative Factors

In general, pneumatization in the temporal bone connects to the antrum through numerous mastoid air cells (Fig. 2A). In this analysis, tracts that directly connected to the antrum from the squamous part of the temporal bone and petrous apex, rather than through numerous air cells, were identified, thereby defining “squamous direct tract” and “petrous direct tract” (Fig. 2B). All of the air cells in the temporal bone (including mastoid, squamous, and petrous parts) typically connect to the attic through the mastoid antrum. However, our analyses revealed different tracts that connected to the attic, tympanic cavity, or eustachian tube, rather than through the mastoid antrum, thereby defining “unusual tracts” (Fig. 2C).
The incidence ratio of CSF leakage did not differ significantly between patients with and without air cells in the squamous part of the temporal bone (incidence ratio 16 of 95 [17%] vs 1 of 22 [5%], p = 0.14). In contrast, the incidence ratio of CSF leakage differed significantly between patients with and without air cells in the petrous apex (incidence ratio 14 of 56 [25%] vs 3 of 61 [5%], p = 0.002). The incidence ratio of CSF leakage differed significantly between patients with and without squamous or petrous direct tract (the squamous direct tract incidence ratio 10 of 38 [26%] vs 7 of 79 [9%], p = 0.012; the petrous direct tract incidence ratio 13 of 47 [28%] vs 4 of 70 [6%], p = 0.005). Squamous and petrous direct tracts were demonstrated in 80% of patients with a CSF leak. Notably, the incidence ratios of CSF leakage differed significantly between patients with and without unusual tracts (incidence ratio 14 of 19 [74%] vs 3 of 98 [3%], p < 0.001). In addition, all patients who exhibited a refractory CSF leak that required closure had unusual tracts.

The tegmen tympani was also evaluated in this analysis. A thin tegmen tympani was defined as a thickness < 0.9 mm. For 58 patients in whom the coronal CT image was obtained, 10 patients (17%) had a thin tegmen tympani, and 3 of these 10 patients had a CSF leak. In contrast, 14 of 48 patients with a normal tegmen tympani had a CSF leak. Thin tegmen tympani may not be a risk factor for a CSF leak (p = 0.957).

### Intraoperative Factors

The size of craniotomy (> 55 mm) and drilled petrous apex (> 15 mm) also had no significant association with CSF leaks (craniotomy incidence ratio 7 of 51 [14%] vs 10 of 66 [15%], p = 0.835; drilled petrous apex incidence ratio 9 of 66 [14%] vs 8 of 51 [16%], p = 0.688). Regardless of replacement of the petrous apex air cells by fat or muscle tissue and insertion of a spinal drain during the perioperative period, there were no significant differences in the incidence ratio of CSF leakage (replacement of air cells by fat or muscle incidence ratio 7 of 37 [19%] vs 6 of 39 [15%], p = 0.682; spinal drain incidence ratio 2 of 10 [20%] vs 5 of 48 [10%], p = 0.397). These procedures were more likely to be performed for patients with a high risk of CSF leaks. The surgeon’s awareness of opened air cells also had no significant association with CSF leakage (incidence ratio 3 of 17 [18%] vs 4 of 41 [10%], p = 0.401).

### Postoperative Factors

The incidence ratio of fluid collection in the antrum or mastoid air cells detected by a postoperative CT scan varied considerably (antrum incidence ratio 17 of 53 [32%] vs 0 of 64 [0%], p < 0.001; mastoid air cells incidence ratio 17 of 82 [21%] vs 0 of 35 [0%], p = 0.004). All patients with CSF leaks had fluid collection in the mastoid antrum and mastoid air cells. Patients with fluid collection in mastoid air cells but not in the mastoid antrum did not suffer from CSF leaks.

### Discussion

Risk factors for a CSF leak after skull base surgery, including the ATPA, are summarized in Table 2. Regardless of whether exposed air cells were replaced by fat or muscle tissues in these reports, the CSF leak did not completely resolve. Although the incidence ratio of postoperative CSF leakage in our hospital was not high compared with reported results by others, some patients demonstrated a refractory course and required reoperation. Among the studies listed in Table 2, pneuma-
tization of the petrous apex was the most important risk factor, as in our study. Furthermore, we analyzed various types of pneumatization and found air cell tracts that were closely related to CSF leakage after the ATPA. Our analysis indicates that patients at high risk for CSF leaks should be identified before the operation, which may lead to meticulous packing of air cells and decrease the incidence ratio of CSF leak.

Air Cells in the Squamous Part of the Temporal Bone and Petrous Apex

In general, air cells in the mastoid, squamous part of
the temporal bone, and petrous apex typically connect to the attic through the mastoid antrum.\(^8\) Therefore, air cells in the squamous part of the temporal bone was a possible risk factor for CSF leaks. However, air cells in the squamous part of the temporal bone can be replaced by fat and muscle tissues macroscopically and can be compressed by a bone flap; only 3 of 17 cases had CSF leaks in the squamous part of the temporal bone. In contrast, air cells in the petrous apex were a significant risk factor for CSF leaks. We tried to visualize the petrous bone of a patient with a refractory CSF leak after the ATPA by using a 3D printer (Fig. 3A). Although autologous tissues were used to fill in the drilled part of the petrous apex, microscopic confirmation of complete coverage is not easy because of the blind area (Fig. 3B). Therefore, some patients in whom opened air cells were noticed intraoperatively may suffer from a

**TABLE 2. Literature review on risk factors of CSF leaks after skull base surgery**

<table>
<thead>
<tr>
<th>Authors &amp; Year</th>
<th>No. of Patients (ratio of CSF leaks)</th>
<th>Risk Factors</th>
<th>Surgical Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nutik &amp; Korol, 1995</td>
<td>156 (15%)</td>
<td>Opened petrous apex air cell (not opened mastoid air cell at the lat side of the craniotomy). Communication between the IAC &amp; the middle ear</td>
<td>RA</td>
</tr>
<tr>
<td>Leonetti et al., 2001</td>
<td>589 (6%)</td>
<td>CSF in the antrum in postop CT</td>
<td>TLA, RA, CA</td>
</tr>
<tr>
<td>Yamakami et al., 2003</td>
<td>NE</td>
<td>Pneumatized petrous bone</td>
<td>RA</td>
</tr>
<tr>
<td>Fishman et al., 2004</td>
<td>196 (6.6%)</td>
<td>Communication w/ the middle ear space &amp; patent eustachian tube. Extensively pneumatized air cell</td>
<td>RA, MCA, TLA</td>
</tr>
<tr>
<td>Little et al., 2005</td>
<td>137 (7.3%)</td>
<td>The wider exposure of bone after drilling</td>
<td>CA, RA, MCA, TMA</td>
</tr>
<tr>
<td>Stieglitz et al., 2010</td>
<td>519 (5.2%)</td>
<td>Petrous bone air cell vol</td>
<td>RA</td>
</tr>
<tr>
<td>Nanda et al., 2011</td>
<td>50 (4%)</td>
<td>Reop</td>
<td>TPA, OZA</td>
</tr>
<tr>
<td>Walcott et al., 2012</td>
<td>32 (6%)</td>
<td>Reop w/o vascularized temporalis muscle flap. Congenital abnormality in the middle ear. Prior radiation</td>
<td>RA, TPA</td>
</tr>
<tr>
<td>Scheich et al., 2016</td>
<td>148 (13%)</td>
<td>Pneumatized petrous bone</td>
<td>MCA</td>
</tr>
<tr>
<td>Stevens et al., 2016</td>
<td>48 (14.5%)</td>
<td>Abnormally thin tegmen tympani</td>
<td>TMA, MCA, TPA</td>
</tr>
<tr>
<td>Present study</td>
<td>117 (14.5%)</td>
<td>Pneumatized petrous bone. Petrous &amp; squamous direct tracts. Unusual tracts.* Fluid collection in the mastoid antrum on postop CT</td>
<td>ATPA</td>
</tr>
</tbody>
</table>

CA = combined petrosal approach; IAC = internal auditory canal; MCA = middle cranial fossa approach; NE = not examined; OZA = orbitozygomatic approach; RA = retrosigmoid approach; TLA = translabyrinthine approach; TMA = transmastoid approach; TPA = transpetrosal approach (anterior or posterior transpetrosal approach).

* Unusual tracts include the posterosuperior cell tract, hypotympanic tract, perilubular tract, and squamous tympanic tract.
CSF leak postoperatively. Pneumatization of the petrous apex was an important risk factor, and careful packing was needed. An endoscope may help to evaluate incomplete coverage.

**Direct Tracts**

The squamous and petrous direct tracts clearly recognized by a preoperative CT scan can also be strong risk factors for CSF leakage (Fig. 2B). The air cells in the squamous part of the temporal bone and petrous apex typically connect to the antrum through numerous air cells (Fig. 2A). In contrast, squamous and petrous direct tracts do not connect to the antrum through numerous mastoid air cells. These direct tracts were short, resulting in a high risk of CSF leak.
Unusual Tracts

Yamakami et al. have reported that mastoid and petrous apex air cells were risk factors for CSF leakage in skull base surgery. In their report, 31% of patients had petrous apex air cells, and they suggested that preoperative assessment of petrous pneumatization using a bone window CT scan and meticulous intraoperative sealing of the exposed air cells may decrease the incidence of postoperative CSF leaks. The petrous apex air cells sometimes expand to the carotid canal and articular tubercle. Anatomical analysis of the temporal bone has been reported; the air cells of the temporal bone were classified into the mastoid region (antrum, periantral cell area, tegmental cell area, sinodural cell area, perisinus cell area, perifacial cell area, and mastoid tip cell area), the peritalarynghine region (supralarynghine area and infralarynghine area), the petrous apex region (peritalurial area and apical area), and the accessory region (zygomatic cell area, squamous cell area, occipital cell area, and styloid cell area). It has been reported that some tracts directly lead to the attic, tympanic cavity, or eustachian tube rather than through the antrum, .

In our analysis, in addition to the presence of squamous and petrous direct tracts, the presence of unusual tracts was associated with a high risk of CSF leaks after the ATPA (Fig. 2C). The posterosuperior cell tract directly connects to the attic from the petrous apex. The hypotympanic tract courses between the carotid canal, cochlea, and tympanic cavity to reach the apical area of the petrous bone. The peritalurial tract is an extension around the auditory canal air cells into the apical area. Although only 18 patients presented with these unusual tracts in our study, all patients who required reoperation to close a CSF leak had unusual tracts. Four of 7 patients with the posterosuperior cell tract, 3 of 6 patients with the hypotympanic tract, and 5 of 5 patients with the peritalurial tract had a refractory CSF leak. In addition, 1 patient had the squamous tympanic tract from the squamous part of the temporal bone to the tympanic cavity, leading to a refractory CSF leak (Fig. 2C). The peritalurial tract may be the tract of most concern, because the peritalurial tract sometimes opens into the eustachian tube. The existence of these unusual tracts was not related to the level of development of air cells.

These direct and unusual tracts strongly influence the operative method to repair when a refractory CSF leak occurs. If a patient who has the squamous or petrous direct tracts has a refractory CSF leak, regardless of replacing the opened air cells by autologous tissue, packing of the antrum is required (Fig. 4A). In contrast, if a patient with unusual tracts has a refractory CSF leak, it cannot be improved only by packing the antrum. If all else fails, packing the eustachian tube may also be required (Fig. 4B), but it carries the risk of conduction deafness. In our study, with regard to autologous tissues, there was no significant difference in the incidence of CSF leaks between patients in whom air cells in the petrous apex were replaced by muscle and those in whom air cells were replaced by fat. However, fat tissue is considered the better tissue for filling large air cells because some reports have pointed out the advantage that it contains rich mesenchymal stem cells differentiated into the connective tissue.

Other Parameters

With regard to postoperative risk factors, fluid collection in mastoid air cells and the mastoid antrum (Fig. 1D) should be checked. All patients with CSF leaks had fluid collection in the mastoid antrum. Most patients also had fluid collection in mastoid air cells. However, patients with fluid collection in mastoid air cells and not the mastoid antrum did not suffer from CSF leaks. Fluid collection in the mastoid antrum should be evaluated by postoperative CT scans. Stevens et al. showed a relationship between abnormally thin tegmen tympani and CSF leaks after skull base surgery. We have also observed a patient with a CSF leak after the ATPA, which was caused by thin tegmen tympani. A thin tegmen tympani was not explicitly a risk factor for CSF leaks in this analysis. A thin tegmen tympani rarely causes a CSF leak, as shown in other reports and our experience.

According to our results, if air cells of the squamous part of the temporal bone or the petrous apex, or unusual or direct tracts, are identified by a preoperative CT scan, autologous tissue should be carefully packed into the opened air cells to prevent a refractory CSF leak. If fluid collection in the mastoid antrum is increased several weeks postoperatively, a refractory CSF leak should be considered.

Conclusions

Unusual tracts of air cells in the temporal bone to the attic, tympanic cavity, or eustachian tube, rather than through the antrum, are strong risk factors for refractory CSF leaks after the ATPA. Squamous and petrous direct tracts also carry a strong risk of CSF leaks.

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

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