Computed Tomography Evaluation of Air Cells in the Petrous Bone

—Relationship With Postoperative Cerebrospinal Fluid Rhinorrhea—

Iwao YAMAKAMI, Yoshio UCHINO, Eiichi KOBAYASHI, and Akira YAMAURA

Department of Neurosurgery, Chiba University School of Medicine, Chiba

Abstract

The anatomy of air cells in the petrous bone was investigated using thin-slice bone-window computed tomography (CT) of 168 petrous bones in 84 patients. Air cells in the petrous bone were classified into mastoid and petrous cells. Petrous cells were subdivided into perilabyrinthine and apical cells. Perilabyrinthine cells comprised supralabyrinthine and infralabyrinthine cells. Supralabyrinthine cells were subdivided into posterosuperior, posteromedial, and subarcuate cells. The mastoid was classified as eburnated (11%) or pneumatized (89%) by the extent of the mastoid cells. The mastoid cells were classified into presinusoidal (14%), sinusoidal (44%), and postsinusoidal (42%) according to the relationship with the sigmoid sulcus. The extent of the mastoid cells was significantly correlated with the pneumatization of the petrous apex, i.e. the apical cells ($p < 0.01$). CT precisely depicted the complex anatomy of the air cells in the petrous bone. Cerebrospinal fluid (CSF) rhinorrhea is the most common complication after skull base surgery for cerebellopontine angle tumors. Air cells in the petrous bone provide the route for CSF rhinorrhea. Therefore, CT assessment of the air cells is useful for preventing this complication.

Key words: air cell, cerebrospinal fluid rhinorrhea, complication, petrous bone, pneumatization, skull base surgery

Introduction

Cerebrospinal fluid (CSF) rhinorrhea is the most common complication after skull base surgery for cerebellopontine angle (CPA) tumor,^{11,12,20} and may require the continuous lumbar drainage^{4,14,21} or even surgical repair for treatment.^{7,9,13,24} CSF rhinorrhea occurs through air cells in the petrous bone which were exposed by the surgical procedure. Patients with highly pneumatized petrous bone have a higher risk of CSF rhinorrhea.^{2,7,19} This study analyzed thin-slice bone-window computed tomography (CT) of 168 petrous bones in 84 patients to clarify the anatomy of the air cells in the petrous bone.

Materials and Methods

Eighty-four patients with CPA tumor, 38 males and 46 females aged 21–72 years old, underwent

preoperative axial thin-slice bone-window CT of the petrous bone using a 1 mm or 1.5 mm thick slice, parallel to the orbitomeatal line. Coronal thin-slice bone-window CT of the petrous bone was also performed in 20 of the 84 patients. The anatomy of the air cells in the petrous bone was evaluated by analyzing the CT scans of the 168 petrous bones in these 84 patients.

Air cells in the petrous bone were classified into mastoid cells and petrous cells. Mastoid cells were defined as air cells in the mastoid, whereas petrous cells were air cells in the petrous bone except for the mastoid. The petrous cells were subdivided into perilabyrinthine cells and apical cells. The perilabyrinthine cells, the air cells surrounding the labyrinth, included supralabyrinthine cells superior to the labyrinth and infralabyrinthine cells inferior to the labyrinth. The supralabyrinthine cells were subdivided into posterosuperior, posteromedial, and subarcuate cells.^{1,17} The posterosuperior cells, arising from the antrum, are located around the anterior semicircular canal (SCC) and along the posterior

Table 1 Computed tomography classification of air cells in the petrous bone

1. Mastoid cells
a) Presinusoidal
b) Sinusoidal
c) Postsinusoidal
2. Petrous cells
a) Perilabyrinthine cells
1) Supralabyrinthine cells
i) Posterosuperior cells
ii) Posteromedial cells
iii) Subarcuate cells
2) Infralabyrinthine cells
b) Apical cells

Modified from Allam.¹⁾

Fig. 1 Schema of the air cells in the left petrous bone. A: apical cells, EAM: external auditory meatus, FM: foramen magnum, IAM: internal auditory meatus, M: mastoid cells, P: perilabyrinthine cells, T: tympanic cavity.

face of the petrous bone above the internal auditory meatus (IAM). The posteromedial cells extend along the posterior face of the petrous bone beneath the posterosuperior cells.^{1,17)} The apical cells are located medial to the IAM and posteromedial to the carotid canal (Table 1, Fig. 1).

Results

I. Mastoid cells

The extent of the mastoid cells varied greatly among the patients. The mastoid was classified into eburnated (11%) in which the mastoid cells were localized and pneumatized (89%) in which the

Fig. 2 Computed tomography scans showing mastoid cells of the presinusoidal (left), sinusoidal (middle), and postsinusoidal types (right). Retrosigmoid craniotomy can expose mastoid cells of the postsinusoidal type and cause cerebrospinal fluid rhinorrhea.

mastoid cells occupied the whole of the mastoid. The mastoid cell type was symmetrical in 82 of the 84 patients; 74 patients had pneumatized mastoid on both sides and eight had eburnated mastoid on both sides. The mastoid cells were classified into presinusoidal (14%), sinusoidal (44%), and postsinusoidal (42%) according to the relationship with the sigmoid sulcus. Presinusoidal mastoid cells did not extend posteriorly to the anterior margin of the sigmoid sulcus. Sinusoidal mastoid cells extended posteriorly to the lateral wall of the sigmoid sulcus. Postsinusoidal mastoid cells extended posteriorly beyond the sigmoid sulcus, and often expanded to the occipital bone (Fig. 2). The incidence of these three types was similar on both sides. Despite the variability in the extent of the mastoid cells, the mastoid antrum, the largest air cell in the mastoid, was observed in all 168 mastoids.

II. Perilabyrinthine cells

The perilabyrinthine cells include supralabyrinthine and infralabyrinthine cells (Fig. 3). The posterosuperior cells were superior to the IAM. The posteromedial cells, inferior to the posterosuperior cells, extended into the posterior wall of the IAM. Posteromedial cells were observed in 17% of 168 petrous bones (Fig. 4). The subarcuate cells extended through the arc of the anterior SCC into the subarcuate fossa (Fig. 5).

III. Apical cells

The petrous apex medial to the IAM and posteromedial to the carotid canal was usually occupied by soft bone marrow and contained no air cells, so was defined as diploic petrous apex (Fig. 6 left).

Fig. 3 Coronal computed tomography scan of the right petrous bone showing perilyabyrinthine cells, comprising supralabyrinthine (arrow) and infralabyrinthine cells (double arrows), communicating with the mastoid antrum. Exposure of perilyabyrinthine cells can cause cerebrospinal fluid rhinorrhea. A: antrum, Jb: jugular bulb, Jf: jugular foramen, Lb: labyrinth, Sp: styloid process.

Fig. 4 Axial computed tomography scans of the right petrous bone showing the posterior wall of the internal auditory meatus (IAM) usually does not include an air cell (left), but may include posteromedial cells (arrow in the right). A: antrum, T: tympanic cavity.

However, 31% of the 168 petrous bones contained apical cells, and was defined as pneumatized petrous apex (Fig. 6 right). The apical cells communicated with the perilyabyrinthine cells laterally and with the peritubal cells anteriorly. The peritubal cells surrounded the bony Eustachian tube (Fig. 7). The extent of the mastoid cells was significantly related to pneumatization of the petrous apex ($p < 0.01$, Fisher's exact probability test).

Fig. 5 Coronal (left) and axial (right) computed tomography scans of the right petrous bone showing subarcuate cells (arrow) extending through the arc of the anterior semicircular canal (arrowhead) and communicating with the mastoid antrum. A: antrum, EAM: external auditory meatus, IAM: internal auditory meatus, PSSC: posterior semicircular canal, T: tympanic cavity, V: vestibulum.

Fig. 6 Axial computed tomography scans of the left petrous bone showing the diploic petrous apex (left) and pneumatized petrous apex (right). arrow: Apical cells.

Discussion

I. Mastoid cells

The present CT study classified the mastoid into eburnated and pneumatized according to the extent of the mastoid cells, and showed that the incidence of eburnated mastoid was 11%. A histological study using cadaver specimens found an incidence of 13–20%.¹⁷⁾ Bone-window CT demonstrates the extent of the air cells more precisely than histological examination.²²⁾ The extent of the mastoid cells is usually symmetrical on both sides.^{3,15,22)} The present CT study showed that 98% of patients had symmetri-

Fig. 7 Axial computed tomography scans of the left petrous bone showing apical cells (Ap) communicating with the peritubal cells surrounding the Eustachian tube (arrows in the left), with infralabyrinthine cells (arrows in the middle), and with supralabyrinthine cells (arrow in the right). Exposure of apical cells in the subtemporal transpetrosal transtentorial approach may cause cerebrospinal fluid rhinorrhea. CC: carotid canal, EAM: external auditory meatus.

cal mastoid cells.

CSF rhinorrhea after retrosigmoid transmeatal removal of acoustic neurinoma occurs through two potential routes, the mastoid cells exposed by the retrosigmoid craniotomy and the air cells around the IAM.^{9,16,18} Eighty percent of cases of CSF rhinorrhea occurs through the mastoid cells; CSF leaks through the opening of posterior fossa dura to the epidural space, and from there to the mastoid cells.¹⁸ The sigmoid sinus defines the anterior exposure of retrosigmoid craniotomy. The exposure of mastoid cells depends on the relationship of the extent of the mastoid cells to the sigmoid sinus. We classified the mastoid cells into the presinusoidal, sinusoidal, and postsinusoidal types according to this relationship. Retrosigmoid craniotomy exposes postsinusoidal mastoid cells, but not presinusoidal mastoid cells. Therefore, the presence of postsinusoidal mastoid cells increases the risk of CSF rhinorrhea.

II. Petrous cells

The subtemporal transpetrosal transtentorial approach resects the petrous apex region medial to the IAM and posteromedial to the carotid canal.^{6,8} We defined apical cells as air cells in the petrous apex resected in the subtemporal transpetrosal transtentorial approach. The apical cells provide the route for CSF rhinorrhea after this surgical approach. We observed apical cells in 31% of petrous bones, and the reported incidence is 35%.²²

The present CT study showed that pneumatization of the petrous apex is significantly correlated with

the extent of the mastoid cells, although a relationship was known previously.^{1,17} The petrous bone is extensively resected in the presigmoid transpetrosal transtentorial approach, and CSF rhinorrhea occurs with an incidence of 33%. Half of the cases of rhinorrhea require surgical repair.²⁰ The high incidence of CSF rhinorrhea is attributed to the inability to close the dura mater in a watertight fashion in these skull base approaches.^{20,24} Preoperative assessment of petrous pneumatization using bone-window CT and meticulous intraoperative sealing of the exposed air cells may decrease the incidence of postoperative CSF rhinorrhea.

CSF rhinorrhea occurs through the air cells exposed by drilling of the posterior wall of the IAM after retrosigmoid transmeatal removal of acoustic neurinoma.^{9,16,18} The posteromedial cells extend into the posterior wall of the IAM, and provide the route for CSF rhinorrhea.⁵ A histological study showed that the incidence of posteromedial cells is 22%.¹⁰ The present CT study found that the incidence was 17%. The posteromedial cells are tangential to the surgical view in the retrosigmoid transmeatal approach, so the exposed posteromedial cells are often missed during surgery.^{5,9} Preoperative assessment of posteromedial cells is essential to prevent CSF rhinorrhea. Drilling of the posterior wall of the IAM also exposes the apical and perilabyrinthine cells.^{9,16,17} Rostral drilling of the posterior wall of the IAM may expose the posterosuperior cells and caudal drilling may expose the infralabyrinthine cells. Packing of the opened IAM with pieces of fat and muscle is mandatory to prevent CSF rhinorrhea in a patient who has air cells near the IAM on preoperative bone-window CT.²³

III. Conclusion

Thin-slice bone-window CT can depict the complex anatomy of the air cells in the petrous bone, which show great variability in the extent and arrangement among individuals. The air cells in the petrous bone provide the route for CSF rhinorrhea after skull base surgery for CPA tumors, so preoperative CT evaluation of air cells is useful to prevent this complication.

References

- 1) Allam AF: Pneumatization of the temporal bone. *Ann Otol Rhinol Laryngol* 78: 49-64, 1969
- 2) Celikkanat SM, Saleh E, Khashaba A, Taibah A, Russo A, Mazzoni A, Sanna M: Cerebrospinal fluid leak after translabyrinthine acoustic neuroma surgery. *Otolaryngol Head Neck Surg* 112: 654-658, 1995

- 3) Diamant M: Otitis and pneumatization of the mastoid bone. *Acta Otolaryngol Suppl (Stockh)* 41: 1-149, 1940
- 4) Findler G, Sahar A, Beller AJ: Continuous lumbar drainage of cerebrospinal fluid in neurosurgical patients. *Surg Neurol* 8: 455-457, 1977
- 5) Gordon DS, Kerr AG: Cerebrospinal fluid rhinorrhea following surgery for acoustic neurinoma. Report of two cases. *J Neurosurg* 64: 676-678, 1986
- 6) Harsh IVGR, Sekhar LN: The subtemporal, trans-cavernous, anterior transpetrosal approach to the upper brain stem and clivus. *J Neurosurg* 77: 709-717, 1992
- 7) Hoffman RA: Cerebrospinal fluid leak following acoustic neuroma removal. *Laryngoscope* 104: 40-58, 1994
- 8) Kawase T, Shiobara R, Toya S: Anterior transpetrosal transtentorial approach for sphenopetroclival meningiomas: Surgical method and results in 10 patients. *Neurosurgery* 28: 869-876, 1991
- 9) Kveton JF, Sasaki CT: Management of cerebrospinal fluid rhinorrhea after suboccipital transmeatal acoustic tumor removal, in Tos M, Thomsen J (eds): *Acoustic Neuroma*. New York, Kugler, 1992, pp 747-752
- 10) Lang J, Kerr AG: Pneumatization of the posteromedial air-cell tract. *Clin Otolaryngol* 14: 425-427, 1989
- 11) Lanman TH, Brackmann DE, Hitselberger WE, Subin B: Report of 190 consecutive cases of large acoustic tumors (vestibular schwannoma) removed via the translabyrinthine approach. *J Neurosurg* 90: 617-623, 1999
- 12) Macfarlane R, King TT: Acoustic neuroma (vestibular schwannoma), in Kaye AH, Laws ER Jr (eds): *Brain Tumors*. New York, Churchill Livingstone, 1995, pp 577-622
- 13) Magliulo G, Sepe C, Varacalli S, Fusconi M: Cerebrospinal fluid leak management following cerebellopontine angle surgery. *J Otolaryngol* 27: 258-262, 1998
- 14) McCallum J, Maroon JC, Jannetta PJ: Treatment of postoperative cerebrospinal fluid fistulas by subarachnoid drainage. *J Neurosurg* 42: 434-437, 1975
- 15) Myerson MC, Rubin H, Gilbert JG: Anatomic studies of the petrous portion of the temporal bone. *Arch Otolaryngol* 20: 193-210, 1934
- 16) Nutik SL, Korol HW: Cerebrospinal fluid leak after acoustic neuroma surgery. *Surg Neurol* 43: 553-557, 1995
- 17) Pellet W, Cannoni M, Pech A: Basic anatomy, in: *Otoneurosurgery*. Berlin, Springer-Verlag, 1990, pp 5-72
- 18) Samii M, Matthies C: Management of 1000 vestibular schwannomas (acoustic neuromas): Surgical management and results with an emphasis on complications and how to avoid them. *Neurosurgery* 40: 11-23, 1997
- 19) Sanna M, Saleh E, Panizza B, Russo A, Taibah A: Complications, in: *Atlas of Acoustic Neurinoma Microsurgery*. New York, Thieme, 1998, pp 200-205
- 20) Sekhar LN, Schessel DA, Bucur SD, Raso JL, Wright DC: Partial labyrinthectomy petrous apicectomy approach to neoplastic and vascular lesions of the petroclival area. *Neurosurgery* 44: 537-552, 1999
- 21) Shapiro SA, Scully T: Closed continuous drainage of cerebrospinal fluid via a lumbar subarachnoid catheter for treatment or prevention of cranial/spinal cerebrospinal fluid fistula. *Neurosurgery* 30: 241-245, 1992
- 22) Virapongse C, Sarwar M, Bhimani S, Sasaki C, Shapiro R: Computed tomography of temporal bone pneumatization: 1. Normal pattern and morphology. *AJNR Am J Neuroradiol* 145: 473-481, 1985
- 23) Yamakami I, Kobayashi E, Ono J, Yamaura A: Prevention of cerebrospinal fluid leakage and delayed loss of preserved hearing after vestibular schwannoma removal: Reconstruction of the internal auditory canal in the suboccipital transmeatal approach. Technical note. *Neurol Med Chir (Tokyo)* 40: 597-601, 2000
- 24) Yamakami I, Serizawa T, Yamaura A, Nakamura T: [Cerebrospinal fluid leak after cranial base surgery]. *No Shinkei Geka* 24: 29-33, 1996 (Jpn, with Eng abstract)

Address reprint requests to: I. Yamakami, M.D., Department of Neurosurgery, Chiba University School of Medicine, 1-8-1 Inohana, Chuo-ku, Chiba 260-8670, Japan.
e-mail: yamakami@faculty.chiba-u.jp

Commentary on this paper appears on the next page.

Commentary

This paper reports on the CT scan findings on 168 temporal bones, evaluating the distribution of air cells. It has some interesting findings. About 10% of mastoid bones are not aerated. Even in these situations the mastoid antrum is still present. This is an important landmark to identify the lateral semicircular canal and the facial nerve. Mastoid aeration is usually symmetrical and a well-aerated mastoid predicts an aerated petrous apex. Understandably, all these air cells are potential sites for CSF leaks. I am not sure whether a preoperative CT scan would be necessarily helpful in avoiding a postoperative CSF leak. I find that intraoperative inspection with an endoscope at the end of the operation is useful in locating air cells that have been opened and to ascertain that they have been adequately occluded. It would have been helpful to learn from the authors' experience as to the number of CSF leaks they had in their series and if the preoperative CT scan really helped in reducing this in comparison to historical data.

Chandranath SEN, M.D.
Department of Neurosurgery
St. Luke's-Roosevelt Hospital Center
New York, N.Y., U.S.A.

This is an excellent article on the surgical anatomy and classification of the air-cells in the petrous pyramid and the mastoid. The corresponding knowledge is very important for neurosurgeons and ENT-surgeons dealing with CPA lesions, when using one of the three following approaches: retro-sigmoid (transmeatal), presigmoid transpetrosal (transtentorial) or subtemporal transpetrosal transtentorial especially for vestibular schwannomas and CPA or petroclival meningiomas. We consider it mandatory to include in the preoperative set-up of investigations: an axial and coronal, (1.5 mm) thin-slice, bone-window, CT, so as to design a tailored approach according to air-cells abundance and locations. A high probability to open petrosal and/or mastoid cells make wise to harvest fascia for a tight closure of the dura and fat-tissue for a tight packing of the cells, in order to prevent secondary CSF-leakage and its harmful consequences.

Marc P. SINDOU, M.D., D.Sc.
University of Lyon
Lyon, France