Imaging of Labyrinthine Fistula After Repair With Bone Pate

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Objectives/Hypothesis: To demonstrate imaging of labyrinthine fistula due to cholesteatoma and illustrate outcome following repair with bone pate.

Study Design: Retrospective review.

Methods: Patients with labyrinthine fistula due to cholesteatoma were identified, and pre- and postoperative imaging was assessed. Method of repair was recorded. The fistula site was examined for patency and bone density after repair.

Results: Twenty-nine fistulae were seen in a cohort of 375 cholesteatoma cases (8%). Preoperative computed tomography (CT) imaging for fistula detection showed sensitivity of 96% and specificity of 90%. The lateral semicircular canal was the most common site of dehiscence occurring in all cases. Facial nerve dehiscence is observed in 91% of fistula cases and stapes erosion in 69%. Severe hearing loss was present preoperatively in four (14%) cases. Bone pate was used to repair the fistula with CT-documented restoration of the otic capsule in 11/13 cases with postoperative imaging. When bone pate was not used, the otic capsule defect persisted.

Conclusions: Spontaneous repair of the otic capsule following treatment of cholesteatoma is expected to be an uncommon occurrence. Repair of the fistula with bone can result in long-lasting restoration of the otic capsule.

Key Words: Cholesteatoma, labyrinthine fistula, lateral canal fistula, management, imaging, bone pate, computed tomography, otic capsule, density.

Level of Evidence: 4.

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INTRODUCTION

Long-standing cholesteatoma can produce erosion of otic capsule bone resulting in a labyrinth fistula. The duration of disease necessary to produce bone erosion is difficult to define but requires significant associated inflammation. The incidence is approximately 7% of cholesteatoma cases. The most aggressive cholesteatomas may result in inner ear symptoms of vertigo, sensorineural hearing loss, and facial nerve dysfunction. Any inner ear symptoms or intracranial complications, indicating aggressive disease, would raise suspicion of a labyrinthine fistula.

Clinical findings may include pressure induced dizziness. The Hennebert sign was initially described in the setting of labyrinthine fistula due to otosyphilis, but is frequently elicited with fistulae due to cholesteatoma. The pathophysiology and location of the fistula will dictate presence of other third-window symptoms. In contrast to superior canal dehiscence syndrome, symptoms of pulsatile tinnitus and enhanced bone-conducted sounds such as eye movement or foot taps are not common with lateral canal fistulae due to cholesteatoma. Otomicroscopic findings of bulky disease extending medial to the incus or into the oval window will also raise suspicion of labyrinthine fistula.

Preoperative identification of a fistula could always be accomplished if computed tomography (CT) imaging were performed for all cases, though most clinicians employ more selective criteria for ordering CT scans. Suspected mastoid involvement or any of the clinical findings above would constitute a strong recommendation for imaging.

Management of labyrinthine fistula has evolved over time. Some authors favored exteriorization of disease by creation of a canal wall down (CWD) cavity in all cases. Advocates of intact canal wall surgery favored leaving disease on the fistula and addressing the residual disease at the second-stage operation. The status of the fistula at second stage surgery is uncommonly described. Sheehy and Brackmann found spontaneous repair of the fistula in fewer than 10% of cases. In contrast, Sanna et al. reported finding a 50% spontaneous closure rate at the second-stage operation. The subjects included in each series seem comparable with regard to age, timing of the second stage procedure, and fistula size. Imaging is not provided in either report, and CT would have been unavailable or with low resolution for many of the cases included in each report. This report uses experience gained from conventional imaging capabilities to address the conflicting data on the natural history of labyrinthine fistula due to cholesteatoma.

MATERIALS AND METHODS

Retrospective review of cholesteatoma cases by the author between 2002 and 2012 was conducted to identify cases with...
labyrinthine fistula. The demographics of the population are recorded. Special attention is given to cases with pre- and postoperative imaging. Practice indications for ordering imaging studies varied over the study period, with the tendency for more liberal criteria for obtaining imaging over time. In general, preoperative imaging is conducted in cases of cholesteatoma with suspected mastoid involvement, or when accompanied by sensorineural hearing loss, vertigo, or disequilibrium. Indications for postoperative imaging are varied, though most often for surveillance or acute exacerbation of infection.

Intraoperative management intended to preserve function of the inner ear. Labyrinthectomy was not done as a primary operation, only for persisting vertigo. When a fistula is encountered intraoperatively, bulky cholesteatoma is excised, but dissection of the fistula is deferred until the end of the case. Matrix removal is attempted in all cases. The fistula is covered with bone pate, but it is not packed into the semicircular canal defect. No attempt is made to compress the membranous labyrinth or obliterate the lumen as may be employed with canal plugging procedures for superior canal dehiscence and benign paroxysmal positional vertigo. The presence of the fistula does not alter management of the mastoid cavity. Bone pate is typically used to obliterate the mastoid in both intact canal wall and CWD cases.

The fistula size is expressed as the maximal length of dehiscence as measured on CT in the plane of the canal (axial plane for lateral semicircular canal [LSCC]) or estimated intraoperatively. The fistula circumference reflects the amount of bone erosion when imaged in cross-section to the canal (coronal plane for LSCC) or estimated intraoperatively. Bone erosion typically does not distort the normal architecture of the membranous labyrinth. However, collapse of the membranous labyrinth or cholesteatoma on the inner surface of the labyrinthine bone is defined as invasion.

Image review provides a qualitative assessment of the otic capsule bone. Absence of bone is defined as soft tissue density in continuity with the membranous labyrinth. If the bone of the otic capsule completely covers the membranous labyrinth, it is deemed intact. Postoperative imaging was obtained at multiple different facilities. Some of the imaging software allows measurement of density in Hounsfield units. Measurement of thin bone requires a small (<1 mm²) region of interest. The bone density was measured in five locations: over the repaired fistula, within the bone pate placed in the mastoid, posterior fossa plate over the sigmoid sinus, cochlear promontory, and medial otic capsule (between the vestibule and internal auditory canal). Multiple point density measurements were taken at each location and expressed as a range.

RESULTS

From a population of 375 individuals with cholesteatoma, there were 29 (8%) with labyrinthine fistula confirmed by surgical exploration. Of these 29 cases, 28 had preoperative imaging. Preoperative imaging suggested the fistula in 27 cases for sensitivity of 96%. Interval between imaging and surgery was 5 months in the only case with inaccurate preoperative identification, likely accounting for this finding. Three additional cases had radiographic evidence of a labyrinthine defect, but were found to have thin bone covering the lateral canal intraoperatively, thus the specificity of preoperative imaging was 90% (27/30). All cases were unilateral. The median age was 36 years (range, 5–64 years). Nineteen subjects were male (66%), and 20 were on the right (69%). There is no obvious explanation for any predilection for gender or side. Most of the fistulae were encountered at the initial surgery, though six (21%) cases were previously operated. For the revision cases, the presence or absence of the fistula at the initial operation could not be definitively stated because operative reports from the prior procedure were rarely available. Five of six had recurrent attic cholesteatoma, whereas one case had recurrence in a CWD cavity. The latter case had a head CT 4 years prior to the revision surgery showing a stable cavity, though low resolution prevents confirmation of intact otic capsule or fistula.

All cases had involvement of the lateral semicircular canal. Other sites of invasion included the superior semicircular canal in seven (24%) cases, vestibule in three (10%) cases, posterior canal (PSCC) in two (6%) cases, and cochlea in one (3%) case. Other anatomical abnormalities were common. The facial nerve was dehiscent in 26 (91%)
cases and displayed impaired function in two (6%) cases. Stapes erosion was seen in 20 (69%) cases. The tegmen was dehiscent in four (14%) cases. Anacusis was documented in four (14%) cases. Severe loss (pure-tone average [PTA] >75) was present in an additional four (14%) cases. One patient had a brain abscess.

Fistula size was <2 mm in four (14%) cases, 2 to 4 mm in 15 (52%) cases, and >4 mm in 10 (34%) cases. Fistula circumference was less than 180° in 20 (69%) cases, and greater than 180° in 9 (31%) cases. The labyrinth was invaded in seven (24%) cases. Four of these individuals had anacusis, whereas the others had severe sensorineural loss.

Twenty-one of the patients had postoperative audiometric data (Fig. 1). Hearing improved in seven cases, usually reflecting correction of conductive hearing loss. Improvement in bone conduction thresholds was seen in one case. Hearing was stable in 12 cases and declined in two cases. Preoperative thresholds of those developing anacusis were 90 and 85 dB, respectively, with poor speech discrimination.

Vestibular function was not routinely measured using ENG. The presence of nystagmus using pneumatic otoscopy was recorded in 4/7 cases, with the negative responses attributed to preoperative severe vestibular deficit or bulky disease over the fistula. Five patients in this series had preoperative disequilibrium that persisted after fistula repair. Four were adequately compensated with exercises, whereas the fifth required labyrinthectomy.

Postoperative imaging is available in 14/29 cases, though one did not have a preoperative study. Intervals between reconstruction and postoperative imaging are highly varied. The timing of postoperative imaging ranged from 1 week to more than 5 years. Indications for postoperative imaging were variable, and studies were not always ordered by the otolaryngology service. Restoration of the otic capsule density is seen in 11/13 (85%) cases when bone pate was used for repair (Figs. 2 and 3). The two cases showing low density bone over the repair site are attributed to one case with imaging at 1 week postoperatively and one case with severe labyrinthine dysfunction (anacusis and persistent disequilibrium). The latter case was managed with completion labyrinthectomy. One patient with a labyrinthine fistula (2–4 mm in size) and postoperative imaging did not have bone pate placed intraoperatively. The postoperative imaging shows a persistent fistula. Fistula size was <2 mm in one patient, 2 to 4 mm in seven patients, and >4 mm in
three of the patients with documented otic capsule repair. Thus, it does not appear fistula size impacts probability of repair.

Measurement of bone density in Hounsfield units was possible in five of the cases with postoperative imaging. The range of density measurements for the repaired fistula is much greater than the density of the rest of the bone pate in the mastoid cavity. The bone density of the repaired fistula exceeds that of the posterior fossa bone overlying the sigmoid, but is slightly less dense than other otic capsule measurements (Table I).

### DISCUSSION

Labyrinthine fistulae occur as a consequence of aggressive cholesteatoma; therefore, other anatomical defects are expected. The frequent findings of facial nerve dehiscence and stapes erosion are also documented by others. The rate of preoperative sensorineural hearing loss observed in this series is also similar to prior reports. Others find increasing hearing loss in fistula cases correlating with size. The duration of disease in this series and prior reports is highly variable, indicating that the rate of bone resorption is not uniform, but likely influenced by factors such as the degree of inflammation and infectious organism. The presence of a fistula does not mean that sensorineural loss will definitely occur. However, the potential for infectious organisms and ototoxic agents to enter the labyrinth is enhanced by presence of the fistula.

Histopathological study of fistulae finds that the inner ear may appear normal in some cases, whereas others will show serous or suppurative labyrinthitis. The inner ear immediately adjacent to the fistula was normal in four of seven cases, and no evidence of intralabyrinthine inflammation was seen. Cases with labyrinthitis show inflammatory changes adjacent to the fistula, but also demonstrate that any inflammatory process spreads rapidly to involve the entire inner ear. Interestingly, the temporal bone collections do not include an example of the invasive fistulae described in this report. However, the clinical findings of anacusis, disequilibrium, and altered magnetic resonance imaging signal imply that severe intralabyrinthine inflammation is likely with invasive fistulae.

Surgical management is typically recommended for fistulae due to cholesteatoma. The timing of surgery and consequences of no treatment are not commonly discussed. Preoperative recognition of the fistula is probably more common now due to availability of CT imaging. Cases that present with acute sensorineural hearing loss, vertigo, and facial palsy warrant urgent surgery, though there are few, if any, reports that discuss outcomes in this setting. Intervention includes antibiotics, steroids, and surgical debridement, though it remains undetermined which intervention is most critical for optimal outcome. The degree of inner ear impairment may be the most relevant variable, as the more severe the initial insult, the lower the probability of improvement. In this report, there is a single case with preoperative sensorineural loss showing hearing improvement, but most will remain stable or progress to anacusis. Invasion of the labyrinth also predicts greater chance of immediate postoperative hearing loss.

Most prior reports discussing management of fistulae concentrate on intraoperative decision making including whether to attempt removal of squamous epithelium from the surface of the defect and what type of mastoidectomy is required. Consensus opinion indicates that manipulation of a cochlear fistula is associated with sensorineural hearing loss, whereas semicircular canal fistula appear to have the same risk of hearing loss with matrix removal or preservation. Long-term complications of the method of repair are less commonly discussed, though if a fistula persists, some suggest that a risk of future hearing loss remains.

Vestibular symptoms with labyrinthine fistula due to cholesteatoma are variable and depend on the duration of disease and remaining vestibular function. If the vestibular function is intact, the patient may be sensitive to pressure changes, though this is less likely if there is bulky disease in the antrum and an intact canal wall. However, postoperative patients with persisting otic capsule defects in CWD cavities are almost always sensitive to pneumatic otoscopy and suctioning in the cavity, because the exposed fistula more easily transmits pressure and temperature changes. Individuals with long-standing disease may have developed a severe labyrinthitis with resulting loss of vestibular function. These individuals will typically not display a response to pneumatic otoscopy or caloric testing. Some compensate adequately, whereas others have significant pre- and postoperative disequilibrium. Inadequate compensation after vestibular rehabilitation may indicate the need for labyrinthectomy as applied in one case in this series.

As outlined earlier, there are limited data on the probability of spontaneous repair. The disparity of intraoperative findings in prior reports is striking; however, resolving the difference requires more detailed reporting. Ideally, a series should depict imaging prior to and after intervention to document the adequacy of repair. Successful repair of the otic capsule with bone pate has been previously reported. However, there are no reports to date with radiographic evidence of spontaneous repair in the absence of pate coverage. Other cases observed by the author that had been exteriorized or repaired with fascia or cartilage (Fig. 4) continue to show presence of the fistula. Although Jang and Merchant noted new bone growth adjacent to the fistula in 3 of 7 cases, this does not guarantee that spontaneous repair will ultimately occur.

| TABLE I. Bone Density Measurement Range (Hounsfield Units). |
|-----------------|-----------------|
|                  | Median Low      | Median High |
| Repaired fistula | 1333            | 1984        |
| Bone pate laterally | 536            | 1016        |
| Promontory       | 1831            | 2327        |
| Medial otic capsule | 1676           | 2246        |
| Posterior fossa  | 1013            | 1453        |
Bone turnover in the otic capsule is very low, a finding that is unique compared to other bone. This process is controlled by the local ratio of osteoprotegerin (OPG) to receptor ligand for nuclear factor kappa B (RANK). The ratio of OPG:RANK in otic capsule bone is dramatically different than other bone. Perilymph concentration of OPG is also far greater than in serum or cerebrospinal fluid, indicating production within the inner ear. OPG levels decrease with distance from the otic capsule, thus bone deposition and turnover are variable throughout the temporal bone. This effect may account for the difference the density of the bone pate on postoperative imaging (Figs. 2 and 3). Adjacent to the otic capsule (at the fistula site) the pate is high density, whereas peripherally, the density is much lower. Age-related changes in the otic capsule bone include decreasing concentration of OPG and number of viable osteocytes. The net effect is stability of the inner ear structure, but any possibility of bone regeneration is further reduced.

Other examples of acquired otic capsule defects include trauma, fenestration for otosclerosis, and superior canal dehiscence syndrome. The pathophysiology of otic capsule defect development is obviously quite different than in cholesteatoma cases. However, spontaneous repair of the otic capsule defect is rare in these entities. Trauma cases usually involve a linear fracture line with minimal displacement. Inner ear function may be lost or preserved, whereas the defect heals with fibrous tissue. Intralabyrinthine ossification is possible after trauma or infection, though this may occur without obvious change to the adjacent otic capsule. Surgical fenestration for otosclerosis or congenital conductive loss has shown good long-term stability with a spontaneous closure rate of approximately 6%. There are several possible explanations for the low probability of spontaneous repair. Coverage of the defect by a squamous epithelium may inhibit repair. The measles virus likely alters OPG:RANK ratio in the otic capsule adjacent to the inner ear, leading to demineralization at the otosclerotic focus and possibly impaired healing of the fenestration. Finally, there are no reports of spontaneous closure in a case of superior canal dehiscence. The thickness of the squamous portion of the temporal bone in superior canal dehiscence syndrome (SCDS) patients is thinner than controls implying a regional or systemic difference in bone growth or turnover.

Development of the fistula in the presence of cholesteatoma is likely due to osteoclast activation. There are multiple potential mechanisms for this process including secretion of inflammatory cytokines such as tumor necrosis factor, interleukin (IL)1, and IL6, and T-cell activation. Reversal of this process is a prerequisite for spontaneous repair. Necessary factors would likely include presence of new osteoblasts and a normal OPG:RANK ratio to inhibit osteoclast formation. Absence of bacterial infection is also likely to be necessary. The effect of an epithelial covering (persisting cholesteatoma matrix) in contact with the membranous labyrinth may be inhibitory, though there are no definitive data to support or refute this hypothesis.

All of the clinical observations cited above favor a low probability of spontaneous repair. However, when bone growth is more rapid, as in pediatric patients, prospects for repair are increased. Figure 5 depicts a 6-year-old with a lateral canal fistula due to cholesteatoma that also shows bone growth adjacent to the otic capsule defect. New bone formation in the presence of chronic inflammation is occasionally observed in management of

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Fig. 4. Persistent fistula after surgery. (a) Right LSCC fistula 3.3 years postoperative cartilage repair, fistula circumference 180°. (b) Right LSCC fistula 16 years postoperatively, persisting squamous debris invading the lateral canal. (c) Left LSCC fistula >30 years postoperatively, exteriorized. LSCC = lateral semicircular canal.

Fig. 5. Spontaneous repair in evolution. Left LSCC fistula from cholesteatoma, preoperatively. LSCC = lateral semicircular canal.
cholesteatoma cases, though more likely in younger patients.

In this series, unsuccessful otic capsule repair despite use of bone pate was observed. This case presented with advanced disease, including acute facial paralysis, vertigo, and severe hearing loss. Pate density at 5 months was grossly hypolucent compared to successful repairs (Figs. 2 and 3). The imaging was obtained for symptoms of persisting disequilibrium that ultimately required labyrinthectomy. Inadequate repair implies abnormal intralabyrinthine physiology as a consequence of a severe or chronic inflammatory process, presumably due to unfavorable OPG:RANK ratio. Other cases in this series with nonhearing ears show adequate otic capsule repair. Thus, measurable hearing or vestibular function is not necessary for OPG production.

CONCLUSION
The probability of restoration of an otic capsule defect secondary to cholesteatoma likely depends on multiple factors including patient age, inner ear function, severity of infection, persistence of cholesteatoma over the fistula, and mechanism of repair. Use of bone pate for repair of labyrinthine fistula usually results in restoration of the otic capsule, thus facilitating long-term elimination of third-window symptoms and protection of inner ear function.

BIBLIOGRAPHY