It is important to restore aer a tion in the middle ear cleft to conduct sound and maintain middle ear pressure, especially in postoperative ears. Tumarkin in 1957 and Holmquist in 1978 suggested that the mastoid serves as an air reservoir for the middle ear and plays a role in middle ear pressure regulation. Sade pointed out the link age of good middle ear aeration with large mastoid pneumatization and vice versa, which sug gests that the mastoid has a role as a pressure buffer in the middle ear. Takahashi et al. in 1997 found that the degree of mastoid pressure increase in the ears after surgery correlated well with the degree of mastoid aer a tion on postoperative mastoidectomy with cartilage obliteration of the open cavity.

Methods. We used high resolution computed tomography (HRCT) to evaluate middle ear aeration. Statistical analysis was used to investigate the correlation between postoperative middle ear aeration and associated clinical factors such as middle ear mucosa condition found intraoperatively (intact or defective), stage of cholesteatoma, level of mastoid pneumatization, range of cartilage obliteration, and tympanoplasty type.

Results. Forty-four cholesteatoma ears of forty-three patients (aged 13 to 74 years) underwent tailored mastoidectomy with cartilage obliteration of the open cavity from 1988 to 1998. Aeration of the middle ear cleft was evaluated using HRCT performed in a mean of 6.77 years after surgery. There was no aeration in 10 ears (22.7%), aeration only in the tympanic cavity in 19 ears (43.2%), and aeration in both the tympanic and mastoid cavities in 15 ears (34.1%). There were 26 ears (59.1%) with intact and healthy mucosa and 18 ears (40.9%) with defective mucosa. The correlation between the mucosal condition and recovery of middle ear aeration was significant ($r = 0.6855$, $p < 0.001$). Recovery of aeration was negatively correlated with the stage of cholesteatoma ($r = -0.4951$, $p = 0.0156$) and positively correlated with the level of postoperative mastoid pneumatization ($r = 0.8036$, $p < 0.001$).

Conclusions. Preserving healthy middle ear cleft mucosa and uninvolved mastoid air cells during cholesteatoma surgery enables gas-exchange through the remaining mucosa and maintains the pressure buffer effect of the mastoid, both of which are important for recovery of middle ear cleft aeration. HRCT is useful for the postoperative evaluation of middle ear cleft aeration.

Original Article

Using High Resolution Computed Tomography to Evaluate Middle Ear Cleft Aeration of Postoperative Cholesteatoma Ears

Background. Middle ear mucosa and mastoid air cells are important for middle ear cleft aeration. However, the postoperative cholesteatoma ears treated in traditional open or closed techniques are often complicated by an atelectatic condition. In order to preserve the healthy mastoid air cells and also eradicate the cholesteatoma completely, we treated cholesteatoma ears by "tailed mastoidectomy with cartilage obliteration of the open cavity."

Methods. We used high resolution computed tomography (HRCT) to evaluate middle ear cleft aeration of postoperative cholesteatoma ears. Statistical analysis was used to investigate the correlation between postoperative middle ear aeration and associated clinical factors such as middle ear mucosa condition found intraoperatively (intact or defective), stage of cholesteatoma, level of mastoid pneumatization, range of cartilage obliteration, and tympanoplasty type.

Results. Forty-four cholesteatoma ears of forty-three patients (aged 13 to 74 years) underwent tailed mastoidectomy with cartilage obliteration of the open cavity from 1988 to 1998. Aeration of the middle ear cleft was evaluated using HRCT performed in a mean of 6.77 years after surgery. There was no aeration in 10 ears (22.7%), aeration only in the tympanic cavity in 19 ears (43.2%), and aeration in both the tympanic and mastoid cavities in 15 ears (34.1%). There were 26 ears (59.1%) with intact and healthy mucosa and 18 ears (40.9%) with defective mucosa. The correlation between the mucosal condition and recovery of middle ear aeration was significant ($r = 0.6855$, $p < 0.001$). Recovery of aeration was negatively correlated with the stage of cholesteatoma ($r = -0.4951$, $p = 0.0156$) and positively correlated with the level of postoperative mastoid pneumatization ($r = 0.8036$, $p < 0.001$).

Conclusions. Preserving healthy middle ear cleft mucosa and uninvolved mastoid air cells during cholesteatoma surgery enables gas-exchange through the remaining mucosa and maintains the pressure buffer effect of the mastoid, both of which are important for recovery of middle ear cleft aeration. HRCT is useful for the postoperative evaluation of middle ear cleft aeration.

Key Words
cholesteatoma;
gas exchange function;
mastoid pneumatization;
middle ear cleft aeration;
middle ear cleft mucosa
computed toography (CT). Moreover, recovery of both gas exchange function and aeration in the mastoid is expected only when the mastoid mucosa is preserved, even partially.45

There is much debate about surgical treatment of cholesteatoma ears. Both the open and closed techniques have advantages and disadvantages.6 In our study, we treated cholesteatoma ears by “tailed mastoidectomy,” which pre serves both un involved mas toid air cells and middle ear mucosa, and used car til age to obliterate the open cavity. High resolution CT (HRCT) was performed at least 2 years after surgery to evaluate the status of middle ear cleft aeration after this surgical procedure. The correlation was further investigated between the postoperative state of aeration and clinical factors such as middle ear mucosa condition found intraoperatively (intact or defective), stage of cholesteatoma, level of mastoid pneumatization, range of cartilage obliteration, and tympanoplasty type.

METHODS

Forty-three patients (44 ears) with cholesteatoma underwent “tailed mastoidectomy with cartilage obliteration of the open cavity” via an endaural approach from 1988 to 1998. There were 16 males and 27 females. Their ages ranged from 13 to 74 years (mean, 42.9 years). The period between surgery and postoperative HRCT ranged from 2.25 years to 12.58 years, with a mean of 6.77 years.

Aeration of the postoperative middle ear cleft was examined using HRCT of the temporal bone (all sections) and was classified into 3 groups (Fig. 1). Group 1: no aeration (soft tissue density); group 2: aeration only in the tympanic cavity (*); group 3: aeration both in the tympanic cavity and the mastoid cavity (*).

Fig. 1. Temporal bone CT images of postoperative middle ear cleft: (A,B): no aeration; (C,D): aeration only in the tympanic cavity (*); (E,F): aeration both in the tympanic cavity and the mastoid cavity (*).

Fig. 2. Temporal bone CT images of levels of mastoid pneumatization: I: sclerotic mastoid (no air cells); II: diploic mastoid (spongy-bone density); III: middle-sized mastoid (irregular air cell system, confined to a few cells in the vicinity of the mastoid antrum or aditus); IV: large mastoid (regular air cell system, comprised the whole mastoid).

...
regular, comprised the whole mastoid and could extend beyond its boundaries).\(^7\!\!^,\!\!^9\)

All 44 ears were staged according to the CAO system (Table 1) developed by Lien\(^10\) in 1985. “C” represents the extension of the cholesteatoma into the middle ear cleft; “A” represents the degree of atelectasis; “O” represents the number of ossicles destroyed by the cholesteatoma. Each C, A, and O was scored as 1, 2 or 3, according to the degree of severity. The total score of C, A, and O ranged from 3 to 9. The scores 3 and 4 represented the early stage of cholesteatoma; the scores 5 and 6 represented mid stage, and the scores 7, 8, and 9 represented the advanced stage of cholesteatoma.\(^10\)

Table 1. CAO staging system of cholesteatoma

<table>
<thead>
<tr>
<th>Score</th>
<th>C (Cholesteatoma)</th>
<th>A (Atelectasis)</th>
<th>O (Ossicle)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>At 1 area of middle ear cleft(^a)</td>
<td>Normal or grade I atelectasis</td>
<td>Normal or destruction of 1 ossicle</td>
</tr>
<tr>
<td>2</td>
<td>At 2 areas of middle ear cleft</td>
<td>Grade II or III, but anterior half of mesotympanum is still aerated(^b)</td>
<td>Destruction of 2 ossicles</td>
</tr>
<tr>
<td>3</td>
<td>At 3 or more areas of middle ear cleft</td>
<td>Grade IV, more than posterior half of mesotympanum is unaerated(^c)</td>
<td>Destruction of 3 ossicles</td>
</tr>
</tbody>
</table>

\(^a\) Five areas of middle ear cleft are tympanic cavity, attic, aditus, antrum, and mastoid air cells.
\(^b\) In case of tympanic membrane perforation, less than half of the middle ear mucosa is destroyed.
\(^c\) In case of tympanic membrane perforation, more than half of the middle ear mucosa is destroyed.

The range of cartilage obliteration was divided into 3 levels corresponding to 3 types of “tailored mastoidectomy” (Fig. 3). Level I: cartilage obliteration over the attic; level II: cartilage obliteration from the attic to the antrum; level III: cartilage obliteration beyond the antrum.

The correlation between recovery of aeration and the following clinical factors were assessed by statistical analysis: middle ear mucosa condition found intraoperatively (in tact or de ferive), stage of cholesteatoma, level of mastoid pneumatization, range of cartilage obliteration, and tympanoplasty type. The statistical analysis was done using Spearman correlation coefficient test and Fisher’s exact test. The \(p\) value < 0.05 was considered statistically significant.

**RESULTS**

Of the 44 cholesteatoma ears that underwent tailored mastoidectomy with cartilage obliteration of the open cavity, 10 (22.7%) had no aeration of the middle ear cleft, 19 (43.2%) had aeration only in the tympanic cavity, and 15 (34.1%) had aeration in both the tympanic and the mastoid cavities. The duration between surgery and performance of HRCT was not significantly correlated with postoperative middle ear cleft aeration.

**Relationship between middle ear mucosa condition and postoperative middle ear cleft aeration**

Healthy middle ear cleft mucosa was preserved during surgery. In 26 ears with intact and healthy mucosa, 10
had aeration only in the tympanic cavity and 15 had aeration in both the tympanic and mastoid cavities. On the other hand, in the remaining 18 ears with defective mucosa, 9 had no aeration and 9 had aeration only in the tympanic cavity (Table 2). Postoperative middle ear cleft aeration was significantly correlated with middle ear mucosa condition ($r = 0.6855, p < 0.001$).

**Table 2. Clinical factors and postoperative state of middle ear cleft aeration**

<table>
<thead>
<tr>
<th>Factors</th>
<th>Aeration (number of ears)</th>
<th>$p$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No aeration</td>
<td>Aeration in tympanic cavity</td>
</tr>
<tr>
<td>Mucosa condition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intact</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Defective</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Stage of cholesteatoma</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early stage</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Moderate stage</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>Advanced stage</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td>Level of postoperative mastoid pneumatization</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level 1 (sclerotic)</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Level 2 (diploic)</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>Level 3 (middle-sized)</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Level 4 (large-sized)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Range of cartilage obliteration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level I</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Level II</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Level III</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Tympanoplasty type</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type I</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Type II</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Type III</td>
<td>7</td>
<td>15</td>
</tr>
<tr>
<td>Type IIII</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

**Relationship between stage of cholesteatoma and postoperative middle ear cleft aeration**

Of 10 ears with early stage cholesteatoma, 2 had aeration only in the tympanic cavity and 8 had aeration in both the tympanic and mastoid cavities. Of the 20 ears with advanced stage cholesteatoma, 10 had aeration only in the tympanic cavity and 3 had aeration in both the tympanic and mastoid cavities (Table 2). Postoperative middle ear aeration was significantly correlated with the stage of cholesteatoma ($r = -0.4951, p = 0.0156$).

**Relationship between level of mastoid pneumatization and postoperative middle ear cleft aeration**

Of the 14 ears with level 3 mastoids (middle-sized mastoid), 13 had aeration of both the tympanic and mastoid cavities postoperatively. In contrast, of the 29 ears with levels 1 and 2 mastoids (sclerotic and diploic mastoid), only 1 ear had aeration of both the tympanic and mastoid cavities postoperatively (Table 2). Postoperative aeration of the middle ear cleft was positively correlated to the level of mastoid pneumatization ($r = 0.8036, p < 0.001$).

**Relationship between the range of cartilage obliteration and postoperative middle ear cleft aeration**

The range of cartilage obliteration was not significantly correlated with postoperative middle ear cleft aeration, as shown in Table 2.
Relation between the tympanoplasty type and postoperative middle ear cleft aeration

The tympanoplasty type was not significantly correlated with postoperative middle ear cleft aeration, as shown in Table 2.

DISCUSSION

Management of cholesteatoma is controversial. In the open technique, also termed the “canal wall down” operation, the posterior canal wall is removed to create a mastoid cavity. Examples are radical and modified radical mastoidectomy. A proportion of cavities may be come chronically troublesome when this technique is used. In the closed technique, also termed the “canal wall up” operation, the cholesteatoma is removed through an extended simple mastoidectomy or an extended atticomastoidectomy, leaving the posterior canal wall intact. A staged “second look” surgery is often required with the closed technique to eradicate recurrent or residual disease.

In order to preserve the healthy mastoid air cells and also eradicate the cholesteatoma completely, we developed a procedure we term “tailored mastoidectomy with cartilage obliteration of the open cavity.” This procedure is similar to the open technique but only cholesteatoma-involved mastoid air cells are removed. Moreover, meatoplasty is performed to form the open cavity shallower. Pieces of chonchal cartilage are harvested and placed within the cavity, then the temporals fascia is replaced. There are several advantages to this procedure. First, it is important to preserve healthy middle ear cleft mucosa so that middle ear pressure can be maintained by functional mucosal gas exchange. Furthermore, preserving uninvolved mastoid air cells results in better pressure buffering. Second, using pieces of chonchal cartilage to obliterate the open cavity not only prevents a trouble some open cavity, but also acts as a solid support to prevent retraction pocket formation which is often a cause of cholesteatoma recurrence. In addition, there is still space between the pieces of cartilage used to obliterate the open cavity, which allows the air-containing space to be continuous from the tympanic cavity to the pre served mastoid air cells.

Postoperative cholesteatoma ears are often complicated by an atelectatic condition. There is a report of CT evaluation of middle ear aeration following intact canal wall tympanoplasty. In this report, the mastoidectomy cavity was totally aerated in all cases of simple suppurative otitis and in over 60% of the cases of adhesive otitis. Attic type cholesteatoma and adhesive type cholesteatoma were obliterated by a soft-tissue-density mass. In our study, 10 (22.7%) ears had no aeration of the middle ear cleft after surgery, 19 (43.2%) had aeration only in the tympanic cavity after surgery, and 15 (34.1%) had aeration both in the tympanic and mastoid cavities. Thus, 34 (77.3%) ears showed aeration in the middle ear cleft after surgery. Preserving considerable middle ear cleft mucosa and uninvolved mastoid air cells during surgery might be the primary reason for the higher rate of postoperative aeration recovery in our study.

Twenty-six (59.1%) ears had in intact and healthy mucosa preserved using our surgical procedure. Defective mucosa, including granulation or fibrosis tissues, was removed during surgery in 18 (40.9%) ears. In middle ear mucosa condition and recovery of middle ear cleft aeration were significantly correlated. There is a tendency for recovery of middle ear cleft aeration after surgery if preserved mucosa is intact and healthy, which may be better for postoperative gas-exchange function and mucociliary movement. More over, cholesteatoma stage was negatively correlated with postoperative middle ear cleft aeration. This may be explained by the fact that the advanced stages of cholesteatoma are often accompanied by more mucosal and mastoid air cell destruction, thus reducing the chances for recovery of postoperative aeration.

Sade and Luntz pointed out that a physiologic middle ear is a gas pocket balanced by diffusion of gases into and from the mucosal tissues, as well as by ventilation through and out of the eustachian tube. However, the mucosa seems to play a much more important role in regulating middle ear pressure than does the eustachian tube. Some studies found that preoperative ventilatory function of the eustachian tube has no clear role in aeration of the mastoid after surgery. On the other hand, an investigation of gas exchange function through...
the mastoid mucosa in ears after surgery using nitrous oxide found that the decree of the mastoid pressure increase of those ears after surgery was correlated with the presence or absence of mastoid aer a tion on CT. Gas did not diffuse into the mastoid when the mucosa of the whole mastoid cavity was resected by drilling (mastoidectomized), but gas exchange and aeration of the mastoid still occurred when the mastoid mucosa was at least partially preserved. Recovery of the gas exchange function correlated well with the presence or absence of mastoid mucosa. Gas exchange function may complement for the negative mastoid pressure caused by their volume decrease when the mastoid is filled with clots and effusion after mastoid surgery. Presence or absence of the mastoid mucosa during surgery, especially epitympanic mucosa, was found to be most important for postoperative recovery of mastoid aeration. It is postulated that an air space is created in the epitympanic area at the early postoperative stage as the result of mucociliary clearance of exudates by the preserved epitympanic mucosa. The air space then facilitates gas exchange through the preserved epitympanic mucosa.

Tissues with high CT density (Hounsfield's Unit) will appear white and tissues with low CT density will appear black on the CT scan. The CT density of air (-1000) is quite different from that of soft tissue (-100 to 100) and water (0), so it is not difficult to distinguish between aer a tion from soft tissue and aeration from secretion in the middle ear cleft on HRCT. There have been several studies using HRCT as a tool to evaluate the status of aeration in the mastoid cavity after mastoid surgery and found that the results were correlated with the presence or absence of mastoid pressure increase. Be sides, CT provides not only information about the presence and extension of a cholesteatoma, but also excellent views of the middle ear anatomy in either the coronal or axial planes. However, cholesteatoma, cholestein granulomas, granulation tissues, fibrous tissues, mucosal edema or effusion, and obliterated cartilage during surgery may be indistinguishable on CT. The value of CT for the detection of recurrent cholesteatoma following “closed cavity” mastoid surgery has been studied with disappointing results. Nevertheless, it is still a good tool for evaluating aeration of the middle ear cleft in postoperative ears.

In previous reports, several methods and grading schemes were used to measure and assess mastoid pneumatization, such as the Schuller projection x-ray film by visual method, the planimetric method, and the rectangular area method. However, CT images reveal more information than Schuller projection, not only about the detailed middle ear anatomy and pathology, but also the degree of mastoid pneumatization whether or not the mastoid air cells are aerated. In our study, we used HRCT to evaluate postoperative mastoid pneumatization, and divided the postoperative mastoid pneumatization into 4 degrees. There were 17 (38.6%) ears with sclerotic mastoids, 12 (27.3%) with diploic mastoids, 14 (31.8%) with middle-sized mastoids, and 1 (2.3%) with large-sized mastoids. In a previous study by Sade et al. in 1994, most (82.3%) of the cholesteatomas were asociated with sclerotic or diploic mastoids. As in our study, there were also more (65.9%) cholesteatoma ears with poorly pneumatized mastoids.

Mastoid pneumatization is reported to terminate around the age of 10 years. There is a general recognition that cholesteatoma in adults is associated with poorly pneumatized mastoids, while in children this association may be reversed. A study of 190 adults and 109 children with cholesteatoma found that poorly pneumatized mastoids were more common in adults (96.3%) than in children (57.8%). Be cause the patients enrolled in this study were aged 13 and older, the difference in pneumatization of cholesteatoma ears between adults and children was not analyzed.

Poor mastoid pneumatization is often correlated with a number of conditions in which middle ear aeration is compromised, such as secretory otitis media, atelectasis and cholesteatoma. Richards et al. postulated that the mastoid acts as a pressure buffer in the middle ear, which was further pointed out by Sade et al. and several other studies. A study on the variation of middle ear pressure during nitrous oxide anesthesia has found a better buffering capacity with a larger volume of the mastoid. We also found a positive correlation between mastoid pneumatization and aeration of middle ear cleft after surgery. It supported that the well-pneumatized mastoid has better pressure buffering effect, which is helpful for reaeration of postoperative ears.
middle ear cleft.

Recovery of aeration in the middle ear cleft after ear surgery also has a role in sound conduction. The compressible air within the middle ear alows the tympanic membrane and the ossicles to move. Non-aeration of middle ear leads to retraction pocket or loss of ossicular coupling in middle ear transduction. Post operative ears with middle ear aeration will hear better than non-aerated post operative ears.

In summary, tailored mastoidectomy with cartilage obliteration of the open cavity foramen and a solid support to main ing mucosa. Pre serving healthy middle ear will hear better than non-aerated postoperative ears.

REFERENCES