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Using Surgical Observations of Ossicular Erosion Patterns to Characterize Cholesteatoma Growth

*Alison Maresh, Olga F. Martins, †Jonathan D. Victor, and *†Samuel H. Selesnick

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*Departments of *Otorhinolaryngology and †Neurology and Neuroscience, Weill Cornell Medical College, New York, U.S.A.*

Objective: To describe and quantify growth patterns of cholesteatomas within the middle ear using a scaled rating system that characterizes patterns of ossicular erosion.
Study Design: Retrospective case review.
Setting: Tertiary referral center.
Patients: Patients undergoing first-time surgery for primary and secondary acquired cholesteatomas.
Interventions: Intraoperative assessments of ossicular destruction by cholesteatoma growth were performed.
Main Outcome Measures: A scaled system was created to classify the degree of erosion for each ossicle. Ossicular destruction patterns were quantified and compared with study growth patterns of cholesteatomas.
Results: A total of 157 ears of 152 patients with cholesteatomas, who met our inclusion criteria, were operated on by the senior author (S.H.S.) between 1992 and 2009. The incus was the most significantly affected ossicle, whereas the stapes was the most variably affected ossicle. The most commonly represented ossicular erosion patterns for primary acquired cholesteatomas demonstrated an intact malleus abutting cholesteatoma, erosion of the incus, and minimal stapes involvement, whereas the common erosion patterns for secondary acquired cholesteatomas demonstrated intact malleus abutting cholesteatoma, erosion of the incus, and erosion of the stapes.
Conclusion: Previous assessments of ossicular destruction by cholesteatomas were largely created for staging purposes and for guiding surgical reconstruction. Minimal information can be obtained from these data that both describe and quantify cholesteatoma growth patterns. Our ossicle categories more completely described how erosion develops using a scaled system. Common erosion patterns for both primary acquired and secondary acquired cholesteatomas validate anatomic studies and observations of how middle ear anatomy and compartment boundaries guide cholesteatoma growth. **Key Words:** Cholesteatoma—Ossicles—Ossicular erosion.
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Cholesteatoma growth patterns have been described based on observations of their tendency to expand into compartments based on embryologic and anatomic barriers within the ear space (1). Because cholesteatomas demonstrate such typical growth patterns and surgical treatment strongly depends on the anatomy of this disease process, it becomes important to standardize classification systems for meaningful communications among otologists (2). There are several such staging systems that are widely used to categorize cholesteatomas for this purpose. The standard classification places cholesteatomas into 1 of 3 clinical categories: congenital, primary acquired, and secondary acquired. An alternative classification by Tos (3) describes cholesteatomas by anatomic localization as attic, tensa, and sinus cholesteatomas.

These categories, however, do not fully elucidate aspects of advanced cholesteatoma growth that have functional and treatment implications such as the progressive ossicular destruction that occurs as the disease evolves. Although many investigators choose to describe the ossicular chain as either intact or discontinuous, there have been several attempts to standardize a more involved classification of ossicular status. In 1956, Wullstein (4) described 5 types of reconstructions based on residual ossicular anatomy; his efforts have served as a foundation from which other systems are based. Austin (5) described categories of ossicles based on whether the malleus and stapes were intact or absent because the reconstructive technique and the type of prosthesis largely depend on the status of these 2 ossicles. These categories were formalized by Kartush (6) who added categories to report ossicular head fixation and stapes fixation. An alternative classification was proposed by Saleh and Mills in 1999 (7) who described a 4-category system based on the common progression of ossicular destruction.

Address correspondence and reprint requests to Samuel H. Selesnick, M.D., Department of Otorhinolaryngology, 5th Floor, 1305 York Avenue, New York, NY 10021, U.S.A.; E-mail: shselesn@med.cornell.edu
AQ2 Olga F. Martins is a student at Weill Cornell Medical College, New York, New York, U.S.A.
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Such classifications are functional for the purpose of managing the surgical reconstruction of ossicles; however, as descriptors of cholesteatoma growth, they are limited by binary categorization and only partial inclusion of possible ossicular destruction patterns. We describe a unique and comprehensive rating scale that identifies the level of destruction of each ossicle. This allows for improved descriptions of erosion patterns that demonstrate how cholesteatomas grow within the middle ear as well as better quantifications of such growth patterns.

MATERIALS AND METHODS

Clinical data for patients undergoing surgery for cholesteatoma by the senior author (S.H.S.) at Weill Cornell Medical Center from 1992 to 2009 were entered into a database. A retrospective review of these patients was performed to evaluate the status of their ossicles. Patients were excluded from this study if they had a history of previous ear surgery, previous radiation treatment, or trauma to their ear; if their type of cholesteatoma was congenital; or if they had any incomplete ossicle status data.

Intraoperative microscopic evaluations of ossicular status were conducted by the senior author who was the surgeon performing the operation in all cases. Ranks were assigned to each ossicle as follows: 1 when it was completely normal, 2 when it was abutting cholesteatoma but intact, 3 when it was partially eroded by cholesteatoma, and 4 when it was completely absent. In the case of the stapes, a rank of 4 indicated complete erosion of the stapes
T1 suprastructure, with or without an intact footplate (Table 1). The mean and SD was found for each ossicle to assess overall severity and variability of destruction. Mean ossicle ranks were compared using the Friedman test, and post hoc testing was performed with the Tukey test. Mean ranks for identical ossicles were compared between primary acquired and secondary acquired cholesteatomas using the Mann-Whitney U test. $p < 0.05$ was considered significant.

A complete picture of ossicular erosion was created for each patient by using a 3-digit numerical representation that combines the ranks of each ossicle in the order of malleus-incus-stapes. Common erosion patterns were grouped together and quantified. Trends in the distributions of the different ossicle patterns as well as differences in the distributions between primary and secondary acquired cholesteatomas were evaluated. Statistical significance was determined by a surrogate data set method. To determine significance of erosion patterns, the surrogate data sets had the same distribution of grades of erosion as in the actual data set for each ossicle, but the grade of ossicular erosion for each bone was independent. To determine significance of the difference between primary and secondary cholesteatomas, the surrogate data sets contained the same patterns of erosion as the actual data set, but they were randomly assigned to ''primary'' and ''secondary'' subgroups. We then performed the same analysis on 10,000 such surrogates as on the actual data. Observations were considered statistically significant if the findings in the actual data set occurred to the same or greater degree in less than 5% of the surrogates.

TABLE 1. *Summary of ossicle status by rank*

Rank	Ossicle status
1	No contact with cholesteatoma, ossicle intact
2	Cholesteatoma abutting, ossicle intact
3	Partial erosion of ossicle
4	Complete erosion of ossicle[a]

[a]For stapes, complete erosion of suprastructure with or without an intact footplate.

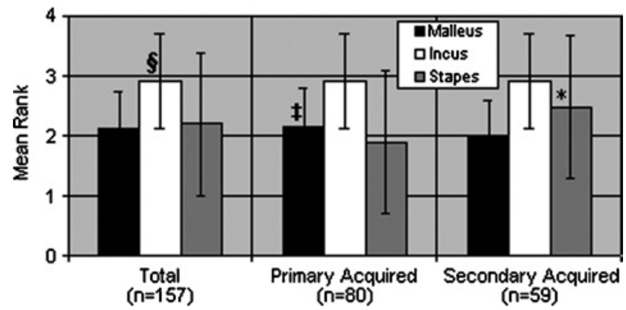

FIG. 1. Summary of average ossicle ratings by type of cholesteatoma. The incus is the most highly affected ossicle across all types, whereas the stapes is the most variably affected ossicle. §Significant compared with malleus and stapes, $p < 0.01$. ‡Significant compared with secondary acquired, $p = 0.02$. *Significant compared with primary acquired, $p < 0.01$.

RESULTS

A total of 157 ears on 152 patients underwent first-time cholesteatoma surgery for acquired cholesteatomas and met inclusion criteria. Of the patients included, there were 71 females and 81 males. Their ages ranged from 3 to 81 years, with a mean of 40 years; however, these age data do not include the earliest 9 patients for which no age data were available. Of all ears, 80 were primary acquired cholesteatomas, 59 were secondary acquired, whereas 18 could not be determined from intraoperative evaluation because of extensive destruction of the local anatomy. The average rank for the incus across all patients was 2.92, which is significantly higher than 2.11 for the malleus ($p < 0.01$) and 2.20 for the stapes ($p < 0.01$). In addition, the distribution shows greatest variability for the stapes with an SD of 1.19 compared with the SD of the malleus, 0.62, and that of the stapes, 0.78 (Fig. 1). The mean rank for stapes in F1 secondary acquired cholesteatomas was 2.47, which was significantly higher than the mean rank for stapes in primary acquired cholesteatoma, 1.89 ($p < 0.01$). The mean rank for the malleus in primary acquired cholesteatomas was 2.16, which was significantly higher than for secondary acquired, 1.97 ($p = 0.02$).

We found that the patterns of ossicular erosion were highly stereotyped. Of the 64 possible numerical representations of ossicular status, only 25 actually occurred (Fig. 2); this clustering is significant ($p < 0.01$). More- F2 over, the top 5 combinations accounted for 87 of the cases: 232 (n = 23), 221 (n = 20), 231 (n = 17), 234 AQ3 (n = 15), and 222 (n = 14). The distribution of 87 of 157 cases within the top 5 erosion pattern categories is also significant ($p = 0.03$).

There were differences between the patterns seen in primary and secondary acquired cholesteatomas. The top

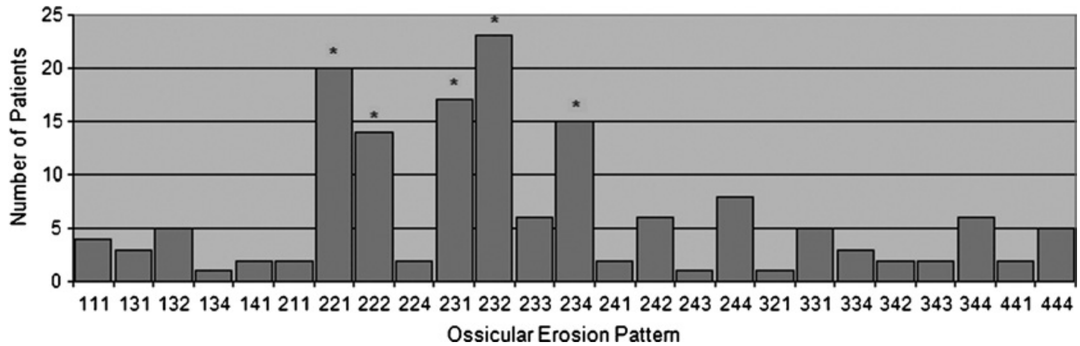

FIG. 2. Distribution of ossicular erosion patterns. The 3-digit number represents the ossicular rank for each ossicle in the order of malleus-incus-stapes. Erosion patterns clustered in only 25 of possible 64 categories, $p < 0.01$. *Further significant clustering seen with 87 of 157 cases clustered in the top 5 categories, $p = 0.03$.

combinations for primary acquired cholesteatomas are 221 (n = 16), 231 (n = 11), 222 (n = 10), 232 (n = 6), and 242 (n = 6), whereas the top combinations for secondary acquired cholesteatomas are 232 (n = 14), 234 (n = 7), 231 (n = 6), 244 (n = 6), 222 (n = 4), and 233 (n = 4) (Fig. 3). When evaluating these 2 types of cholesteatomas separately, significant differences include the 221 grouping pattern, which was more highly represented in the primary acquired group ($p = 0.04$), as well as 232, which was more highly represented in the secondary acquired group ($p = 0.04$).

DISCUSSION

Jackler (1) described typical routes of growth of cholesteatomas based on anatomic boundaries and compartments within the ear space. The most common types of cholesteatomas extend from the epitympanum through the Prussack space next to the incus. They can then spread to the aditus ad antrum and mastoid or to the middle ear through the floor of the Prussak space. Less commonly, cholesteatomas can develop into the mesotympanum via the posterior portion of the pars tensa, commonly involving the sinus tympani and facial recess. These cholesteatomas travel to the mastoid passing medial to the malleus and incus.

On the basis of these anatomic studies, the theoretical ossicular erosion patterns for different types of cholesteatomas can be extrapolated. These theoretical growth patterns based on middle ear anatomy and compartment boundaries have been observed and described qualitatively. Our data quantitatively reflect these data. Of the most common patterns of ossicular destruction, all have a malleus rating of 2, indicating abutment but no erosion of the malleus, consistent with the position of the malleus anteriorly within both the epitympanum and the mesotympanum. The malleus did have a significantly higher level of erosion in epitympanic cholesteatomas compared with that in mesotympanic cholesteatomas. This is potentially because most mesotympanic cholesteatomas occur in the posterior superior quadrant away from the handle of the malleus, so significant erosion occurs only after growth of the cholesteatoma grows significantly within the mesotympanic space, whereas in the epitympanic space, the head of the malleus is in a smaller area that is confined within the direct pattern of growth guided by anatomic boundaries. The incus had the highest level of erosion for both types of cholesteatomas; however, it was associated with

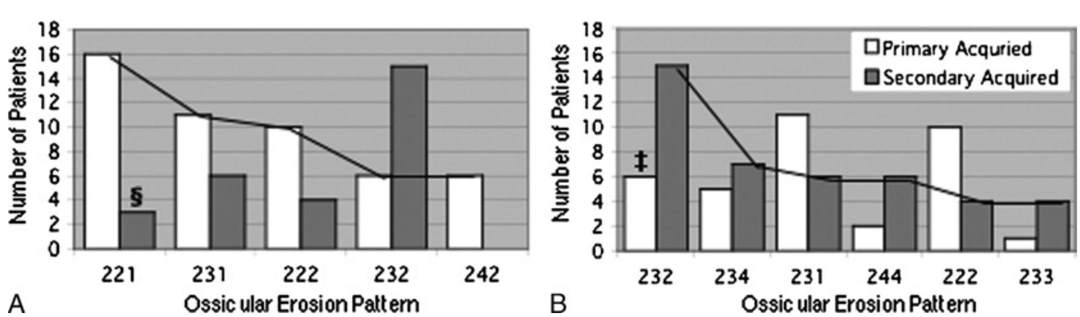

FIG. 3. Most common ossicular erosion patterns by cholesteatoma type. The 3-digit number represents the ossicular rank for each ossicle in the order of malleus-incus-stapes. *A*, Most common erosion patterns for primary acquired cholesteatomas, comparing their frequency to secondary acquired cholesteatomas. *B*, Most common erosion patterns for secondary acquired cholesteatomas. Common patterns for primary acquired cholesteatomas demonstrate less stapes involvement compared with those for secondary acquired cholesteatomas. §Significantly more common for primary acquired, $p = 0.04$. ‡Significantly more common for secondary acquired, $p = 0.04$.

significantly higher levels of stapes destruction in secondary acquired mesotympanic cholesteatomas compared with those in primary acquired epitympanic cholesteatomas. The difference between stapes erosion in these 2 types of cholesteatomas is likely why the stapes has the highest variability in erosion rank compared with both other ossicles.

Ossicular erosion status has long been studied as a consequence of cholesteatoma growth and as the anatomic basis on which ossicular reconstruction techniques are guided. Therefore, most classification techniques are based on staging severity or detailing relevant anatomy needed to plan for reconstruction. Cholesteatoma growth patterns have been validated by qualitative observations; however, limitations in previous classifications have prevented extensive quantification of these data. Our system uses a more complete scaled assessment that allows for statistical validation and better describes the progressive destruction of ossicles caused by cholesteatomas. These results confirm anatomic studies and previously reported data regarding ossicular erosion by cholesteatoma growth.

REFERENCES

1. Jackler R. The surgical anatomy of cholesteatoma. *Otolaryngol Clin North Am* 1989;22:883–96.
2. Meyerhoff W, Truelson J. Cholesteatoma staging. *Laryngoscope* 1986;96:935–9.
3. Tos M. Pathology of the ossicular chain in various chronic middle ear diseases. *J Laryngol Otol* 1979;93:769–80.
4. Wullstein H. Theory and practice of tympanoplasty. *Laryngoscope* 1956;66:1076–93.
5. Austin D. Ossicular reconstruction. *Otolaryngol Clin North Am* 1972;5:145–60.
6. Kartush J. Ossicular chain reconstruction. Capitulum to malleus. *Otolaryngol Clin North Am* 1994;27:689–715.
7. Saleh H, Mills R. Classification and staging of cholesteatoma. *Clin Otolaryngol Allied Sci* 1999;24:355–9.