Frequency-Specific Hearing Outcomes in Pediatric Type I Tympanoplasty

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**IMPORTANCE** Middle ear disease is the primary cause of hearing loss in children and has a significant impact on language development and academic performance. Multiple prognostic factors have previously been examined, but there is little published data regarding frequency-specific hearing outcomes.

**OBJECTIVE** To examine the relationship between type I tympanoplasty in a pediatric population and frequency-specific hearing changes, as well as the relationship between several prognostic factors and graft retention.

**DESIGN, SETTING, AND PARTICIPANTS** Retrospective medical chart review (February 2006 to October 2011) of 492 consecutive pediatric otolaryngology patients undergoing type I tympanoplasty for tympanic membrane (TM) perforation of any etiology at a tertiary-care pediatric otolaryngology practice.

**INTERVENTIONS** Type I tympanoplasty.

**MAIN OUTCOMES AND MEASURES** Preoperative and postoperative audiometric data were collected for patients undergoing successful TM repair. It was hypothesized before data collection that conductive hearing would improve at all frequencies with no significant change in sensorineural hearing. Data collected included air conduction at 250 to 8000 Hz, speech reception thresholds, bone conduction at 500 to 4000 Hz, and air-bone gap at 500 to 4000 Hz. Demographic data obtained included sex, age, size, mechanism, location of perforation, and operative repair technique.

**RESULTS** Of 492 patients, 320 were excluded; results were thus examined for 172 patients. Surgery was successful for 73.8% of patients. Perforation size was significantly associated with repair success (mean [SD] surgical success rate of 38.6% [15.3%] vs surgical failure rate of 31.4% [15.0%]; P < .01); however, mean (SD) age (9.02 [3.89] years [surgical success] vs 8.52 [3.43] years [surgical failure]; P > .05) and repair technique (medial [73.08%] vs lateral [76.47%] graft success; P > .99) were not. Air conduction significantly improved from 250 to 2000 Hz (P < .001), did not significantly improve at 4000 Hz (P = .08), and there was a nonsignificant decline at 8000 Hz (P = .12). Speech reception threshold significantly improved (20 vs 15 dB; P < .001).

**CONCLUSIONS AND RELEVANCE** This large review found an association of TM perforation size with surgical success and an improvement in speech reception threshold, air conduction at 250 to 2000 Hz, air-bone gap at 500 to 2000 Hz, and worsening bone conduction at 4000 Hz. Patients with high-frequency hearing loss due to TM perforation should not anticipate significant recovery from type I tympanoplasty. Hearing loss at higher frequencies may require postoperative hearing rehabilitation.
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yringotomy with tympanostomy tube insertion is the most common pediatric surgery. Approximately 1% to 4% of these cases will have persistent tympanic membrane (TM) perforation after spontaneous extrusion. The rate of persistent perforation for tympanostomy tubes retained for more than 3 years has been reported as high as 40%. One of the primary reasons surgery is performed after TM perforation is for restoration of hearing, but reports of hearing improvement have been variable. Chronic otitis media is known to cause mild to moderate conductive hearing loss in greater than 50% of cases, and TM perforation carries a theoretical risk of up to a 40-dB loss in conductive hearing independent from ossicular chain disease or sensorineural hearing loss resulting from chronic otitis media. Children with hearing loss are known to have impaired social interactions and academic performance, as well as inhibited language and cognitive development.

Frequency-specific hearing studies are important because the average pure tone threshold does not directly correlate to patterns of hearing perception. Determining patterns of hearing loss and restoration in type I tympanoplasties will help improve prognostic accuracy.

Methods

This study was approved by the institutional review board of the Children’s Hospital of the University of Pittsburgh Medical Center. It was designed as a retrospective medical chart review of 492 patients who underwent type I tympanoplasty between February 2006 and October 2011. Surgery was performed by 11 different attending surgeons, individually and with assistance from otolaryngology residents and fellows. The decision for lateral or medial graft tympanoplasty technique was at the discretion of the attending surgeon. Study exclusion criteria included the following: a history of congenital hearing loss, identification of cholesteatoma or other middle ear mass lesions, identification of ossicular chain discontinuity or destruction, and missing preoperative audiometric testing. Surgical success was defined as an intact TM on clinical examination and by tympanometry testing at the time of the final postoperative assessment. Demographic data collected included age, sex, laterality of affected ear, mechanism, location and size of perforation as reported by the treating clinician, and surgical technique (medial or lateral graft tympanoplasty).

A total of 320 patients were excluded: cholesteatoma was found intraoperatively in 140 patients, 137 had missing audiométric data, and 43 met other exclusion criteria. Thus, 172 patients (95 male and 77 female) were included in analyses. At postoperative assessment, 45 were found to have surgical failure. These patients were included for analysis of demographic differences between surgical success and failure but were excluded from frequency-specific analyses along with 18 surgical success patients who had missing postoperative audiometric testing. Frequency-specific analyses were therefore completed on 109 patients.

Pure-tone audiometry was conducted in a double-walled sound room using standard procedures. Audiometric testing of the air conduction (AC) threshold was performed at 250, 500, 1000, 2000, 4000, and 8000 Hz. Bone conduction (BC) thresholds were recorded at 500, 1000, 2000, and 4000 Hz if AC was greater than 20 dB at the corresponding frequency, with appropriate masking of the opposite ear. Air conduction testing at 250 Hz was not recorded in 48.3% of preoperative audiograms and 26.2% of postoperative audiograms; at 8000 Hz, AC testing was not completed in 25.0% of preoperative audiograms and 10.0% of postoperative audiograms. The median time from preoperative audiometric testing to surgery was 2 months (range, 0-39 months), and the median time to postoperative audiometric testing from surgery was 3.1 months (range, 1-14.2 months).

Demographic data for surgical success and failure patients were compared using an unpaired t test for age and perforation size, using a significance level of .05. The Fisher exact test was used to compare surgical technique between surgical success and failure. Preoperative and postoperative AC, BC, and air-bone gap (ABG) values were compared using Wilcoxon signed-rank testing.

Results

Among the 172 patients, ages ranged from 3 to 17 years (mean, 8.9 years) and 55.2% were male and 44.8% were female. Surgery was successful for 73.8% of patients in this series. Laterality was approximately equal (56.4% left vs 43.6% right), consistent with prior studies. The majority of TM perforations were iatrogenic (75.6%), due to either failure of a tympanostomy tube to extrude or failure of the TM to heal after extrusion (Table 1). More than half (54.1%) of the perforations were found in the region of the anterior-inferior quadrant, consistent with prior tympanostomy tube placement (Figure 1).

Surgical success patients did not significantly differ from surgical failure patients in mean age (9.0 vs 8.5 years; P = .49) or surgical technique (P > .99) (Table 2). There was a small but significant difference in the mean perforation size between surgical success and failure groups (38.6% vs 31.4%; P < .01).

In the surgical success group, AC improved at all frequencies except at 4000 and 8000 Hz (Figure 2 and Figure 3). At
8000 Hz, there was a nonsignificant decline in hearing ($P = .12$). Bone conduction did not change significantly at any frequency except for 4000 Hz, where it was found to decline marginally. Air-bone gap improved at all frequencies except for 4000 Hz. Speech-reception threshold improved significantly from preoperatively to postoperatively (20-15 dB; $P < .001$) (Figure 2 and Figure 3).

**Discussion**

Conventional wisdom holds that pediatric tympanoplasties enjoy a relatively high rate of surgical repair success, but a review of 20 publications found historical success rates ranging from 35% to 93% in children. The 73.8% success rate in this study falls below the mean of these reported rates. Hypotheses for this lower rate of success include the possibility of a higher rate of revision tympanoplasty referrals to this...
Hearing Outcomes in Pediatric Type I Tympanoplasty

Age has long been considered one of the most important prognostic factors for successful tympanoplasty, but there has been conflicting evidence presented in more recent literature. Older studies have found significant associations between age and outcome, with various recommendations to delay repair until sometime between the ages of 7 and 12 years, and a meta-analysis of articles published over a 30-year interval found that age was the only factor related to surgical success. The primary argument for postponing surgery because of age is that it functions as a predictor of adequate eustachian tube function. However, several large studies conducted within the last decade have found no association between age and surgical success. No significant difference was found in age between surgical success and failure groups in this study, consistent with these more recent publications.

Reports conflict on whether perforation size is a significant prognostic factor, with decreased rates of success for perforations greater than 50% found in several large studies. More recent studies have found no association between size and success rate. In contrast, results of this study reveal greater surgical success with larger perforations, though the difference in perforation sizes is marginal. It has been hypothesized that perforation size does not affect surgical success because lateral graft repairs are more frequently used for larger perforations with similar success rates to medial graft repairs used for smaller perforations. Previous reviews agree with this hypothesis, since they have found no significant difference between medial and lateral repair techniques and success rates, a finding further supported by this study. There may truly be no difference in success rates between these 2 techniques, but outcomes are difficult to study well because the choice of repair is often based on surgeon expertise and comfort with a particular technique. In addition, many modifications of both techniques are practiced. It may instead illustrate that patients are being successfully triaged to the currently available repair technique most likely to succeed with their particular anatomy.

The perforated TM significantly contributes to hearing loss independent of other middle ear structures. Decreased coupling of acoustic pressure to ossicular torque and loss of a pressure differential across the TM impairs ossicular coupling, especially at low frequencies. The perforated TM is essentially less efficient at translating movement to the ossicles and is relatively less mobile, especially at lower frequencies. Recent research has shown that conductive hearing loss increases with perforation size, but that it is independent of location within the TM.

Air conduction and ABG values showed significant improvements in low and mid-range frequencies in this study, with a trend towards worsening of high-frequency hearing that did not reach significance. Low- and mid-frequency improvements likely represent normalization of the ossicular coupling effect after restoration of a functional TM. It has previously been shown that alterations in middle ear conductance are dependent on ossicular coupling, acoustic coupling, and sta-
tion should theoretically be able to achieve ABGs as low as 20 dB even in suboptimal TM-ossicle configurations. This gain is most prominent at low frequencies and tapers off above 1000 Hz. Pathologic changes within the chronically infected ear can alter this relationship through development of increased osseous impedance (eg, from fibrotic adhesions) or poor aeration. Poor aeration significantly increases impedance and decreases ossicular coupling and may result from structural alterations due to an atelectatic TM or may be a functional outcome secondary to persistent eustachian tube dysfunction. The end result may be large ABGs of up to 60 dB, especially at lower frequencies.

Adequate TM-ossicular linkage and TM mobility are significant factors when attempting maximal restoration of hearing, and they are controlled in large part by the choice of surgical technique and graft material. Shape and thickness of the TM has previously been shown to affect sound transmission, and the temporalis fascia graft most commonly used in this study is histologically different from the native pars tensa. A very thick TM graft will have increased impedance, and poor or inappropriate choice of technique may result in lateralization of the graft and blunting of the tympanomeatal angle from fibrous adhesions.

The cause for a decrease in BC at 4000 Hz in this study is possibly an artifact of changes to middle ear conduction, although the exact mechanism for this is not clear. In contrast, prior studies have found improvements in measured BC levels after tympanoplasty (primarily in the lower frequencies), and it is hypothesized that this may be due to reduction of inflammation in the inner ear and restoration of conductive hearing after successful surgery. The decrease in BC seen in the present study may represent iatrogenic occult inner ear injury from sources such as bone drilling if a canalplasty is required for visualization prior to tympanoplasty, but this study is not adequately powered to evaluate this hypothesis.

This study is limited by necessity for a larger sample population. The retrospective design is limited by significant variation in the timing and reporting of clinical examinations and interventions. Another limitation is that approximately two-thirds of patients undergoing tympanoplasty were excluded owing to various causes, most of which were missing audiometric data. Further study would benefit from a larger sample size and standardization of examination procedures and reporting, such as routine acquisition of BC data in all audiograms regardless of AC thresholds in order to support or refute published data that perforation size correlates with hearing loss but perforation location does not.

Conclusions

No correlation between age and success of type I tympanoplasty was found in this study, consistent with several recent reviews of tympanoplasty outcomes. The frequency-specific findings presented herein illustrate that successful type I tympanoplasties effectively repair ossicular coupling and restore an ABG of 20 dB or lower, despite the use of autologous graft tissue and alteration of TM anatomy. These improvements are most pronounced in the low frequencies and are due to significant improvements in AC. A trend towards decreased hearing at higher frequencies is likely due to a repaired TM acting as a pressure wave shield and decreasing acoustic coupling without the resultant gain from ossicular coupling that is more pronounced in the lower frequencies. Patients diagnosed as having high-frequency hearing losses in the setting of a TM perforation should not anticipate significant recovery from type I tympanoplasty because these losses may be due to other factors. Hearing loss at higher frequencies may therefore require postoperative hearing rehabilitation. The etiology of a decrease in BC at 4000 Hz after successful surgical repair is not clear at this time.