Persistent conductive or mixed hearing loss after the placement of tympanostomy tubes

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1. Introduction

The most common cause of conductive hearing loss (CHL) in children is middle-ear effusion (MEE) resulting from Eustachian tube dysfunction [1]. Evaluation of a child with hearing loss includes age-appropriate audiological testing, medical history, surgical history, family history, and comprehensive physical evaluation. If a child is found to have a CHL in the presence of MEE, they may be a candidate for tympanostomy tube (TT) placement. The decision to place TTs may vary among surgeons and depends on the audiological evaluation, history, speech and language development, and physical examination.

One of the goals in the placement of TTs in a child with a CHL in the setting of a MEE is the return of normal hearing. One rare, but unfortunate, outcome with this procedure is the persistence of conductive or mixed hearing loss unrelated to MEE. This potential outcome is important to explain to the caregiver prior to surgery. Described is a series of children with conductive or mixed hearing loss following TT placement. Documented are their clinical evaluations, courses, and final diagnoses if determined. A test that is not generally considered in the normal battery of pediatric evaluation, the vestibular-evoked myogenic potential (VEMP) test, will also be discussed, as it may aid in diagnosis.

2. Methods

A retrospective chart review was performed for children treated in the Department of Otolaryngology and Communication Enhancement at Boston Children's Hospital over a three year period.

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Objective: Described is a case series of clinical findings in children with persistent conductive or mixed hearing loss following tympanostomy tube placement for serous otitis media.

Study design: Retrospective chart review.

Setting: Tertiary pediatric hospital.

Subjects/methods: Medical records of thirty-nine children who were referred for either conductive or mixed hearing loss post-tympanostomy tube placement were reviewed for clinical histories, physical examinations, audiological evaluations, diagnostic studies, consultations, and surgical findings. Approval was obtained from the Boston Children's Hospital Institutional Review Board.

Results: Causes of hearing loss included ossicular abnormalities, cochlear abnormalities, ‘third window’ effects, cholesteatomas, genetic syndromes, and unknown causes. In four patients with isolated mild low-frequency conductive hearing loss, the cause was the presence of functional tubes. All patients diagnosed with a genetic syndrome had bilateral hearing loss. Patients with mixed hearing loss were diagnosed with cochlear abnormalities, ‘third window’ effects, or genetic syndromes. Computed tomography led to diagnosis in sixteen of twenty-five patients. Vestibular-evoked myogenic potential testing suggested a diagnosis in three of four patients.

Conclusion: In children with persistent hearing loss following tympanostomy tube placement, identifying the laterality and type of hearing loss appears to be of importance in diagnosis. Patients with bilateral hearing loss should be considered for genetic testing, given the possibility of a syndrome. Patients identified with a mixed hearing loss should be evaluated for inner ear anomalies. Patients with mild, low-frequency hearing losses should be monitored audiologically and investigated further only if the hearing loss progresses and/or there is no resolution following tube extrusion.

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period. Thirty-nine children, twenty-two boys, were identified with persistent conductive or mixed hearing loss after TT placement upon referral by otolaryngologists at Boston Children's Hospital. Seventeen patients were referred from outside institutions following the diagnosis of post-TT placement hearing loss. Each patient's history was reviewed for age, sex, audiometric evaluation, medical and surgical history, age at most recent placement, imaging studies, VEMP testing, surgical findings, and final diagnosis if determined. Approval was obtained from the Boston Children's Hospital Institutional Review Board.

3. Results

3.1. Representative case studies

1. A 5-year-old boy, who passed his newborn hearing screen, was diagnosed with MEE after failing a kindergarten hearing screen. He had TTs placed and follow-up audiometric testing showed a persistent CHL in the left ear. A temporal bone computed tomography (CT) scan revealed a fixation of the left malleus head to the anterior epitympanum (Fig. 1). The right temporal bone was normal. He underwent a left transcanal tympanoplasty with ossicular reconstruction.

2. A 5-year-old boy was referred from an outside institution for evaluation of a CHL after the placement of TTs. An audiogram revealed normal hearing for the right ear, and a 50–60 dB HL CHL for the left ear. Tympanometry revealed a large ear canal volume on the right, consistent with a patent TT. The left side exhibited a small ear canal volume in the presence of a clearly patent TT. The small volume raised suspicion for a space occupying lesion in the middle ear or mastoid. A temporal bone CT revealed partial opacification of the epitympanum (Fig. 2). A canal wall-up tympanomastoidectomy was performed and cholesteatoma was found to have eroded the malleus, the long process of the incus, and the stapes supra-structure. The cholesteatoma extended into the protympanum and mastoid. A post-operative audiogram showed a persistent 50–60 dB HL CHL (Fig. 3). Further reconstructive surgery is planned.

3.2. Patient demographics

The average age at most recent TT placement was 5.92 years (range: 9 months to 16 years). Twenty-two (56.4%) children exhibited bilateral hearing loss and the remaining seventeen (43.6%) had unilateral hearing loss. Thirteen children in this study passed their newborn hearing screen, seven had a unilateral hearing loss and six had a bilateral hearing loss. Eight children did not pass their newborn hearing screen, one with a unilateral hearing loss and seven with a bilateral hearing loss. Newborn hearing results were not available for the remaining eighteen patients. Twenty-nine patients had a CHL post-TT placement, and ten had a mixed hearing loss.

3.3. Workup

All post-operative audiological evaluations were performed at our facility by licensed audiologists using age appropriate behavioral test measures, e.g. Conditioned Play Audiometry (CPA).
(CPA) or conventional pure tone audiometry. Ear specific and frequency specific thresholds were obtained for all test subjects post-operatively. Tympanometry was completed for all test subjects to ensure patency of previously placed TTs. Pre-operative audiological evaluations were completed at our facility for twenty-two subjects utilizing age appropriate test measures, e.g. Unsedated Auditory Brainstem Response (UABR), Visual Reinforcement Audiometry (VRA), CPA, or conventional pure tone audiometry. Two subjects underwent UABR, fourteen subjects completed ear specific testing, and six subjects completed evaluations in the soundfield environment due to age and/or development level. Tympanometry was completed for twenty-two subjects pre-operatively and indicated normal ear canal volume with decreased middle-ear compliance. Seventeen subjects had pre-operative audiological evaluations with subsequent TT placement completed at outside facilities. Those subjects were referred to our facility following identification of persistent hearing loss post-TT placement. Of these seventeen, ten had mixed hearing loss. It is unknown if pre-operative masked bone conduction was completed and whether or not mixed hearing loss was indicated.

Twenty-five children (64.1%) had a CT scan, four (10.3%) had a magnetic resonance imaging (MRI) scan, seven (17.9%) underwent a genetics evaluation, eight (20.5%) had exploratory surgery, and four (10.3%) underwent vestibular evoked myogenic potential (VEMP) testing. Two of the patients who underwent VEMP were 4 years old, one patient was 3 years old, and one patient was 15 years old.

Sixteen children (41.0%) were diagnosed following a CT scan, representing 64% of the CT scans performed. None of the four MRI scans performed gave conclusive evidence to lead to a final diagnosis. Five children (12.8%) were diagnosed following surgery, a 62.5% success rate for determination of diagnosis. Three children (7.7%) were diagnosed following VEMP testing: 75% of the VEMP tests lead successfully to a diagnosis. Two of those successful VEMP tests suggested diagnosis in cases that CT could not, and one corroborated CT results.

CT scans aided in the diagnoses of four middle-ear abnormalities, four inner ear abnormalities, five lesions that can result in a ‘third window’ effect, one cholesteatoma, and two cases of CHARGE syndrome. Exploratory surgery revealed the diagnosis of one middle-ear abnormality and four cases of cholesteatoma. VEMP testing led to the diagnosis of possible ‘third window’ effects in three patients (Fig. 4).

3.4. Syndromes associated with hearing loss

Two children (brothers) were diagnosed with Branchio-Oto Renal syndrome (BOR), two children with CHARGE syndrome, one with VACTERL, two with Klippel-Feil, and three with Trisomy 21. Genetics evaluations were very helpful and necessary in some cases for a final diagnosis.

3.5. Final diagnoses

Final etiologic determination of hearing loss included six middle-ear abnormalities, five cholesteatomas, four cochlear abnormalities, five enlarged vestibular aqueducts (EVA), three semicircular canal dehiscences (SCD), and five syndromes known to be associated with hearing loss. Seven patients remained undiagnosed. In four cases, the tubes were identified as the etiology of the hearing loss; all four patients had normal hearing between 1000 and 8000 Hz with a slight to mild conductive loss limited to 250 Hz and 500 Hz which resolved following either tube removal or extrusion. The distribution of diagnosis regarding sex (Fig. 5), type of hearing loss (Fig. 6) and laterality of hearing loss (Fig. 7) are shown.
3.6. Family history

Very few patients had a family history of hearing loss. One had a grandfather with hearing loss thought to be from noise exposure. Two patients with BOR syndrome were brothers; their mother also had BOR syndrome. One patient had a brother who also had an EVA. One patient with EVA had hearing loss of unknown etiology two generations removed on both sides of the family.

3.7. Newborn hearing

Twenty records of the thirty-nine patients included made specific mention of whether or not a newborn hearing screen was performed; twelve passed and eight referred. The referred patients included two with EVAs, one with cholesteatoma, one with superior SCD, one with a middle ear abnormality, one with CHARGE syndrome, and two for which diagnosis is unknown. Those patients who passed the newborn hearing screen included one with cholesteatoma, three with EVA, one with cochlear dysplasia, one with a possible ossicular abnormality, one with a posterior SCD, two with CHL due to the tubes, one with CHARGE syndrome, and two for which diagnoses remain unknown.

4. Discussion

The most common cause of CHL in children is MEE [1]; in cases where fluid does not resolve spontaneously, TT placement is typically performed. Once tubes are in place and functional, the expectation held by families and physicians alike is that the resolution of fluid will bring a resolution of the hearing loss. Rarely children experience persistent hearing loss after TT placement which can be very frustrating for the child, family, and physician.
Potential causes of conductive or mixed hearing loss unrelated to MEE include both congenital and acquired conditions (Table 1). This study examined the medical workup of children who experienced persistent conductive or mixed hearing loss following TT placement. A CT of the temporal bone was the test most commonly used in this population. CT was the most accurate imaging method leading to diagnosis in fourteen out of twenty-six patients. MRI only indicated diagnoses; all instances of the test necessitated corroborations by CT. Due to its costliness and relative inaccuracy in this population, it may be more efficient to begin with a CT scan of the temporal bone; however, one needs to consider the radiation exposure associated with CT imaging. VEMP testing suggested a diagnosis in three of four children.

When looking at sex distribution (Fig. 5), the data suggest that boys may be at higher risk for developing a cholesteatoma. Kemppainen et al. in their 1999 study indicate that boys have a 1.49 greater relative risk of developing a cholesteatoma [2]. Interestingly, within our small cohort, boys also had a higher rate of a third window effect. Further investigation with a larger patient population is needed to confirm this finding.

Review of newborn hearing screen status raises questions with regard to children who have a congenital anomaly and yet passed their newborn screens. A refer status on the newborn hearing screen may not be expected in the cases of EVA, cochlear dysplasia, or SCD as hearing loss associated with these anomalies is often progressive. Two of the patients in this study, one with CHARGE syndrome and one with a possible ossicular anomaly, passed their newborn hearing screens when they theoretically should not have; these are possibly due to false negatives. When children refer on the newborn hearing screen, typical follow-up care includes tympanometric measures, auditory brainstem response (ABR) test, and medical evaluation. Otitis media with effusion is the major reason for failure on newborn hearing screens [3]. If fluid is present following a failure on the newborn hearing screen, the hearing loss is likely to be attributed to that presence. If an infant presents with reduced middle ear compliance with conductive hearing loss at the time of initial ABR follow-up, it is normal to wait several weeks or months to re-evaluate. If reduced middle ear compliance is observed again, the child may be referred for medical management. Another waiting period may occur, after which TT placement may be recommended if the reduced middle ear compliance has not resolved. Following TT placement, the persistent hearing loss will be identified.

Two characteristics of identified persistent CHL aid in diagnosis of underlying etiology: type of hearing loss (Fig. 6) as well as laterality of hearing loss (Fig. 7). All of the children diagnosed with a hearing loss-associated syndrome had bilateral hearing loss. Syndromes associated with patients in this study included Trisomy 21, BOR, CHARGE, and Klippel-Feil. A previously documented association between Trisomy 21 and CHL has been found [4]. Genetic evaluation should be considered if persistent bilateral HL is identified. Third window origin was the most common cause of a mixed hearing loss in this group. Tests that could be used to investigate the presence of a third window include temporal bone CT and/or VEMP testing.

VEMP testing can be measured quickly and fairly easily, and the results can be used to aid in diagnosis of hearing loss from causes such as EVA and SCD, as well as various vestibular disorders. A study by Zhou et al. found that, for SCD, VEMP testing is a highly sensitive test which is more specific than CT [5]. When negative, VEMP essentially rules out a dehiscence, and when positive a high-resolution CT can be performed to confirm. VEMP testing is also useful for evaluating patients with EVA as those patients exhibit abnormally low threshold responses [6]. VEMP testing can be difficult in very young children, though it is possible to perform. The youngest child in this study was 3 years of age when VEMP testing was done, and the results led to diagnosis.

Four patients were identified with mild CHL limited to 250 Hz and 500 Hz. Hearing levels remained stable while the tubes were in place, and hearing loss resolved following TT removal or extrusion (Fig. 8). When results such as these are observed, serial audiological and otological evaluations should be performed to ensure stability of the hearing loss while tubes are in place and functional. An audiological evaluation following TT extrusion or removal is imperative in these cases, to ensure a return to normal hearing.

Identification of hearing loss as early as possible is critical for children’s social and cognitive development. The link between hearing loss and speech/language development and delay is well documented. Prompt intervention with amplification and support services, if indicated, leads to better outcomes for children with hearing loss [7]. It is with this in mind, and with the knowledge that many children who undergo TT placement have preoperative transient CHL, the imperative steps to obtain a postoperative audiological evaluation to rule out persistent CHL is understood.

**Table 1**

| Causes of CHL and mixed hearing loss unrelated to middle-ear effusions. |
|---------------------------|---------------------|
| **Congenital**                      | **Acquired**                  |
| External auditory canal atresia or stenosis | Cerumen                      |
| Ossicular malformation, e.g.: | External auditory canal mass |
| – Stapes fixation                | Tympanic canal perforation   |
| – Malleus fixation               | Tympanosclerosis            |
| – Incus fixation                 | Trauma to the middle ear    |
| – Ossicular discontinuity        | Otochleisis                  |
| Congenital cholesteatoma         | Acquired cholesteatoma      |
| Cochlear conductive hearing loss | Chronic infection resulting |
| Syndrome assoicated hearing loss | in ossicular loss            |
| e.g., Trisomy 21, CHARGE, BOR    | Eustachian tube dysfunction leading |
| Enlarged vestibular aqueduct     | to atelectasis and ossicular erosion |
| Semicircular canal dehiscence*   | Granulation tissue          |

* This may be an acquired condition as well, similar to the proposed theory regarding bone loss over time from pulsation of the meninges and arachnoid granulations over the tegmen causing bone loss and deafness.

Fig. 8. Audiogram shows persistent mild bilateral conductive hearing loss, isolated to low frequencies, in the presence of patent tympanostomy tubes. Persistent conductive hearing loss resolved completely following tympanostomy tube extrusion.
This study examined characteristics found in a population of children who presented with persistent conductive or mixed hearing loss after TT placement. A wide variety of causes of hearing loss were found using a variety of clinical assessments. The results suggest that when hearing loss is present in the company of reduced tympanic membrane movement, one should consider counseling the family that the hearing loss may not be a result of the fluid alone, although this is rare. The actual incidence of persistent hearing loss following tube placement could not be determined in this study, as many of the patients were referred from outside institutions, and data regarding TT placement were unobtainable. Limitations of the study result from its retrospective nature: the contents of patient records were not uniform (e.g. newborn hearing screen results were not always available) and different physicians implemented a variety of evaluations for their patients.

References