



Ossiculoplasty for Tympanosclerosis

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Abstract

Purpose of Review The utility of surgery for tympanosclerosis has been a controversial topic among otologic surgeons for many decades. Knowing the variations in tympanosclerotic involvement, different aspects of surgical technique, and audiologic outcomes data can help inform the discussion of optimal management between surgeon and patient.

Recent Findings Tympanosclerosis can involve all structures in the middle ear, and the distribution of that involvement determines the likelihood of surgical success in hearing improvement. Most recent studies indicate that having a mobile stapes is a key prognostic factor and increases the chance of meaningful hearing improvement following surgery. Stapes surgery for tympanosclerosis can also be successful, but results are more variable.

Summary Tympanosclerosis is a challenging condition to treat, and the decision regarding surgical management should be thoughtful and carefully weighed against benefits obtained from amplification alone.

Keywords Tympanosclerosis · Ossiculoplasty · Ossicular chain reconstruction · Stapedectomy · Conductive hearing loss

Introduction

Tympanosclerosis is a disease state of the ear characterized by chalky, calcium-containing deposits located in the tympanic membrane and cavity, surrounding the ossicular chain, and also within the mastoid. First described as “chalky patches” by Cassebohm in 1734, the middle ear lesions were later described as “taukensklerose” by Von Trolsch in 1873 [1••]. Zollner introduced the term “tympanosclerosis” into the English literature in 1955 [2]. Although surgeons have been familiar with this pathological state for more than a century,

the optimal management of tympanosclerosis continues to remain highly controversial.

Pathogenesis

Tympanosclerosis is thought to arise from sclerotic, degenerative changes in the middle ear submucosa as a result of chronic infection. It is a post-inflammatory or post-traumatic condition and can be a sequela of purulent and serous effusions, as well as following myringotomy and tube placement. This was demonstrated in an interesting study by Skinner et al. in which 46 pediatric patients with bilateral otitis media with effusion received an ear tube in one ear while leaving the other ear untreated [3]. After 15 years of follow-up, tympanosclerosis was observed in 41% of the ears in which tubes were placed and also in 15.2% of unoperated ears. This showed the close association of tympanosclerosis with both otitis media and ventilation tubes. Tympanosclerosis is often regarded as an irreversible, end-stage middle ear process developing from a prior insult. However, observations of recurrent ossicular refixation following surgery call this tenet into question [4].

The hallmark of tympanosclerosis is abnormal calcium deposition within the middle ear tissues. In its simplest form, it is manifested by opaque patches localized only in

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the tympanic membrane, known as myringosclerosis. However, deposits can often be pervasive and can occur in many locations within the middle ear. The degree of ossicular chain involvement can range from a single focus of disease on one ossicle to complete fixation of all ossicles. Large plaques of tympanosclerosis may be firmly adherent to the facial nerve and can also completely obliterate the oval and round windows. The degree of conductive hearing loss is therefore determined by the amount and distribution of tympanosclerotic disease.

Classification

Given the variable locations of tympanosclerosis, Wielinga and Kerr developed a classification scheme that remains in common use [1••]. This classification describes four types of tympanosclerotic disease (Table 1). In type 1, only the tympanic membrane and possibly the malleus are involved, and a perforation may or may not be present. Type 2 is characterized by fixation of the malleus-incus complex with a mobile stapes. In contrast, type 3 consists of a fixed stapes with a mobile or absent malleus-incus complex. In type 4, there is complete fixation of the malleus-incus-stapes complex.

Incidence and Association

The incidence of tympanosclerosis in ears with chronic otitis media ranges from 3 to 33% [5], and myringosclerosis rates can be as high as 51% [1••]. The incidence in females is generally reported to be slightly higher than that in males. Bilateral involvement has been observed in 40–60% of cases. The majority of ears with tympanosclerosis are typically dry, which reinforces the belief that tympanosclerosis is an end-stage result of chronic infection and inflammation. In contrast, the rates of tympanosclerosis co-existing with cholesteatoma are lower, ranging from 0 to 30% in reported studies [2].

Table 1 Classification of tympanosclerosis

Type 1	Involvement of intact or perforated tympanic membrane may have limited malleus involvement
Type 2	Epitympanic fixation of malleus and incus, stapes remains mobile
Type 3	Fixation of the stapes footplate and suprastructure if present, malleus and incus mobile if present
Type 4	Fixation of malleus, incus, and stapes

(Table 1 was created using data from Wielinga et al. [1••])

Surgical Considerations and Outcomes

Numerous studies reporting audiological outcomes following tympanosclerosis surgery have been published within the last few decades. Below we highlight some of the more recent reports, as well as review key older studies. A compilation of these audiological outcomes is shown in Table 2. Since hearing outcomes often depend on the type of tympanosclerosis, data for studies within the past 10 years are categorized based on tympanosclerosis type when possible.

Type 1 Tympanosclerosis

Type 1 tympanosclerosis typically consists of involvement of only the tympanic membrane, with or without perforation. The malleus may also have limited involvement in these cases. The tympanosclerotic plaques are almost exclusively located in the *pars tensa* [26]. These thick deposits can stiffen the tympanic membrane, contributing to conductive hearing loss depending on their size. Moreover, the hearing loss may be more severe if the deposits are adherent to the annulus or surrounding bone [1••]. Tympanoplasty techniques vary, but many surgeons do not remove plaques from the tympanic membrane unless they are significantly impairing mobility or are adjacent to a perforation and would impair healing. When plaques are removed, they should be carefully separated from the overlying epithelium, which can often be preserved. An example of removal of tympanosclerosis from the tympanic membrane extending to the malleus is shown in Fig. 1A and B. Success rates for type 1 tympanoplasty in the setting of tympanosclerosis are generally high. In their series of 37 patients, Aslan et al. reported a perforation closure rate of 67% [19]. In Mutlu's series of 151 cases, perforation closure was achieved in 89% of cases with a mean follow-up of 1 year [20•]. This is similar to perforation closure rates commonly observed in the setting of chronic otitis media.

Significant hearing improvement has also been shown with tympanoplasty procedures in cases of type 1 tympanosclerosis. Mutlu et al. showed improvement of the mean preoperative air-bone gap from 19.5 dB to 9 dB postoperatively in 46 patients with type 1 tympanosclerosis who underwent tympanoplasty [20•]. Stankovic et al. demonstrated in a group of 33 patients that the mean air-bone gap improved from 27.3 dB to 16.8 dB at 3–6 months after surgery and was stable at 5 year follow-up [18]. These studies indicate that modest improvements in hearing are generally obtained following surgical management of type 1 tympanosclerosis.

Type 2 Tympanosclerosis

Type 2 tympanosclerosis is characterized by fixation of the malleus-incus complex, while the stapes remains mobile.

Table 2 Compilation of audiological outcomes of tympanosclerosis surgery*

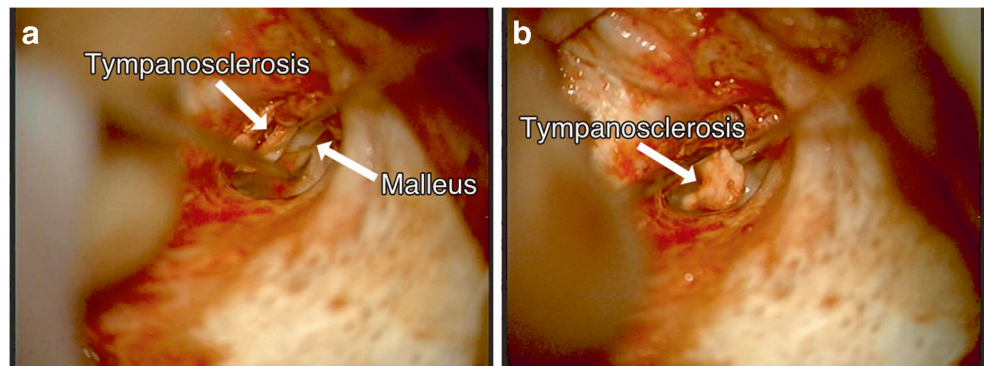
Study (year)	Patients	Preop PTA (dB)	Preop ABG (dB)	Postop PTA (dB)	Postop ABG (dB)	Postop ABG < 20 dB (%)
Gormley 1987 [4]	67	60	37	39	18	58
Austin 1988 [6]	32		33		13	68
Giddings and House 1992 [7]	154		36		16	72
Albu et al. 2000 [8]	90	59.6	35.7	42.6	21.4	52
Teufert and De La Cruz 2002 [9]	203	54.3	30.9	36.8	17.4	64.6
Vincent et al. 2002 [10]	68	62		44		70
Welling et al. 2003 [11]	15	45.2	34.1	33.5	24.9	33.3
Bayazit et al. 2004 [12]	42	50	32	44.3	13	33
Tsuzuki et al. 2006 [13]	29	57.9		46.3		65.5
Yetiser et al. 2007 [14]	30	59.3	35.3	48.5	29.1	33
Magliulo et al. 2007 [15]	10					70
Celik et al. 2008 [16]	25	63.3	39.7	44	20.4	48
Kizilkaya et al. 2008 [17]	51	Type 1/2: 45.6 Type 3/4: 44	Type 1/2: 34.1 Type 3/4: 35.3	Type 1/2: 34.5 Type 3/4: 33.2	Type 1/2: 23.1 Type 3/4: 24.5	Type 1/2: 50 Type 3/4: 45.2
Stankovic et al. 2009 [18]	117		Type 1: 27.3 Type 2: 28.9 Type 3/4: 37.5		Type 1: 16.8 Type 2: 17.2 Type 3/4: 22.9	Type 1: 66.7 Type 2: 47 Type 3/4: 50
Ho et al. 2010 [5]	84	57.5		47.3		Type 1/2: 55.6 Type 3/4: 42.9
Aslan et al. 2010 [19]	37		37.8			Type 1: 72.7 Type 2: 20 Type 3: 0 Type 4: 6.3
Mutlu et al. 2015 [20•]	151	Type 1: 36.5 Type 2: 44 Type 3: 49 Type 4: 49	Type 1: 19.5 Type 2: 30 Type 3: 30.5 Type 4: 30	Type 1: 20 Type 2: 30 Type 3: 40 Type 4: 38	Type 1: 9 Type 2: 15 Type 3: 23 Type 4: 21	Type 1: 82 Type 2: 70 Type 3: 50 Type 4: 54
Sakalli et al. 2015 [21]	30	Type 1/2: 48	Type 1/2: 39	Type 1/2: 24.9	Type 1/2: 16.1	Type 1/2: 80
Zaugg and Linder 2015 [22]	23		Type 3/4: 36.3		Type 3/4: 19.6	Type 3/4: 61
Kikkawa et al. 2015 [23]	12	Type 3/4: 68.8	Type 3/4: 38.7	Type 3/4: 42.8	Type 3/4: 15.2	Type 3/4: 50 (< 5 dB)
Sennaroglu et al. 2015 [24•]	5	Type 2: 55	Type 2: 42.8	Type 2: 18	Type 2: 6	Type 2: 100
Bedri et al. 2018 [25•]	67		Type 3/4: 43		Type 3/4: 24	Type 3/4: 37

*Outcomes by tympanosclerosis type shown for recent studies where available

Surgical management in these cases can consist of either removal of tympanosclerotic plaques and mobilization of the malleus and incus or ossicular reconstruction that bypasses the lateral ossicular chain by placing partial ossicular

reconstruction prosthesis (PORP) or autologous graft on the mobile stapes suprastructure. In a series of 30 patients with malleus fixation secondary to tympanosclerosis, Sakalli et al. demonstrated that removal of plaques via drilling and creating

Fig. 1 Removal of tympanosclerosis involving the tympanic membrane and malleus. Tympanosclerosis underneath the tympanic membrane extending to the malleus is shown in (A). The tympanosclerotic plaque is freed from the tympanic membrane and malleus in (B). Arrows with labeling denote key structures



a 2 mm space surrounding the ossicles in the epitympanum yielded excellent results [21]. They saw an improvement in the mean air conduction pure-tone average from 48 dB to 25 dB with an average follow-up of 32 months. Although drilling on or near the ossicles poses a risk of sensorineural hearing loss, they did not see any variance between pre- and postoperative bone conduction threshold levels. In a similar study, Seidman et al. performed release of malleus fixation using a combination of laser and drilling in 20 patients and reported improvement in mean air-bone gap levels from 33 dB preoperatively to 13 dB postoperatively that was stable over 1–7 years of follow-up [27]. One patient experienced a high-frequency sensorineural loss of 20 dB likely due to drill contact with the ossicles. Silastic sheeting was placed in the epitympanum to reduce the chance of re-fixation, which was not observed in this study. Both authors mention that fixation may be present in the suspensory ligaments of the malleus, and these must be closely evaluated during surgery.

A surgical alternative to malleus-incus release is separating the incudostapedial joint and bypassing the lateral ossicular chain using an incus interposition graft or PORP. An example of removal of tympanosclerotic plaques fixing the malleus-incus complex in the attic is shown in Figs. 2A and B. This was accomplished by delivering the plaques through the antrum (Fig. 2A) as well as dissection via a transcanal atticotomy (Fig. 2B), and a PORP was later placed. This approach would seem to have a decreased risk of re-fixation; however, it carries with it a risk of prosthesis extrusion. Albu et al. compared their results in 10 patients with type 2 tympanosclerosis who underwent ossicular mobilization to 15 patients who underwent a PORP or interposition procedure and found a trend toward improved hearing with mobilization that did not reach statistical significance (postoperative mean air-bone gap of 15.2 dB vs. 20.8 dB, respectively) [8]. Using an incus interposition bypass technique, Stankovic et al. showed improvement in the mean air-bone gap from 28.9 dB to 17.2 dB that was stable in long-term follow-up [18].

Sennaroglu et al. report an interesting method in which they address lateral chain fixation by separating the incudostapedial joint, removing the incus, and placing bone cement between the

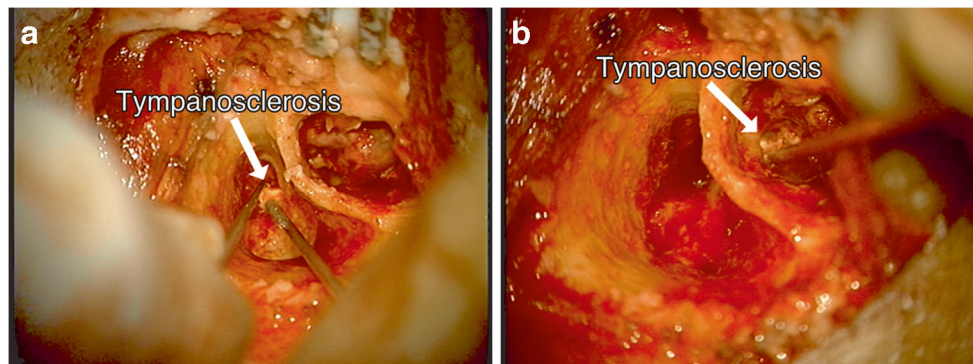
manubrium of the malleus and stapes capitulum [24•]. Using this technique in a series of 5 patients, they observed an improvement in the mean air conduction pure-tone average from 55 dB to 18 dB and improvement in the mean air-bone gap from 42.3 dB to 6 dB over a mean follow-up period of 22 months. They postulate that this technique provides more stability and lower risk of extrusion than using traditional prostheses [24•]. That being said, extrusion rates with titanium prostheses remain low and are generally reported to occur in <3% of cases if cartilage is used between the head of the prosthesis and the tympanic membrane. Perhaps the presence of a tympanosclerotic plaque in the posterior-superior tympanic membrane obviates the need for additional cartilage between the plaque and prosthesis, although this has not been well studied and extrusion rates in this setting remain unclear.

Taken together, it seems that satisfactory results are possible using either malleus-incus mobilization or PORP/interposition procedures, with rates comparable to those reported in chronic ear literature in general. The risk of re-fixation with mobilization of the malleus and incus remains a concern and may be decreased by creating an adequate space surrounding the ossicles in the epitympanum. Longer-term data on re-fixation of the lateral chain with the mobilization approach are needed.

Type 3 and 4 Tympanosclerosis

The management of a fixed stapes secondary to tympanosclerosis remains a highly contentious topic. There are multiple factors that must be considered, including the chance of meaningful hearing improvement with surgery compared to amplification, durability of that improvement, and the risks of sensorineural hearing loss. Further, there are situations in which the tympanosclerotic plaque is adherent to the adjacent facial nerve; manipulation of the plaque to address stapes fixation in this particular scenario could place the facial nerve at risk. If operative management is undertaken, the surgeon must again decide whether to remove the tympanosclerotic plaques in order to mobilize the stapes or instead perform stapedotomy/stapedectomy. The status of the lateral chain is critical in this decision-making process. Given the

Fig. 2 Removal of tympanosclerosis fixing the malleus-incus complex in the epitympanum. Dissection of a tympanosclerotic plaque in the epitympanum via the antrum is shown in (A). Dissection of the remaining plaque via a transcanal atticotomy is shown in (B). Arrows with labeling denote key structures



complexity of these decisions and the difficulty of reconstruction, particularly in situations in which stapedotomy/stapedectomy is performed and the lateral chain is absent, many surgeons elect to manage tympanosclerotic stapes fixation non-operatively. However, published reports have described good outcomes and low complication rates with a variety of surgical techniques. Below we will highlight studies that address some of these salient questions.

Stapes Release/Mobilization

Tympanosclerosis types 3 and 4 are characterized by a fixed stapes. In contrast to otosclerosis, the stapes is often mechanically fixed by large, bulky plaques surrounding the oval window. One method of surgical management is to carefully remove these plaques with sharp or laser dissection, thereby mobilizing the stapes. An example of removal of tympanosclerotic plaque fixing the stapes is shown in Fig. 3A and B. If the remaining ossicles are absent or cannot be mobilized, a prosthesis can then be placed. The primary concerns with this technique are refixation following surgery, sensorineural hearing loss due to hydraulic forces transmitted to the inner ear, and facial nerve injury. Advantages of this technique are that it can be accomplished in a single stage, the vestibule is not surgically opened, and concurrent repair of tympanic membrane perforation. In a recent study, Bedri et al. demonstrated that their stapes release technique improved the mean air-bone gap by 18 dB in 67 subjects with a follow-up period of 3–23 months [25]. In 97% of cases, an ossiculoplasty with interposition graft was also performed for lateral chain fixation. They reported no cases of sensorineural hearing loss but did identify two cases of transient postoperative facial paralysis. They felt this was due to removal of tympanosclerotic plaques from the facial nerve canal, and after omitting this portion of their technique, they saw no further cases of facial weakness. Ho et al. performed stapes mobilization on 31 patients with tympanosclerosis types 3 and 4, with interposition grafts placed in 48.4% and stapes mobilization alone in the setting of a mobile lateral chain in 51.6% [5]. They reported a postoperative air-bone gap < 15 dB in 42.9% of

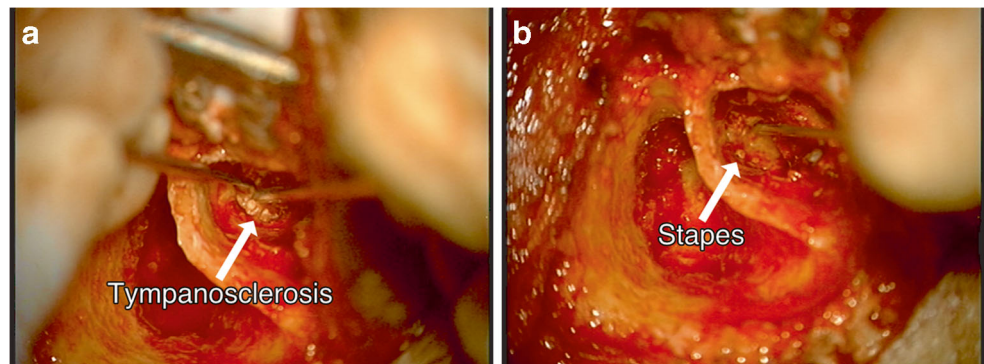
patients and observed no cases of sensorineural hearing loss. These reports indicate that some hearing improvements can be achieved via this technique, although the follow-up periods are not sufficient to address the question of refixation and the magnitude of hearing improvement can be variable.

Stapedectomy

The alternative surgical strategy to mobilization is stapedotomy or stapedectomy. However, as one would expect, the primary risk of this technique is sensorineural hearing loss due to opening the inner ear. Further, the status of the lateral chain greatly impacts the surgical approach. For cases in which the lateral ossicular chain is present and mobile, surgery is performed very similarly to routine surgery for otosclerosis and a prosthesis that spans from vestibule to incus is placed. In contrast, if the lateral chain is absent or needs to be removed secondary to fixation, stapedotomy/stapedectomy then requires placement of a prosthesis from the open vestibule to either the malleus handle or posterosuperior tympanic membrane. In either scenario, as with surgery for otosclerosis, the vast majority of authors recommend a staged approach to stapedectomy if a tympanic membrane perforation is present. In the initial procedure, any tympanic membrane perforations are repaired, and cholesteatoma or chronic ear disease are removed. Stapedectomy is only considered after a period of 6–12 months in which the ear remains stable, dry, and aerated.

In a recent report, Zaugg and Linder described a series of 23 patients who underwent stapedotomy in the setting of tympanosclerosis, with 73.9% of patients undergoing malleostapedotomy with a titanium piston prosthesis [22]. A mean air conduction pure-tone average gain of 20.8 dB was observed with a mean follow-up of 2 months, and a mean preoperative air-bone gap of 33.8 dB improved to 17.5 dB postoperatively. A long-term follow-up period of 43 months was available for 65% of patients, and no hearing deterioration was observed, and 73% of patients had an air-bone gap < 20 dB. There was a sensorineural loss of more than 5 dB in one patient. Notably, the authors remarked that their data

Fig. 3 Removal of tympanosclerosis encasing the stapes. Tympanosclerosis surrounding and fixing the stapes is shown in (A). Complete excision of the plaque is shown in (B) with subsequent mobilization of the stapes. Arrows with labeling denote key structures



indicated that outcomes for stapedotomy in tympanosclerosis were poorer than those observed for otosclerosis. Similarly, Kikkawa et al. reported on a series of 12 patients with well-pneumatized middle ears following staged procedures who underwent stapedectomy using cartilage graft (41.7%), incus interposition (25%), teflon piston (16.7%), or total ossicular replacement prosthesis (TORP) (16.7%) [23]. They observed improvement in the mean air conduction threshold of 65.7 dB to 42.8 dB at 6 months follow-up with a mean postoperative air-bone gap of 15.2 dB, and gains were stable at follow-up of at least 1 year. Celik et al. described another study that reported on long-term stability of stapedectomy in tympanosclerosis [16]. They described a group of 25 patients, 17 of which had reconstruction with a TORP with a mean postoperative air-bone gap of 24.4 dB. The remaining patients had reconstructions with a piston or incus interposition and had a mean postoperative air-bone gap of 18.5 dB. Out of this original group, seven had a follow-up period of at least 10 years over which their postoperative hearing improvements were stable.

Two studies have described in detail the malleostapedotomy approach for tympanosclerosis [10, 15, 28]. Magliulo et al. described a series of 10 patients in which malleostapedotomy was performed [15]. In this technique, the incus and head of malleus were removed, and the prosthesis was hooked onto the mobile handle of the malleus. Notably, they advocated for removal of the anterior malleolar ligament, as subsequent calcification of this structure could cause re-fixation of the malleus handle. They reported closure of the air-bone gap < 20 dB in 80% of patients with one patient having sensorineural loss > 10 dB and no dead ears. In a similar report, Vincent et al. describe a variation on traditional malleostapedotomy technique in which they reposition the handle of the malleus so that it directly overlies the oval window and is optimally oriented [10, 28]. This is accomplished by excising the malleus head, dividing the tensor tympani tendon, and then stretching the anterior malleolar ligament to pull the handle of the malleus posteriorly while the superior malleolar ligament remains the primary structural support. They argue that this provides an improved vector for prosthesis placement and allows a TORP to rest directly underneath the malleus handle.

Hybrid Approach

Some groups advocate for a hybrid approach in management of a stapes fixed by tympanosclerosis. Teufert et al. described an approach whereby stapes mobilization is attempted initially, and if this is not successful and a tympanic membrane perforation is present, the perforation is repaired and stapedectomy is performed in a second stage procedure [9]. They recommended a mobilization technique characterized by carefully dissecting the plaques off the stapes rather than rocking the stapes suprastructure, since rocking the stapes can fracture the footplate

and increase the risk of delayed re-fixation. Using this technique, they reported on a subset of 66 patients, 40 of whom underwent mobilization while the remaining 26 underwent stapedectomy. They observed that an air-bone gap < 20 dB was achieved in 62% of patients, and this was stable in the group of 40 patients for which long-term follow-up was available. While they saw slightly better results with mobilization, the results were not statistically significant. In their larger group of 203 cases with all types of tympanosclerosis including stapes fixation, they performed ossiculoplasty using a PORP in 63% of patients and a TORP in the remaining 47%. They saw prosthesis extrusion in 4.4%, and no dead ears in the group undergoing stapes surgery.

Stapes Surgery for Pediatric Tympanosclerosis

Stapedectomy in the pediatric population is a controversial topic and even more so when it occurs in the setting of tympanosclerosis. While most literature focuses on adult populations, some studies have reported outcomes of stapedectomy in children with tympanosclerosis. In an excellent study, Welling et al. described their series of 66 pediatric ears undergoing either primary or revision stapedectomy or mobilization with a mean age of 9.4 years [11]. They compared children with tympanosclerotic fixation to those with otosclerosis or congenital stapes fixation and found that tympanosclerosis was associated with poorer hearing outcomes following stapedectomy. The mean postoperative air-bone gap among the 15 ears with tympanosclerosis was 24.9 dB compared to 13.1 dB in otosclerosis and 15.7 dB in congenital stapes fixation. A variety of prostheses and reconstruction techniques were employed in these groups, and no significant associations between prosthesis type and postoperative hearing outcomes were reported. In a similar study, Kizilkaya et al. reported on a group of 31 children who underwent stapes mobilization or stapedotomy with a teflon piston prosthesis and observed a mean postoperative air-bone gap of 24.5 dB [17]. Children who underwent mobilization or stapedotomy had a postoperative air-bone gap < 20 dB in 47.8% and 37.5% of cases, respectively. Taken together, these reports suggest that stapes surgery in children with tympanosclerosis yields poorer results than seen for other types of stapes fixation. In addition, outcomes also appear to be worse compared to many adult studies reported in the literature.

Round Window Vibroplasty in Tympanosclerosis

Active middle ear implants have been shown to improve hearing in cases of sensorineural, conductive, and mixed losses [29], and there have been several reports of their use in the

setting of tympanosclerosis. This approach has the advantage of bypassing all fixed ossicles as well as a stapes footplate or oval window obliterated with tympanosclerotic plaque. The inherent risk with this procedure is causing a perilymphatic fistula and/or hearing loss by removing plaques in the round window region. Iwasaki et al. describe a single patient with tympanosclerosis immobilizing the stapes and partially obliterating the round window [30]. They performed only a limited drill-out of the round window niche to avoid disruption of the round window membrane and used a coupler that allowed placement of the floating mass transducer into a smaller round window diameter. They reported no loss of hearing following placement and observed improvements in high frequency thresholds as well as increases in word recognition from 5 to 25% compared to conventional amplification. Pau et al. describe a single patient with near complete tympanosclerotic obliteration of the round window [31]. The risk of removing the plaque was deemed too great, and they therefore drilled an anterior-inferior cochleostomy leaving the membranous endosteum intact. The floating mass transducer was placed into the cochleostomy, and the patient experienced significant improvements in hearing thresholds, although no comparison was made to conventional amplification. These reports demonstrate a potential route to hearing restoration in cases of tympanosclerotic obliteration of the oval and round windows, but data is very limited and further research is required to determine the efficacy of vibroplasty in tympanosclerosis.

Conclusions

The management of tympanosclerosis continues to generate significant discussion and disagreement among otologic surgeons. As in all surgical procedures, the decision of whether or not to pursue surgery for tympanosclerotic disease requires a careful analysis of risks and benefits. A key branch point in the decision tree is the fixation status of the stapes. In tympanosclerosis types 1 and 2, the stapes remains mobile. This allows for ossiculoplasty without opening the inner ear. Most studies report good hearing results using a variety of reconstruction techniques in the setting of a mobile stapes, and hearing gains appear to be fairly stable in the long-term. A risk of sensorineural hearing loss remains particularly if the ossicular chain is manipulated with an intact incudostapedial joint, but this risk appears to be low.

In contrast, the stapes is fixed in tympanosclerosis types 3 and 4, and surgical management carries a higher risk of significant hearing loss and facial nerve weakness. In addition, many studies describe hearing improvement results that trend toward being inferior to those obtained in the setting of otosclerosis, especially in the pediatric population. Even so, the literature generally demonstrates satisfactory results with relatively low complications when these cases are performed by

experienced stapes surgeons. When counseling patients, it is important to consider the role of amplification in the decision-making process, since a patient with a significant improvement in air-bone gap may still require a hearing aid in the operative and/or contralateral ear. New advances in round window vibroplasty and bone-anchored hearing aid technology may provide additional avenues of treatment for hearing loss secondary to tympanosclerosis in the future.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

Compliance with Ethical Standards

Conflict of Interest Matthew M. Dedmon and Brendan P. O’Connell declare that they have no conflict of interest.

Alejandro Rivas reports being a consultant for Grace Medical, Stryker, Cook Medical, Cochlear Corp., Advanced Bionics, and Med-el.

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- Of major importance

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