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OSSICULAR CHAIN RECONSTRUCTION (A RIVAS AND N MANZOOR, SECTION EDITORS)

State of the Art: Reconstruction with Synthetic PORP and TORP

John Dornhoffer[1] · David D. Walker[1]

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Abstract

Purpose of Review The purpose of this review article is to present salient pearls of successful ossiculoplasty, with particular attention paid to reconstructive strategies with synthetic partial ossicular prostheses and total ossicular prostheses.

Recent Findings A refined level of dexterity and an appropriate attention to detail are needed to optimize audiometric outcomes in ossiculoplasty, as is a fundamental understanding of middle ear mechanics and the consistent anatomical relationships that exist in the middle ear, but perhaps the most important determinant of long-term hearing outcomes in ossiculoplasty is the middle ear environment.

Summary Successful ossiculoplasty requires a prudent and thoughtful approach to all phases of the patient's care, and the final audiometric result is a synergistic product requiring both careful preoperative assessment, thoughtful prosthesis selection, and proficient technical execution.

Keywords Ossicular reconstruction · Ossiculoplasty · Middle ear · Ossicular prosthesis · PORP · TORP

Introduction

The primary objective of ossicular reconstruction is seemingly straightforward: to maximally couple the stapes footplate to the tympanic membrane. In practice, however, successful ossiculoplasty is both nuanced and complex. While numerous factors influence the final postoperative result, the most important determinant of long-term hearing outcomes is the environment of the middle ear. For many ear surgeons, both experienced and novice, this can be a difficult concept to reconcile. The realization that surgery itself is *not* the most formative variable in ossiculoplasty outcomes is a surprising revelation. With that said, a refined level of dexterity and an appropriate attention to detail are needed to optimize audiometric outcomes. Equally important is a fundamental understanding of middle ear mechanics and the consistent anatomical relationships that exist even in the diseased middle ear. Finally, there is the consideration of the ossicular prosthesis itself. For the contemporary otologist, numerous synthetic partial ossicular prostheses (PORPs) and total ossicular prostheses (TORPs) are available for use. However, despite garnering significant attention within the field, the qualities of the modern prosthesis are of subordinate importance to the aforementioned considerations.

Analyzing each of these variables independently proves to be a useful exercise in illustrating the relative impact of each clinical decision. In practice, however, the final audiometric result is a synergistic product requiring careful preoperative assessment, thoughtful prosthesis selection, and proficient technical execution. In this article, we present the salient pearls of successful ossiculoplasty with particular attention paid to reconstructive strategies with synthetic PORPs and TORPs [1].

This article is part of the Topical Collection on *Ossicular Chain Reconstruction*

✉ John Dornhoffer
dornhofferjohnl@uams.edu

[1] Department of Otolaryngology—Head and Neck Surgery, University of Arkansas for Medical Sciences, 4301 West Markham, #543, Little Rock, AR 72205, USA

Patient Selection

Successful ossicular reconstruction begins with a comprehensive clinical evaluation. This includes a thorough history, physical examination, and audiometric evaluation of both ears. Otoscopic examination of both the diseased and the non-diseased ear serves as the cornerstone of the physical exam. Binocular otomicroscopy with pneumatic insufflation, following careful removal of debris, provides a wealth of information. If an active otologic infection is noted, aggressive medical treatment should be undertaken prior to surgery, including aural toilet and ototopical agent application. The information obtained on otoscopic examination should be correlated with the results of the audiogram, including the Weber and Rinne tuning fork tests, especially when a masking dilemma is present. If the audiogram and tuning fork exam do not agree, surgery should not be performed until this discrepancy is reconciled.

Preoperative pure tone audiometry can be helpful in suggesting underlying middle ear pathology. Generally, a perforation will cause a conductive hearing loss between 5 and 40 dB depending on its characteristics [2]. When the tympanic membrane is intact, a conductive hearing loss greater than 35–40 dB strongly suggests the possibility of ossicular chain dysfunction. Furthermore, the pattern of hearing loss may be suggestive of certain scenarios. For example, fixation of the lateral ossicular chain generally causes a prominent low-tone conductive hearing loss having an air-bone gap (ABG) that partially closes in the middle and high frequencies. Meanwhile, fluid or granulation tissue may result in mass-loading of the ossicular chain, resulting in preserved low-frequency thresholds but with an ABG in the high frequencies [3].

As has been previously referenced, the most important prognostic factor in determining the ultimate reconstructive outcome is the functionality of the Eustachian tube. When functioning optimally, the Eustachian tube provides protection, clearance, and ventilation of the middle ear. Inability to perform even one of these functions will significantly impact surgical outcomes. Unfortunately, there is no consensus on the optimal way to reliably assess its function preoperatively. Various clinical tests are available although each has its limitations. Auto-inflation using the Valsalva or Toynbee maneuver is helpful, but both are non-physiologic tests of tubal patency. The clinical status of the contralateral ear can also provide insight into tubal maturity and function in the diseased ear [4]. As part of the Eustachian tube evaluation, anterior rhinoscopy should also be performed so that allergy, adenoiditis, and rhinosinusitis can be treated in an effort to promote optimized tubal function.

Once the preoperative evaluation is complete, a few general rules should be applied to surgical candidacy. First, one should avoid elective surgery on an only-hearing ear as much as is reasonably possible. Second, when bilateral disease is present, surgery should be undertaken on the worse-hearing ear in the absence of any other compelling reason to do otherwise on account of underlying disease. Finally, special consideration should be given to the timing of surgery in the pediatric patient.

Contemporary Synthetic Prostheses

Materials

A number of different synthetic materials have been employed as ossicular prostheses, including porous high-density polyethylene, plastics, bioactive glass, stainless steel, gold, titanium, and hydroxylapatite (HA). The latter two are the current most commonly used materials in the USA and Europe. Promising short-term results continue to be published for most of these materials [5], but the long-term histological fate is uncertain in many instances. With regard to the two most commonly used materials, HA and titanium, each has advantages and disadvantages. HA is produced by molding, resulting in smooth edges and grooves that have benefit when placed against the tympanic membrane and notched under the malleus, compared with the sharp stamped edges of titanium. Titanium, however, is lighter and more malleable, which allows changing the angle of the prosthesis to facilitate coupling with the conical shape of the drum and to create a cradle for secure fit to the stapes. Composite prostheses have since been created in an attempt to harness the best features of each material. In fact, numerous prostheses now exist employing an HA head mounted on an adjustable titanium shaft. Despite the considerable amount of energy spent discussing the merits of material, it is important to note that there seems to be no clear acoustic advantage of one over the other. Instead, results seem to be dictated more by the technique used and experience of the surgeon [6].

Prosthesis Design

Much has been discussed with regard to prosthesis design, including ideal weight, length, and general shape. However, most studies are performed with laser vibrometry in non-diseased cadaver bones, and whether or not these results can be extrapolated to the diseased ear is yet to be appreciated. The ideal weight of the prosthesis has been examined by a number of investigators. Some researchers suggest that a lighter prosthesis in the range of 3–4 mg functions more effectively [7] whereas others have suggested a weight between 10 and 35 mg to yield the best acoustic response with the vibrometer [8]. In the latter study, prostheses above this weight would cause low-frequency displacements to fall out of acceptable ranges, and prostheses below this weight would lead to high-frequency losses. Interestingly, the human incus normally weighs 30–40 mg. Realistically, prosthesis weight is probably not of critical importance in the diseased middle ear as long as it falls within these acceptable ranges. Cartilage is usually placed on top of the prosthesis head to prevent extrusion in most cases, and the added weight to the reconstruction appears to have no detrimental effect on the hearing result regardless of which material is used.

There is a myriad of prosthesis shapes available and an equal number of surgeons advocating one over the other. Suffice it to say that the goal of ossiculoplasty is to provide a reconstruction with immediate stability and long-term durability. It should comply with as many of the gain–benefit principles of ossicular acoustic mechanics as is practical. As such, the more stable the initial reconstruction, the higher likelihood of a good long-term outcome. Most synthetic prostheses are divided into PORPs, to be used with an absent incus but present stapes superstructure, and TORPs, which are used when both the incus and stapes superstructure are absent or in poor anatomical position. The former usually consists of a head to make contact with the tympanic membrane and/or malleus and a shaft or cradle to facilitate the stapes capitulum and superstructure. These can be further subdivided into designs that are intended to directly impact the undersurface of the drumhead and those that are intended to engage the manubrium of the malleus.

Most ossicular prosthesis designs are inherently unstable in that they are top-heavy and will tend to tip unless adequately supported by the reconstruction technique. This effect can be negated somewhat with a design that uses a lightweight material, such as titanium, or a head design that shifts the center of gravity over the shaft, as with some molded HA designs. Short-term stability is likewise facilitated by effective two-point (preferably bony) fixation. Thus, any design that incorporates the malleus should offer improved stability in that the prosthesis may be "locked" into place between the malleus manubrium and stapes. Furthermore, recent basic science research using infrared laser vibrometry as well as retrospective clinical studies on ossiculoplasty suggests that incorporating the malleus in the reconstruction provides increased acoustic gain [9].

Surgical Technique

General Principles

While it is generally possible to ascertain the need for ossiculoplasty during the preoperative evaluation, one should be prepared for this contingency in every middle ear case. In addition, it should be considered routine practice to inspect the ossicular chain visually and mechanically every time the middle ear is entered. This can be performed with gentle palpation of the malleus, taking note of concomitant movement of the stapes and visualization of the round window reflex (movement of the membrane and fluid in the niche with palpation of the chain). Specific technical considerations can best be illustrated by addressing specific situations encountered in chronic middle ear surgery. The prostheses used in the examples to follow are a combination of HA and titanium of the senior author's design, but the surgical technique and anatomical relationships extrapolate to many other synthetic PORPs and TORPs being used today.

Incus Erosion

Due to its location relative to the common pathways of development of cholesteatoma and tympanic membrane atelectasis as well as its rather tenuous blood supply suspended between the stapes and malleus, erosion of the incus long process is the most common ossicular defect. It can be encountered in roughly one-third of cases involving a chronic posterior tympanic membrane perforation due to a variety of factors, such as pressure necrosis, inflammation, and hydrolytic enzymes produced by cholesteatoma matrix.

While an eroded incus is usually obvious during middle ear exploration, in some cases, palpation is required to uncover the presence of a more subtle fibrous union between the stapes and incus. The key factor in this situation is the degree of bony contact remaining, which, if present to some reasonable degree, may compel the surgeon to leave the incus untouched. However, if contact is deficient and movement with palpation is incomplete, reconstruction is recommended.

There are basically two options for reconstruction when incus erosion is present. The first involves an attempt to reconstruct the incudostapedial joint with a type II tympanoplasty. All of the type II reconstructive techniques share many of the same theoretical advantages and disadvantages. On the positive side, they reestablish the natural malleoincudal lever with minimal disruption of the normal anatomical relationships and native ossicular connections. The primary disadvantages relate to uncertain long-term durability as little is known about the pathophysiology and natural history of incus necrosis. If erosion is related to avascular necrosis, one may speculate that the remnant of the lenticular process, if used in ossicular reconstruction, may be subject to future loss. Given the relatively small acoustic gain afforded by the preservation of the malleoincudal lever, type II reconstruction of the diseased middle ear (2–3 dB) might not be worth the risk of possible revision.

The most commonly used reconstructive option for incus necrosis involves removal of the incus remnant and reconstruction between the stapes and malleus (or tympanic membrane), generally as a type III minor columella mechanism. The fundamental anatomic principles governing this reconstruction are the same regardless of the graft or prostheses used. Some key relationships include the vertical height from the stapes capitulum to the plane of the neck of the malleus at the attachment of the tensor tympani tendon (2–2.5 mm) and the horizontal or translational distance from the capitulum to this same point (3–3.5 mm) (see Fig. 1). Although the malleus manubrium can become rotated medially as an effect of middle ear disease processes, especially along its distal aspect, the malleus neck is typically spared from major rotational

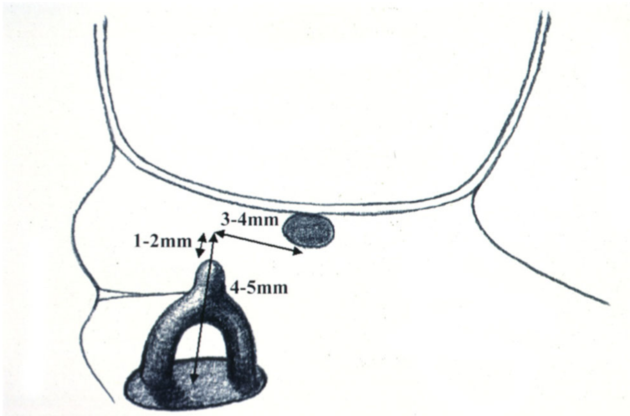

Fig. 1 Measurements in the ear

variation due to its anchoring attachments. This is due to the fact that the axis of malleus medial rotation lies at the attachment of the fan-shaped anterior malleolar ligament to the anterior tympanic spine as well as the underlying tensor tympani tendon, which anchors the malleus to the cochleariform process. This means the neck of the malleus can be used as a consistent prosthesis target in ossicular reconstruction. In the rare instance where the neck of the malleus is pathologically displaced to an extreme degree, it may be necessary to translate it.

If the incus is deemed unusable or if the time and work involved with autograft preparation are not embraced, most surgeons opt for the use of a synthetic PORP. The recommended surgical technique utilizing a PORP as a minor columella is based on the principle that the vertical height to the malleus should be 2–2.5 mm and the horizontal reach should be 3–3.5 mm. While many commercially prepared prostheses are produced with a wide range of lengths or are adjustable, if reconstruction is made to the malleus neck, adjustments are not often necessary. It has been the senior author's experience that similar consistency in measurements to what is encountered in stapes surgery is seen in incus replacement if the proper site at the malleus neck is utilized and the ligamentous malleus attachments have not been severely disrupted. Although it is sensible to confirm by measuring, a prosthesis with a vertical height of 2–2.5 mm and a horizontal reach of 3 mm can be used in the vast majority of cases as long as it is designed to engage the malleus handle and there is no stapes capitulum erosion or exaggerated inferior rotation onto the promontory (see Fig. 2 and Fig. 3). It is also the authors' opinion that improper prosthesis sizing and failed reconstruction are much more likely if the surgeon attempts to measure the distance from the stapes capitulum to the estimated undersurface of the posterior–superior drumhead as opposed to utilizing the relatively consistent relationship between the stapes and malleus that is outlined above.

Another important point to consider when using a PORP is that many of them have broad heads that make contact with the tympanic membrane in addition to the malleus (in contrast to the "strut-like" structure of a sculpted incus autograft that spares tympanic membrane contact). Since the tympanic membrane is a conical structure and not a flat disk, it is desirable to use a prosthesis that can be bent approximately 30 degrees at the junction of the shaft and head to facilitate this shape. Doing so will encourage the superior edge of the prosthesis head under the malleus neck to become "locked" by the acute angle defined by the attachment of the tensor tympani tendon. In the end, the goal is to create a freestanding reconstruction that fixes to the tympanic membrane and stapes head, but not to other structures, such as the tympanic ring or cochlear promontory. A limited amount of absorbable packing can be used to achieve this end, but it should be noted that its use has been implicated with postoperative middle ear fibrosis, especially when denuded mucosa is present.

To combat synthetic prosthesis extrusion, a cartilage graft cap is recommended at the interface between the tympanic membrane and the adjacent prosthesis head. Although it has been suggested that this barrier may be optional with a prosthesis that features an HA head with smooth edges, cartilage is essential with sharper titanium prosthesis heads. As opposed to host incompatibility and lateral prosthesis migration

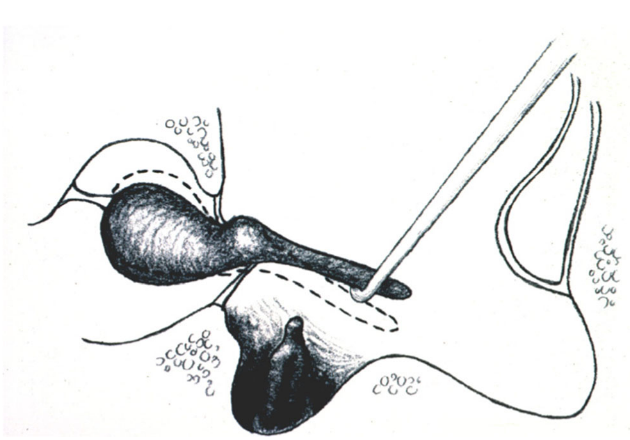

Fig. 2 Lateralizing the malleus

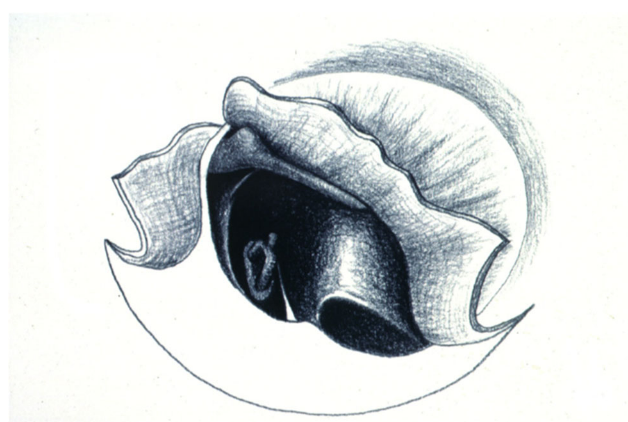

Fig. 3 Relationship of malleus to stapes

beyond the tympanic membrane, the pathophysiology of prosthesis extrusion with an appropriate-length prosthesis more often seems to involve postoperative medial retraction of the tympanic membrane around the prosthesis. Cartilage can be placed in conjunction with the reconstruction of the posterior half of the tympanic membrane in order to prevent retractions or cholesteatoma formation.

Incus and Stapes Absent

When both the incus and stapes superstructure are absent, common options for reconstruction include a type III major columella mechanism or a type IV tympanoplasty, the latter being suitable only in certain advanced cases of chronic ear disease involving a canal wall–down mastoidectomy. A synthetic TORP is typically what is used as a major columella. The same basic principles of reconstruction and recognition of anatomical consistencies discussed with the use of a PORP apply to a TORP. To account for the absence of the stapes superstructure, an additional 2–2.5 mm is added to the vertical height recommendation. Thus, the desired TORP dimensions will be approximately 4.5 mm in height, with 3 mm of reach in order to reconstruct the malleus neck while maintaining the shaft oriented 90 degrees to the footplate.

One of the real challenges in this type of reconstruction relates to the lack of stability at the level of the footplate. Although the presence of the stapes superstructure offers no mechanism for acoustic gain, it does provide a convenient point for stable prosthesis fixation. The literature often shows superior hearing outcomes with a PORP versus a TORP, which is likely due to this difference in stability as opposed to acoustic advantage imparted by the presence of the superstructure. The same 30-degree angled interface with the neck of the malleus and tympanic membrane is utilized for lateral stability, as described earlier. However, this alone does not ensure a stable centered footplate contact point because the forces exerted by the tympanic membrane and malleus onto the TORP head encourage the shaft to displace. Several techniques have been introduced to counteract this phenomenon, including the use of footplate-stabilizing "shoes" made of titanium, HA, or cartilage (see Fig. 4). Related techniques that utilize small oval-shaped pieces of cartilage with a central hole have also been described [10].

While it is advisable to utilize the stapes superstructure when present, inferior rotation toward the promontory due to disease or previous surgery can make a minor columella reconstruction unsuitable. In such instances, a PORP or incus interposition may produce rocking of the stapes toward the promontory instead of the desired piston motion. A TORP placed on the footplate superior to the rotated superstructure is a more suitable alternative that tends to rotate the stapes superiorly into a more favorable position [11]. In other rare cases, the superstructure may be deemed at risk of partial fixation if the adjacent middle ear structures are fibrotic or involved with tympanosclerosis, in which case careful removal of the superstructure and placement of a TORP may be desirable [11].

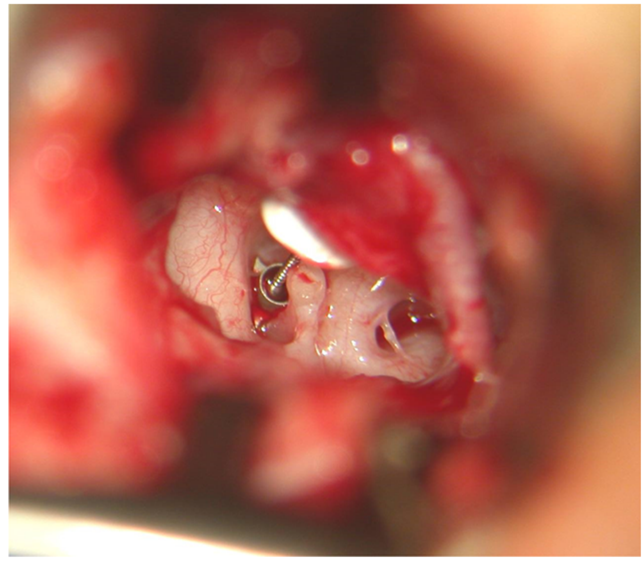

Fig. 4 A titanium footplate-stabilizing shoe

Malleus Absent

The techniques previously described emphasize the use of the malleus for prosthesis stability and as an anatomical landmark for consistent length measurements; however, the malleus manubrium is not always present. Some otologists believe that the malleus is such a tremendous benefit in ossiculoplasty that techniques have been developed to create a "neo-malleus" from a piece of bone or a synthetic implant that is grafted into the tympanic membrane to be used later in staged ossicular reconstruction [12]. Nonetheless, several options do exist for single-stage tympano-ossicular reconstruction in the absence of a malleus manubrium [11].

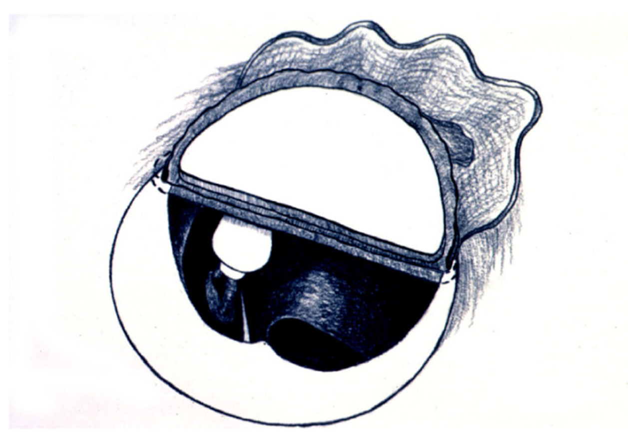

Fig. 5 The cartilage island graft creating a neo-malleus with the anterior island

The simplest of these single-stage techniques is reconstruction directly between the drumhead and stapes superstructure with a type III stapes columella mechanism (especially in a canal wall–down procedure). When a wider gap between the stapes and drumhead is present or when the superstructure is absent, the use of a PORP or TORP that directly contacts the drumhead (with or without the cartilage cap, depending on the prosthesis material used) is generally required. These techniques can be effective, but great care should be exercised in measuring the correct prosthesis length. It is recommended that the reconstructed drumhead be slightly tented by the prosthesis; however, a major reason for prosthesis extrusion, regardless of material, is excessive length. Because these cases involving an absent malleus harbor the potential for graft/prosthesis adherence to the undersurface of the reconstructed tympanic membrane and ossiculoplasty failure due to delayed lateralization of the capitulum or footplate as the reconstructed tympanic membrane heals and matures, many surgeons favor staged ossiculoplasty. One innovative way to accomplish this during the second stage is to perform an ossiculoplasty via the facial recess so that elevation of a tympanomeatal flap is avoided and a stable tympanic membrane measurement is afforded [13].

Finally, an alternative single-stage technique favored by the senior author involves the creation of a "pseudo-malleus" by reconstructing the tympanic membrane with a composite perichondrium–cartilage island graft that forms a creased midline ridge to act in place of the manubrium. This is achieved by creating a circular cartilage island graft measuring 8–9 mm in diameter, with a 1-mm midline strip of cartilage removed from the perichondrium, bisecting the island into two half-circles. The anterior half-circle is inserted as an underlay below the tympanic ring inferiorly and anterior tympanic spine superiorly while supported medially with absorbable packing in the anterior mesotympanum. The posterior half-circle is then lifted to expose the posterior edge of the anterior island, which is placed near the position of the absent malleus handle (see Fig. 5). This pseudo-malleus ridge can then be used for ossicular reconstruction using the same length of prostheses described earlier.

Conclusions

Numerous synthetic prostheses are available to the contemporary otologist. Despite any suggestion otherwise, there are no inherent properties of the prostheses themselves that can overcome an incomplete preoperative assessment or careless surgical technique. On the contrary, successful ossiculoplasty requires a prudent and thoughtful approach to all phases of the patient's care.

Compliance With Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

References

1. Dornhoffer JL. Ossiculoplasty with synthetic PORPS and TORPS. In: Dornhoffer, Gluth, editors. The chronic ear. Stuttgart: Thieme Publishing; 2016.
2. Mehta RP, et al. Determinants of hearing loss in perforations of the tympanic membrane. Otol Neurotol. 2006;27(2):136–43.
3. Vincent R, Lopez A, Sperling NM. Malleus ankylosis: a clinical, audiometric, histologic, and surgical study of 123 cases. Am J Otolaryngol. 1999;20(6):717–25.
4. Collins WO, Telischi FF, Balkany TJ, Buchman CA. Pediatric tympanoplasty: effect of contralateral ear status on outcomes. Arch Otolaryngol Head Neck Surg. 2003;129(6):646–51.
5. Coffey CS, Lee FS, Lambert PR. Titanium versus nontitanium prostheses in ossiculoplasty. Laryngoscope. 2008;118(9):1650–8.
6. Yung MW. Titianium versus nontitanium ossicular prostheses-a randomized controlled study of medium-term outcome. Otol Neurotol. 2010;31(5):752–8.
7. Huttenbrink K. Middle ear mechanics in research and otosurgery. Dresden, Germany: Department of Oto-Rhino-Laryngology, University Hospital Carl Gustav Carus; 1997.
8. Goode R, Nishihara S. Experimental models of Ossiculoplasty. Otolaryngol Clin N Am. 1994;27(14):663–75.
9. Bance M, et al. Comparison of the mechanical performance of ossiculoplasty using a prosthetic malleus-to-stapes head with a tympanic membrane-to-stapes head assembly in a human cadaveric middle ear model. Otol Neurotol. 2004;25(6):903–9.
10. Beutner D, Luers JC, Huttenbrink KB. Cartilage 'shoe': a new technique for stabilisation of titanium total ossicular replacement prosthesis at centre of stapes footplate. J Laryngol Otol. 2008;122(7):682–6.
11. Vincent R, et al. Ossiculoplasty with intact stapes and absent malleus: the silastic banding technique. Otol Neurotol. 2005;26(5):846–52.
12. Black B. Neomalleus ossiculoplasty. Otol Neurotol. 2002;23(5):636–42.
13. Blevins NH. Transfacial recess ossicular reconstruction: technique and early results. Otol Neurotol. 2004;25(3):236–41.