

Ossiculoplasty for Trauma



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KEYWORDS

- Ossicular chain disruption • Temporal bone fracture • Conductive hearing loss
- Incudostapedial joint dislocation • Stapes superstructure fracture

KEY POINTS

- The most common mechanism of traumatic ossicular chain disruption is blunt force injury, though penetrating, barotrauma, and iatrogenic injury contribute as well.
- Types of traumatic ossicular disruption include incudostapedial joint dislocation (most common) followed by incus avulsion, stapes fracture, malleus fracture, and delayed malleus or incus fixation.
- Initial management of traumatic ossicular chain disruption should be conservative for 6 to 12 weeks, unless there are concerning findings or other indications for prompt intervention.
- Ossiculoplasty can be considered for an air–bone gap of 20 dB or greater, provided bone conduction thresholds are better than severe-to-profound levels.

INTRODUCTION

The tympanic membrane (TM) and ossicular chain evolved to overcome the impedance mismatch that sound encounters as it transitions from the atmosphere into the fluid-filled environment of the inner ear. Without these structures, human hearing thresholds would be approximately 60 dB higher.^{1,2} The precise structure and articulation of the ossicles allow sound to traverse the middle ear with almost no attenuation. However, this delicate arrangement makes the ossicular chain highly susceptible to traumatic disruption. Traumatic mechanisms that cause ossicular disruption include blunt force, penetrating injury, barotrauma, or blast exposure. However, the exact pattern of disruption can vary substantially even for a single mechanism, creating a management challenge for the otolaryngologist.

In this article, we will focus on trauma-specific assessment and decision-making for ossicular injury, including mechanisms, injury patterns, diagnostic evaluation, and timing/selection of repair.

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Abbreviations

ABG	air–bone gap
BCDs	bone conduction devices
BPPV	benign paroxysmal positional vertigo
CSF	cerebrospinal fluid
CT	computed tomography
EAC	external auditory canal
PORP	partial ossicular replacement prosthesis
TM	tympenic membrane
TORP	total ossicular replacement prosthesis

MECHANISMS

Blunt force trauma to the head, especially when resulting from temporal bone fracture, is the most common cause of ossicular injury.^{3,4} Longitudinal otic capsule-sparing temporal patterns have a higher risk of ossicular chain disruption, as the force of impact travels in a linear vector along the thinner, superior aspect of the external auditory canal (EAC) into the epitympanum, most commonly causing separation at the IM joint, which lies in line with this trajectory.^{5,6} Blunt force trauma may also cause ossicular disruption in the absence of skull fracture due to rapid changes in acceleration and deceleration, which put significant strain on fragile ossicular ligaments and tendons. The incus is tenuously attached to the malleus and incus buttress. In contrast, the malleus is supported by the anterior and lateral malleolar ligaments, the tensor tympani tendon, and the TM, and the stapes is stabilized by the stapedial tendon and annular ligament.⁴ Consequently, the incudostapedial (IS) and incudomalleolar (IM) joints are the most vulnerable to separation, with IS dislocation being the most common.^{3–5,7,8} These forces can also fracture the ossicles themselves, most commonly at the stapes superstructure's attachment to the stapes footplate.^{3,5} Complete incus dislocation can also compress the facial nerve along its tympanic segment, leading to immediate or delayed facial weakness (**Fig. 1**).⁹

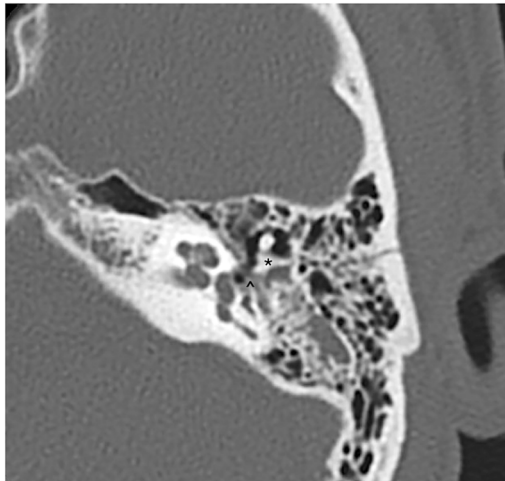


Fig. 1. Incus avulsion compressing facial nerve. CT, axial view, showing a left temporal bone fracture with incus (*) avulsion and compression of the tympanic segment of the facial nerve (^). The patient had a preoperative House-Brackmann score of 4, which improved to 1 postoperatively. Ossiculoplasty was performed with a PORP.

Penetrating injuries to the ossicular chain can result from direct, low-velocity penetration of a foreign body through EAC and TM (eg, ear pick injury), and, less commonly, from high-velocity projectiles crossing through or near the middle ear.^{10–13} As with blunt force trauma, the most common injury pattern is IS joint dislocation. However, patterns of disruption with penetrating trauma are more variable since the malleus manubrium and stapes are also at risk depending on the force and vector of penetration. Further, high-velocity penetrating injuries (eg, gunshot trauma) can cause devastating ossicular chain disruption, and the pattern of injury may vary widely depending on the trajectory of the projectile.¹⁴ Such injuries share features of blunt force and barotrauma, due to kinetic energy transferred through the temporal bone to the ossicular chain. For this reason, ossicular injuries can be far more extensive in the setting of high-velocity penetrating trauma. For example, Shindo and colleagues¹⁵ found that in a sample of 43 patients who suffered gunshot wounds to the temporal bone, 11 had destruction of the entire ossicular chain, while disarticulation of the incus and/or malleus was seen in only 3 patients. Additionally, the force of high-velocity injury can damage the cochlear neuroepithelium, resulting in a severe to profound mixed or sensorineural hearing loss, and facial nerve injury, resulting in paresis or paralysis.¹⁵

Barotrauma results from large-scale changes in ambient fluid pressure, such as with explosions, scuba diving, or sudden compression or decompression of the EAC (eg, water impact, open-hand strikes to the ear, explosions, rapidly removing a finger from the EAC).^{16–18} In most cases of barotrauma, injury is limited to TM perforation.^{19,20} However, when sufficient force is present, the ossicular chain is also susceptible to damage, particularly in the setting of explosions. The rate of concurrent ossicular chain injury alongside blast-related TM perforations requiring repair has been reported as high as 36%, although more recent studies have reported rates around 10% to 14%.^{21–23} Similar to other forms of traumatic injuries, IS joint separation is the most common type of injury resulting from blast injuries. However, malleolar and stapedia fractures, as well as ossicular hypermobility, are also possible depending on the amount of energy transmitted to the middle ear.²⁴

Even when initially unaffected by trauma, the ossicular chain is susceptible to delayed, secondary injury, including bony fixation from adjacent healing fractures, ankylosis of suspensory ligaments and tendons, and erosion from cholesteatoma resulting from traumatic TM perforation.^{15,25,26} While less common, these ossicular pathologies can emerge long after initial trauma, which underscores the importance of careful history taking and imaging review when evaluating a patient with a progressive conductive hearing loss (Fig. 2A, B).

A final traumatic mechanism that deserves mention, while rare, is iatrogenic injury during middle ear or mastoid surgery. Excess force or manipulation applied to an intact ossicular chain during middle ear and/or mastoid surgery can result in hypermobility, IM or IS dislocation, incus subluxation, stapes fracture, and stapes subluxation. A specific consideration is cochlear implantation if hearing preservation is possible, as disruption of the incus can lead to conductive hearing loss, compromising a patient's access to preserved low-frequency sensorineural hearing.

INITIAL HISTORY

Clinicians should have a high degree of suspicion for traumatic ossicular chain disruption in patients who present with conductive hearing loss following head trauma. It is important to collect a mechanism-focused history that also clarifies urgency. The following outline summarizes key aspects of an initial history.

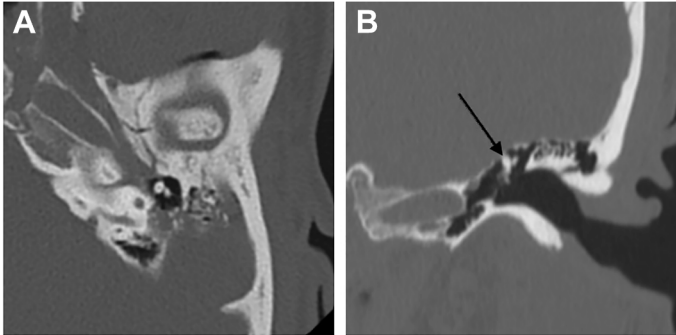


Fig. 2. Progressive ossicular fixation following temporal bone fracture. (A) CT, axial view, showing acute left temporal bone fracture extending into the epitympanic region. (B) Repeat CT, coronal view, 2 years later for progressive conductive hearing loss, showing fixation of the malleus head to the tegmen tympani (arrow).

- **Mechanism:**
 - Blunt trauma, including motor-vehicle collision (seatbelt use, impact against dashboard/window, and loss of consciousness), fall (height, side of impact, and higher suspicion in elderly patients), and direct blow.
 - Penetrating injury (ear instrumentation—higher suspicion in pediatric patients, flying debris, and penetration by brush/foilage),
 - Barotrauma (scuba diving and proximity to blast)
 - Iatrogenic (recent otologic surgery)
- **Hearing loss timing/progression:**
 - Persistent versus improving hearing loss after inciting trauma
 - Late or progressive onset after trauma (suggests secondary fixation or erosion)
 - Prior history of hearing loss
- **Vestibular symptoms:**
 - Vertigo elicited by loud sounds (ie, Tullio phenomenon) suggests a perilymphatic fistula or superior semicircular canal dehiscence, which can also be induced by trauma and itself cause conductive or mixed hearing loss.
 - Brief positional vertigo elicited by changes in head position (trauma is a common cause of loose otoconia and benign paroxysmal positional vertigo [BPPV])
- **Other neurologic symptoms:**
 - Facial weakness (suggests damage to the fallopian canal, but must rule out pre-existing facial nerve pathologies such as Bell's Palsy)
 - Dysgeusia (suggests damage to the chorda tympani or proximal facial nerve)
 - Hyperacusis (suggests damage to the stapedius or proximal facial nerve)
 - Watery otorrhea or rhinorrhea (suggestive of cerebrospinal fluid [CSF] leak)
- **Bleeding or anticoagulation history:**
 - Important to assess in the setting of hemotympanum or when considering operative intervention
- **Prior otologic history:**
 - Prior otologic surgeries, chronic otitis media, eustachian tube dysfunction, and pre-existing hearing loss.
- **Other otologic symptoms**
 - Pulsatile/nonpulsatile tinnitus, otalgia, aural fullness, and autophony

PHYSICAL EXAMINATION

In addition to performing a thorough head and neck examination, it is critical to be able to perform a detailed neurologic examination that includes otoscopy to visualize the ear canal, TM, and middle ear; tuning fork testing to distinguish between sensorineural and conductive hearing loss; facial nerve evaluation; and vestibular evaluation to assess for concomitant vestibular involvement. Initial assessment may be limited, especially in the setting of acute trauma. As such, follow-up history taking and examination are critical for preventing delays in diagnosis and treatment.

External Ear Examination and Otoscopy

Thorough assessment of the external ear and ear canal is best performed with microscopy whenever possible and includes evaluating the mastoid tip for Battle signs, the EAC for obstructing debris, lacerations, displaced fractures, and otorrhea. The TM should be assessed for integrity, position, and mobility. Posterior perforations raise the likelihood of IS joint damage, while flattening of the and hypermobility on pneumotoscopy suggest malleus or IM disruption.²⁷ The middle ear should be assessed for aeration, with hemotympanum or effusion creating a confounding scenario for conductive hearing assessment, and clear pulsatile fluid or otorrhea suggesting possible CSF leak. In the setting of an intact TM, pneumatic otoscopy may also help identify a perilymphatic fistula by inducing positive pressure nystagmus.²⁸

Tuning-Fork Test

Tuning-fork examination is critical for distinguishing between sensorineural and conductive hearing loss in the acute setting and for confirming conductive hearing loss when appropriately timed pure-tone audiometry is performed. A Weber test establishes the presence of asymmetric hearing loss due to conductive or sensorineural loss (ie, conductive loss causes lateralization to the affected side, sensorineural loss causes lateralization to the contralateral side). A subsequent Rinne test distinguishes between conductive and sensorineural loss. Importantly, in the setting of profound sensorineural hearing loss, the Rinne test may be heard in the opposite ear when testing for bone conduction.²⁹ For patients with extensive injury caused by high-energy blunt, blast, or penetrating trauma, this finding should be correlated with imaging for otic capsule involvement and bedside vestibular evaluation showing unilateral hypofunction.

Facial Nerve Assessment

Grading facial nerve function with a validated scoring system (eg, House-Brackmann score) is important for all patients with known or suspected ossicular trauma, especially in the acute setting.³⁰ Assessment may reveal weakness, suggesting concomitant injury to the facial nerve, which can be caused by adjacent injury or by direct impingement by the displaced ossicles along the nerve's tympanic segment. Such a finding would generally be an indication for steroid treatment and may impact the timing of surgical intervention.³¹ Conversely, a well-documented, normal facial nerve examination provides a baseline to assess and manage delayed changes in facial function. Such documentation is critical, as delayed facial weakness, even if severe, typically recovers to normal or near-normal levels without surgical intervention.³²

Vestibular Assessment

The intimate association between the ossicular chain and the inner ear places the vestibular system at risk in all cases of ossicular disruption. The most common

associated vestibular disorder accompanying ossicular disruption is BPPV caused by traumatic dislocation of otoconia from the otolithic membrane covering the saccule and utricle.³³ In cases of inner ear violation, such as footplate subluxation, acute vestibular hypofunction may be seen by examining for gaze-evoked nystagmus.³⁴ Clinicians should have a high index of suspicion for sensorineural hearing loss (SNHL) in such cases, prompting early audiometric testing of bone conduction thresholds and possible treatment with corticosteroids.^{24,35} In the subacute period, chronic hypofunction can be evaluated using a head impulse test, head shake test using Frenzel goggles, or, if available, dedicated vestibular testing.

TESTING

Imaging

First-line imaging for visualization of ossicular injury relies on noncontrast, high-resolution computed tomography (CT) of the temporal bone. In the acute setting, findings may include IS or IM joint widening, incus dislocation, or injury to the stapes superstructure.⁵ Findings that correlate with long-term conductive hearing loss (CHL) include fractures involving the middle ear or scutum, the degree of widening at the IM joint, and the degree of axis deviation between the incus body and head of malleus.³⁶ Other important findings may include otic capsule involvement, a fracture involving the fallopian canal or EAC, and a tegmen fracture with an associated CSF leak. For patients presenting with delayed or progressive hearing loss following injury, additional attention should be paid to areas susceptible to posttraumatic ossicular fixation, especially in the attic, where neo-osteogenesis or fibrosis can immobilize the incus body and head of malleus (see [Fig. 2](#)).

Audiometry

Pure-tone audiometry is a critical component of assessing the nature and degree of hearing loss after middle ear trauma. However, testing in the acute setting is often confounded by ear canal debris or lesions, TM perforation, and middle ear effusion or hemotympanum, which may cause transient conductive hearing loss. Further, neurologic injury may make behavioral testing impossible or unreliable. Tuning fork examination remains a valuable tool in such settings to categorize hearing loss as conductive or sensorineural, but detailed audiometric testing is needed to fully assess for ossicular injuries. At our institution, unless there is an indication for more rapid assessment, we perform audiometry 6 to 12 weeks after the initial injury to allow resolution of confounding factors. Patients with persistent hearing loss are then referred for further otologic evaluation. Additionally, patients with fracture patterns at risk of causing delayed ossicular fixation are monitored at 6 month intervals with audiometric testing and otoscopy.

The degree of conductive loss noted on audiometric testing can vary widely, depending on the extent of ossicular injury. In general, a wide, flat air-bone gap (ABG) of 50 to 60 dB (aka “maximal conductive hearing loss”) suggests complete discontinuity, smaller curvilinear ABGs suggest widening of either the IM or IS joints, and notched ABG closure between 2000 and 3000 Hz suggests ossicular fixation. Bone-line patterns can also provide some additional detail, with upsloping thresholds to 1000 Hz followed by down-sloping thresholds to 3000 Hz, suggesting incomplete discontinuity and overall down-sloping thresholds from 250 to 500 Hz to 3000 Hz, suggesting complete discontinuity.^{37,38}

Assessing overall bone-line thresholds and speech audiometry is also critical, as significant head trauma can cause sensorineural loss that may require amplification

with or without ossiculoplasty or cochlear implantation. Similarly, antecedent SNHL from any cause can impact the success of ossiculoplasty, as studies have shown poor hearing outcomes in patients with severe-to-profound preoperative bone thresholds.^{39,40} Further, injury to the retrocochlear auditory pathway can lead to poor word recognition with preserved bone thresholds. Such findings may suggest a poorer prognosis for rehabilitation.⁴¹

MANAGEMENT

Management of ossicular trauma depends on the extent of injury, as well as other factors that may prompt expedited versus delayed intervention. Limited injuries often resolve with conservative management, whereas complete disruption is typically an indication for surgical intervention. Further, concomitant traumatic injuries or neurologic impairment often take precedence over ossicular reconstruction. Conversely, stable patients with isolated ossicular trauma severe enough to require intervention can proceed with surgery without significant delay. In cases where ossicular injury causes secondary facial nerve paresis via direct compression, prompt surgical intervention is indicated. The following section is summarized in the algorithm depicted in Fig. 3A–F.

Conservative Versus Operative Management

Up to 77% of traumatic conductive hearing loss will fully or partially resolve spontaneously with improvements in ABGs to acceptable ranges.^{42–44} Therefore, in the absence of critical clinical or radiographic findings, such as facial nerve injury, an initial

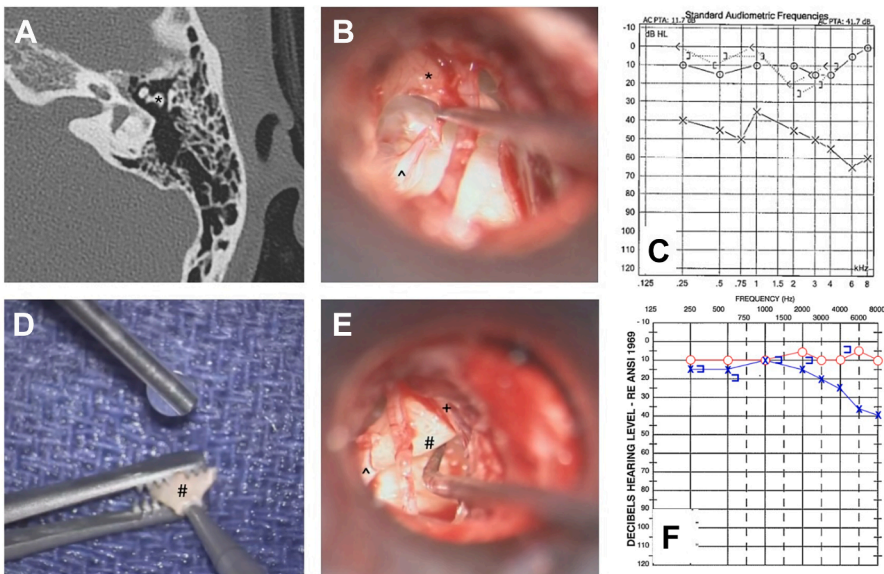


Fig. 3. Stepwise ossiculoplasty for incus avulsion following trauma. Composite series from a case of left temporal bone fracture with persistent conductive hearing loss. (A) CT, axial view, showing incudomalleolar joint separation. (Incus = *). (B) Intraoperative view showing incudostapedial joint separation (Incus = *, Stapes = ^). (C) Preoperative audiogram showing moderate-to-moderately-severe conductive hearing loss. (D) Creation of incus interposition graft (#) using a 1 mm diamond drill. (E) Placement of the interposition graft (#) between stapes (^) and malleus (+). (F) Postoperative audiogram showing closure of the air-bone gap to 10 to 15 dB.

period of observation of 6 to 8 weeks is typically recommended before obtaining audiometry.^{4,45,46} Standard conservative management includes dry-ear precautions, reduced high-impact activity, treatment of EAC lacerations and TM perforation, and avoiding activities that cause significant changes in middle ear pressure (eg, flying, ear clearing, nose blowing, and positive airway pressure treatment).

For patients with known ossicular disruption and a significant, persistent conductive loss after a period of watchful waiting, surgical intervention is reasonable. Updated imaging can help reassess the status of the ossicles. For those with a widened IM and/or IS joint, a transcanal approach with physiologic repositioning of the incus can be effective. This strategy has been described with and without fixation techniques, including soft-tissue support, fibrin adhesive, and bone cement.^{42–44} For cases with complete avulsion of the incus from its stapedial and malleolar attachments, the incus can be removed and replaced with a partial ossicular replacement prosthesis (PORP). Both options re-establish ossicular continuity between the TM and the stapes superstructure, either directly through articulation with the malleus or through both. In cases where the stapes superstructure is compromised, placement of a total ossicular replacement prosthesis (TORP) re-establishes continuity between the TM/malleus and the stapes footplate.

Prostheses come in a wide variety of configurations, with some acting as a linear strut directly connecting the stapes to the malleus manubrium or TM, and others using a hook-and-platform design that connects the stapes to both. While less commonly performed today, repurposing the incus as an interposition graft is also a well-established technique for re-establishing continuity with the stapes superstructure or footplate (Fig. 4).^{47,48} Similar methods have been described using cartilage and cortical bone.^{49,50}

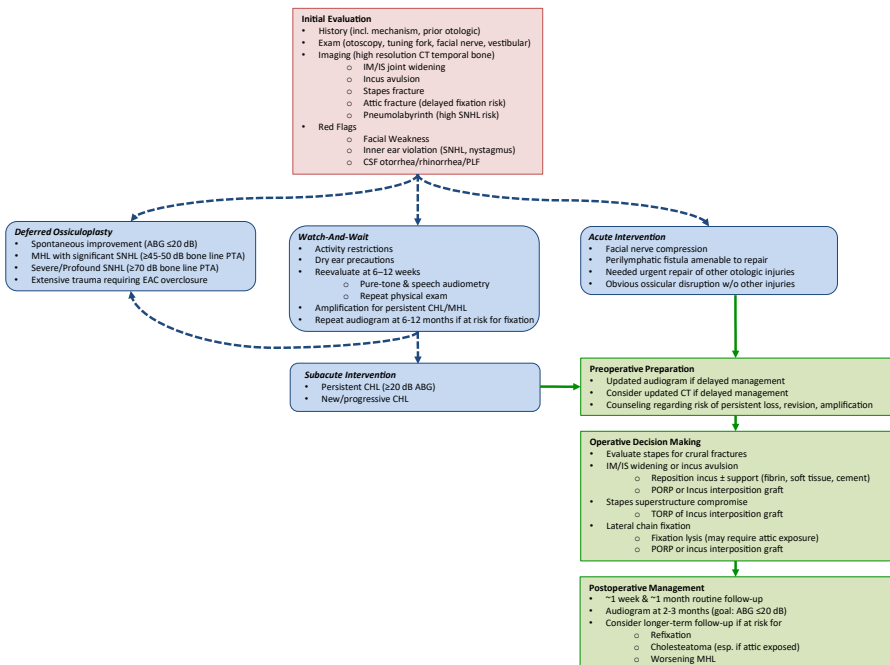


Fig. 4. Algorithm for management of traumatic ossicular chain injury. Flowchart summarizing evaluation, conservative management, and indications for surgical ossiculoplasty.

Before re-establishing lateral chain continuity with any of these techniques, it is critical to evaluate the integrity of the stapes superstructure, as unrecognized, unhealed crural fractures can undermine repair. In such cases, a TORP that articulates with the stapes footplate is preferable. Similarly, in cases where the stapes is suboptimally positioned for secure PORP placement or the middle ear cleft is small, a TORP can be placed through an intact stapes arch with comparable audiologic outcomes.⁵¹

Audiologic Outcomes

Due to the complexity of sound transmission through the native ossicular chain, reconstructive efforts often fail to achieve complete ABG closure.⁵² As such, many studies define successful ossiculoplasty as a reduction of the preoperative ABG to 20 dB or less. Large population-based studies and systematic reviews show that PORPs outperform TORPs (mean postoperative ABGs of 13–22 dB vs 14–30 dB, respectively), while restoration of the native ossicular chain produces the best outcomes (ABG 11–16 dB).^{53–56} Studies comparing ossiculoplasty with autologous versus non-autologous materials generally show comparable outcomes, although some point out that autologous grafts may have subtle, frequency-specific advantages.^{57,58} Regardless of type, optimal graft or prosthesis positioning is critical for maximizing ABG closure, with ideal placement resulting in a movement vector perpendicular to the stapes footplate.⁵² However, grafts and prostheses are tenuously articulated when first placed and are subject to shifting, which can negatively impact hearing outcomes. Factors contributing to postoperative malpositioning include changes in middle ear pressure and significant mechanical forces following surgery. Given the possibility of a persistent ABG after surgery and the risk of prosthesis or graft migration, patients should be appropriately counseled regarding realistic outcomes, including the possible need for supplemental amplification and additional surgery.

Ossiculoplasty in the Setting of Fracture

In addition to causing acute ossicular disruption, temporal bone fracture can lead to delayed ossicular fixation, especially when fractures cross into the middle ear space through the epitympanum. Neo-osteogenic bridges in this region or ossified suspensory ligaments can fixate the incus body or head of malleus, thus immobilizing the ossicular chain.^{4,10,36} One option for managing lateral chain fixation is to remove the incus in its entirety and place an interposition graft or a PORP.⁵⁹ This is effective for treating isolated incus fixation as well as improving access to manage malleus head fixation, which can be done by performing an atticotomy to lyse superiorly based bone bridges or by resecting the head of malleus. This approach is more definitive and less likely to result in refixation, but it compromises the lever function of the ossicular chain and may result in less ABG closure.^{53,54,56,60} Further, separating a fixated lateral chain from the stapes superstructure can put significant stress on a mobile stapes superstructure, unlike during stapedectomy surgery, resulting in crural fracture or even footplate subluxation.⁶¹ As such, separation of the IS joint with lateral chain fixation must be performed with care.

Alternatively, the ossicular chain can be preserved by removing only points of bony fixation, but several factors must be considered with this approach. First, when fixated to surrounding bone, the ossicular chain can transmit acoustic and mechanical energy from the surgical drill directly into the inner ear, thereby increasing the risk of iatrogenic sensorineural hearing loss. Using generous irrigation, diamond burs, low drill speeds, laser ablation, and mechanical curettage may lower this risk.^{62–64} Second, refixation can occur. For this reason, it may be necessary to widen the gap between the ossicles and the surrounding areas of potential neo-osteogenesis, which can be difficult to

achieve with fixation within the tegmen tympani.^{62,65} Lastly, access to epitympanic points of fixation generally requires a wide atticotomy or mastoidectomy with attic exposure through the zygomatic root. While these more extensive approaches may produce superior audiologic outcomes, they inherently entail greater operative risk, including sensorineural hearing loss, facial nerve injury, delayed cholesteatoma formation, and CSF leak.^{64–67}

Ossiculoplasty in the Setting of Severe Ossicular Disruption

As noted, extensive temporal bone fractures from high-energy injury can cause complete disruption of the ossicular chain. The elevated risk for SNHL and other complications in such cases requires balancing the risks and benefits of ossiculoplasty versus other auditory injuries. For example, in cases where injury causes severe to profound SNHL, cochlear implantation may be a more reasonable option. In cases where ossiculoplasty remains an option, severe disruption may limit reconstructive options to TORP placement. However, with extensive disruption of the EAC and skull base, mastoid obliteration and EAC overclosure may be necessary. In such cases, implantable bone conduction devices (BCDs) can be considered. However, the need for future surveillance imaging (eg, diffusion weighted MRI for cholesteatoma) should guide device selection, given the potential for radiographic artifact.⁶⁸

Isolated malleus manubrium fracture presents a final challenging situation. Few ready-made options exist for reconstruction, although several have been described, including primary reconstruction with bone cement and malleus replacement prostheses.^{69,70} The senior author of this article has successfully reconstructed the malleus manubrium in a limited number of cases using the coiled portion of a Grace Medical K-helix prosthesis, “paper clipped” to the neck and head of malleus then coated with a glass ionomer bone cement (Fig. 5A–C).

POSTOPERATIVE REHABILITATION

In most cases, recovery and postoperative management follow a path similar to other ossiculoplasty indications. This includes postoperative evaluation in the first weeks and months following surgery and repeat audiometric testing at 2 to 3 months, when any middle-ear packing has dissolved. For patients with sufficient ABG closure, follow-up may be discontinued, provided there are no other indications for further surveillance. For patients with a persistent, significant ABG, revision surgery can be

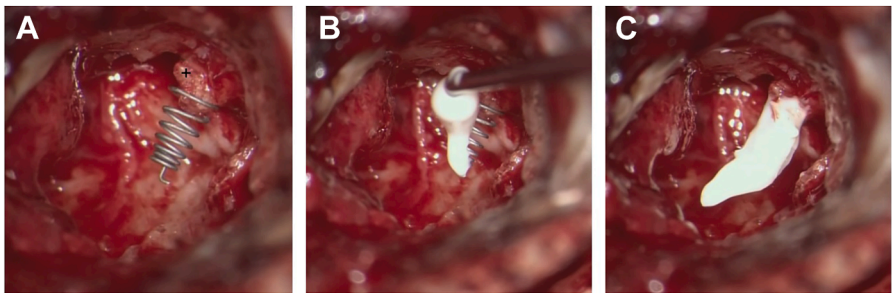


Fig. 5. Malleus manubrium reconstruction using modified Grace K-Helix PORP. (A) The foot clip has been removed, and the coil has been “paper-clipped” around the lateral process of the malleus (+). (B) Application of glass ionomer cement to the coil, which provides a rigid framework for the reconstructed manubrium. (C) Completed reconstruction.

considered. Repeat CT scans can be useful for determining prosthesis positioning. Alternatively, patients may be offered amplification or BCD placement.

SUMMARY

Most traumatic ossicular chain injury results from blunt head trauma associated with temporal bone fracture, though penetrating, barotraumatic, and iatrogenic causes are also encountered. Dislocation of the IS joint is the most common lesion, followed by IM separation and a stapes superstructure fracture. Management depends on the mechanism and severity. In most cases, conductive hearing loss improves spontaneously, and an initial observation period of 6 months with repeat audiometry is appropriate unless there are concerning findings that require prompt intervention (eg, compressive facial paralysis) or findings highly unlikely to resolve without intervention (eg, complete avulsion of the incus).⁴⁵ Persistent ABGs 20 dB or greater to 30 dB warrant surgical exploration and ossiculoplasty once middle-ear conditions stabilize.

High-resolution temporal bone CT aids in localizing disruption and identifying delayed ossicular fixation. Surgical reconstruction with autologous or artificial materials typically achieves postoperative ABGs of 10 to 20 dB. Long-term hearing stability depends on prosthesis position, eustachian tube function, and the integrity of the stapes superstructure. With timely diagnosis and tailored management, most patients regain functional hearing and avoid the long-term sequelae of chronic middle-ear dysfunction. However, additional interventions or alternative rehabilitation may be necessary, including amplification, bone conduction devices, or cochlear implantation.

CLINICS CARE POINTS

- Initial evaluation for possible ossicular injury should include otoscopy, tuning-fork examination, and facial nerve examination. Vestibular examination should be included for patients with evidence of sensorineural hearing loss or balance disturbance.
- Audiometry at 6 to 12 weeks is advisable before considering surgery. Persistent conductive hearing loss with an ABG 20 dB or greater to 30 dB, especially across speech frequencies, is an indication for ossiculoplasty.
- High-resolution CT (≤ 0.6 mm slices) is the preferred imaging modality for assessing ossicular injury and adjacent trauma that may lead to delayed fixation.
- Early surgical exploration may be warranted for facial paralysis resulting from ossicular displacement or findings suggestive of a perilymphatic fistula.
- All patients requiring ossiculoplasty for trauma are at risk of persistent CHL. Restoration of the native ossicular chain is associated with the best postoperative hearing outcomes. Reconstruction with autologous grafts or prostheses is associated with wider postoperative ABGs.
- Postoperative reassessment with pure-tone audiometry at 2 to 3 months should be performed to confirm closure of the ABG to 10 to 20 dB.
- Longer term follow-up is advised for patients at risk for delayed ossicular fixation or cholesteatoma resulting from TM perforation or surgical exposure of the epitympanum.

DECLARATION OF AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this article, the authors used OpenEvidence to assist with literature review and ChatGPT to refine wording and formatting. After using these

tools, the authors reviewed and edited the content as needed, taking full responsibility for the publication's content.

DISCLOSURE

A. Tu has no conflicts to disclose. K.W. Doerfer has served as a consultant for Stryker Corporation and Advanced Bionics.

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