Endoscopic Stapes Surgery

Pearls and Pitfalls

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KEYWORDS

• Endoscopic ear surgery • Surgical techniques • Stapedotomy • Middle ear disease

KEY POINTS

- Although an investment in time is required to master transcanal endoscopic stapes surgery, this approach offers an expanded view of the middle ear, as it allows visualization beyond the shaft of surgical instruments and increased illumination.
- Evidence suggests endoscopic techniques result in similar audiologic outcomes as traditional microscopic stapes surgery.
- Establishing a relatively bloodless field is key. Strategies to optimize intraoperative visibility include instrument and camera choice, anesthetic and hemodynamic considerations, and patient positioning.

Videos on the endoscopic stapes surgery cases described in this article can be found at http://www.ototheclinics.com/.

INTRODUCTION

The first reported stapes surgery is often credited to Johannes Kessel in 1876 and the first stapes mobilization for otosclerosis to Samuel Rosen in 1953.[1] Further advances include the incorporation of the laser in stapedotomy by Rodney Perkins in 1978 and the use of endoscopic approaches.[2] Endoscopic techniques for visualization of the middle ear was initially described in 1967 by Mer and colleagues, and the use of transcanal endoscopic ear surgery (TEES) has since expanded to a wider range of otologic applications including tympanoplasty, excision of cholesteatomas, and other middle ear lesions, as well as ossiculoplasty and stapes surgery.[3–8]

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The main advantages of TEES include increased visibility of the operative field and its minimally invasive approach. Enhanced visibility is especially advantageous in the setting of patients with abnormal middle ear anatomy, whether from prior surgeries, congenital anomalies, or other pathology. Proponents of endoscopic techniques also cite a lower incidence of complications from chorda tympani manipulation and injury.[9–13] Drawbacks include the learning curve, single-handed operative techniques, loss of stereopsis, and the potential risk for thermal injury.[14,15] Specifically during endoscopic stapes surgery, the lack of depth perception can make the maneuvers centered on the stapedial footplate (ie, creation of a fenestra) more challenging, especially in the setting of deep oval window niches.[9]

Outcomes in Endoscopic Stapes Surgery

Literature to date supports endoscopic approaches as safe and effective in the management of stapes fixation[16] (**Table 1**). Surgical success in stapes surgery is often defined as air-bone gap closure to within 10 dB.[17] With TEES, reported rates of air-bone gap (ABG) closure less than or equal to 10 dB range between 56% and 88% of patients,[18,19] with pooled analysis rates ranging between 72% and 77%.[16,20] Furthermore, audiologic outcomes are comparable to the microscopic approach, with recent systematic reviews reporting no significant difference between the two techniques.[11,20,21]

Regarding complications, published data indicate endoscopic stapes surgery has a comparable risk profile as microscopic techniques, with similar rates of tympanic membrane perforation,[21,22] dizziness,[11,21,23–25] and facial nerve dysfunction.[22] Facial nerve injuries are rare, with temporary nerve palsies occurring in 0.95% (N = 3) in a pooled analysis of 314 patients undergoing endoscopic stapes surgery.[16] Of note, 2 of these cases were attributed to local anesthetic. Postoperative sensorineural hearing loss (SNHL) is also rare following stapes surgery. Hall and colleagues performed a pooled analysis of 313 endoscopic stapes cases, identifying 2 patients (0.6%) who developed moderate SNHL (bone conduction pure tone averages of 43- and 46-dB HL) in a single series, but no severe cases or cophosis have been reported.[16]

In contrast, recent systematic reviews have found chorda tympani nerve injury is up to 3 times more likely in microscopic stapes surgery.[11,21,22] Similarly, reported rates of dysgeusia are lower with TEES (5.9% vs 16.9%), representing an approximately 69% lower chance of incurring postoperative taste disturbance (odds ratio = 0.31, 95% confidence interval 0.14, 0.69).[20]

Few studies have directly compared mean operating times between endoscopic and microscopic approaches, and there is no consensus regarding superiority of a given approach. Koukkoullis and colleagues and Manna and colleagues did not find a significant difference in their recent meta-analyses.[11,21] However, the limited number of existing studies precludes drawing definitive conclusions. Not surprisingly, operating time is influenced by surgeon experience. Iannella and Magliulo found endoscopic stapes surgery initially took longer than microscope approaches. However, this difference disappeared by the last third of their year-long study as surgeons gained more experience.

EQUIPMENT AND INSTRUMENTS

Success in endoscopic stapes surgery is supported by having access to the appropriate equipment and instruments (**Box 1**). For the novice TEES surgeon, this includes a draped microscope should significant bleeding occur or if the surgeon needs to verify the footplate depth with the microscope's binocular view. With the exception

Table 1
Review of published outcomes on endoscopic stapes surgery. Ranges and standard deviations are provided when available

Author, Year	Country	Endoscopic Procedure (Footplate Management)	N	Mean Follow-up (Months)	ABG (%) <10 dB	ABG (%) <20 dB	Mean ABG Improvement (dB)	Chorda Tympani Preservation	Chorda Tympani Dysgeusia	Mean Operative Time (min)
Tarabichi,[5] 1999	UAB	Stapedectomy (NR)	13	NR	86	NR	NR	NR	NR	NR
Poe,[56] 2000	USA	Stapedioplasty (L)	5	≥6	NR	NR	NR	100%	NR	NR
Nogueira et al,[12] 2011	Brazil	Stapedotomy (P)	15	1	NR	NR	NR	100% (manipulated in 20%)	7%	NR
Migirov & Wolf,[57] 2013	Israel	Stapedotomy (D)	8	≥6 (6–11)	75	100	NR	100%	NR	NR
Sarkar et al,[58] 2013	India	Stapedotomy (P)	30	3	56	100	NR	NR	NR	NR
Kojima et al,[24] 2014	Japan	Stapedotomy (P)	15	8.6	87	93	17.9 ± 9.06	100%	0%	53[a]
Naik & Nemade,[18] 2015	India	Stapedotomy (P)	20	1.5	55	85	NR	100% (manipulated in 25%)	0%	31 (20–48)
Özdek et al,[59] 2016	Turkey	Stapedotomy (L)	29	13 (4–27)	79	93	NR	NR	NR	NR
Daneshi & Jahandideh,[25] 2016	Iran	Stapedotomy (P)	19	7.4 (1–15)	58	95	NR	100%	NR	31.8[b]
Hunter et al,[60] 2016	USA, Columbia, Brazil	Stapedectomy, stapedotomy (D, L)	51	13.4 (0.8–57.4)	NR	90	NR	88%	10%	77.4 (35–170)

(*continued on next page*)

Table 1
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Author, Year	Country	Endoscopic Procedure (Footplate Management)	N	Mean Follow-up (Months)	ABG (%)		Mean ABG Improvement (dB)	Chorda Tympani		Mean Operative Time (min)
					<10 dB	<20 dB		Preservation	Dysgeusia	
Iannella & Magliulo,[23] 2016	Italy	Stapedotomy (P)	20	10.3 (6–15)	85	95[a]	NR	100% (manipulated in 85%)	20%[a] (transient)	45[c]
Marchioni et al,[44] 2016	Italy	Stapedectomy (83%, NR), stapedotomy (17%, NR)	6	NR	83	100	28.5 ± 18.2	NR	NR	NR
Surmelioglu et al,[61] 2017	Turkey	Stapedotomy (D)	22	15.8 (12–28)	NR	NR	27.6 ± 8.7[b]	NR	5%	65.1[b]
Sproat et al,[62] 2017	Scotland	Stapedotomy (D)	34	5 (1–26)	79[a]	100[a]	21 ± 10[b]	94%	6%	NR
Harikumar & Kumar,[63] 2017	India	Stapedotomy (P)	30	NR	57	90	NR	100% (manipulated in 7%)	0%	54.1[a]
Moneir et al,[64] 2018	Egypt	Stapedotomy (P)	14	4.5 (1–8.5)	71	93	22.5	NR	7%	39.1[b]
Kuo & Wu[19] 2018	Taiwan	Stapedotomy (L)	14	NR	88	100	22.0[a]	100%	0%	107 (40–160)[c]
Nassiri et al,[65] 2018	USA	Stapedectomy (52%; L), stapedotomy (48%; D, L)	81	Median 5.3 (1.2–50.4)	84	100	NR	93%	8%	Median 86 (43–151)
Bianconi et al,[66] 2020	Italy	Stapedotomy (D)	150	≥6	78	93	20 ± 22	99%	1%	34 (18–76)

Abbreviations: ABG, air-bone gap; D, drill; L, laser; NR, not reported; P, perforator.

[a] Indicates outcomes were not significantly different from microscopic stapes surgery. Statistical significance was set at $P<.05$.

[b] Outcomes were better in the patients undergoing endoscopic stapes surgery compared with a microscopic approach ($P<.05$).

[c] Outcomes were superior for the microscopic group ($P<.05$).

Data from Refs[5,12,18,19,23,24,44,56–65]

Box 1
Basic equipment required for endoscopic stapes surgery

- High-definition, 3CCD camera
- High-definition monitor
- Rigid endoscopes: 0°, 30°, 45°; 14 cm long, 3 mm in diameter
- Standard otologic instrument set that includes a measuring rod
- Suction elevator
- Laser, micro drill, or hand drill

of a micro-ear suction elevator, a standard set of otologic instruments is sufficient for stapes surgery and most TEES procedures. A 3-chip (3CCD) camera is preferred to avoid the red-dominant hue associated with single-CCD cameras that can skew the optics within the narrow confines of the middle ear cavity.

Although acknowledging endoscope selection is subject to individual surgeon preference, the senior author recommends the 3-mm diameter, 14-cm long endoscopes as balancing an optimal working length with maneuverability within the ear canal. Image stabilization and operator fatigue can be compromised with longer working lengths, and instrument crowding can occur with shorter scope lengths. In addition, greater temperature elevations have been associated with larger diameter scopes and xenon light sources.[26] Dundar and colleagues measured oval window temperature changes during endoscopic stapedectomy in a Guinea pig model and found the least temperature change was associated with a 3-mm endoscope and LED light source.[27] The senior author also prefers to keep the light intensity less than or equal to 40 to help mitigate the risk for thermal injury (**Box 2**). The 0° and 30° scopes are most often used, with rare need for the 45° scope. Larger angulations have not been found to aid visualization and may inadvertently pose risk to the ossicular chain or tympanic membrane from the disoriented view.

PERIOPERATIVE CONSIDERATIONS AND SURGICAL TECHNIQUE

Although the procedural steps are essentially the same in endoscopic stapes surgery as the traditional microscopic approach, the surgeon should be aware of particular nuances specific to TEES. Optimizing visualization by minimizing blood in the operative field is crucial to support the one-handed surgeon's ability to efficiently progress through the case without having to continually pause and suction. Total intravenous anesthesia (TIVA) is a useful mechanism for decreasing intraoperative blood loss and improve visualization, as it produces comparatively less vasodilation than inhalational agents.[28,29]

Box 2
Strategies to mitigate risk of potential thermal injury

- LED light source and light intensity $\leq$ 40
- Smaller diameter endoscopes
- Limiting the middle ear to prolonged, uninterrupted endoscope exposure
- Frequent suctioning
- Intermittent irrigation

After induction with TIVA, the patient is positioned into a modified “beach chair” (Fig. 1B). The back of the bed is raised between 15° and 30° to increase venous return, and the head is extended to improve exposure of the stapes footplate and oval window. Two-channel, bipolar facial nerve electrodes are placed into the orbicularis oris and oculi muscles for continuous electromyography monitoring. Local anesthesia (1% lidocaine 1:100,000 epinephrine) is injected into the tragus. The patient is then prepped and draped in the usual fashion. An example room and Mayo instrument set-up is shown in Figs. 1A and 2.

Using a zero-degree endoscope, standard, 4-quadrant canal injections are made just lateral to the osseocartilaginous junction with approximately 1 mL of 2% lidocaine 1:50,000 epinephrine. A cotton ball soaked in 1:1000 epinephrine is placed into the external auditory canal (EAC) for additional vasoconstriction, and the canal hair is trimmed to further aid visibility in preventing smearing of the scope lens. Standard stapes tympanomeatal flap incisions are made at 6 and 12 o’clock, connected with a

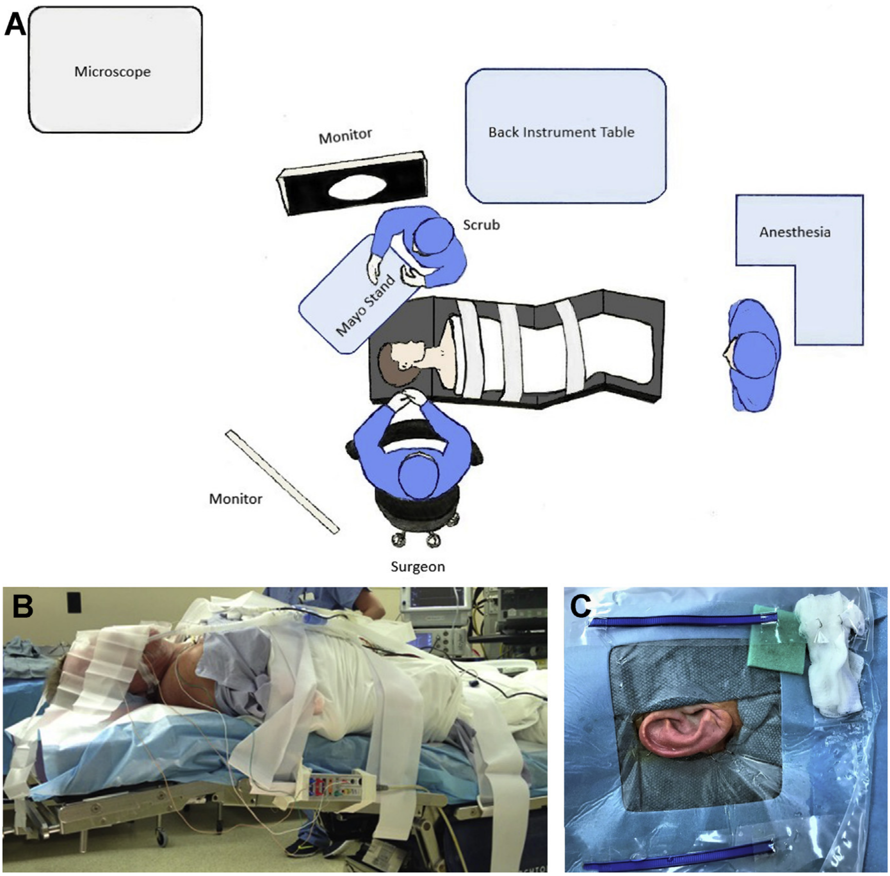

Fig. 1. Example room set-up and patient positioning for endoscopic ear cases. (*A*) Perspective shown from above. (*B*) Patient positioning for standard endoscopic middle ear procedures. The back of the bed is raised between 15° and 30° to increase venous return. Head extension also improves exposure of the stapes footplate and oval window. (*C*) Ear is draped with placement of defogging pad and wet sponge to facilitate efficient cleaning of scope.

Fig. 2. Example layout for Mayo stand with various microear instruments. The senior author prefers to use dental carpules for canal injections to guarantee correct dosing of local anesthetic and the ease of administering injection under controlled pressure.

lateral incision parallel to and 5 to 8 mm from the annulus (Video 1). In cases where substantial scutum removal is anticipated, a wider flap is designed in order to accommodate redraping at closing.

The tympanomeatal flap is raised down to the annulus and elevated from the annular sulcus. A cotton ball or pledget soaked in 1:1000 epinephrine is used to provide hemostasis and can aid in flap elevation along with a suction elevator. The middle ear is entered preferentially along the posteroinferior annulus to facilitate identification of the chorda tympani nerve and thereby avoid traction injury or avulsion. The ear drum is then reflected anteriorly to the level of the malleus neck and lateral process.

Although excellent visualization of the oval window niche is generally feasible without scutum removal, an ear curette is used to partially take down its posterior aspect to allow sufficient access for the endoscope and instruments (**Fig. 3**). To gain stability during curetting, the anterior EAC can serve as a fulcrum for the instrument shaft to help direct the vector of force inferiorly and laterally. The lateral chain and stapes are then palpated to identify the location and degree of fixation. If stapes pathology is not encountered, and instead ossicular fixation is due to lateral chain pathology such as a fixed and immobile anterior malleolar ligament, the tympanomeatal flap should be elevated further anteriorly, beyond the malleus (**Fig. 4**). If necessary, malleus or incus fixation can be addressed endoscopically with a limited atticotomy and malleostapedotomy (**Fig. 5**).

The stapedius tendon is first cut with a microscissor or laser, and the posterior crus of the stapes is divided with a carbon dioxide (CO_2) laser. The incudostapedial joint is then separated with a joint knife or small, right-angled micro pick. Next, the stapes suprastructure is downfractured and removed. Of note, the anterior crus can also be divided if needed, a distinct advantage of the endoscopic approach. Subsequently, the distance between the footplate and the incudal lenticular process is measured with a measuring rod.

If a stapedectomy is being performed, the mucosa adjacent to the oval window niche can be removed or laser ablated. A tissue graft (perichondrium, fascia, vein or fat) is placed on the promontory, inferior to the oval window before addressing the footplate. After partial or total stapedectomy, the tissue graft on the promontory is then positioned over the oval window to seal the vestibule. The prosthesis is placed between this graft and long process of the incus.

The senior author typically performs stapedotomies and uses a CO_2 laser at 3 W to create the fenestra. When footplate disease is excessive and cannot be effectively addressed with the laser, a stapedotomy can be made with a 7 mm burr to drill at 7000 rpm. Using serial perforators from 0.5 to 0.7 mm, the hole is measured. Sizing is confirmed, and a piston-type prosthesis is placed into the stapedotomy hole and hooked around the long process of the incus. The laser is then used to crimp the prosthesis securely onto the lenticular process. Next, the promontory is scratched in order to create a blood patch to help secure the prosthesis to the footplate (**Fig. 6**).

The round window reflex is assessed with the endoscope to confirm appropriate coupling of the prosthesis. The endoscope also enables a detailed examination of the round window to readily determine its potential involvement by disease, estimated in up to 13% of cases.[30] Furthermore, a pulsating round window can be easily identified with an endoscope (Case example 3). This finding can indicate an underlying gusher, and responsible consideration should be given to abort the procedure before manipulating the stapes to decrease the risk of sensorineural hearing loss.

At the end of the procedure, the tympanomeatal flap is laid back into position, covering the exposed osseous canal. The ear canal is packed with Gelfoam anteriorly and then filled with antibiotic ointment, followed by a cotton ball and a band-aid.

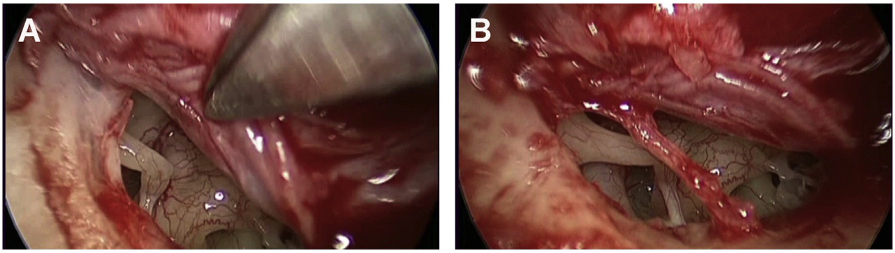

Fig. 3. View with a 0° endoscope after tympanomeatal flap elevation (*A*) and following limited curettage of posterior scutum (*B*).

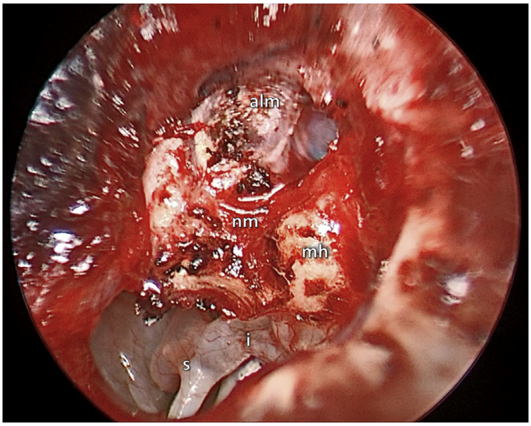

Fig. 4. Congenital abnormalities of the ossicular chain with prominent anterior malleolar ligament fixation. i, malformed incus; mh, malleolar head; nm, neck of malleus; alm, anterior malleolar ligament; s, malformed stapes.

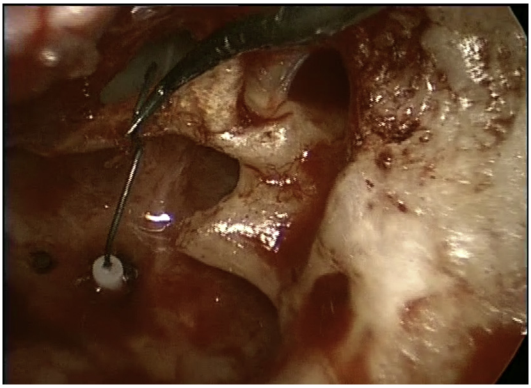

Fig. 5. A curved pick is used to position a piston prosthesis from the malleus to the fenestra following a malleostapedotomy.

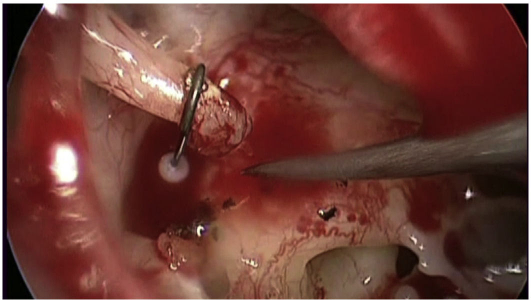

Fig. 6. Piston prosthesis has been crimped in place, and a straight pick was used to create a blood patch.

HIGHLIGHTED SCENARIOS IN ENDOSCOPIC STAPES SURGERY

Revision Stapedotomy

TEES offers a viable option for revision cases and affords excellent visualization of the middle ear space to determine the cause of prior surgical failure.[31,32] Lack of diagnosis has been associated with poorer outcomes.[33] In general, however, revision cases are associated with worse hearing outcomes compared with primary stapes surgeries for otosclerosis.[34–36]

Failure following stapes surgery can be temporally divided into 2 categories—immediate and delayed. When patients deny hearing improvement immediately after surgery, causes include an incorrect diagnosis that led to an unaddressed lateral chain fixation, excess tissue graft, or reparative granuloma.[34,37,38] In contrast, patients may report initial improvement only to experience a decline in hearing later. Delayed hearing loss may indicate a progression of otosclerosis within the middle ear and recurrence of oval window pathology, tympanosclerosis, and ossicular chain discontinuity from incus erosion or displaced prosthesis.[36,38] Overall, a misaligned prosthesis with or without ossicular erosion is the most common cause detected at revision cases.[38]

Video 2 demonstrates a revision stapes surgery performed in a 46-year-old woman who presented to clinic 9 years after undergoing a previous stapedotomy. She denied improvement in hearing following the initial surgery and wished to undergo revision to address her left conductive hearing loss. On otoscopy, there was retraction at the scutum, and the prosthesis could be seen contacting the tympanic membrane.

Intraoperatively, once the flap was elevated and adhesions were cleared, the prosthesis was found to be malpositioned. The old prosthesis was removed, and a new prosthesis was sized. A laser was used to make a new stapedotomy fenestra, and the piston prosthesis was then lowered into place. Care is taken to crimp the prosthesis proximal to the prior prosthesis-incudal attachment where there is often some degree of bony erosion (**Fig. 7**). A tragal cartilage graft was used to reconstruct the scutum. Her postoperative audiogram showed closure of the ABG within 10 dB.

Perilymphatic Leak Gusher

Robust perilymphatic leaks or gushers are an uncommon complication encountered during stapes surgery for otosclerosis, with an estimated rate of 0.3%.[39] Video 3 demonstrates a case in a 16-year-old female patient with a history of osteogenesis imperfecta, left greater than right conductive hearing loss, and a normal examination on otoscopy. Intraoperatively, round window pulsations were noted, and perilymph could be visualized leaking through the fenestra following stapedotomy. After placing the

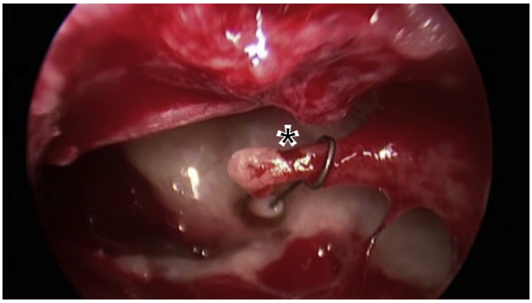

Fig. 7. When revising a prior stapedotomy, there is often ossicular erosion. The new prosthesis is placed proximal to area of focal bone loss (*) on the incus long process.

prosthesis, a perichondrium graft was tucked around its base to seal the vestibule. The patient did well postoperatively with ABG closure less than 5 dB, representing a 20 dB improvement. She endorsed disequilibrium on the first postoperative day, which subsequently spontaneously resolved. Of note, her preoperative computed tomography did not demonstrate any radiologic abnormality.[40]

The most common cause for stapes gushers is thought to be secondary to an abnormal connection with the subarachnoid space via defects in the internal auditory canal or a patent cochlear aqueduct.[41,42] As others have reported, the senior author has found most cases of perilymphatic leaks can be managed with tissue grafts, and a prosthesis can often be placed.[39] However, poorer outcomes may be expected in the setting of perilymphatic leaks with more than half of patients reporting postoperative hearing that is either unchanged (28%) or worse (31%).[39,43]

Narrow Oval Window Niche

The most prominent advantage of TEES is the wider intraoperative field of view. This can be particularly useful in the setting of particular anatomic variants including narrow oval window niches. In this case example, a 57-year-old man with a history of otosclerosis presented for left-sided endoscopic stapes surgery after a prior microscopic approach was aborted in the setting of a narrow oval window niche (Video 4). His preoperative audiogram demonstrated bilateral conductive hearing loss, maximal on the left. Intraoperatively, a view of the stapes was obtained with the 0° endoscope and demonstrated bony overgrowth of the promontory and a low lying, prolapsed facial nerve. Limited amount of promontory drilling was performed to enlarge the niche to accommodate a prosthesis (**Fig. 8**). There was also a slow perilymph leak that was managed with a perichondrium graft tucked around a piston prosthesis. The patient did well postoperatively, with closure of his ABG to within 5 dB.

Congenital Stapes Fixation

An otherwise healthy 52-year-old woman presented with several years of progressive right-sided conductive hearing loss (Video 5). Her history was consistent with

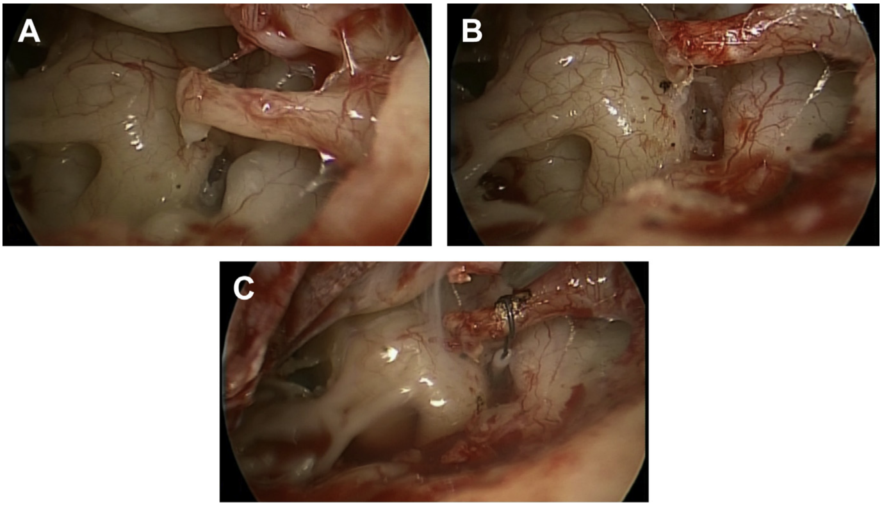

Fig. 8. A narrow oval window niche before (*A*) and after (*B*) limited drilling of the promontory. The prosthesis is crimped into place with a laser (*C*).

otosclerosis, but intraoperatively, the stapes was noted to be malformed. On inspection, the stapes was fixed posteriorly but mobile anteriorly. The stapedius tendon and pyramidal process were absent, but the tympanic segment of the facial nerve followed a traditional course. The lateral chain was mobile, and an ossicular chain reconstruction was performed following stapedotomy. There were no complications, and her postoperative course was uneventful. Follow-up audiometry demonstrated closure of her ABG to less than or equal to 10 dB.

Endoscopic techniques are often ideally suited to address congenital fixations due to the improved visibility that facilitates identification of anatomic variations.[44] In addition, concomitant middle ear structural abnormalities have been reported,[45–51] including an anomalous facial nerve in up to 11.2% of cases.[46,47,52] When the tympanic course of the facial nerve is dehiscent and overlaps the oval window niche, prosthesis placement can be challenging (**Fig. 9**) and in some cases impossible (**Fig. 10**). In addition, several investigators have reported lateral chain pathology (37%–100%) or involvement of the stapes superstructure coexistent with a congenital fixed stapes footplate, underscoring the importance of examining the entirety of the ossicular chain.[44,46,49–51] Thomeer and colleagues found no significant difference in hearing outcomes between patients who underwent malleostapedotomy versus incudostapedotomy (P = .09).[50]

In general, reported hearing results are worse following surgery for congenital stapes footplate fixation (CSFF), indicating the need for appropriate preoperative counseling regarding expectations.[46,48,53] Published rates of postoperative ABG closure less than 10 dB vary, ranging between 44% and 77%.[48,50,53–55] Massey and colleagues compared outcomes between isolated congenital fixation and otosclerosis, noting poorer performance for CSFF patients.[53] Nearly half (48%) of the cases with congenital stapes fixation achieved ABG closure within 10 dB, compared with 86%

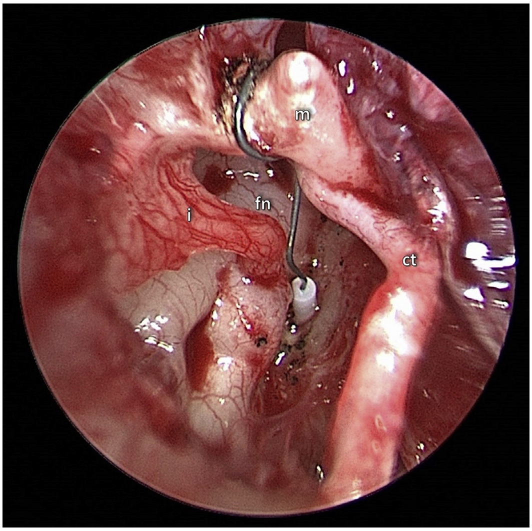

Fig. 9. Right ear during malleostapedotomy in a patient with congenital stapes fixation. The stapes superstructure was partially eroded in the setting of a prominent dehiscent tympanic segment of the facial nerve, and the crura were malformed. Only a small portion of the anterior footplate was visible and accessible for the malleostapedotomy. ct, chorda tympani; fn, facial nerve; i, incus; m, malleus.

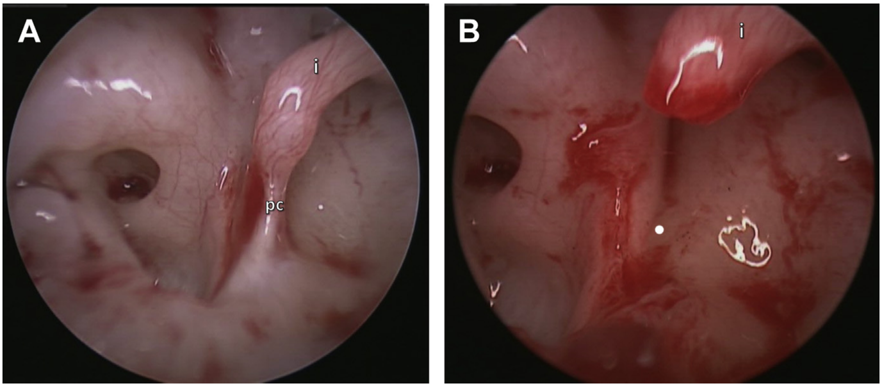

Fig. 10. (*A*) An endoscopic view of left ear. The stapes is malformed with an absent footplate, foreshortened anterior crura, and posterior crura lacking distal attachment. (*B*) After the malformed stapes was removed, the entirety of the footplate recess resulted in facial nerve stimulation secondary to a bifid facial nerve obliterating the oval window. This revented ossiculoplasty, and the procedure was concluded. i, incus; pc, posterior crura.

of otosclerosis cases, respectively (*P* = .001). However, the mean postoperative ABG was 12.2 dB, and no complications occurred, supporting the role of surgery in appropriate candidates.[53]

SUMMARY

Over the last 20 years, an endoscopic approach to stapes surgery has been increasingly pursued, with favorable results. Similar audiologic and safety outcomes have been reported in TEES compared with traditional, microscopic approaches. The endoscope increases visibility in stapes surgery with a wider, magnified field of view. Its use is particularly advantageous in the setting of variant anatomy including revision cases and congenital abnormalities. Limitations include the lack of depth perception and single-handed instrumentation, yet TEES can still be a useful tool in challenging cases as the above examples demonstrate.

DISCLOSURE

The senior author (A.R) is a consultant for Cook Medical, Stryker, Grace Medical, Cochlear Corporation, Med-EL, Advanced Bionics. K.L.Y. and N.F.M. have nothing to disclose.

SUPPLEMENTARY DATA

Supplementary data related to this article can be found online at https://doi.org/10.1016/j.otc.2020.09.015.

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