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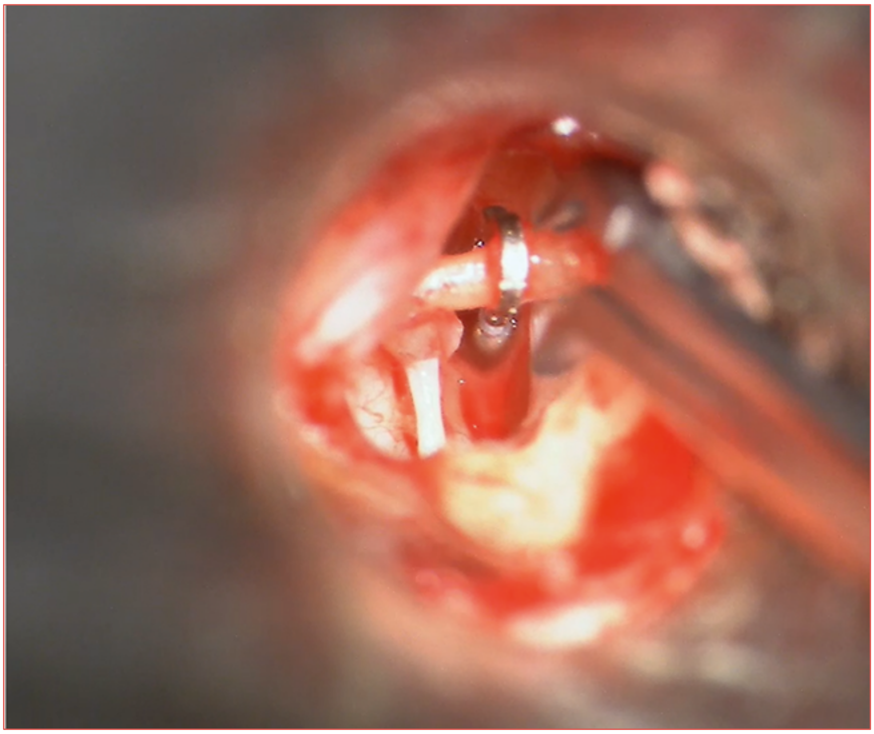
REVIEW

Update on stapes surgery



Cover figure. Preparing to crimp the stapes prosthesis to the long process of the incus during a stapedotomy procedure.

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Summary

Stapes surgery has significantly evolved from the early identification of stapes fixation as a cause of hearing loss in the 18th century to advanced modern techniques. This narrative review examines the historical development and contemporary advancements in stapes surgery, focusing on all the critical aspects of surgical procedures: from patient positioning, to microscopic versus endoscopic visualisation, type of anaesthesia, characteristics of prosthesis, and different surgical techniques. A further analysis of special conditions has been made.

Key words: stapes surgery, otosclerosis, prosthesis, endoscopic surgery, microscope, local anesthesia, general anesthesia

Introduction

The history of stapes surgery is a demonstration that the relentless pursuit of medical innovation has significantly advanced our understanding and treatment of hearing loss (HL). Stapes fixation causing HL was first identified by

Antonio Maria Valsalva in 1704. In 1841, Toynbee's dissection of 1,659 temporal bones found 39 cases of stapes fixation, linking it to deafness. By 1893, Adam Politzer's histological studies indicated otosclerosis as the cause [1].
Johannes Kessel described stapes surgery in 1876, attributing HL to increased inner ear fluid pressure. His methods included mobilising or removing the stapes, with mixed success and some risks like labyrinthitis and meningitis [2]. His techniques were criticised and deemed dangerous by the early 20th century [1]. Surgeons then shifted to "third-window" fenestration techniques, fully established by Jenkins in 1913 with contributions from Lempert, who simplified the procedure [3,4]. Samuel Rosen reintroduced stapes mobilisation in the mid-20th century, achieving immediate but often temporary hearing improvement [5].
John Shea revolutionised stapes surgery in 1956 by successfully using a Teflon prosthesis to replace the stapes after a complete stapedectomy, with the interposition of autologous material, usually constituted by a vein or perichondrium [6]. His technique, initially considered dangerous, became standard by the 1960s [7]. Schuknecht later developed a steel-wire prosthesis in 1960, while Plester proposed a partial footplate removal method, leading to further advancements in stapedectomy procedures [8]. This advancement paved the way for modern stapes surgery, featuring the use of piston prostheses and the creation of small holes in the footplate.
This narrative review aims to provide an overview of the evolution of surgical techniques in stapes surgery, analysing each technical aspect in detail, including the position of the patient during surgery, the instruments used for visualising the middle ear, type of anaesthesia administered, methods for removing the stapes' superstructure, techniques for creating a hole in the footplate, and the characteristics of the prosthetic piston. Additionally, the review will include a dedicated section on stapes surgery in special conditions.

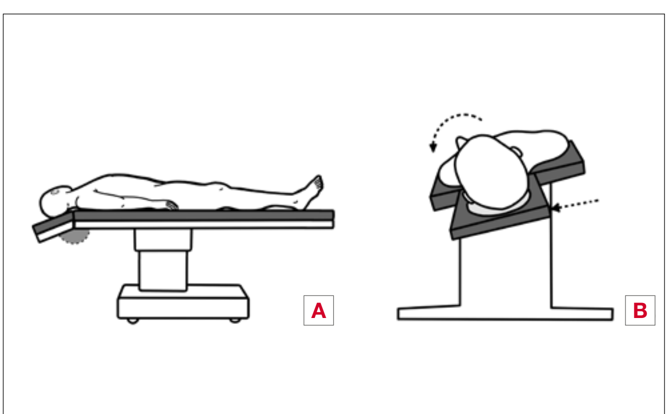

Figure 1. Patient positioning for stapes surgery: **A**) the patient should be positioned supine on the operating table with the head hyperextended and rotated to expose the ear to be operated; **B**) to obtain a better exposure, the table can be tilted on the frontal (coronal) plane.

Surgical procedures

Due to the intrinsic danger of sensorineural hearing damage and the higher rate of complications [7,9], stapedectomy is nowadays outdated and stapedotomy is the preferred surgical treatment for fenestral otosclerosis with good cochlear reserve.
Traditionally, modern stapes surgery through stapedotomy involves the use of a microscope and a transcanal approach under local anaesthesia. The procedure includes preparing the tympanomeatal flap, removing part of the bony frame to visualise the ossicular chain (stapes, incus, second portion of the facial nerve, pyramidal eminence), removing the stapes superstructure, preparing the footplate hole, placing the piston prosthesis between the incus and the footplate hole, and finally repositioning and packing the tympanomeatal flap.
For an optimal surgical result, it is crucial to carefully analyse every step and aspect of the procedure.

Patient position

Traditionally, the patient should be supine on the operating table with the head hyperextended and rotated to expose the ear to be operated (Fig. 1). The surgeon stands very close to the patient, resting their wrists on the patient's head to minimize hand movement errors. Even in the paper by Mantokoudis and colleagues that recently revised classical microscopic transcanal approach in stapes surgery, the positioning of the patient is considered a crucial step in the surgical procedure [10]. In our opinion, furthermore, the operating table should be placed as low as possible and tilted in a reverse Trendelenburg position, with the headrest angle maximally reclined.

Instruments to visualise: microscope and endoscope

The first documented use of a binocular microscope in otologic surgery is attributed to Gunnar Holmgren in 1922. However, Emilio De Rossi is often cited as the first to use a binocular magnification system in 1869, although it consisted of a single lens rather than a true binocular microscope. Carl Olof Nylen was the first to use a monocular microscope in 1921, which was quickly replaced by Holmgren's binocular model [11].
Afterwards, the evolution of the binocular operating microscope in otologic surgery marked a significant advancement, enabling a less invasive transcanal approach to the mid-

dle ear. Previously, more invasive methods like endoaural incisions or retroauricular approaches were common. Although it limits the working space, a transcanal microscopic approach provides binocular vision into the middle ear without needing an extensive skin incision, thus reducing postoperative pain and bleeding. Moreover, this minimally invasive technique avoids complications such as scar tissue formation, hypoaesthesia of the auricle, and pinna protrusion. However, its limited field of view can necessitate additional procedures, such as endoaural incisions and drilling of the auditory canal or scutum, and frequent repositioning of the surgeon and patient [10,12-14] (Fig. 2).

One alternative to using a microscope is endoscopy. Endoscopic surgery for otosclerosis offers a significant advantage with its wide-angle view, reducing the need for scutum removal and enhancing exposure for teaching and training [14,15]. This wide-angle view allows for closer and more precise visualisation of the footplate, with no or minimal bone removal and need to manipulate the chorda tympani nerve [12-14]. Despite these benefits, there is currently no objective method to quantify the improved visibility provided by the endoscope, making this advantage largely subjective and based on the individual surgeon's experience. Moreover, endoscopic surgery has its drawbacks, including reduced depth perception due to its two-dimensional view and the need to operate with one hand, which can complicate the procedure and increase the learning curve [13]. Usually, surgeons familiar with using the microscope prefer to continue with it for these reasons. Regarding the size of the endoscopes, 4 mm nasal endoscopes were initially used, but 3 mm endoscopes have become standard in otology. Studies have not demonstrated a clear superiority of narrower endoscopes, as hearing outcomes and complication rates are similar with both sizes, despite reports of better visibility with smaller endoscopes [16].

The introduction of endoscopes did not alter the fundamental surgical techniques but provided an alternative access route, with hearing outcomes remaining comparable to those of microscopic surgery. This was confirmed by systematic reviews showing no significant difference in air-bone gap closure across frequencies [13,14,17,18]. No significant difference in complications such as chorda tympani nerve injury, dysgeusia, or residual perforation was found between endoscopic and microscopic procedures, although some studies suggested lower chorda tympani injury rates with endoscopes due to less scutum removal [18]. Despite some studies indicating higher complication rates with endoscopic surgery, also due to thermal injury, recent reviews have not found significant differences between the two approaches [13,19]. As assessed in the study by Molinari and collaborators, surgeon's experience is also a critical factor, potentially biasing outcomes, for instance leading to reduced operating times if an experienced endoscopic surgeon carries out the procedure [18].

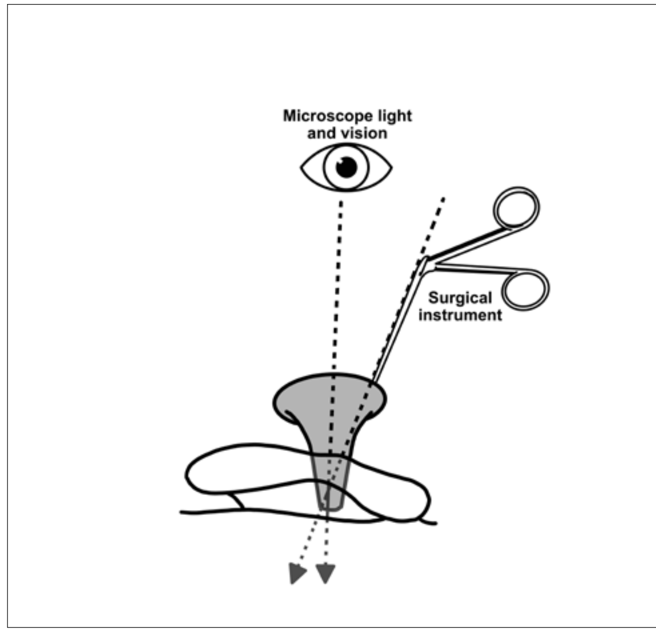

Figure 2. Microscope vision during transcanal stapes surgery.

In conclusion, while both microscopic and endoscopic approaches to stapes surgery have their pros and cons, neither can be definitively considered superior. The choice of surgical method should be based on the surgeon's expertise, training, and the availability of appropriate tools to ensure the safe execution of stapedotomy or stapedectomy.

Instruments to visualise: speculum and other approaches

In microscopic approaches, the choice of auricular speculum is crucially important. It is first useful to assess the diameter of the canal by placing an auricular speculum with a diameter of 5 mm, in order to understand whether it is reasonable to carry out a transcanal approach or if another route is indicated. In fact, a classical transcanal microscopic approach could be challenging if a narrow external auditory canal does not accept at least a 5 mm diameter speculum [20]. According to Mantokoudis and collaborators, the largest speculum usable according to the size of the external auditory canal and allowing visualisation of the hammer handle anteriorly and the posterior wall of the ear canal posteriorly should be preferred [10]. The instruments must be held like a

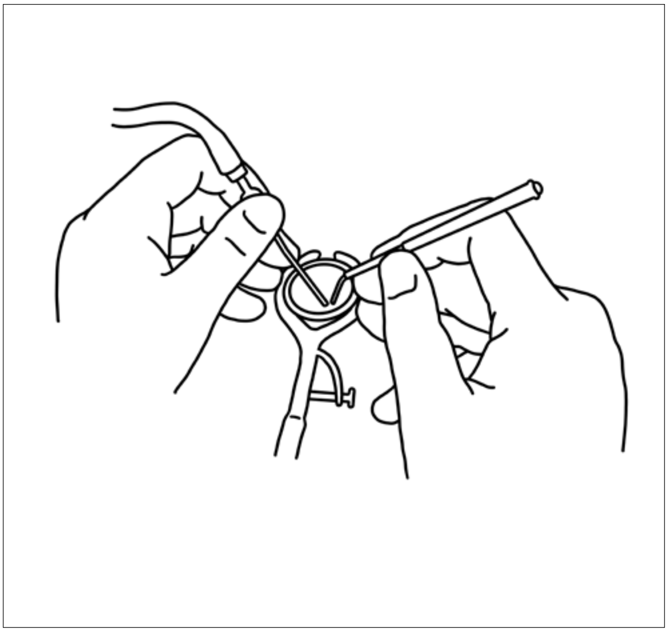

Figure 3. Hand and speculum position for transcanal stapes surgery. The instruments must be held like a pencil with the first three fingertips, stabilising the hand on the speculum or the patient's head with the other two fingers.

pencil with the first three fingertips, stabilising the hand on the speculum or the patient's head with the other two fingers [10] (Fig. 3). Even if not all the surgeons use it, a speculum holder – consisting of a mobile extension mounted on the operating table – can be used to fix the speculum thus simplifying the surgeon's bimanual actions [10].

An alternative way to stapes surgery is the endoaural approach, especially by an intertragal incision. This method allows surgeons to bypass the need for an auricular speculum. This type of approach can help bimanual surgery, offers a clear view of the middle ear, and can be advantageous in cases involving narrow external ear canals [21].

Type of anaesthesia

Stapedotomy can be performed both under local and general anaesthesia. Some surgeons prefer to use local anaesthesia with or without sedation to monitor auditory and vestibular responses during surgery, while others prefer general anaesthesia for the patient's comfort.

In a 2008 study, Vital and collaborators found a higher incidence of profound HL in patients under general anaesthesia (1.8%) compared to local anaesthesia (0%) [22]. On the other hand, a systematic review of 417 procedures showed no significant differences in postoperative outcomes between anaesthesia methods [23].

In our opinion, local anaesthesia is preferable, since it allows the surgeon to monitor the patient's reactions during surgical manipulation of middle ear structures. Typically, 2% lidocaine with 1:100,000 epinephrine is used for its quick anaesthetic effect. About 10 mL is injected at various sites, not exceeding 7 mg/kg. Infiltration starts in the retroauricular region, blocking nerves to the outer ear, and continues between the tragus and helix, and in the posterior external auditory canal. The association with adrenaline can further reduce bleeding and improve haemostasis [24].

Tympanomeatal flap harvesting and scutum removal

The tympanomeatal flap should be U-shaped and created from 6 to 12 o'clock, encompassing the upper, rear, and lower walls of the ear canal [10,25]. The skin should be incised a few mm distally from the end of the speculum. The skin of the flap is then detached up to the posterior bony annular edge [10,25]. This step may cause bleeding, which can be controlled using an adrenaline-soaked absorbable gelatin sponge [10]. Accessing the tympanic cavity and detaching the tympanic membrane is best done at the posterosuperior quadrant, referred to as Rivino's engraving, where the fibrous annulus of the tympanic membrane is less adherent to the bony edge. Once the tympanic membrane has been detached from the bony rim, the tympanomeatal flap is folded anteriorly [25]. If the surrounding bracket and structures are not sufficiently exposed, the back-top of the ear canal can be removed using a bone curette or a 2 mm low-speed diamond drill [10]. The structures that must be visualised before proceeding to the next step are the bracket, the long process of the incus, the tympanic part of the facial nerve, and the pyramidal eminence with the tendon of the stapedius muscle [10].

Removing the superstructure of the stapes

The traditional stapedotomy procedure involves removing the superstructure of the stapes before creating an opening into the footplate and inserting the prosthesis. In 1987, Fisch proposed to reverse these steps during stapedotomy to reduce the risk of a floating footplate, inner ear damage, and dislocation of the ossicular chain [9]. Instead of removing the stapes superstructure first, Fisch proposed performing the fenestration first and then placing the prosthesis, keeping both the incudostapedial joint and stapedius tendon intact. Once the prosthesis is secured, the stapes and the lenticular process of the incus are separated, the stapes crura is fractured, the stapedius tendon is cut, and the superstructure is removed. This reversal of steps decreases the exposure time of the vestibule, minimises blood entry, and reduces the need for manipulation and the risk of inner ear injury. An additional benefit of Fisch's reversed steps stapedotomy is the increased stability of the ossicular chain, making it easier to position the piston on the long process of the incus [9]. In 2008, Fiorino and Barbieri described a reversal steps stapedotomy technique with early removal of the posterior crus. In our opinion, this technique can provide better visualisation of the stapes footplate and, simultaneously, by retaining the anterior crus of the stapes until after the prosthesis is secured, the technique maintains the stability of the ossicular chain throughout the procedure [26].

Performing the footplate hole

The next surgical step is creating the footplate hole. Fenestration techniques in stapedotomy have advanced significantly with the introduction of microdrills and lasers, moving beyond conventional manual drills (Trefine) [10]. Historically, manual drills were widely used and favoured due to their familiarity among surgeons and their simplicity, especially when dealing with thin footplates. The advent of microdrills marked a certain improvement in stapedotomy, particularly in shortening the operation time, especially when the footplate is very thick. Microdrills, equipped with small diamond burrs of 0.6-0.7 mm in diameter, operate with low noise intensity and low torque, making them a safer option for footplate drilling without causing significant acoustic trauma. This was shown in numerous recent studies [27-31]. Studies have further demonstrated that microdrills can create precise, round holes that match the size of the prosthesis, reducing the risk of fistula and granulation tissue formation [29], as well as that they result in better audiologic outcomes compared to manual drills [30]. However, despite their benefits, microdrills also present certain risks, such as the possibility of advancing into the vestibule and causing sensorineural HL and vertigo [27]. Additionally, their use in endoscopic surgery is complicated by reduced depth perception, leading to longer operation times [32].

The introduction of lasers in stapedotomy in the 1980s aimed to minimise mechanical manipulation of the footplate and inner ear [33]. Lasers allow for soft touch or no-touch-at-all perforation of the footplate, thereby reducing the risk of mechanical trauma [34,35].

Various types of lasers, including argon, diode, KTP, thulium, and CO_2, offer distinct characteristics that cater to different surgical needs. Laser technology provides high precision, a bloodless surgical field, and the ability to cut, vaporise, and coagulate tissue using thermal energy. Despite these advantages, lasers also pose potential risks, such as overheating of the perilymph, acoustic trauma, and other complications specific to each laser type. Furthermore, the high cost and need for specialised training and equipment can be limiting factors [35].

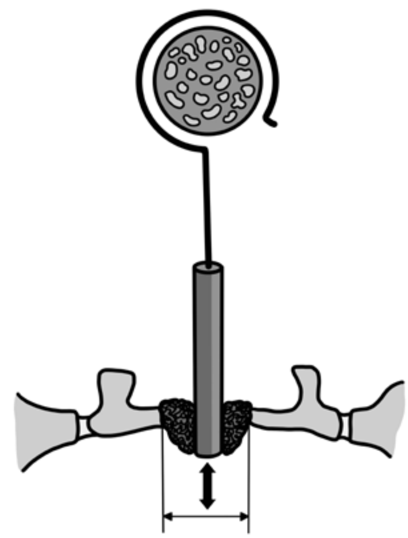

Figure 4. Vibration model of a piston stapes prosthesis.

Comparative studies have yielded mixed results regarding the superiority of microdrills and other conventional methods over lasers. On the other hand, research comparing laser techniques with conventional methods showed varied outcomes. Silverstein and colleagues reported improved audiologic outcomes with the KTP laser, but noted prolonged dizziness and instability in some patients [36]. Similarly, Arnoldner and collaborators found that while hearing results were comparable, the incidence of perilymphatic fistula was higher in laser-assisted surgeries [37]. Other studies, such as those by Pauli and colleagues and Altamami and colleagues, found no significant differences in hearing thresholds between different surgical techniques involving the use of lasers [38,39]. A systematic review by Wegner and collaborators in 2013 reported no evidence that laser techniques were superior to others in postoperative hearing outcomes, even if the rates of footplate fracture and sensorineural hearing damage seemed to be increased with the use of perforators or microdrills [40].

Moreover, even if each type of laser used in stapedotomy has unique characteristics, there is no conclusive evidence proving the clinical superiority of one laser type over another or over traditional techniques [40]. In the systematic review by Wegner and colleagues, it also emerged that many studies suffer from biases, small sample sizes, and methodological inconsistencies, making it difficult to draw definitive conclusions [40]. In the absence of robust evidence, the choice of operative technique often depends on the surgeon's preference, experience, and specific clinical circumstances.

Characteristic of the piston

The rigidity of the annular ligament constitutes 90% of the total impedance in the human middle ear at lower frequencies, thereby playing a crucial role in sound transmission, particularly for speech frequencies. The solid collagen fibres of the annular ligament significantly influence the amplitude of stapedial vibrations during low-frequency acoustic stimulation. The sound pressure at the cochlear entrance correlates directly with the volume velocity of the stapes, which is defined by the product of the area and amplitude of the vibrating footplate. With an area of approximately 3.2 mm^2, the footplate vibrates at amplitudes of only a few nanometers to displace a sufficient volume of liquid to transmit sound pressure into the cochlea under physiological conditions [41,42]. Replacing an otosclerotic stapes with a piston prosthesis eliminates the annular ligament as the primary impedance factor in the middle ear, allowing the ossicles to vibrate with greater amplitudes at equivalent sound pressures at the tympanic membrane. Consequently, a piston prosthesis with a smaller contact area, such as a 0.4 mm piston, can vibrate with a much larger amplitude at equivalent sound pressures, compensating for its smaller surface area [41] (Fig. 4). However, reducing the diameter of a piston is limited by the vibrational capacity of the tympanic membrane and the ossicles. Animal experiments suggest that the maximal vibrational amplitude of sound-transmitting structures is achieved with a piston diameter smaller than 0.4 mm, and volume velocity decreases with smaller diameters [42]. Clinical findings support this lower limit, with Grolman et al. reporting decreased sound transmission, especially below 1 kHz, for a 0.3 mm compared to a 0.4 mm piston [43]. Pistons with diameters of 0.4 mm and greater generally exhibit similar sound transmission properties if the vibrational capacity of the middle ear structures remains unrestricted. However, literature on the acoustic results following stapedoplasty with various piston diameters is inconsistent. For instance, Fisch [9] and Shabana et al. [44] found no significant difference in hearing outcomes at speech frequencies between 0.4 and 0.6 mm pistons. In contrast, as reported in Hüttenbrink review, a significant advantage for the larger diameter at 500 Hz was observed, although both diameters performed equally at higher frequencies [41]. Other studies, such as those by Häusler, and Coletti et al., have reported varying results, indicating better performance at different frequencies depending on the piston diameter used [41,45]. Mathematical models have also been used to predict the impact of piston diameter on sound transmission, generally suggesting that larger diameters may offer advantages. However, these models often rely on experimental data with inherent methodological discrepancies, leading to varying results. These studies must be carefully interpreted, as inaccuracies in parameter estimation can distort results. The vibrating area in stapedoplasty is not solely defined by the piston's diameter, as the surrounding connective tissue membrane also contributes to sound transmission (Fig. 4). Clinical audiology, in fact, typically does not register large deficits after stapedoplasty with a 0.4 mm piston, despite theoretical predictions of significant losses. Fucci et al. found that 0.4 and 0.6 mm steel pistons inserted into identically sized fenestrations performed equally well [46].

Moreover, many studies comparing acoustic outcomes with different piston diameters do not specify the size of the footplate fenestra, and most surgeons aim to perforate the footplate slightly larger than the piston diameter to minimise inner ear trauma. The area that vibrates the labyrinthine fluids is actually determined by the size of the footplate hole, not the diameter of the piston [47], and this aspect could lead to bias.

The material of the piston may also impact on the acoustic performance. Heavier prostheses, like those made from steel or gold, tend to perform better at lower frequencies, while lighter materials, such as Teflon, transmit sound more effectively at higher frequencies. This effect is due to shifts in the resonance frequency of the reconstructed middle ear [43,48,49]. However, the overall influence of piston mass on sound transmission is relatively minor, as even significant increases in mass result in less than a 10 dB reduction in transmission. This minor influence was demonstrated in early animal experiments [50] and later supported by mathematical models [47] and temporal bone studies [51,52], although some of these studies reported contradictory data [41]. In any case, surgeons currently use only lightweight prostheses. Therefore, the only fundamental principle behind prostheses used in otosclerosis surgery is to create a secure connection between the mobile long process of the incus and the perilymph in the oval window. Since Shea and Treace first introduced a Teflon stapes replica in 1956 [3], many types of stapes prostheses have been developed. Advancements in surgical materials, including those with greater biocompatibility, have played a key role in the development of new prostheses. Innovations like shape-memory prostheses were also introduced [53], as well as non-ferromagnetic implants for magnetic resonance compatibility [54].

Fritsch and Naumann classified stapedectomy prostheses into 4 categories: wire loop, piston, bucket, and homemade [54]. Commercial prostheses (wire loop, piston, and bucket) typically consist of 3 parts: the incus attachment end, the shaft, and the oval window attachment base [54]. Innovations in these areas have aimed to prevent complications like incus necrosis, often caused by ischaemia from pressure during crimping or foreign body reactions, as well as dislocation, and maximise hearing outcomes as well as facilitate the surgeon's work during the procedure [54].

Materials used for stapes prostheses include stainless steel, platinum, titanium, nitinol, and Teflon. Stainless steel is chosen by some surgeons for its rigidity, shape retention, and malleability. Platinum, although malleable, has been associated with higher incus necrosis rates, possibly due to local toxicity [54]. Titanium is lightweight, rigid, and biocompatible, forming a protective titanium oxide layer upon oxidation, reducing granulation and scar tissue formation. Nitinol prostheses, made in a nickel-titanium alloy, which revert to their original shape when heated, offer advantages in fixation but its nickel content may raise concerns about biocompatibility, even if some studies seem to reject this hypothesis [55]. Teflon, a common material, is chemically stable, malleable, and resistant to corrosion, with a 'memory effect' that minimises incus necrosis due to ischaemia. Comparative studies have shown no significant differences in audiologic outcomes between various materials [49,56,57], or in the rate of complications [57].

Some prostheses come in predefined sizes, while others can be trimmed to fit during surgery. Shaft diameter can also vary. Some studies suggest better hearing results with larger diameter prostheses, although the choice often depends on the surgeon's skill and the specific case [58]. As described by Fisch in 1994 [59], and confirmed by the review from Hüttenbrink in 2003 [41], the length of the stapes prosthesis should be calibrated so that approximately 0.5 mm of the prosthesis extends into the vestibule. This length should help to prevent the prosthesis from dislocating during lateral movements of the incus, such as those caused by sneezing or during a Valsalva manoeuvre. Additionally, it safeguards the delicate structures of the inner ear, particularly the utriculus and sacculus, from damage when the incus moves medially, as might occur during an increase in atmospheric pressure.

Crimping of the prosthesis

One of the critical steps during stapes surgery is the coupling or crimping of the prosthesis onto the incus (Cover figure). Improper crimping, whether too tight, too loose, or causing mechanical trauma during the process, can potentially lead to incus erosion [60,61]. Furthermore, both experimental and clinical studies have demonstrated that the quality of crimping is directly associated with postoperative hearing outcomes [62]. Consequently, various prostheses have been developed with different crimping methods. Current stapes prostheses can be categorised into self-crimping and manually crimped types. Self-crimping options eliminate the need for manual crimping and its potential complications, even if the incus end loop diameter of these types of prosthesis is often predefined and in our opinion cannot always adequately fit all subjects.

Initially, some prostheses, such as bucket-handle and cup prostheses, as well as Teflon self-crimping prostheses, were designed to couple with the incus without additional crimping. More recently, shape-memory heat-crimping prostheses made from a nickel-titanium alloy known as nitinol have been introduced [63]. These prostheses are crimped by applying heat via a laser or bipolar forceps, which activate the shape-memory properties of nitinol, causing the prosthesis loop to close. Using a laser-crimped nitinol prosthesis avoids direct contact with the prosthesis or the incus, thereby preventing trauma that may occur with manual crimping [64].

Even if manual crimping is technically more challenging, heat crimping can also have drawbacks, such as the potential for vaporisation of blood vessels, leading to necrosis of the long process of the incus [55]. The effect of various crimping methods on hearing outcomes after stapes surgery has been the focus of numerous studies, although the quality of these papers is relatively low [63,65-68]. Most of these studies are small and do not reach statistical significance. Among those that do, the findings consistently favour heat-crimped prostheses over manually crimped ones, and manual crimping over no crimping. None of the crimping methods appear to increase the incidence of adverse events [62]. Until further high-quality studies with sufficient follow-up duration are conducted to confirm these findings, it is reasonable for surgeons to use the type of prosthesis and crimping method with which they feel most comfortable [62].

Sealing of the footplate

The necessity of sealing the oval window is debated, with some studies suggesting that a well-executed technique is more important than the use of a sealant for preventing perilymphatic fistula [69]. However, some surgeons choose not to seal the oval window at all, as the additional step may complicate an otherwise straightforward procedure [69].

Different materials for sealing the oval window in stapes surgery exist, both autologous and heterologous, all with advantages and drawbacks. The principal autologous are fat, vein, fascia, perichondrium, and blood clot. The most widely used are heterologous represented by hyaluronic acid, gelatin sponge, and the acellular porcine-derived matrix [69].

Fat is seen as a practical and effective option for sealing, being both cost-effective and stable over time, with outcomes similar to other autologous tissues like vein and fascia. The use of vein grafts, which are compatible with middle ear mucosa and stable over the long term, is well-established. Veins are traditionally harvested from the wrist or hand, but using the superficial temporal vein offers better cosmetic results and convenience by utilising the same operative site [69]. Gelfoam, introduced by House for stapes surgery [70], is easy to handle and widely available. It does not require an additional surgical incision, thus reducing surgical time and associated risks. However, it can cause adhesions and fibrosis, especially in inflamed or exposed mucosa. Some studies have shown no significant difference between using Gelfoam and not sealing at all, leading some practitioners to stop using it. Autologous materials such as perichondrium and fascia are also cost-effective and compatible with the middle ear, although harvesting these tissues can extend the duration of surgery [69]. There are concerns about the chondrogenic potential of perichondrium, but these can be mitigated with proper handling. Scarpa et al. found that hearing outcomes and vestibular complication rates are similar regardless of the sealant used, suggesting that the choice of material should be based on the surgeon's preference, as no clear evidence favours one material over another [69]. The authors of the present review drop only a blood clot to seal the footplate.

Special conditions

Age – Stapes surgery is a safe and effective treatment for any age, once stapes fixation is confirmed. There is not a superior [71] or inferior [72] age limit for undergoing such a procedure.

Chefs and sommeliers – Stapes surgery should be carefully counselled in chefs and sommeliers due to the risk of permanent taste disorders. Alternative treatments like hearing aids should be considered. If surgery is chosen, patients must be informed of the potential loss of work function [73].

Aviation – Thiringer and Arriaga studied 16 US Air Force aircrew members who returned to flight duty post-stapedectomy without complications [74]. Katzav et al. reported similar success in Israeli Air Force pilots [75]. While military pilots in Brazil are deemed unfit post-surgery, civil aviation does not restrict stapedectomy, although those with permanent vestibular disorders cannot be certified [76].

Diving – Scuba diving may increase the risk of perilymphatic fistula and prosthesis displacement. Studies show no significant risk, but 54.3% of surgeons recommend permanent diving restrictions after stapes surgery. Despite some postoperative otologic symptoms, no strong evidence links these to diving [76,77].

Conclusions

This narrative review on stapes surgery provides an overview of this surgical procedure, highlighting both historical and modern advancements. Below are some personal considerations based on the comprehensive content presented. The historical evolution of stapes surgery is a testament to the relentless pursuit of medical innovation. Starting from Valsalva's initial identification of stapes fixation to Shea's introduction of the Teflon prosthesis, each advancement has been built on the shoulders of previous discoveries. The shift from microscopic to endoscopic techniques represents an appreciable technological step. Endoscopy offers certain advantages, but also has some limitations, such as reduced depth perception and the need for one-handed operation.

The choice of technique for creating the footplate hole, whether using manual perforators, microdrills or lasers, remains a topic of debate. While microdrills offer precision and reduced operation times, they carry risks such as vestibular penetration. On the other hand, lasers minimise mechanical trauma but present challenges like potential overheating and higher costs. The variety of prosthetic designs, dimensions and materials reflects the complexity and individuality of medical practice. The fact that no single type or material has emerged as superior underscores the importance of a personalised approach. Surgeons must weigh the benefits and drawbacks of each type of prosthesis based on the specific patient characteristics, as well as their own surgical experience. The advancements in design of the prosthesis, particularly the move towards lighter and more biocompatible materials, and the possibility of self-crimping technologies, have not only enhanced the functionality of this surgical procedure, but also reduced the risk of complications. The ongoing evolution of stapes surgery is a reminder that medical practice is never static, and that continuous improvement is vital for achieving the best possible patient outcomes. It is also important to underline the importance of historical knowledge, technological innovation, and ongoing research in the field, which is essential for practitioners to provide the highest standard of care in otologic surgery.

Conflict of interest statement

The authors declare no conflict of interest.

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Author contributions

LB, FL, ADV: conceived the initial idea for the narrative review and developed the structure of the article; FF, SB: performed the literature review and critically analyzed the sources. All authors contributed significantly to drafting the manuscript, revising it for important intellectual content, and approving the final version to be submitted. Each author has read and agreed to the published version of the manuscript.

Ethical consideration

Not applicable.

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