Innovations in stapes surgery

Doctoral (PhD) Thesis

Author: Alexandros Koukkoullis MD

Doctoral School Leader: Lajos Bogár med. habil. PhD

Program Leader: András Vereczkei med. habil. PhD

Supervisor: Péter Révész MD, PhD

Doctoral School of Clinical Medical Sciences
Medical School, University of Pécs, Hungary

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1 ABBREVIATIONS

ABG:	air-bone gap
AC:	air conduction
BAHA:	bone anchored hearing aid
BC:	bone conduction
CBCT:	cone beam computed tomography
CI:	confidence interval
HRCT:	high resolution computed tomography
I-S:	incudostapedial
LP:	long process
NOS:	Newcastle-Ottawa scale
OR:	odds ratio
PRISMA:	preferred reporting items for systematic reviews and meta-analysis
PTA:	pure tone audiometry
SD:	standard deviation

SSCDS:	superior semicircular canal dehiscence syndrome
VEMP:	vestibular evoked myogenic potential
VSB:	vibrant sound bridge
WMD:	weighted mean difference

2 OTOSCLEROSIS/ OTOSPONGIOSIS

2.1 EPIDEMIOLOGY/PATHOPHYSIOLOGY

Otosclerosis is an autosomal-dominant hereditary disease with variable penetrance and expression. It is the most common cause of progressive conductive hearing loss in adults, and two-thirds of those affected are women. The disease, which can start in the early twenties, affects the otic capsule (the bone that surrounds the inner ear the cochlea and semi-circular canals) by remodelling it (spongification). This in turn can cause fixation of the stapes to the wall of the otic capsule resulting in a conductive hearing loss. This is progressive and usually affects both ears.

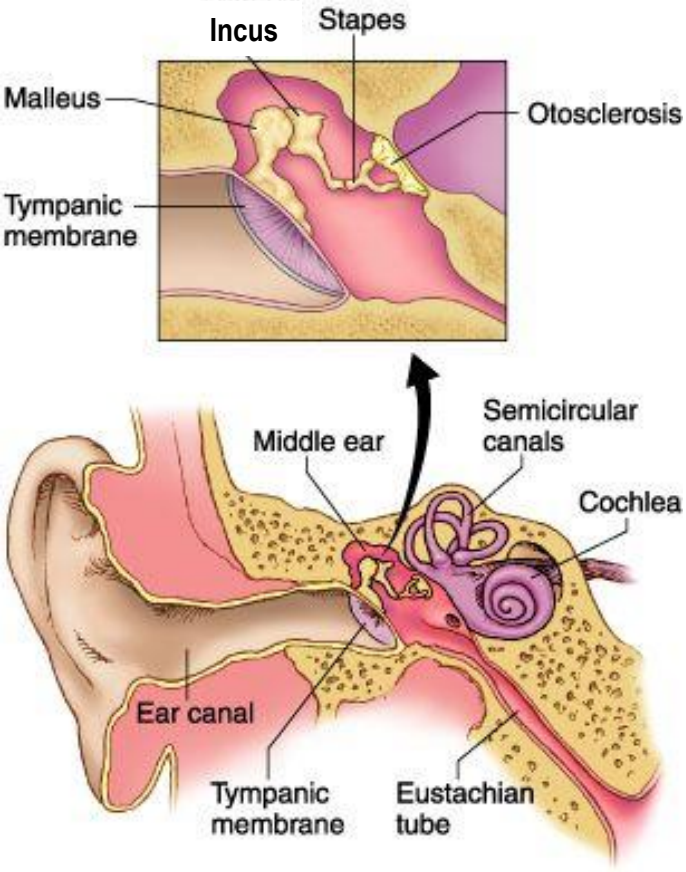


FIGURE 1: Basic anatomy of the ear with otosclerosis. The stapes is the last bone in the ossicular chain and the smallest of the body. Its footplate is connected to the inner ear via the oval window of the bony labyrinth. Otosclerosis begins on the bony labyrinth and expands on to the footplate and crura of the stapes.

2.2 DIAGNOSIS

Patient history is the first indication, but clinical examination is unhelpful as the disease is behind the tympanic membrane. The main diagnostic tools are hearing tests and stapedial reflex examination which show a mainly conductive hearing loss and absent stapedial reflex due to ossicular bone fixation. Hearing loss can be sometimes mixed or rarely sensorineural, depending on the location of the lesion and stage of the disease. Vestibular evoked myogenic potential can be performed to rule out superior semicircular canal dehiscence syndrome. Imaging can offer some additional information about the location and extent of the disease and exclude other pathology.

2.3 TREATMENT

Stapes surgery is the main procedure used to treat advanced disease. Depending on whether the stapes footplate is removed or not, the procedure is called stapedectomy or stapedotomy respectively.

Patients with early disease can be monitored with periodic hearing tests, and they can be offered external hearing aids for additional support until surgery is indicated.

Patients who do not want stapes surgery or for whom surgery is contraindicated can be treated with external or implanted hearing aids.

3 STAPES SURGERY

3.1 MOBILIZATION AND EARLY STAPEDECTOMY

Surgery was initially focused on remobilising the ossicular chain by intra-operative manipulation of the stapes. In certain cases, the stapes was removed entirely (early stapedectomy). Pioneers included Kessel from Germany, Boucheron and Miot from France, Blake and Jack from the US, and Faraci from Italy. However, any improvement was short lived as the abnormal bone would grow back again and fix the stapes, once more. In addition, the force needed to mobilise the stapes in advanced cases, and the lack of antibiotics at that time

resulted in a high rate of complications and mortality. As a result, the procedure was abandoned.

3.2 FENESTRATION

It was Lempert who popularised stapes surgery once more. He perfected the surgical techniques of Bárány and Sourdille which focused on bypassing the stapes fixation to the natural oval window by creating another one (fenestration) on the otic capsule. However, this worked only for about two thirds of the patients.

3.3 INTRAOPERATIVE SELECTION AND THE REDISCOVERY OF MOBILIZATION

Rosen further improved the technique by intra-operatively selecting on whom to perform the fenestration by confirming the fixation of the stapes. While attempting to confirm fixation in a patient, he accidentally mobilised the stapes. The patient's hearing improved dramatically and Rosen rediscovered mobilization of the stapes as a treatment.

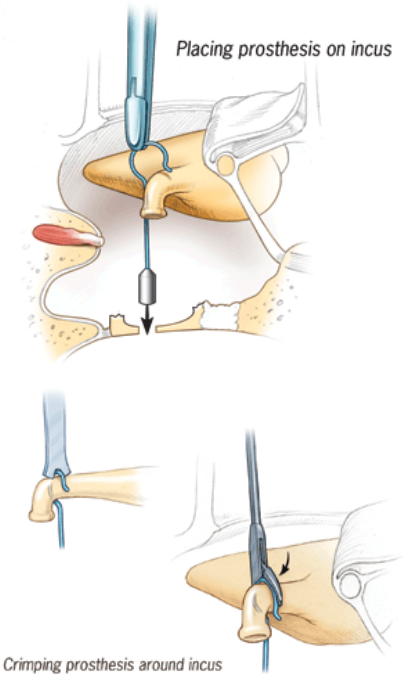
3.4 STAPEDECTOMY

Shea added the last piece of the puzzle by removing the entire stapes with the footplate (like Kessel) and replacing

it with a Teflon prosthesis. Stapedectomy is still used today for advanced cases but less frequently.

3.5 STAPEDOTOMY

In stapedotomy a hole is made on the footplate instead of removing it with the stapes and has reduced complications.



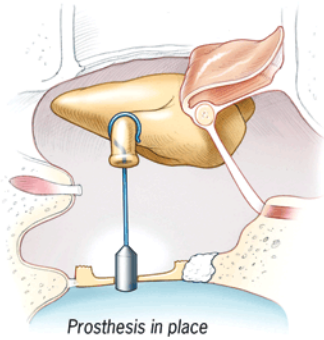


FIGURE 2: The basic steps of placing stapes prosthesis with crimping.

4 MAJOR INNOVATIONS IN STAPES EAR SURGERY

4.1 THE MICROSCOPE

Undoubtedly the most important innovation in ear surgery, it was only after 1950 that became widely used. In 1951, Hans Littmann of the Zeiss Company developed a new microscope by partially collaborating with Horst Wullstein and Fritz Zollner on new techniques in tympanoplasty and ossicular reconstruction. This new microscope could be mounted on a fixed stand (rather than the patient) with a mobile arm, allowing for fine

movement. The light source was in the coaxial plane (eye level without obstructing the view), had a selective magnification and a working focal length of 20cm (which could be changed to 25cm). This model (Zeiss Model I) was so successful that all subsequent models are based on it. It allowed for the development of tympanoplasties and stapes surgery.

4.2 THE PROSTHESIS

It all began in 1956 with Shea's newly devised microsurgical technique, the stapedectomy. The basic physical requirement of a stapes prosthesis is to achieve a secure connection between the mobile incus and the sealed perilymph in the oval window. It must be long enough to stay in the fenestra but short enough not to intrude excessively within the vestibule and risk injury to the otolith organs. The stapes prosthesis has changed shape over the years with improvements in surgical technique, and with innovations in surgical materials.

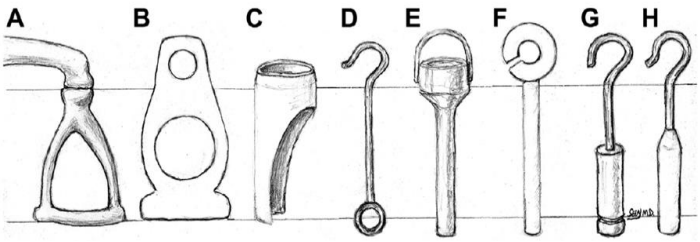


FIGURE 3: Different prosthesis over the years. Early and representative stapes prostheses. (A) Human stapes and incus long process; (B) first stapes prosthesis, Shea and Treace, carved Teflon fluoroplastic; (C) Shea strut, polyethylene; (D) House wire loop, stainless steel; (E) Robinson bucket handle, titanium; (F) fluoroplastic loop; (G) platinum wire hook, stainless steel piston; and (H) nitinol wire hook and fluoroplastic piston.

4.3 THE LASER

The main tool used to create fenestration in the oval window was the surgical pick whose precision was very operator dependent. A stapedotomy could change into either partial or total stapedectomy as the footplate might fracture during fenestration. However, the microdrill and the laser have since improved on this precision with more accurately created windows for a better fitting with the prosthesis.

The laser microscope was first developed and used by Rodney C. Perkins in 1980s who used it to vaporize the

stapes tendon, the posterior crus and a rosette of holes in the stapes footplate in the surgical treatment of otosclerosis. He used an autogenous vein—stainless steel piston assembly to reconstruct the stapes portion of the ossicular chain.

According to literature ‘the ideal laser for stapes surgery should have high bone ablation efficiency, small tissue penetration depth to avoid damaging the underlying structures, low transfer of heat to the surrounding tissue and no or minimum acoustic side-effects (due to rapid and explosive vaporization)’.

In addition, they need a precise delivery method, such as the fibre optic cable, and visibility.

5 OBJECTIVE

Innovations in surgical techniques happen constantly, improving the operating and patient experience while meeting, or even surpassing, established surgical outcomes. The endoscopic approach and the NiTiBOND stapes prosthesis are two such innovations in stapes

surgery. Every innovation, to demonstrate its effectiveness and usefulness, needs to be validated by comparing it to the established conventional method. Our objectives were to evaluate the endoscopic approach and the NiTiBOND stapes prosthesis and provide the necessary information to help in their validation, and in their consideration for utilization in surgery.

6 ENDOSCOPIC VS. MICROSCOPIC STAPES SURGERY OUTCOMES: A META-ANALYSIS AND SYSTEMATIC REVIEW

6.1 INTRODUCTION

Although the endoscope has been used for surgery for decades, it's only recently been introduced as an alternative viewing apparatus for middle ear surgery. The endoscope can offer a close-up view of the stapes footplate, with minimal drilling of the external auditory canal and reduced manipulation of the chorda tympani nerve. In addition, there is no need for any external incisions. However, the endoscope is not without its

drawbacks which include the loss of three-dimensional vision and the use of one hand, resulting in surgeons being reluctant to change from the microscope because of a possible long learning curve (Figure 4).

6.2 AIM

The aim of this study was to systematically review the literature for studies that compared endoscopic with microscopic stapes surgery to perform a meta-analysis to test our hypothesis that endoscopy performs better than microscopy on certain standard clinical outcomes.

6.3 METHOD

Performed a systematic review and meta-analysis as per PRISMA guidelines for studies that compared endoscopic stapes surgery with microscopic stapes surgery. Only studies that met predetermined criteria were selected and assessed for bias and quality. Primary outcomes: ABG and chorda tympani nerve injury. Secondary outcomes: Average operating time, tympanic membrane (TM) perforation and postoperative taste disturbance, pain and dizziness. We calculated pooled OR with 95% CI for dichotomous outcomes and WMD with 95% CI for

continuous outcomes. I^2 and chi^2 tests were used to quantify statistical heterogeneity. We used funnel plots to look for publication bias and performed a sensitivity analysis.

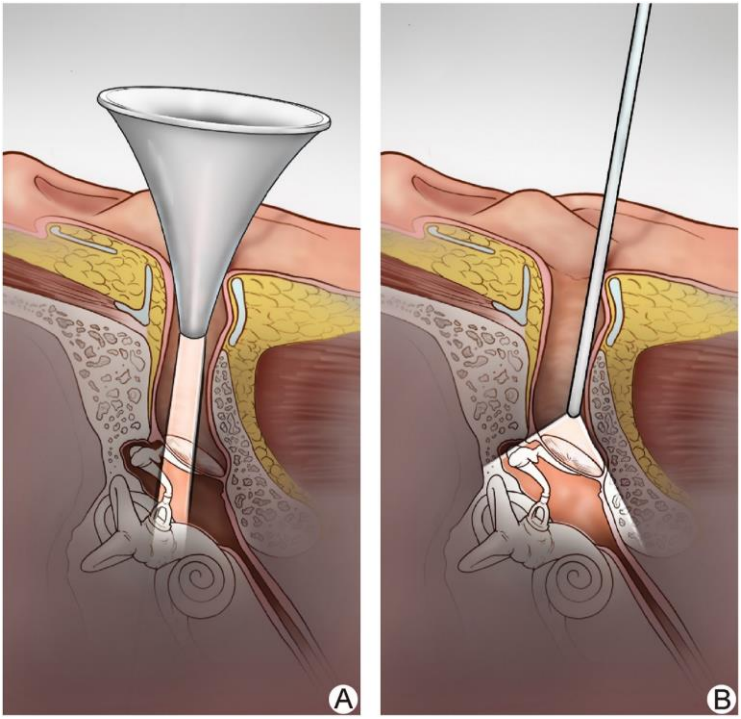


FIGURE 4: Anatomy illuminated by microscope versus endoscope. A: The size and shape of the external auditory canal and speculum limit the microscopic view. B: The endoscopic image is captured in close proximity to the surgical field with a wide-angle lens, overcoming many of the anatomic limitations of the microscope.

6.4 RESULTS

The search yielded a total of 3017 articles of which 6 non-randomized cohort studies were eligible. Outcomes were divided into primary and secondary depending on the impact on the surgical success.

6.4.1 Primary outcomes

Post-operative ABG <10 dB; OR = 1.80 [95% CI 95% CI: 1.55 – 7.93].

6.4.2 Secondary outcomes

Change in taste; OR=2.36 [95% CI: 1.01 – 5.51]. Average operation time; WMD = 0.14 [95% CI, -11.69 - 11.98]. Tympanic Membrane Perforation: OR=1.70 [95% CI: 0.44 – 6.58]. Pain; OR= 0.84 [95% CI: 0.36 – 1.96]. Post-operative Dizziness: OR=2.15 [95% CI: 0.94 – 4.89].

6.5 DISCUSSION

Our study was the first to systematically review and perform a meta-analysis between these two approaches. It had concluded that the hearing outcomes of the endoscopic approach are similar to those of the microscope, validating the endoscope as an alternative. The main advantage of the endoscope over the microscope

is the better visualization of the middle ear structures, requiring less bone removal and chorda tympani nerve manipulation. This means the patient is less likely to experience post-operative taste disturbance, dizziness and pain. In addition, we found statistically significant evidence that with the endoscopic approach there was a less likely injury to the Chorda Tympani nerve and to subsequently in post-operatively taste disturbance. Operating time and accidental tympanic membrane perforation were also similar and more likely to be associated with the operating surgeon's skills at that the time of the study. The learning curve of transiting from the microscope to the endoscope was again similar to that of learning the microscopic approach and should encourage surgeons to train to utilize the new approach.

7 COMPARING INTERMEDIATE-TERM HEARING RESULTS OF NITIBOND AND NITINOL PROSTHESES IN STAPES SURGERY

7.1 INTRODUCTION

Thermal shape-memory nickel-titanium alloy stapes prosthesis has been used for more than a decade now in stapedotomy, with studies showing equal and sometimes superior hearing outcomes to older types. Their main advantage is that they offer crimp-free coupling as opposed to manual crimping, resulting in less damage to the incus and less chance of incus luxation. The loop of the newer, structurally improved thermal-shape memory NiTiBOND (Kurz, Germany) piston has a daisy shape form, which results in reduced coverage of the surface of the long process of the incus when compared with the crosier-shaped SMart Nitinol piston (Olympus, USA). When closed, the Nitinol prosthesis covers almost two-thirds of the mucosal surface of the long process, while the NiTiBOND covers significantly less. The NiTiBOND loop has four integrated contact zones, conforming to the asymmetrical dimensions of the incus. Additionally, the

loop also features three independent activation zones which keep thermal transfer from the mucosa surface during laser activation. These activation zones can be sequentially closed producing a custom coupling to the individualized incus (Figure 5).

FIGURE 5: The two different types of prostheses. Nitinol (A) and NiTiBOND (B).

7.2 AIM

The aim this study was to compare the hearing thresholds following the application of a self-crimping heat-memory NiTiBOND piston or a Nitinol piston in the long term in two cohort of patients. Our hypothesis was that the NiTiBOND is superior to the Nitinol prosthesis in the long term.

7.3 METHOD

This was a retrospective study of hearing thresholds of two cohorts that underwent stapedotomy for stapes fixation at our centre. NiTiBOND prosthesis (n=53) was used in one cohort group and Nitinol (n=38) in the other group. We calculated the statistical difference with a univariate analysis between the pre- and post-operative values in the NiTiBOND group (p1), the statistical difference between the pre- and postoperative values in the Nitinol group (p2), the statistical difference between the two groups' preoperative values (p3) and the statistical difference between the two groups' the postoperative values (p4).

7.4 RESULTS

The average follow-up time for the NiTiBOND and Nitinol groups was 4.1 and 4.4 years respectively. A p value < 0.05 was statistically significant. The difference in postoperative ABG $\leq$10 dB ($p = 0.620$). The mean difference in ABG ($p1 < 0.001$, $p2 < 0.001$, $p3 = 0.631$, $p4 = 0.647$). The 4-frequency BC threshold ($p1 = 0.076$, $p2 = 0.129$. $p3 < 0.001$, $p4 = 0.005$). The mean 4-

frequency AC threshold (p1 < 0.001, p2 < 0.001, p3 = 0.043, p4 = 0.041). The mean 3-frequency (1, 2 and 4 kHz) BC threshold preoperatively (p1 = 0.639, p2 = 0.495, p3 = 0.001, p4 = 0.01). The mean AC threshold at 4 kHz (p1 < 0.001, p2 < 001, p3 = 0.03 p4 = 0.058). The results were consistent after adjustment for cofounders in 2 multivariant analysis.

7.5 DISCUSSION

Our paper is the first to compare the audiological results of Nitinol vs NiTiBOND prosthesis with the longest follow-up period up to date. It has shown comparable audiological outcomes at an average 4.1 and 4.4 years postoperatively for NiTiBOND and Nitinol respectively. We have demonstrated similar audiological outcomes in the short-term when comparing the prostheses in 2016. However, much larger patient cohorts are needed for an evaluation of long-term prosthesis stability. The intermediate-term postoperative mean ABG <10 dB achieved with the NiTiBOND piston in our study is similar to those reported by both the *Roosli* and *Green* studies. The ratio of postoperative ABG closure achieved

was comparable with the data demonstrated by other authors reporting intermediate- or long-term results following the implantation of Nitinol prosthesis.

8 NOVEL FINDINGS

Our two studies succeeded in their aim to provide the scientific and medical community with additional, more robust information on whether these two new innovations in stapes surgery can be considered as effective as their conventional counterparts. Furthermore, our research has found deficiencies in the methodology of studies and gaps in knowledge that lead to new research goals.

8.1 THE ENDOSCOPIC APPROACH VS THE MICROSCOPE

We were the first to pool the data of several studies and to improve the strength of their results when comparing the two methods. This has allowed us to confirm or reject the findings of each individual study, which sometimes contradicted each other and caused confusion. In addition, we have given gravitas to the validity of any positive findings.

Our evidence supports and re-enforces the findings that endoscopic surgery hearing outcomes are similar to the microscope, and therefore confirms the endoscope as a valid alternative. In addition, our evidence has confirmed the main benefit of the endoscope is its ability to look past structures that would otherwise obstruct view of the microscope. This allowed less manipulation of the chorda tympani nerve resulting in fewer nerve injuries and taste disturbances and would be preferable in cases where the opposite nerve has been damaged due to illness or surgery in the past.

We cannot not support with our evidence that endoscopic surgery would cause less dizziness, pain or tympanic membrane perforations. Unfortunately, we could not answer the question of which surgery was quicker as the evidence was not sufficient. Similarly, we could not verify that endoscopic surgery requires less bone removal although this is another one of its advantages.

The operating time and hospital stay are very important factors in both surgical and patient experience as well as for hospital costs. They need to be evaluated as

microscopic approach stapedectomy by certain surgeons can be done with patient awake, completed under 30 minutes and same day discharge. Can the endoscopic approach be performed the same way?

8.2 NITINOL VS NITIBOND STAPES PROSTHESIS

We are the first to have provided evidence of long-term hearing level outcomes for both prostheses and to compare those outcomes. Our evidence supports that over 4 years both prostheses perform similarly, validating the use of the NiTiBOND as an alternative. Hearing has not been reduced within those years which could indicate that:

- There is no displacement of the prostheses
- There is no incus necrosis
- The disease (otosclerosis) has not affected the prostheses

On reflection, imaging might have provided further information on the above deductions. However, this would require ethical approval as justification for Computer Tomography, which is the preferred modality,

carries significant radiation exposure. It is a research goal worth exploring.

9 PUBLICATIONS

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