Stapedial surgery in otosclerosis: analysis of results and prognostic factors

Original Article

Authors

Diogo Valente Dias
Serviço de Otorrinolaringologia da Unidade Local de Saúde da Região de Aveiro, Portugal; Centro Académico Clínico Egas Moniz, Portugal

Miguel Padrão
Serviço de Otorrinolaringologia da Unidade Local de Saúde da Região de Aveiro, Portugal; Centro Académico Clínico Egas Moniz, Portugal

Margarida Bulha
Serviço de Otorrinolaringologia da Unidade Local de Saúde da Região de Aveiro, Portugal; Centro Académico Clínico Egas Moniz, Portugal

José Romão
Serviço de Otorrinolaringologia da Unidade Local de Saúde da Região de Aveiro, Portugal; Centro Académico Clínico Egas Moniz, Portugal

Luísa Azevedo
Serviço de Otorrinolaringologia da Unidade Local de Saúde da Região de Aveiro, Portugal; Centro Académico Clínico Egas Moniz, Portugal

Correspondence:
Diogo Valente Dias
diogovalentedias@gmail.com

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Abstract

Otosclerosis corresponds to a localized disorder of bone metabolism, which develops in the otic capsule. It is responsible for the development of conductive hearing loss, with stapedial surgery being considered the gold standard therapeutic intervention. The goal of the present study was to evaluate the outcomes of stapedial surgery, aiming to identify prognostic factors. A descriptive, cross-sectional, and retrospective study was designed and conducted on a cohort of patients with a diagnosis of otosclerosis (N=98).

The following variables were analyzed: age at the time of surgery, sex, bilaterality of disease, presence of Carhart's notch, type of prosthetic material used, presence of anatomical variations, intraoperative complications, audiometric results, and functional success. The overall rate of functional success (defined as an average air-bone gap < 15 dBHL) was 89.80% (n = 88). Regarding audiometric results, air conduction thresholds (PTA 500, 1000, 2000, and 4000 Hz) improved from 55.14 ± 1.42 to 32.00 ± 2.01 dBHL ($p < 0.001$, paired t-test), and bone conduction thresholds (PTA 500, 1000, 2000, and 4000 Hz) changed from 25.98 ± 1.07 to 24.09 ± 1.33 dBHL ($p = 0.270$, paired t-test) between preoperative and postoperative values. The air-bone gap decreased from 29.16 ± 0.79 to 7.91 ± 0.88 dBHL ($p < 0.001$, paired t-test) between the preoperative and postoperative periods.

In our study, the only variable that significantly influenced the primary outcome (functional success) was the presence of anatomical variations and/or intraoperative complications, which were negatively correlated with functional success.

Stapedotomy/stapedectomy is an effective procedure with high rates of functional success. The presence of anatomical variations and/or intraoperative complications is a predictor of lower audiometric gain and less surgical success.

Keywords: Otosclerosis; stapedotomy; stapedectomy; stapes surgery.

Introduction

Otosclerosis is a localized bone metabolism disorder caused by autoinflammatory processes and affects the otic capsule. This osteodystrophic process, characterized by dysregulated osteoclastic and osteoblastic activity, leads to the replacement of compact cortical bone with foci of spongiotic or sclerotic bone, ultimately resulting in the fixation of the stapes footplate to the oval window.[1]

This condition is one of the leading causes of conductive hearing loss in young adults.[2,3] Furthermore, it can lead to sensorineural hearing loss[4] due to the progressive involvement of the cochlea, particularly the cochlear endosteum, spiral ligament (which undergoes atrophy),[5] and stria vascularis, with subsequent dysfunction of the hair cells.[6]

Stapes surgery is the standard therapeutic intervention for managing otosclerosis and is considered the state-of-the-art surgical treatment of this condition.[7]

However, there are ongoing debates regarding the accurate identification of prognostic factors and parameters that substantially influence audiometric outcomes, including the dimensions of the prosthetic material and potential impact of the Carhart notch.

This study aimed to evaluate the outcomes of stapes surgery, in addition to identifying the key prognostic factors.

Materials and methods

This descriptive, cross-sectional, and retrospective study evaluated patients who were diagnosed with otosclerosis and underwent stapes surgery at our hospital between 2013 and 2023. Data were collected by reviewing the digital clinical records.

The diagnosis of otosclerosis was established based on the following criteria: normal otoscopy findings, conductive hearing loss with an air conduction pure-tone average (PTA) ≥ 30 decibels (dB) (frequencies of 0.5, 1, 2, and 4 kHz), preoperative air-bone gap (ABG) ≥ 15 dB, and type A or As tympanogram with an absent stapedial reflex.[8]

The exclusion criteria were revision surgery, fluctuating hearing loss (with or without vertigo), chronic otitis media, intraoperative findings indicating conductive hearing loss, or dehiscence of the superior semicircular canal. All patients underwent pure-tone audiometry within three months preoperatively and six months postoperatively. Audiometric results were based on the PTA of frequencies 0.5, 1, 2, and 4 kHz.

The surgical procedure was performed under general anesthesia by an otorhinolaryngologist. A fluoroplastic (Teflon) prosthesis of varying length and diameter was used in all surgeries. The transcanal technique was used, which involved the creation of a tympanomeatal flap and use of a Portmann ear speculum holder . After entering the tympanic cavity, the chorda tympani nerve was anteriorly-inferiorly folded, followed by curettage of the posterior-superior aspect of the annulus bone at the notch of Rivinus. Ossicular chain mobility was checked, if required. If the malleus and incus were mobile and the stapes was immobile, a stapedotomy was performed. After sectioning the stapes tendon, the stapes superstructure was removed and a small fenestra was created in the stapes footplate using a microdrill. After the necessary measurements, a Teflon piston was placed between the stapedotomy fenestra and long process of the incus using a prosthesis gauge. The mobility of the remaining chain and prosthesis was then verified.

The main outcome evaluated was functional success, defined in this study as a mean ABG < 15 decibels hearing level (dBHL).

The following parameters were evaluated and their association with functional success was analyzed: age at surgery; sex; bilaterality of the disease; presence of a Carhart notch; characteristics and dimensions of the prosthesis (length of 4, 4.25, 4.5, 5, and 6 mm and diameter of 0.4, 0.5, and 0.6 mm); anatomical variations and intraoperative complications (e.g., narrowing of the oval window niche, obliteration of the stapes footplate, dehiscence of the facial nerve over the oval window, accidental platinectomy,

and conversion to stapedectomy); pre- and postoperative audiometric outcomes; and functional success (average ABG < 15 dBHL). To determine the presence of a Carhart notch, we used the technique proposed by Lamblin et al.,[9] which involves identifying a cochlear notch at various frequencies (ranging between 0.5–2 kHz). The Carhart notch was defined as an impairment in the bone conduction threshold ≥ 7.5 dB for the notch frequency (0.5, 1, or 2 kHz) above the average bone conduction thresholds at the adjacent frequencies. Additionally, the notch frequency threshold had to be higher than the thresholds of the adjacent frequencies to prevent overestimation.

Results

A total of 98 ears underwent surgical intervention. The average age of the patients was 48 years (range 27–74 years). Women constituted 70.4% (n = 69) of the sample, while men accounted for 29.6% (n = 29). The disease was bilateral in 66.3% (n = 65) patients and unilateral in 33.7% (n = 33). A summary of the patient characteristics is presented in Table 1.

We identified seven cases (7.1%) with anatomical variations or intraoperative complications. Among them, two cases (2.0%) were of accidental platinectomy, necessitating conversion to stapedectomy; one case (1.0%) presented with obliterative otosclerosis; another case (1.0%) showed significant narrowing of the oval window niche; and two cases (2.0%) exhibited dehiscence of the facial nerve over the oval window (Table 2).

In audiometric terms, air conduction thresholds (PTA 500, 1000, 2000, and 4000 Hz) decreased from 55.14 ± 1.42 preoperatively to 32.00 ± 2.01 dBHL postoperatively (p < 0.001, paired samples t-test), while the bone conduction thresholds (PTA 500, 1000, 2000, and 4000 Hz) decreased from 25.98 ± 1.07 preoperatively to 24.09 ± 1.33 dBHL postoperatively (p = 0.270, paired samples t-test). The ABG decreased from 29.16 ± 0.79 preoperatively to 7.91 ± 0.88 dBHL postoperatively (p < 0.001, paired samples t-test), as shown in Table 3.

Age at surgery, sex, bilaterality of the disease, and presence of a Carhart notch demonstrated no significant effects on the rate of functional success, with the correlation

Table 1
Patient characteristics

	N = 98 (procedures)
Age (years) Min. Max.	48 (average) 27 74
Male sex	29 (29,6%)
Laterality Bilateral Unilateral	 65 (66,3%) 35 (35,7%)

Table 2
Cases with anatomical variations or intraoperative complications

	Description
Case 1	Obliterative otosclerosis
Case 2	Presence of abundant adhesions between the oval window, stapes, pyramidal eminence, and facial canal
Case 3	Dehiscence of the facial nerve and narrowing of the oval window niche, requiring drilling of the promontory to approach the oval window
Case 4	Reduced diameter of the external auditory canal requiring canalplasty via an endaural approach
Case 5	Facial nerve dehiscence with partial overlap over the oval window
Case 6	Accidental platinectomy (conversion to stapedectomy)
Case 7	Accidental platinectomy (conversion to stapedectomy)

The overall surgical success rate was 89.80% (n = 88).

Table 3
Audiometric outcomes

	N = 50 (procedures)
Functional success	88 (89,90%)
Air conduction thresholds (PTA 500, 1000, 2000, and 4000 Hz) Preop Postop	 55,14 ± 1,42 dBHL 32,00 ± 2,01 dBHL
Bone conduction thresholds (PTA 500, 1000, 2000, and 4000 Hz) Preop Postop	 25,98 ± 1,07 dBHL 24,09 ± 1,33 dBHL
ABG Preop Postop	 29,16 ± 0,79 dBHL 7,91 ± 0,88 dBHL

ABG, air-bone gap; Preop, preoperative; Postop, postoperative; PTA, pure tone average

Table 4
Correlation between the analyzed parameters and functional success

Parameter		Rate of functional success	Correlation matrix value (Spearman correlation)	p-value (chi-square test)
Age at surgery	54 - 74 years	80,8%	- 0,016	0,163
	47 - 54 years	100%		
	42 - 47 years	88,5%		
	27 - 42 years	90,9%		
Sex	Male	89,7%	0,003	0,976
	Female	89,9%		
Laterality of the disease	Bilateral	92,3%	0,116	0,253
	Unilateral	84,8%		
Presence of a Carhart notch	Yes	89,6%	0,007	0,946
	No	90,0%		

Table 5
Correlation between delta ABG and diameter and length of the prostheses

Parameter	Correlation matrix value	p-value
Diameter	- 0,025	0,81
Length	- 0,127	0,212

matrix values being close to zero and p-values > 0.05 (Table 4). On analyzing the relationship of surgical success with the diameter and length of the prostheses used, no positive or negative effects were observed. This was reflected by the absence of a significant correlation between these parameters and the continuous distribution variable delta ABG, defined as the difference between the pre- and postoperative ABG (postoperative ABG - preoperative ABG) (Table 5).

On analyzing the effect of the Carhart notch on bone conduction, an improvement of 0.975 ± 1.852 dBHL was observed in the bone conduction PTA between the pre- and postoperative periods when the Carhart notch was present. In contrast, in the absence of a Carhart notch, the improvement was 2.833 ± 1.669 dBHL, but this difference showed no statistical significance (p = 0.459, *t*-test).

In our study, the only parameter that significantly influenced the primary outcome

of functional success was the presence of anatomical variations or intraoperative complications. These factors were negatively correlated with functional success (p = -0.248, p = 0.016), and the functional success rate was only 66.7% in patients with these conditions, compared to 92.1% in patients without these conditions.

Discussion

This retrospective study analyzed patients who underwent stapes surgery at our hospital to identify the predictors of surgical success or failure and critically assess the clinical practices currently employed at our institution.

Our case series of 98 ears showed high functional success rates, consistent with the results reported in the literature. The average postoperative ABG was 7.91 ± 0.88 dBHL, with a surgical success rate of 89.80%. These results align with the findings of previous studies.[10,11]

Furthermore, as documented in previous studies, our findings revealed a predominance of female patients and patients with bilateral disease.[3] However, age at surgery, sex, and laterality of the disease did not considerably influence the functional outcomes.

The only parameter that significantly affected functional success in our study was the presence of anatomical variations or intraoperative complications. These factors correlated negatively with functional success, resulting in less effective ABG closure. The observed anatomical variations included one case of obliterative otosclerosis (1.0% of the sample). The condition accounts for 1–33% of all otosclerosis cases and is generally associated with poorer audiometric outcomes.[12] We also identified one case of significant narrowing of the oval window niche (1.0%) and two cases of facial nerve dehiscence overlapping the oval window (2.0%). The review of the literature revealed comparable incidence rates for these anatomical variations, with narrowing of the oval window niche occurring in 2.6–31% of patients with otosclerosis[13] and dehiscence of the facial nerve over the oval window occurring in a high percentage of individuals without otological pathology.[14] Previous studies have also claimed that these anatomical variations pose additional surgical challenges and are associated with reduced audiometric gains. Nevertheless, stapes surgery is still associated with functional improvement in such cases.[15] In two cases of accidental platinectomy requiring conversion to stapedectomy, we achieved satisfactory functional outcomes, with postoperative ABG closure of 1.25 and 5 dbHL. These results demonstrate the effectiveness of stapedectomy, despite larger studies recommending stapedotomy as the preferred technique.[16]

Some studies have also reported the positive effect of the prosthesis diameter on audiometric outcomes, with larger diameters yielding better results, as revealed in a meta-analysis by Laske et al.[17] This improvement is hypothesized to result from a greater cross-sectional area of contact between the prosthesis and vestibule, leading to greater volume displacement and enhanced energy transmission. However, in our study, the prosthesis diameter and length did not significantly influence audiometric outcomes (correlation values of -0.016 and -0.145, respectively; p > 0.05).

The Carhart notch, first described in 1950, is characterized by a reduction in the bone conduction threshold at approximately 2 kHz. This phenomenon results from the immobilization of the stapes footplate at the oval window and subsequent disruptions in ossicular chain resonance.[18] These disruptions affect all three bone conduction pathways described by Tondorf in 1968,[19] bone to cochlea, bone to middle ear and then cochlea, and bone to external auditory canal to middle ear and then cochlea. The greatest contribution comes from the middle ear ossicular resonance, particularly at a frequency of around 2 kHz. Recent studies have examined the prognostic value of the Carhart notch as a predictor of unfavorable outcomes, particularly for cochlear reserve closure and improvement in postoperative bone thresholds.[20,9] However, our results did not support this hypothesis, as

the presence of the Carhart notch did not lead to significant differences between the pre- and postoperative bone conduction PTA.

Conclusion

Our study demonstrates that stapedotomy and stapedectomy are effective surgical procedures, yielding high functional success rates and significant improvements in hearing by reducing auditory thresholds. The presence of anatomical changes or intraoperative complications is a predictor of reduced audiometric gain and surgical success.

Conflict of Interests

The authors declare that they have no conflict of interest regarding this article.

Data Confidentiality

The authors declare that they followed the protocols of their work in publishing patient data.

Human and animal protection

The authors declare that the procedures followed are in accordance with the regulations established by the directors of the Commission for Clinical Research and Ethics and in accordance with the Declaration of Helsinki of the World Medical Association.

Privacy policy, informed consent and Ethics committee authorization

The authors declare that they have obtained signed consent from the participants and that they have local ethical approval to carry out this work.

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Scientific data availability

There are no publicly available datasets related to this work.

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