ORIGINAL ARTICLE

Study of the Improvement in Bone Conduction Threshold After Stapedectomy

Leire García-Iza, * Juan José Navarro, Miren Goiburu, Nuria Pérez, Xabier Altuna

Servicio de Otorrinolaringología, Hospital Universitario Donostia, San Sebastián, Spain

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Abstract

Introduction and objectives: Bone conduction threshold depression is not always a result of inner ear and cochlear nerve pathology. In fact, middle ear pathologies may be responsible for such threshold depression, as occurs in otosclerosis. The aims of this study were to evaluate the improvement of bone conduction threshold in patients with otosclerosis that underwent stapedectomy and to study the postoperative audiological results.

Materials and methods: This was a retrospective study on 95 patients (116 ears) diagnosed with otosclerosis having conductive or mixed hearing loss that received surgery (stapedectomy and complete removal of the footplate) consecutively. Audiometry was performed on all patients pre- and postoperatively (one month and one year after surgery). Bone and air conduction thresholds were measured at 4 frequencies (500, 1000, 2000 and 4000 Hz).

Results: The air-bone gap was closed, with a residual air-bone gap below 10 dB in 92.2% of the patients and below 5 dB in 79.3% of the cases. The air conduction threshold improved an average of 25 dB. The patients that had an affected bone conduction threshold preoperatively improved bone conduction postoperatively at the frequencies of 1000 and 2000 Hz (6 and 12 dB, respectively). Consequently, the Carhart notch disappeared on the audiogram. These results were maintained at one year of follow up.

Conclusions: We found a significant improvement in the bone conduction threshold at the frequencies of 1000 and 2000 Hz and a disappearance of the Carhart notch in the audiogram after stapedectomy and total footplate removal in patients diagnosed with otosclerosis having mixed hearing loss.

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KEYWORDS

Otosclerosis; Stapedectomy; Audiometry; Bone conduction

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* Corresponding author.

E-mail addresses: leire.garcia.iza@gmail.com, leire.gartzi.i@gmail.com (L. García-Iza).

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Evaluación del cambio en el umbral de la vía ósea en pacientes operados de estapedectomía

Resumen

Introducción y objetivos: La alteración del umbral auditivo de la vía ósea no solo corresponde a enfermedad localizada en el oído interno y nervio coclear, sino que puede ser secundaria a enfermedad presente en el oído medio, como ocurre en la otosclerosis.

El objetivo de este estudio es analizar el resultado audiológico posquirúrgico y evaluar el efecto de la estapedectomía en el umbral auditivo de la vía ósea en pacientes con otosclerosis.

Material y métodos: Estudio retrospectivo de 95 pacientes (116 oídos) con hipoacusia de transmisión mixta, diagnosticados de otosclerosis e intervenidos de forma consecutiva con la misma técnica de estapedectomía con platinectomía total. Se realizó audiometría tonal de las frecuencias 500, 1.000, 2.000 y 4.000 Hz para la vía aérea y ósea en todos los casos de forma pre- y posquirúrgica (al mes y al año del procedimiento).

Resultados: Se obtuvo un cierre del umbral diferencial de audición, con un valor residual < 10 dB en el 92,2% de los pacientes y < 5 dB en el 79,3%. La ganancia media obtenida en la vía aérea fue de 25 dB. Los pacientes con afectación preoperatoria de la vía ósea mostraron una mejoría significativa en las frecuencias 1.000 (6 dB) y 2.000 (12 dB), con desaparición del escotoma de Carhart. Estos resultados se mantuvieron sin cambios al año de seguimiento.

Conclusiones: Comprobaron una mejoría significativa en la vía ósea en las frecuencias 1.000 y 2.000 Hz, con desaparición del escotoma de Carhart tras estapedectomía en pacientes diagnosticados de otosclerosis que presentan hipoacusia mixta.

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Introduction

It has been observed after years of study of the pathophysiology of sound, that the integrity of different interrelated structures is required to ensure the correct functioning of air conduction (AC) and bone conduction (BC). The correct functioning of AC depends on the integrity of a series of elements such as the external auditory canal, the tympanic membrane and the ossicular chain. Historically bone conduction depression was explained by a lesion in the inner ear and the cochlear nerve. However, a drop in the hearing threshold of bone conduction is not always indicative of a lesion in the inner ear, but can be caused by disease in the middle ear. Therefore, 5 factors have been described which help to maintain the integrity of BC: external auditory canal, ossicular chain inertia, inertia of the cochlear fluids, compression of the cochlear walls and transmission of the pressure of cerebrospinal fluid. Of these 5, the integrity of cochlear fluid inertia seems to be of greatest relevance. The role of the external auditory canal is more obvious at bass frequencies, lower than 1000 Hz, while the role of cochlear fluid inertia is very important at frequencies lower than 4000 Hz. This explains that a reduction in BC threshold, at the heart of a disease which principally affects the middle ear such as otosclerosis, might be resolved after this disease has been treated surgically. This phenomenon was described by Carhart more than 50 years ago.

Otosclerosis is a bone disease which can result in conductive, mixed or sensorineural hearing loss. The objective of surgery for otosclerosis (stapedectomy/stapedotomy) is to close the air-bone gap (ABG) by removing anomalous foci of ossification in the footplate and restoring the correct transmission of sound, and has a high success rate. However, taking the aforementioned physiology of BC into account, several studies have demonstrated an improved BC threshold after stapedectomy or stapedotomy in patients diagnosed with otosclerosis and presenting mixed hearing loss.

The objective of this study was to evaluate postsurgical hearing outcomes in patients with conductive or mixed hearing loss diagnosed with otosclerosis that underwent stapedectomy with total footplate removal, and to study the progress of BC in patients who started out with previously altered BC.

Materials and Methods

We performed a retrospective clinical study which included 95 adult patients (116 ears) attended at the otology clinics of the Hospital Universitario Donostia and operated consecutively over a period of one year.

All of the patients had the following inclusion criteria: conductive hearing loss or mixed hearing loss with a clinical diagnosis of otosclerosis, treated surgically by 2 different surgeons, with the same surgical technique, as described below. In the cases where both ears met the inclusion criteria, each ear was treated separately.

Patients with different surgical findings that required a surgical technique other than the one described, such as fixation of the ossicular chain secondary to tympanosclerosis or with congenital anomalies or erosion of the incudostapedial
joint, were excluded from the study. None of our patients had been operated previously for any middle ear disease.

The mean follow-up time was 12 months for all the patients in the sample, except for 8, who were lost during the year of follow-up.

The Student's $t$-test was used to compare the quantitative variables and $P$ values lower than .05 were considered significant.

### Surgical Technique

Surgery took place under local anaesthesia and sedation in all cases. The flap was elevated at its posterior half via the endomeatal approach and Rosen's incision. After reducing the bony framework, the incudostapedial joint was then separated, and the footplate perforated, platinotomy, the superstructure of the stapes was extracted after sectioning the tendon, and the entire footplate was removed. Finally the tragal perichondrium that had been removed was placed over the oval window. Polyethylene prostheses were used in all cases in the study.

Patients that required prostheses with different characteristics and that were operated during the months over which the data were collected were excluded from the study.

### Demographic Data

Our sample's demographic characteristics are shown in Table 1. Only 18% of the cases was operated bilaterally. The fact that there were so few patients operated bilaterally is explained by the mean follow-up time of 12 months, since the contralateral intervention was not performed until 12-18 months after the first surgery.

Hearing loss was the most frequent reason for consultation.

### Audiological Study

A pre and post-operative audiometric assessment (at one month and at one year) was made of all the patients in the study. A Grason Stadler GSI 61 audiometer was used in the study, calibrated in 2015. Tonal audiometry of AC and BC was undertaken at frequencies of 500, 1000, 2000 and 4000 Hz. The presurgical ABG was calculated and the resulting postoperative ABG at one month after surgery in all cases. The 108 ears were measured again one year after the operation. During this time 8 were lost. We tested the net decibel (dB) gain obtained in each of the patients, both for AC and BC at each of the described frequencies comparing the preoperative audiometry with the final postoperative audiometry in each case.

### Results

#### General Results

Firstly, the results of all the patients in the study were analysed together in Table 2 and Fig. 1.

We noticed a significant gain ($P<.05$) in AC at the frequencies measured, from a pre-operative pure-tone average (PTA) of 52 dB and with an average of 27 dB from the first post-operative follow-up. This gain was maintained over time.

As all the patients were included in the same study group, in other words, without making distinctions between those who presented BC depression and those who did not, we started with a mean BC within normal levels (27 dB), therefore a significant post-operative improvement (post-operative average 25 dB) in this BC threshold was not noted. No case of cophosis or significant decrease in BC was observed in this series of 116 ears either.

The pre-operative ABG was 25 dB, with practically complete post-operative resolution from the first follow-up (mean post-operative ABG of 1.8 dB); this outcome was maintained over time ($P<.05$). According to pre-established criteria, a post-operative ABG of <10 dB was considered a therapeutic success. In our series, this outcome was achieved in 92.2% of the patients, with a ABG of <5 dB in 79.3% of cases (n: 92).

Table 2 also shows us the average hearing gain achieved, which was 23 dB from the first follow-up, maintained over time.

Fig. 1 shows the mean hearing gain obtained at each of the frequencies under study. The first audiogram (Fig. 1a) reflects the pre-operative situation, where the difference between AC and BC is evident. The second audiogram (Fig. 1b) reflects the results at one month, and the third (Fig. 1c) the results at one-year follow-up, where we can see almost complete resolution of the ABG, without observing a significant variation of BC.

### Outcomes of Patients With Preoperatively Depressed Bone Conduction

We performed a comparative study of the gain obtained in BC. To that end, we divided the patients into 2
subgroups, according to whether or not they had preoperative CO depression, defined by a threshold of 30 dB or less at 2 frequencies at least.

A comparison was made of the mean age of both subgroups without finding significant differences, in order to avoid bias which might indicate that the decrease in BC was due to age. In the group with normal pre-operative BC, the mean age was 46.7 (SD 11.7) and in the group of patients with depressed BC it was 47.7 (SD 10.9).

We did not observe significant variations in subsequent audiometries in the patients who had previously normal BC (pre-operatively 24 dB; post-operatively 23.8 dB).

However, we did find interesting audiometric variations in the patients who started with previously depressed BC.
average outcomes obtained at each frequency under study are shown in Table 3 and Figs. 2 and 3, showing that the frequency presenting the greatest depression was 2000 Hz, corresponding to Carhart’s notch. The gain achieved for the 1000 Hz frequency was a mean 6 dB (pre-operatively 32.6 dB; post-operatively 25.8 dB); an average gain was achieved of 12 dB at 2000 Hz frequency (pre-operatively 39.1 dB; post-operatively 27.9 dB). This gain was maintained at one-year follow-up. Both outcomes are statistically significant ($P<.05$).

No significant audiometric variation was found at 4000 Hz frequency (pre-operatively 31 dB; post-operatively 32.9 dB).
Table 4  Comparison of the Different Audiological Data From Published Articles.

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>n</th>
<th>Follow-up time</th>
<th>Pre-operative audiometry (dB)</th>
<th>Post-operative audiometry (dB)</th>
<th>dB mean gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vijayendra&lt;sup&gt;10&lt;/sup&gt;</td>
<td>2011</td>
<td>100</td>
<td>3-6 months</td>
<td>PTA: 22.4</td>
<td>PTA: 11.1</td>
<td>11.3</td>
</tr>
<tr>
<td>Yazdi&lt;sup&gt;11&lt;/sup&gt;</td>
<td>2009</td>
<td>84</td>
<td>One year</td>
<td>PTA: 36.7</td>
<td>PTA: 25.5</td>
<td>11.14</td>
</tr>
<tr>
<td>Aarnisalo&lt;sup&gt;12&lt;/sup&gt;</td>
<td>2003</td>
<td>142</td>
<td>6 months</td>
<td>500 Hz: 19.7</td>
<td>1000 Hz: 29.1</td>
<td>4.5-11.3</td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td>2000 Hz: 31.1</td>
<td>1000 Hz: 19.3</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>4000 Hz: 28.4</td>
<td>4000 Hz: 31.5</td>
<td></td>
</tr>
<tr>
<td>Mokhtarinejad&lt;sup&gt;15&lt;/sup&gt;</td>
<td>2013</td>
<td>83</td>
<td>One year?</td>
<td>500 Hz: 17.5</td>
<td>1000 Hz: 19</td>
<td>1.85</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2000 Hz: 25.5</td>
<td>2000 Hz: 19.2</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>4000 Hz: 23</td>
<td>4000 Hz: 24.7</td>
<td></td>
</tr>
<tr>
<td>Moscillo&lt;sup&gt;17&lt;/sup&gt;</td>
<td>2005</td>
<td>110</td>
<td>3 years</td>
<td>500 Hz: 18.5</td>
<td>1000 Hz: 22</td>
<td>7.1/4</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>2000 Hz: 32</td>
<td>2000 Hz: 25</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>4000 Hz: 26</td>
<td>4000 Hz: 26.5</td>
<td></td>
</tr>
<tr>
<td>Garcia-Iza&lt;sup&gt;15&lt;/sup&gt;</td>
<td>2015</td>
<td>116</td>
<td>One year</td>
<td>500 Hz: 27.75</td>
<td>1000 Hz: 32.65</td>
<td>5.33</td>
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<td>P&lt;.05)</td>
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<td></td>
<td></td>
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<td>2000 Hz: 39.18</td>
<td>2000 Hz: 27.93</td>
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<td></td>
<td>4000 Hz: 31.43</td>
<td>4000 Hz: 32.93</td>
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</tr>
</tbody>
</table>

n, number of patients; PTA, pure tone average.

Figure 3  Outcomes of bone conduction in patients with previously normal bone conduction (conductive hearing loss).

Fig. 2 shows the audiograms for the audiometric variations in the subgroup of patients with pre-operatively depressed BC (Fig. 2a), at one month (Fig. 2b) and at one year (Fig. 2c) after the intervention. We observed a significant improvement (>5 dB) achieved at the 1000 Hz-2000 Hz frequencies, and the aforementioned Carhart’s notch disappeared. The patients who completed the year’s follow-up (94%) maintained these outcomes.

The most common post-operative complication was vertigo and transient disequilibrium in the early post-operative period, which was recorded in 2 of the 116 cases (1.72), with no repercussions on hearing, and which disappeared in the days following surgery. The tympanic cord was sectioned in 2 patients (1.72%), with the consequent symptoms. There were no cases of cophosis, facial paralysis, tympanic perforation, infection or extrusion of the prosthesis.

Discussion

Many studies throughout the years have demonstrated that stapedectomy is a useful and valid tool for the recovery of AC hearing threshold and to reduce the ABG in patients with otosclerosis, with a high success rate.<sup>10,11</sup> Several studies have observed that in patients with otosclerosis, BC thresholds also improve after surgery and Carhart’s notch (2000 Hz) disappears in the majority of cases post-operatively.<sup>10,11,13,15</sup> Carhart was the first to define this phenomenon, and demonstrated how fixation of the stapes footplate brought about decreased BC in these patients, with the appearance of the familiar notch at 2000 Hz frequency and its resolution after surgery.<sup>7</sup>

Different studies on the physiology of BC have demonstrated how the variations in its threshold are not limited exclusively to involvement of the middle ear; they can also be artefacts of lesions in the middle ear affecting mobility of the stapes footplate which affects the inertia of the ossicles, and the inertia of the cochlear fluids.<sup>5,14</sup>

The percentage of post-operative improvement of BC threshold differs in the various studies published (Table 4). In the study by Mokhtarinejad et al.,<sup>15</sup> an improvement in BC threshold was observed at all frequencies between 500 and 4000 Hz, with a significant increase at 2000 Hz alone. Awen et al.<sup>16</sup> observed an improved BC threshold of a mean 5 dB-6 dB for the 500, 1000 and 2000 Hz frequencies. The best outcomes were presented at the 2000 Hz frequency, and worsened at 4000 Hz frequency. Yazdi et al.<sup>15</sup> showed improved BC thresholds slightly above those of previous studies. This might be because in this study the variation in BC was assessed only in patients with mixed hearing loss.
Seventy-five percent of patients presented an improved BC threshold with mean improvement of 15.6 dB at 3 frequencies and of 19.8 dB at 2000 Hz frequency in 23 of their 62 patients. Vijayendra et al., observed a mean improved BC threshold of 11.1 dB, with an improvement in BC of 15 dB or more at 2 frequencies at least between 500 and 4000 Hz in 60% of their patients. Aarnisalo et al. demonstrated a mean increase in BC of 4.5 dB after stapedectomy. In their study, Moscillo et al. observed an improved BC threshold after stapedectomy of a mean 4 dB and 7.1 dB, according to the technique used in each case; this improvement was more evident in young patients.

In our study, we divided our patients into 2 subgroups, according to whether or not they had presented presurgical depression of BC (an outcome of 30 dB or more at 2 frequencies at least of between 500 and 4000 Hz). In order to assess a change in the depression in patients diagnosed with otosclerosis that underwent stapedectomy. In the patients that presented mixed hearing loss, a significant improvement (P<.05) was observed in BC at all frequencies, except 4000 Hz. A hearing gain of a mean 6 dB was obtained for 1000 Hz frequency, and a mean 12 dB at 2000 Hz frequency, with disappearance of Carhart’s notch. No significant audiometric variation was observed at 4000 Hz frequency (pre-operatively 31 dB; post-operatively 32 dB).

This improvement could be explained by the resolution of hypertension in the labyrinthine fluids due to compression of the otosclerotic foci, resolved after their removal by stapedectomy. This is evident at 500–2000 Hz frequencies, without significant impact at higher frequencies.

Aarnisalo et al. observed a decrease of a mean 0.9 dB at one-year follow-up. However, the effect of presbycusis on deteriorated BC needs to be evaluated, irrespective of the influence of otosclerosis. In our series the gain was maintained at one-year follow-up, without observing a reduction.

With regard to the choice of surgical technique, we opted for stapedotomy based on the available references and after several reviews of our own outcomes, we chose total stapedotomy, in order to achieve the best hearing improvement for both BC and AC.

Conclusions

We observed in this study that stapedotomy with complete footplate removal achieved the objective of restoring AC and closure of the pre-operative ABG in patients with otosclerosis, obtaining a mean residual ABG of below 2 dB. AC threshold improvement was a mean of 25 dB.

In addition, in patients with pre-operatively depressed BC, we observed an improvement in the threshold at 500 and 2000 Hz frequencies of a mean 6 dB and 12 dB respectively. These outcomes support the hypothesis that otosclerosis that affects ossicular inertia, footplate mobility and cochlear fluid inertia causes an audiometric depression in BC which can be resolved by surgery.

Conflict of Interests

The authors have no conflict of interests to declare.

References