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Hearing Results in 151 Primary Stapedotomies for Otosclerosis: The Effects of Using Different Audiologic Parameters and Criteria on Success Rates

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Objective: To describe the 151 hearing results of primary stapedotomy for otosclerosis using different criteria of success rates.

Design: Retrospective case series of 151 patients with a diagnosis of otosclerosis and operated on by the same surgeon with the same technique, using a CO_2 laser. Patients with revision surgery were excluded. The audiometric data were extracted from the patient files and divided into three groups: early postoperative follow-up (<1 mo after surgery), mid-term follow up (between 1 mo and 1 yr), and late postoperative follow-up (>1 yr).

Results: The postoperative air-bone gap (ABG) was 10 dB or less in 45.2% in the mid-term follow up. For this same follow-up, ABG closure less or equal than 20 dB was achieved in 95.6% of cases. The lower percentage of patients with a postoperative ABG closure of less than or equal to 10 dB can be due to the high rate of bone conduction (BC) overclosure of 15.65%. The functional success described as an air conduction (AC) threshold less than or equal to 30 dB was achieved in 52.2% of patients. The mean speech reception threshold (SRT) in the mid-term follow up was 27.4 dB. The analysis of the data according to the Amsterdam Hearing Evaluation Plots (AHEPs) shows a success rate of 87% at early follow-up.

Conclusions: The success rate is mainly dependent on the definition and criteria as a measure of success. An analysis of the evolution of the BC is mandatory to avoid a false positive success rate when the ABG closure is used. Therefore, the use of the AHEPs would acquire additional information. The hearing outcome has also been based on the speech audiometry and the number of patients achieving an AC less than or equal to 30 dB as a more realistic measure of success. Our series confirms good long term hearing results achieved in stapedotomy surgery with the CO_2 laser.

Key Words: Hearing results—Otologic surgery—Otosclerosis.

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Otosclerosis is hereditary temporal bone osteodystrophy, characterized by an increase in bone remodeling activity in the otic capsule. A reduced mobility or fixation of the stapes footplate results from this inflammatory reaction, with consecutive progressive conductive hearing loss with/without additional sensorineural component (1–3). The involvement usually starts around the oval window, in the fissula ante fenestram and spreads to the annular ligament, the anterior crura of stapes, and the footplate. Anterior progression of the disease toward cochlea may cause sensory-neural hearing loss (SNHL) (4). Tinnitus and vertigo are also frequently reported symptoms.

Otosclerosis is more common among women and Caucasians. The etiology is assumed to be multifactorial. The influence of genetics is well established, but there is no firm etiological role for hormonal substances, viral

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Statement of ethics: The study has been approved by the Ethical Committee of C.H.U. UCL Namur, site Godinne, Belgium (Approval Numbers:185/2019) and has been performed in accordance with the ethical standards. As is involved in a retrospective study, formal consent is not required.

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agents, auto-immunity, mechanical stresses, or vasomotor disequilibrium. This disease is often bilateral and is diagnosed when there is a hearing loss with a conductive component in the presence of an intact tympanic membrane (1,2,4,5).

High-resolution computed tomography (HRCT) scan can be used as an additional diagnostic tool for otosclerosis, revealing a hypodensity in the anterior part of the footplate in most cases. This imaging is also mandatory to exclude other causes of conductive hearing loss with intact tympanic membrane such an ankylosis of the malleus or a semi-circular canal dehiscence for example.

The prevalence of clinical otosclerosis is 1% among the European population (6,7). Consequently, it is among the most common causes of acquired conductive hearing impairment after chronic otitis media (5).

Three different cornerstones of treatment are available for clinicians: a ''wait and see'' strategy, prescription of hearing aids, and surgery. Primary stapes surgery performed for otosclerosis is a well-established procedure with excellent postoperative outcomes and low risk of complications (8).

The committee on Hearing and Equilibrium of the American Academy of Otolaryngology–Head and Neck Surgery (AAO-HNS) proposed guidelines to provide more uniformity in reporting hearing results. One of the proposals was to include the hearing thresholds at high frequency (3 kHz) in a four-frequency pure-tone average (PTA) and to use postoperative bone-conduction (BC) levels rather than preoperative BC levels in describing postoperative air-bone gap (ABG) (7,9). Surgical success is defined as a postoperative ABG less or equal than 10 dB in many studies. A cut-off at 20 dB postoperative ABG is often used. Like speech audiometry results, the functional success defined as an air conduction threshold (AC) less or equal than 30 dB postoperatively is rarely used. Another interesting way to show the hearing results is the Amsterdam Hearing Evaluation Plots (AHEPs) (7). It is an easily understood visual presentation of audiometric results of each case, as recommended by the AAO-HNS. Moreover, another advantage of reporting data with these plots is that favorable and unfavorable results concerning surgical success can easily be identified. Additionally, ears with cochlear damage caused by surgery can be recognized (10).

This retrospective study aimed to evaluate the effects of stapedotomy on the audition in a consecutive series of 151 operations performed by the same surgeon with the same technique.

MATERIALS AND METHODS

Study Design

A retrospective review of patients who underwent stapedotomy for otosclerosis with stapes fixation in our tertiary medical center.

Patients

A total of 151 procedures performed between May 2008 and June 2018 at the Department of Otorhinolaryngology of CHU UCL Namur University Hospital were included in this study. The patients were operated on by the same surgeon with the same technique under general anesthesia. Eighteen patients underwent bilateral surgery during the study period. The patient group consisted of 102 women and 49 men with a mean age of 46.9 years (range 18–74, SD ±11.4) at the time of their operation in our hospital. The distribution between left and right ears was approximately even (73 left ears and, 78 right ears).

The inclusion criteria were: 1) primary stapedotomy, 2) diagnosis of otosclerosis excluding other causes of stapes fixation, 3) CO_2 laser stapedotomy, 4) reconstruction with a Fisch-type piston prosthesis (Medtronic Xomed, Jacksonville, FL), 5) preoperative and postoperative audiograms performed at our institution, 6) diagnosis of conductive or mixed hearing loss.

After a Computer Tomography (CT) scan, a diagnosis of a semi-circular dehiscence was made in four of the cases. A CT scan routinely performed preoperatively in 119 cases and, in 12 of them, the imaging was available postoperatively. In most of the cases, a postoperative CT scan was performed to investigate a hearing loss in the opposite side of the surgery or, for revision surgery (five cases).

Surgical Procedure

All surgeries were performed using a transcanal approach under general anesthesia.

The stapedotomy was performed with the CO_2 laser. The laser was set to continuous wave mode (23 W) at a working distance of 275 mm. A laser beam with a 0.6 mm diameter was used for a 0.4 mm diameter prosthesis for the calibrated platinotomy. We used a Fisch-type piston combining a Teflon shaft with a platinum hook in all cases.

All ears underwent a small fenestra stapedotomy, however, in two cases, leading to a hemiplatinectomy. A total platinectomy wasn't observed in this series.

No cases of facial paralysis, dead ear, or chronic vertigo ears were encountered in this study. Revision surgery was necessary for 12 patients due to, most of the time, late hearing impairment (11/12).

Audiometric Assessment

The audiometric evaluation includes the preoperative and postoperative ABG, AC, BC, speech reception threshold (SRT), and word recognition score of 100% (WRS). Only AC and BC results that were obtained at the same time, postoperatively, were used for calculation of ABG as recommended by the Committee on Hearing and Equilibrium of the AAO-HNS (9).

Audiometry for pure tones and speech was performed following the ISO 8253-1 and 8253-3 standards, respectively. The pure-tone average (PTA) was calculated from thresholds at frequencies of 0.5, 1, 2, and 4 kHz in both AC and BC. The 3000 Hz frequency was not used as it is not constantly measured in Europe.

Speech audiometry was performed systematically for the preoperative and postoperative assessment. The SRT and the WRS were assessed using the French Fournier's disyllabic words list.

The audiometric data were extracted from the patient files and divided into three groups: early postoperative follow-up (<1 month after surgery), mid-term follow up (between 1 month and 1 year), and late postoperative follow-up (>1 yr).

A postoperative ABG of less than or equal to 10 dB is considered as a criteria of success in many studies and by The guidelines of the Committee on Hearing and Equilibrium of

the AAO-HNS (9). In the literature, a cutoff at 20 dB postoperative ABG is often used. Therefore, this study presents data divided into groups based on postoperative ABG: 0 to 10 dB, and more than 10 to 20 dB.

The ABG closure goal has to be obtained without postoperative BC deterioration at all frequencies. Moreover, after stapes surgery, we can see an improvement in BC thresholds due to the Carhart effect. Therefore, we describe the postoperative BC variation with the percentage of sensorineural hearing loss (SNHL) defined as a increase of BC threshold of more than 10 dB, and the rate of overclosure defined as a postoperative improvement of BC more than or equal to 10 dB.

The functional success defined as an AC threshold less than or equal to 30 dB postoperatively is also described.

Another interesting way to show the hearing results is the AHEPs.

In one plot, the results concerning postoperative BC thresholds are related to preoperative BC thresholds to evaluate the effect of surgery on BC. In another plot, the preoperative ABG levels are related to postoperative gain in AC to establish the degree of success regarding the restoration of the middle ear hearing transmission function.

In one graph, the two dotted diagonal lines enclose the area within BC that did not change more than 10 dB. Iatrogenic cochlear damage was defined as a postoperative decrease of the BC threshold of 10 dB or more, and it is indicated by every point above the upper dotted diagonal line. In contrast, every point below the lower dotted diagonal line can be considered as an improvement of the BC caused by the Carhart effect.

In the other graph, the horizontal axis represents the postoperative change in AC, and the vertical axis represents the preoperative ABG. The solid diagonal line indicates a total closure of the gap between preoperative AC and BC. Consequently, every point below the solid diagonal line indicates a gain in AC that is larger than one may expect from preoperative ABG, and such a result can be regarded as a successful result with overclosure. An unsuccessful operation result is defined as a negative change in the AC threshold or a change in AC that was not enough to close the gap between postoperative AC and preoperative BC to 20 dB or less. Every point above the dotted diagonal line indicates such an ''unsuccessful result.'' In contrast, every point below the dotted diagonal line can be considered as a ''successful result (10).'' Visual presentation of audiometric results of each case is some of the advantages of this method (10).

Statistical Analysis

Statistical analysis was performed using the R software (The R Foundation for Statistical Computing, Austria, Vienna, 2020, version 3.6.0).

To ensure that the ''lost to follow-up'' group did not bias study results, a mixed linear regression model was used to calculate the evolution of the average over the time, considering the initial score of each patient. The corrected averages are similar to the gross average, which is following the hypothesis that the initial characteristic of the patients not followed are similar to those followed up.

RESULTS

Audiological Data

The audiometric data have been extracted from the files and divided into three groups: early postoperative follow-up (<1 month after surgery) (N = 129), mid-term follow up between 1 month and 1 year (N = 119), and late postoperative follow-up after 1 year (N = 68).

Concerning the ABG, we see an early postoperative improvement of 16.1 dB (CI = [−17.5; −14.7]; p value of the progression = 0.0001). There is a slight improvement (1.6 dB) of the ABG after more than 1 month postoperatively (CI = [−19.2; −16.3]; p value of the progression = 0.0001), and the ABG remains stable after more than 1 year postoperatively (slight improvement of 0.53 dB; CI = [−19.8; −16.3]; p value of the progression = 0.0001).

We have found similar progression with the AC and the BC (Fig. 1):

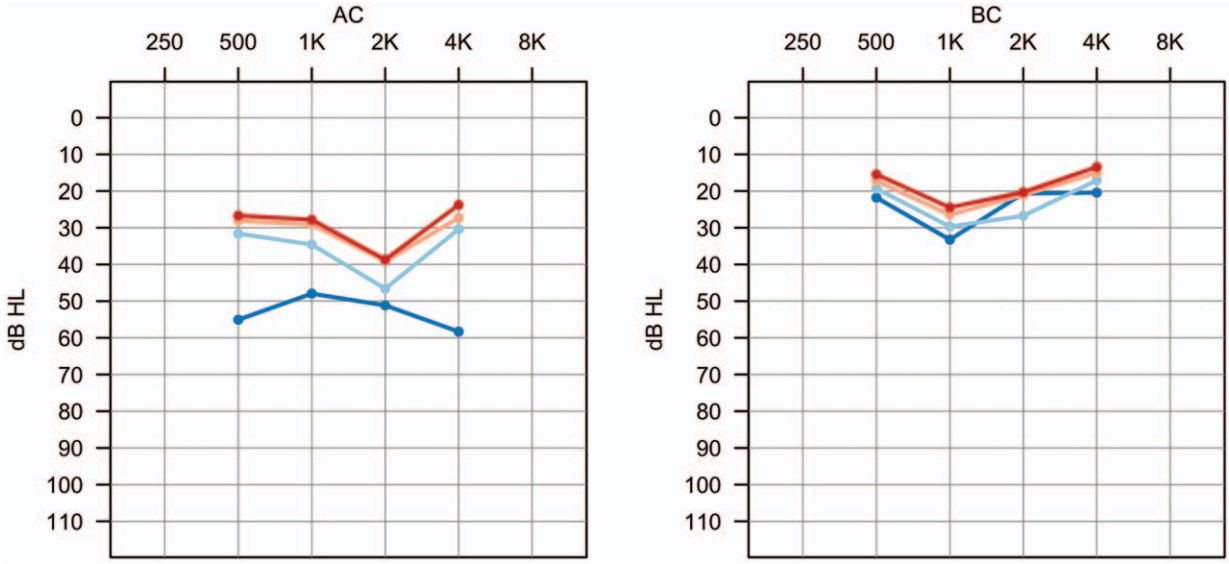

FIG. 1. Mean evolution of BC and AC preoperatively (dark blue), at early (light blue), middle (pink), and late follow up (red). AC indicates air conduction; BC, bone conduction.

1) The early improvement of the AC of 17.2 dB (CI = [−18.8; −15.7]; p value of the progression = 0.0001) increases by 4.7 dB after more than 1 month postoperatively (CI = [−23.5; −20.4]; p value of the progression = 0.0001), and it remains stable after more than 1 year postoperatively (slight improvement of 0.6 dB; CI = [−24.4; −20.5]; p value of the progression = 0.0001).
2) The early improvement of the BC of 0.9 dB increases (CI = [−2; 0.2]; p value fo the progression = 0.1257) by 2.8 dB after more than 1 month postoperatively (CI = [−4.9; −2.5]; p value of the progression = 0.0001), and it remains stable after 1 year postoperatively (slight improvement of 0.7 dB; CI = [−5.9; −3]; p value of the progression = 0.0001).

The audiometric results in pure tone audiometry are also detailed frequency by frequency in Figure 2.

ABG Closure

The postoperative ABG was 10 dB or less in 35.9% of cases early postsurgery, in 45.2% in the mid-term follow up and in 47.8% of cases in long-term follow-up. ABG closure within 20 dB was obtained in 90.63, 95.6, and 100%, respectively.

Postoperative Decrease in BC Threshold

One patient (0.87%) presented a persistent SNHL defined as a increase of BC threshold of more than 10 dB in a four-frequency pure-tone average (0.5, 1, 2, and 4 kHz) remaining at mid-term follow-up. A decrease of BC threshold of more than 10 dB is more frequent at 4000 Hz (11.3%) than at the other frequencies (3.5% at 1000 and 2000 Hz and 0% at 500 Hz). We noted that some patients had a transient SNHL at early follow (4.65% compared with 0.87% at mid-term follow-up). 19.13% of patients remained with a decrease of the BC of

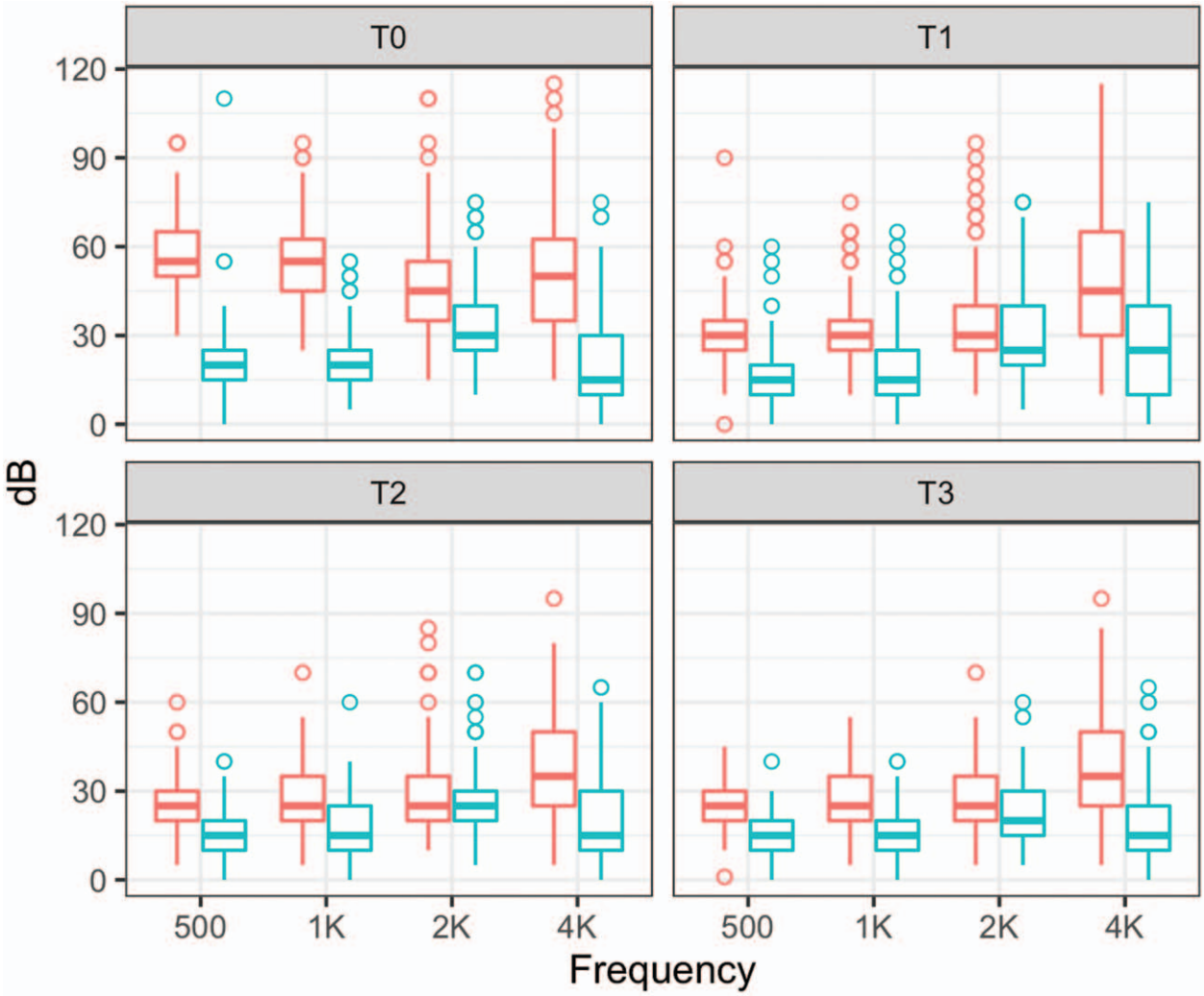

FIG. 2. Box plots of the BC (blue) and AC (red) at the four frequencies (500, 1000, 2000, and 4000 Hz). The result is provided preoperatively (T0), at early (T1), middle (T2), and late follow up (T3). The boxes show the median and 25 to 50% quartile, the whiskers represent 50 to 100% range, and the circles represent the outliers. AC indicates air conduction; BC, bone conduction.

10 dB or less at mid-term postoperative follow-up (27.91% at early postoperative follow-up).

Postoperative Improvement in BC Thresholds

The rate of BC overclosure amounted to 8.53, 15.65, and 16.42% at early, mid-term, and late follow up respectively. The highest percentage of overclosure is seen at 2000 Hz (48.7%), followed by 500 and 1000 Hz with 34.8 and 31.3%, respectively. At 4000 Hz, this improvement is seen in 13.9% of patients at mid-term postoperative follow-up.

An improvement of the BC of 5.39 dB at 500 Hz, 4.57 dB at 1000 Hz, 6.82 dB at 2000 Hz, and a slight decrease of 0.41 dB at 4000 Hz is seen at the mid-term follow up.

Functional Outcome

An AC threshold less than or equal to of 30 dB was achieved in 42.19, 52.2, and 62.7% of the cases at early, mid-term, and late follow up respectively, coming from 0.66% before surgery.

In this group of patients, we see that 32.7% had a BC between 0 and 20 dB, 43.6% between more than 20 and 30 dB, 12.7% between more than 30 and 40 dB, and 10.9% with a BC more than 40 dB at mid-term postoperative follow-up.

Effects of Stapedotomy on Speech Reception

The postoperative average WRS was 49 dB (CI = [−20.4; −16.5]; p value of the progression = 0.0001), 44.1 dB (CI = [−25.7; −21.7]; p value of the progression = 0.0001), and 44.7 dB (CI = [−25.1; −20.2]; p value of the progression = 0.0001) at early, mid-term, and late follow up respectively, compared with 67.4 dB preoperatively.

The postoperative average SRT 31.9 dB (CI = [−21.9; −18.2]; p value of the progression = 0.0001), 27.8 dB (CI = [−26.3; −22.5]; p value of the progression = 0.0001), and 28.4 dB (CI = [−25.4; −20.7]; p value of the progression = 0.0001) at early, mid-term, and late follow up respectively, compared with 50.9 dB preoperatively.

The percentage of patients understanding 100 and 50% of the words with a normal voice (≤55 dB) intensity or lower (≤40 dB) is 89.6 and 96.6%, respectively, at mid-term follow-up.

Hearing Results Evaluated With AHEPs

According to the AHEPs, the number of successfully operated ears concerning the AC is 112 over 128 patients (87%) at early follow-up. From this entire group of ears, 106 ears (82.3%) had a successful result without overclosure, and six ears (4.7%) had a successful result with overclosure. Eight ears (6.25%) with cochlear damage of 10 dB or greater could be defined as having an unsuccessful result. Eleven cases (8.6%) demonstrated a postoperative bone conduction threshold improvement of 10 dB or greater. Sixteen cases (12.5%) could also be defined as having an unsuccessful result concerning AC or due to a postoperative ABG of more than 20 dB (Fig. 3).

DISCUSSION

Primary stapes surgery is a commonly performed procedure that successfully improves hearing in most of the patients with otosclerosis.

The reporting of hearing results has standardizations to compare and analyze easily different studies with each other. Surgical success is defined as a postoperative ABG of 10 dB or less in many studies using the postoperative BC for the measure of the ABG. A review of recent studies demonstrated that ABG closure to within 10 dB was achieved in 56 to 94% of patients, as shown in Table 1. This definition of success has some imperfections, such as an underestimation of the postoperative ABG because of the phenomenon of overclosure and the inability to recognize postoperative changes in BC.

The lower success rate (45.2%) in our study compared with the results reported in the literature is probably due to the high rate of overclosure with a mean improvement

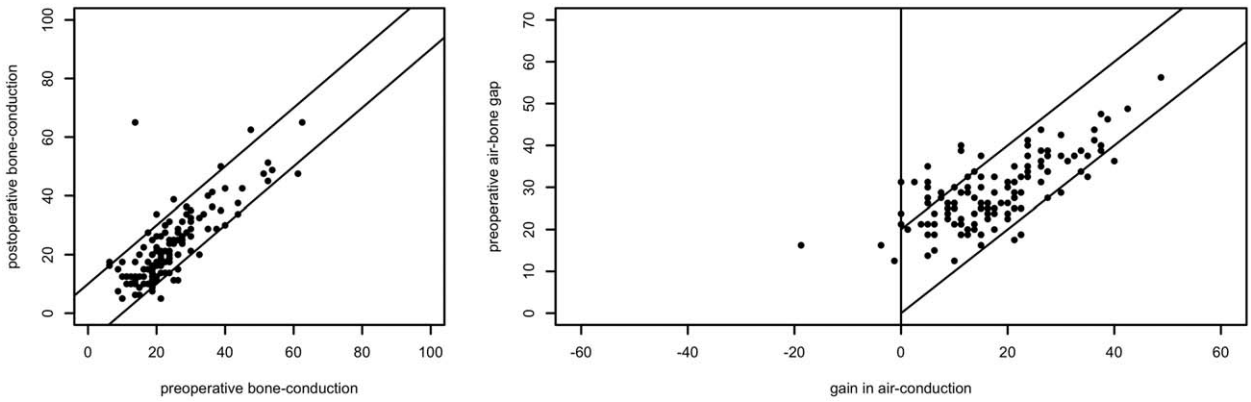

FIG. 3. Audiometric results of 129 stapes operations visualized with the AHEPs. Preoperative and postoperative BC plotted for individual ears. Postoperative gain in AC plotted against preoperative ABG for individual ears. ABG indicates air-bone gap; AC, air conduction; AHEPs, Amsterdam Hearing Evaluation Plots; BC, bone conduction.

TABLE 1. *ABG closure to within 10 dB in recent, comparable studies*

	N	ABG ≤ 10 dB (%)	Frequencies
Khorsandi et al. (1)	995	94	0.5–1–2–3 kHz[a]
Celso et al. (2)	210	88	0.5–1–2–3 kHz
Quaranta et al. (3)	2134	85	0.5–1–2–3 kHz[a]
Dhooge et al. (4)	230	77	0.5–1–2–3 kHz[a]
Szymanski et al. (5)	270	56	0.5–1–2–3 kHz
Vincent et al. (6)	3050	94	0.5–1–2–4 kHz[b]
Czerwińska et al. (7)	105	76	0.5–1–2–4 kHz
Kisilevsky et al. (8)	1145	75	0.5–1–2–4 kHz
Deniz et al. (9)	177	75	0.5–1–2–4 kHz
Bitterman et al. (10)	666	72	0.5–1–2–4 kHz
De Bruijn et al. (11)	473	71	0.5–1–2–4 kHz
Banerjee et al. (12)	100	62	0.5–1–2–4 kHz
Our results	119	45.2	0.5–1–2–4 kHz

[a]When not available, the pure tone threshold at 3 kHz was obtained from the mean of 2 and 4 kHz thresholds.
[b]In the study of Celso et al. (13) cases of postoperative SNHL were not included in the assessment of the postoperative ABG.
ABG indicates air-bone gap.

of the BC of 10 dB or more achieving 15.65% at mid-term postoperative follow up. The highest percentage of overclosure is seen at 2000 Hz (48.7%), followed by 500 and 1000 Hz with 34.8 and 31.3%, respectively. At 4000 Hz, this improvement is seen in 13.9% at mid-term postoperative follow-up. In the study of Vincent et al. (11), overclosure occurred in 98 cases over 2,527 (4%). Kisilevsky et al. (12) have shown a similar percentage of overclosure (5%). De Bruijn et al. report a level of overclosure of 15.1% (10). Postoperative improvement in BC thresholds in patients with otosclerosis was first described by Carhart. The cause of this phenomenon was hypothesized to be a reduction of ossicular chain inertia as a result of stapes fixation (12–14). Stenfelt (15) investigated middle-ear ossicular motion with air and bone conduction stimulation, and also found that the inertia of the ossicular chain contributes to the perception of BC sound mostly between 1.5 and 3.1 kHz. Our results concerning the evolution of the BC after the surgery are in agreement with those of other published series (Table 2).

We can also see in Figures 1 and 2 that the BC remains stable, and even more, improves slightly after more than 1 year postoperatively. This data is in agreement with the finding of Vincent et al. (11) describing that the deterioration in hearing with time after stapedotomy does not exceed the rate of hearing loss because of presbyacusis. Vartiainen et al. (14) and Dhooge et al. (2) describe similar results.

Success in ABG closure is frequency-dependent, being most prominent at low frequencies and almost disappearing at 4 kHz (12). In the study of Kisilevsky et al. (12), a comparison was made between the ABG at 0.5 to 2, 0.5 to 3, and 0.5 to 4 kHz. The inclusion of higher frequencies in the calculation of postoperative ABG did not influence ABG closure within 20 dB. ABG closure within 20 dB was achieved in about 97% of cases, for any frequency combination. When 4 kHz was included in the ABG calculation, the success rate of closure to less than 10 dB fell from 82 to 75% . Berliner et al. (16) have detected similar differences: frequencies included in averaging made little difference in the mean ABG. However, the success rate (gap $<$ or $=$ 10 dB) was lowered by 6% when 4 kHz was used in a four-frequency average rather than 3 kHz. Thereby, because stapes surgery is more likely to worsen high-frequency sensorineural hearing, the decision to include the 4000 Hz for the PTA may negatively bias our results to be more sensitive for SNHL. This deduction can partially explain the lower success rate in our study.

Performing stapes surgery for otosclerosis is known to be potentially irreversibly harmful to the inner ear function in approximately 1% of the cases, with hearing sensitivity at the higher frequencies being especially at risk. One patient (0.87%) presented a persistent SNHL at the mid-term follow-up. The presence of an SNHL is more frequent at 4000 Hz (11.3%) than at other frequencies (3.5% at 1000 and 2000 Hz and 0% at 500 Hz). We noted that some patients had a transient SNHL at early follow up (4.65% compared with 0.87% at mid-term follow-up). This temporary depression of the inner ear function has been reported in other studies. An early inflammatory reaction can be the cause of this transient BC deterioration (3,17–19). A decrease of the BC of 10 dB or less is seen in 27.91% of patients at early postoperative follow-up, and remains persistent at mid-term postoperative follow-up in 19.13%. The incidence of 0.87% of SNHL is in agreement with the literature where the percentage of SNHL in large studies varies from 0.5 to 4.1% (10,11,12,20,21). The frequencies used for the definition is variable from one study to another as it is also seen in the article of Wegner et al. (22).

TABLE 2. *Change in BC after stapes surgery, comparable studies*

	N	500 Hz	1000 Hz	2000 Hz	4000 Hz
Kisilevsky et al. (8)	1145	+1.9 dB	+2.1 dB	+4.7 dB	−1.4 dB
De Bruijn et al. (11)	451	+1.3 dB	+3 dB	+6.1 dB	+0.1 dB
Vartiainem et al. (13)	311	+4.1 dB	+6.6 dB	+8 dB	0 dB
Perez et al. (14)	99	+2.5 dB	+7.5 dB	+8.5 dB	+2.5 dB
Our results	151	+5.39 dB	+4.57 dB	+6.82 dB	−0.41 dB

+ indicates improvement; −, worsening; BC, bone conduction.

Other definitions of success must be taken into consideration, such as the functional success described as an AC threshold less than or equal to 30 dB, which were reported in a small number of studies. Whereas the postoperative ABG reflects the surgical effect, the postoperative AC was used to define the functional outcome for the patients. A postoperative AC less than or equal to 30 dB was achieved in 52.2 and 62.7% of patients at mid-term and late follow-up, respectively. In most ears not reaching functional hearing levels, SNHL was present preoperatively, and stapedotomy was mostly performed to allow the patient to efficiently wear a conventional hearing aid postoperatively. In the literature, we found a range from 63.9 to 68% of functional hearing (2,23).

Most reports are establishing postoperative hearing results by making use of parameters retrieved from pure tone audiometry. However, the essential goal of stapes surgery is to improve the aptitude of a person to understand the speech. In this respect, it is especially important to be informed about the effect of stapes surgery on speech discrimination. A good technical result (ABG $\leq$10 dB) is only relative when at the same time, deterioration in speech discrimination occurs after surgery (7). The mean SRT achieved at mid-term postoperative follow-up is 27.4 dB, which is also in agreement with the literature with a range from 23.9 to 48.8 dB (8,10,12). The percentage of patients understanding 100 and 50% of the words with a normal voice ($\leq$55 dB) intensity or lower ($\leq$40 dB) is 89.6 and 96.6%, respectively, at mid-term follow-up.

Another interesting way to show the hearing results is the Amsterdam Hearing Evaluation Plots. It is an easily understood visual presentation of audiometric results of each case, as recommended by the AAO-HNS. Moreover, another advantage of reporting data with these plots is that favorable and unfavorable results concerning technical success can easily be identified. Besides, ears with cochlear damage caused by surgery can be recognized (10).

With this analysis of the data, we achieve the success rate of 87% at early follow-up, which is in agreement with the literature (Table 3). This percentage is more favorable when compared with other criteria as measures of success, such as ABG closure of 10 dB or less or postoperative AC level of 30 dB or less. Our results were extracted from the analysis of the early postoperative follow-up, which can explain the higher rate of SNHL and the lower rate of successful outcomes with overclosure. We report 3.78% of transient SNHL if we compare the results of BC at early and mid-term follow-up. Moreover, the percentage of overclosure is 7.12% higher at the mid-term postoperative follow-up. De Bruijin et al. (10) have also found that, if PTA values at 0.5, 1, 2, and 4 kHz are compared with PTA values at 0.5, 1, 2, and 3, the percentage of ears with overclosure decreases by 0.67%, whereas the failure rate increases by 0.89% in statistical analysis with the AHEPs.

Of the 127 available CT scans, the diagnosis of otosclerosis was confirmed radiographically in 86 cases (67.8%). Regarding the four patients with a semi-circular dehiscence, a lesion compatible with otosclerosis was observed in three cases. A CT scan was perfomed routinely preoperatively in three cases and, in one of them, the imaging was necessary to explain a poor postoperative result. Concerning their audiometric results, none of them had a SNHL. Three of them had a ABG closure of less than or equal to 10 dB. One had an incomplete ABG closure, the ABG remaining at 23.75 dB. This case had nevertheless a diagnosis of otosclerosis with an association of a superior semicircular dehiscence radiographically. Interestingly, two of these patients had preoperative vertigo remaining postoperatively in one case with good hearing results.

TABLE 3. *Results according to the AHEPs in comparable studies*

	Successful Results With Overclosure	Successful Results Without Overclosure	Unsuccessful Results Caused by Negative Changes in AC Thresholds or ABG >20 dB	Unsuccessful Results Caused by Cochlear Damages (BC Worsening of $\geq$10 dB)	Improvement of the BC $\geq$ 10 dB
De Bruijn et al. (15) (N = 451)[a]	N = 96 21.3%	N = 306 67.8%	N = 49 10.9%	N = 10[b] 2.2%	N = 68 15.1%
Kisilevsky et al. (8) (N = 1145)[c]	N = 132 11.5%	N = 920 80.3%	N = 56 5%	N = 35 3%	N = 57 5%
Gregoire et al. (16) (N = 100)[d]	N = 14 14%	N = 67 67%	N = 19 19%	N = 6 6%	N = 5 5%
Our results (N = 128)	N = 6 4.7%	N = 106 82.3%	N = 16 12.5%	N = 8 6.25%	N = 11 8.6%

[a]For reporting the ABG and AC, data calculated at 0.5, 1, 2, and 3 kHz. For reporting the BC, data calculated at 1, 2, and 3 kHz.
[b]NB: All 10 (2.2%) ears with cochlear damage of10 dB or greater could also be defined as having an unsuccessful result caused by negative changes in air conduction thresholds or ABG $\geq$20 dB.
[c]Data calculated at 0.5, 1, 2, and 3 kHz.
[d]Data calculated at 0.5, 1, 2, and 4 kHz.
AC indicates air conduction; AHEPs, Amsterdam Hearing Evaluation Plots; BC, bone conduction.

We have also noted that sex, age, and side of the operated ear doesn't seem to have any impact on the audiological results (not statistically significant, p value >0.05).

Therefore, the success rate is mainly dependent on the definition and criteria as a measure of success. A detailed analysis of the evolution of the BC is mandatory to avoid a false positive success rate when the ABG closure of less than or equal to 10 dB is used. Therefore, the use of the AHEPs would gain additional information when combined with the guidelines of the Committee on Hearing and Equilibrium of the AAO-HNS in reports of audiometric results. In our opinion, the achievement of socially adequate hearing is a more realistic measure of success. That's the reason why our analysis of hearing outcomes after stapes surgery has also been based on the speech audiometry and the number of patients achieving an AC less than or equal to 30 dB postoperatively.

This study is the first to describe the hearing results in such detail and to use so many different criteria of success. We insist on the need to analyze the change of BC for the description of the hearing results based on the pure tone audiometry. For this purpose, the use of the AHEPs seems interesting to us. Moreover, it would be useful to develop the speech reception aspect of the hearing for talking about the hearing results after stapes surgery.

Our series confirms good long term hearing results achieved in stapedotomy surgery with the CO_2 laser. As a result of this study, we decided to maintain this surgical technique. Moreover, the analysis of the hearing results are still realized at early follow-up to detect early complication such a SNHL.

The limitations of this study include those inherent to retrospective reviews, such as lack of controls. Some records obtained from medical charts may be incomplete or lost in the course of time, leading to missing data. On the other hand, this study avoids potential confounding factors, such as that of having various surgeons perform stapes surgery with variable procedures and differences in the choice of the prosthetic device. Moreover, limiting the number of exclusion criteria, we tended to minimize the risk of selection bias. Though 85.4 and 78.8% follow-up rate in early and the mid-term was achieved, still 55% of all ears included in this study had no long-term follow-up. This can be explained by the fact that we are a tertiary hospital, where patients are referred to for stapedotomy by other ENT specialists to whom they return for later follow-up. Loss of follow-up, however, did not bias our results. Moreover, long-term follow-up is one of the strengths of our study, whereas other research is often limited to less than 6 months of follow-up.

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REFERENCES

1. Eftekharian A, Roozbahany NA, Shomali S. The distance between stapedial footplate and incus in otosclerosis surgery. *J Otol* 2015;10:18–20.
2. Dhooge I, Desmedt S, Maly T, Loose D, Van Hoecke H. Long-term hearing results of stapedotomy: analysis of factors affecting outcome. *Eur Arch Otorhinolaryngol* 2018;275:1111–9.
3. Schönfeld U, Weiming H, Hofmann VM, Jovanovic S, Albers AE. CO2 laser stapedotomy safety: influence of laser energy and time on bone-conduction hearing levels. *Eur Arch Otorhinolaryngol* 2017;274:4131–9.
4. Cavalcante AMG, Silva IMC, Neves BJ, Oliveira CA, Bahmad F. Degree of tinnitus improvement with stapes surgery – a review. *Braz J Otorhinolaryngol* 2018;84:514–8.
5. Deniz B, Ihsan K, Ismail G, Rauf Oguzhan K, Muge O. Analysis of factors affecting postoperative functional outcome in patients with otosclerosis. *Auris Nasus Larynx* 2019;47:203–8.
6. Anniko M, Bernal-Sprekelsen M, Bonkowsky V, Bradley P, Lurato S. *Otorhinolaryngology, Head and Neck Surgery*. 2010th ed. New York: Springer; 2009; 82–5.
7. De Bruijn AJG. Clinical and audiological aspects of stapes surgery in otosclerosis. *Cochrane Database Syst Rev* 2012;11–92.
8. Husain Q, Lin KF, Selesnick SH. Stapes prosthesis length and hearing outcomes. *Laryngoscope* 2018;128:722–6.
9. Monsell E, Balkany TA, Gates GA, Goldenberg RA, William L, House JW. Committee on Hearing and Equilibrium guidelines for the evaluation of results of treatment of conductive hearing loss. *Otolaryngol Head Neck Surg* 1995;113:186–7.
10. De Bruijn AJG, Tange RA, Dreschler WA. Efficacy of evaluation of audiometric results after stapes surgery in otosclerosis, II. A method for reporting results from individual cases. *Otolaryngol Head Neck Surg* 2001;124:84–9.
11. Vincent R, Sperling NM, Oates J, Jindal M. Surgical findings and long-term hearing results in 3,050 stapedotomies for primary otosclerosis: a prospective study with the otology-neurotology database. *Otol Neurotol* 2006;27 (8 suppl 2):25–47.
12. Kisilevsky VE, Dutt SN, Bailie NA, Halik JJ. Hearing results of 1145 stapedotomies evaluated with Amsterdam hearing evaluation plots. *J Laryngol Otol* 2009;123:730–6.
13. Celso J, De Souza R, Ferreira R, et al. Evaluation of functional outcomes after stapes surgery in patients with clinical otosclerosis in a teaching institution. *Int Arch Otorhinolaryngol* 2016;20:39–42.
14. Vartiainen E, Karjalainen S. Bone conduction thresholds in patients with otosclerosis. *Am J Otolaryngol Neck Med Surg* 1992;13:234–6.
15. Stenfelt S. Middle ear ossicles motion at hearing thresholds with air conduction and bone conduction stimulation. *J Acoust Soc Am* 2006;119:2848–58.
16. Berliner K, Doyle K, Goldenberg R. Reporting operative hearing results in stapes surgery: does choice of outcome measure make a difference? *Am J Otol* 1996;17:521–8.
17. Gerard J-M, Serry P, Gersdorff MC. Outcome and lack of prognostic factors in stapes surgery. *Otol Neurotol* 2008;29:290–4.
18. Somers T, Vercruysse JP, Zarowski A, Verstreken M, Schatteman I, Offeciers FE. Transient depression of inner ear function after stapedotomy: skeeter versus CO2 laser technique. *Adv Otorhinolaryngol* 2007;65:267–72.
19. Brase C, Keil I, Schwitulla J, et al. Bone conduction after stapes surgery: comparison of CO2 laser and manual perforation. *Otol Neurotol* 2013;34:821–6.
20. Kos MI, Montandon PB, Guyot JP. Short- and long-term results of stapedotomy and stapedectomy with a teflon-wire piston prosthesis. *Ann Otol Rhinol Laryngol* 2001;110:907–11.
21. Grégoire A, Hanot A, Gérard J-M, et al. First 100 stapedotomies of a surgeon: learning curve and functional results. *B-ENT* 2018;14:141–6.
22. Wegner I, Verhagen JJ, Stegeman I, Vincent R, Grolman W. A systematic review of the effect of piston diameter in stapes surgery for otosclerosis on hearing results. *Laryngoscope* 2016;126:182–90.
23. Kisilevsky V, Bailie NA, Halik JJ. Bilateral hearing results of 751 unilateral stapedotomies evaluated with the Glasgow benefit plot. *J Laryngol Otol* 2010;124:482–9.