Clinical and audiological aspects of stapes surgery otosclerosis

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Chapter 4

Efficacy of Evaluation of Audiometric Results after Stapes Surgery in Otosclerosis. Part II: A Method for Reporting Results From Individual Cases.

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ABSTRACT

To standardise the reporting of hearing results after middle ear surgery, the Committee on Hearing and Equilibrium of the American Academy of Otolaryngology–Head and Neck Surgery proposed two levels of guidelines. Level 1 for reporting summary data and level 2 for reporting raw data. The Committee encourages to report raw data from each individual case. However, in studies where the examined population is too large this can yield difficulties. With respect to this point we designed a method for a simple visual presentation of hearing results in an attempt to provide data from each individually operated ear in a patient group. In this method (1) the relation between the pre- and postoperative bone conduction levels is evaluated to assess overclosure and iatrogenic cochlear damage and (2) the relation between postoperative gain in air-conduction and the preoperative air-bone gap is evaluated as a measure of technical success rate. This results in two plots, which we named the “Amsterdam Hearing Evaluation Plots” (AHEPs). Audiometric data from 451 stapes operations were used to demonstrate the use of the AHEPs.

INTRODUCTION

In evaluating the effect of different surgical techniques on hearing, or to compare hearing results from various patient populations, most often the mean values of specific audiologic parameters are considered. Less often the hearing results in each individually operated ear are surveyed. However, for a good impression of differences between patient groups or between certain surgical techniques, it is illustrative to present results of each operated ear separately. Although reporting raw data from individual cases is also encouraged by the Committee on Hearing and Equilibrium of the American Academy of Otolaryngology – Head and Neck Surgery (AAO-HNS), often the number of operated ears is too high to report all data from each individually operated ear. In an attempt to accommodate with this problem we developed a new method of data analysis in which the effects of operation on hearing can be deduced for each individual ear using two plots, which we named the “Amsterdam Hearing Evaluation Plots” (AHEPs). In the first plot the results with regard to postoperative bone-conduction (BC) thresholds are related to preoperative BC thresholds to evaluate the effect of surgery on bone conduction. In the second plot the preoperative air-bone gap (ABG) levels are related to postoperative gain in air-conduction (AC) to establish the degree of success with regard to restoration of middle ear hearing transmission function. One of the great advantages of reporting data with these plots is that favourable and unfavourable results with regard to technical success can easily be identified and in addition ears with cochlear damage due to surgery can be recognised.

The aim of this study was to report audiometric results of 451 stapes operations with the AHEPs as an attempt to present operation results of individual ears in a simple but clarifying way.
PATIENTS AND METHODS

Amsterdam Hearing Evaluation Plots (AHEPs)

The purpose of these plots is to give a visual representation of hearing results of each individual ear after middle ear surgery. In this study we applied the AHEPs on the audiometric results of stapes surgery, although this method of analysing data could easily be used in other middle ear interventions. One of the potential risks in the case of stapes surgery is sensorineural hearing loss and especially hearing sensitivity at the higher frequencies are at risk. On the other hand it is known that in some ears the BC improves due to the Carhart effect. To visualise the effect of surgery on BC the pre- and postoperative BC thresholds are plotted in the first graph (Fig. 1A). The gain in AC after surgery is largely dependent upon the preoperative gap between AC and BC levels: the greater the ABG the more gain one may expect in AC after a technically successful operation. To show the relationship between these two parameters the second graph was designed in which the postoperative gain in AC is plotted against the preoperative ABG of each individually operated ear (Fig. 1B).

In the first graph (Fig. 1A), the two dotted diagonal lines enclose the area within BC did not changed over more than 10 dB. Iatrogenic cochlear damage was defined as a postoperative decrease of BC threshold of more than 10 dB and it is indicated by every point above the upper dotted diagonal line, while every point below the lower dotted diagonal line can be considered as an improvement of the BC due to the Carhart effect.

In the second graph (Fig. 1B), the horizontal axis represents the postoperative change in AC and the vertical axis represents the preoperative ABG. The solid diagonal line indicates total closure of the gap between preoperative AC and BC. Consequently, every point below the solid diagonal line indicates a gain in AC which is larger than one may expect from preoperative ABG and such a result can be regarded as a “successful result with overclosure”. We defined an unsuccessful operation result as a negative change in AC threshold or a change in AC which 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 in Figure 1B indicates such an “unsuccessful result”. In contrast, every point below the dotted diagonal line can be considered as a “successful result”.

For reporting the AC, BC and ABG values several PTA combinations as well as individual frequencies can be used. To demonstrate the AHEPs a few examples are given which have been listed in Table 1 and have been visualised in Figures 1A and 1B.

In the first graph (Fig. 1A), the two dotted diagonal lines enclose the area within BC did not changed over more than 10 dB. Iatrogenic cochlear damage was defined as a postoperative decrease of BC threshold of more than 10 dB and it is indicated by every point above the upper dotted diagonal line, while every point below the lower dotted diagonal line can be considered as an improvement of the BC due to the Carhart effect.

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Fig. 1. The "Amsterdam Hearing Evaluation Plots" (AHEPs). A, Preoperative bone-conduction plotted against postoperative bone-conduction for each operated ear. The two diagonal lines enclose the area within bone-conduction did not change over more than 10 dB. B, Postoperative gain in air-conduction plotted against the preoperative air-bone gap for each operated ear. The solid diagonal line indicates total closure of the gap between preoperative air-conduction and bone-conduction. Every point below this line is defined as overclosure. An unsuccessful operation result with regard to air-conduction is defined as a negative change in air-conduction or a change in air-conduction which was not enough to close the gap between postoperative air-conduction and preoperative bone-conduction to 20 dB or less. This is indicated by the dotted diagonal line.
In the second graph (Fig. 1B), the horizontal axis represents the postoperative change in AC and the vertical axis represents the preoperative ABG. The solid diagonal line indicates total closure of the gap between preoperative AC and BC. Consequently, every point below the solid diagonal line indicates a gain in AC which is larger than one may expect from preoperative ABG and such a result can be regarded as a “successful result with overclosure”. We defined an unsuccessful operation result as a negative change in AC threshold or a change in AC which 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 in Figure 1B indicates such an “unsuccessful result”. In contrast, every point below the dotted diagonal line can be considered as a “successful result”.

**Table 1. Examples to demonstrate the use of the AHEPs.**

<table>
<thead>
<tr>
<th>Example 1: Successful result</th>
<th>Example 2: Successful result with overclosure</th>
<th>Example 3: Unsuccessful result</th>
<th>Example 4: Unsuccessful result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre AC 60</td>
<td>Post AC 30</td>
<td>Gain AC 30</td>
<td>Gain AC 10</td>
</tr>
<tr>
<td>Pre BC 20</td>
<td>Post BC 20</td>
<td>Gain BC 0</td>
<td>Gain BC 0</td>
</tr>
<tr>
<td>Pre ABG 40</td>
<td>Post ABG 10</td>
<td>Gain ABG 30</td>
<td>Gain ABG 10</td>
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<tr>
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<td>Post AC 10</td>
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<td>Gain AC 10</td>
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<td>Gain AC 25</td>
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<tr>
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<td>Post BC 10</td>
<td>Gain BC 0</td>
<td>Gain BC -25</td>
</tr>
<tr>
<td>Pre ABG 50</td>
<td>Post ABG 40</td>
<td>Gain ABG 10</td>
<td>Gain ABG 50</td>
</tr>
</tbody>
</table>

For reporting the AC, BC and ABG values several PTA combinations as well as individual frequencies can be used. To demonstrate the AHEPs a few examples are given which have been listed in Table 1 and have been visualised in Figures 1A and 1B.

**Example 1:** “Successful result”. Point (1) in Figures 1A and 1B is a fictitious ear with an AC threshold of 60 dB and a BC threshold of 20 dB before operation. Postoperatively the AC improved to a threshold of 30 dB while the BC remained at 20 dB. It is clear that such an outcome can be considered as successful.

**Example 2:** “Successful result with overclosure”. Point (2) in Figures 1A and 1B is a fictitious ear with preoperatively the same AC and BC values as in example 1. However this time the AC improved to a threshold of 10 dB while the BC improved to 5 dB. Such a result can be regarded as an “overclosure” of the ABG as the BC improved with 15 dB.
Example 3: "Unsuccessful result". Point (3) in Figures 1A and 1B is a fictitious ear with preoperatively an AC threshold of 60 dB and a BC threshold of 10 dB. Postoperatively the AC improved only with 10 dB while the BC did not change. An unsuccessful result can be caused by two reasons: it did not succeed in restoring middle ear transmission function as is the case in this example and/or cochlear damage occurred due to surgery. The last named situation is demonstrated in the next example.

Example 4: "Unsuccessful result". Point (4) in Figures 1A and B is a fictitious ear with the same AC and BC values as in example 3 before operation. After surgery the AC improved with 25 dB while the BC deteriorated with 25 dB. If postoperative ABG is conducted with postoperative BC, the ABG after surgery would be 0 dB and could wrongly be interpreted as successful.

SUBJECTS AND MATERIALS

To demonstrate the use of the AHEPs in reporting audiometric results after stapes surgery, the same set of data were used as described in Chapter 3 concerning 451 operations in 374 patients.3

RESULTS

In Figure 2A the preoperative BC thresholds have been plotted against the postoperative BC thresholds while in Figure 2B the postoperative hearing gains in AC are plotted against the preoperative ABGs for every single ear that underwent stapes surgery. For reporting AC and ABG levels in Figure 2B a four frequency average at 0.5, 1, 2, and 3 kHz was used as recommended by the Committee on Hearing and Equilibrium of the AAO-HNS.1 Because it has been stated by the Committee that the preoperative minus the postoperative BC levels for the pure-tone high frequency combination at 1, 2, and 4 kHz is a sensitive measure of overclosure or cochlear damage to hearing, the BC levels in Figure 2A have been calculated for the high frequency PTA. As explained in “Patients and Methods” every point above the upper dotted diagonal line in Figure 2A was regarded as a cochlear damage ≥ 10 dB due to surgery and every point below the lower dotted diagonal line indicates a postoperative gain in BC ≥ 10 dB. From the total group of ears in Figure 2A 373 (82.7 %) had postoperative BC thresholds which are ± 10 dB from preoperative BC levels. The number of ears in Figure 2A with an improvement of BC threshold ≥ 10 dB was 68 (15.1 %).

In Figure 2B every point below the solid diagonal line indicates "overclosure" and every point above the dotted diagonal line indicates an “unsuccessful” result. According to the AHEPs, the number of successfully operated ears with regard to AC is 402 (89.1 %). From this total group of ears 306 ears had a “successful result without overclosure” while 96 ears had a “successful result with overclosure” (Fig. 2B). All ten ears (2.2 %) with cochlear damage ≥ 10 dB in Figure 2A could also be defined as an “unsuccessful result” in Figure 2B. Of all ears in Figure 2B 311 (68.9 %) had postoperative AC thresholds which were ± 10 dB from preoperative BC levels.
From Figure 2B 49 (10.9 %) cases could be defined as an “unsuccessful” result with regard to AC. In this failure group the amount of revision surgeries was relatively high; from the whole group of revision cases (n=65) eleven had an “unsuccessful” hearing result. Figures 2A and B visualise one failure with extreme values regarding to the gain in AC and the postoperative BC.

![Audiometric Results](image)

**Fig. 2.** Audiometric results of 451 stapes operations visualized with the Amsterdam Hearing Evaluation Plots (AHEPs). A, Preoperative bone-conduction and postoperative bone-conduction plotted for individual ears. Pure-tone average (PTA) was calculated for the high frequency combination at 1, 2, and 4 kHz. B, Postoperative gain in air-conduction plotted against preoperative air-bone gap for individual ears. PTA was calculated for the frequency combination at 0.5, 1, 2, and 3 kHz.
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This is an ear with a preoperative BC value of 20 dB and a postoperative BC value of 65 dB (Fig. 2A) while the gain in AC value was – 50 dB and the preoperative ABG value was 15 dB (Fig. 2B). This patient had revision surgery for the second time.

Part I of this study showed that choice of PTA significantly affects postoperative gain in AC thresholds and ABG levels after stapes surgery. Choice of PTA has also some effect on the numbers of “successful results”, “successful results with overclosure”, and “unsuccessful results” according to the AHEPs in our material. If values for AC and ABG in Figure 2B were calculated for the traditional PTA combination at 0.5, 1, and 2 kHz, the numbers of ears with a “successful result without overclosure” and with a “successful result with overclosure” increase with 9 and 12, respectively. The number of ears with an “unsuccessful result” decreases with 8. If PTA values taken at 0.5, 1, 2, and 4 kHz are compared with PTA values at 0.5, 1, 2, and 3 the number of ears with overclosure decrease with 3 while the failure rate increases with 4 ears.

DISCUSSION

The reporting of hearing results in middle ear surgery is not yet standardised. Many authors use different parameters for reporting the audiologic results which makes comparison of different studies very difficult. In 1995 new guidelines were proposed by the Committee on Hearing and Equilibrium of the AAO-HNS\(^1\) to report hearing data in a simple and uniform way after tympanoplasty and stapes surgery. The Committee drafted guidelines for the uniform reporting of audiologic results at two levels: level 1 provides for summary data and level 2 provides for raw data. The Committee encourages to report raw data permitting more precise statistical treatment and meta-analyses. With regard to reporting summary data, the Committee recommends that the postoperative ABG, the number of decibels of closure of the ABG, and the change in high-tone BC level be reported in terms of mean, standard deviation, and range. However, Govaerts et al.\(^4\) has already mentioned the shortcomings of reporting results in this way because choice of mean and standard deviations suggests a normally distributed population, while audiometric data are often not normally distributed. Furthermore, the mean and the standard deviations are very sensitive to variations at the extreme end of the population. To obviate these criticism Govaerts et al.\(^4\) proposed to add the use of multiple box and whisker plots in which the population is described by five parameters: median, lower and upper extremes, and lower and upper quartiles.

To comply with level 2 in reporting raw data, the Committee recommends to report AC thresholds for each octave interval from 0.5 to 8 kHz inclusive 3 kHz, and to report BC thresholds for each octave interval from 0.5 to 4 kHz inclusive 3 kHz. The pre- and postoperative values should be reported for each ear operated on. However, reporting results in this way could enhance difficulties when the population examined is too large to show all data. For this reason we designed the AHEPs in an attempt to give a visual presentation of audiometric results after middle ear surgery. Although data are not represented according to level 2 of the guidelines, we feel that this way of analysing data can add valuable information to the evaluation of audiometric results in a larger population when it is desired to report data from
each case. The plots show the individual results and visualise the amount of “overclosures” (Fig. 2B) which is especially of interest in reporting results of stapes surgery. In addition the unfavourable hearing results can easily be recognised with regard to cochlear damage (Fig. 2A) and residual conductive hearing loss (Fig. 2B).

Although definitions of good, moderate or unfavourable outcome are arbitrary issues, we choose to define an “unsatisfactory result” as a negative change in AC threshold or a remaining gap of more than 20 dB between postoperative AC and preoperative BC levels and this was indicated by the dotted diagonal line in Figure 2B. Actually, this is the same measure for success rate as when success is defined as an ABG closure to 20 dB or less used in Part I of this study provided that postoperative ABG is conducted with preoperative BC for the PTA combination 0.5, 1, 2, and 3 kHz. According to this criterion 89.1 % of the cases in our stapes surgery series had a “successful result”. This percentage is more favourable when compared to other criteria as measures of success like for instance ABG closure ≤ 10 dB or postoperative AC level ≤ 30 dB as shown in Part I of this study. In this perspective criteria for success can easily be changed in the AHEPs if necessary.

We have evaluated the “unsatisfactory results” in our material separately in an attempt to get a better understanding of the reasons why those surgical performances had failed. It appeared that every ear with a postoperative deterioration of BC level of more than 10 dB in Figure 2A, defined as an iatrogenic cochlear damage, could also be identified as an “unsatisfactory result” in Figure 2B. Furthermore, the percentage of revision cases in the unsatisfactory group was relatively high (11/49) underlining that revision surgery is an unfavourable factor with regard to hearing results which is well known from the literature.\(^5\,6\)

As shown in part I of this study it appeared that choice of PTA significantly affects postoperative gain in AC thresholds and ABG levels after stapes surgery. In demonstrating the AHEPs with the audiometric results of stapes surgery we have chosen to use two different PTA combinations as recommended by the Committee of the AAO-HNS.\(^1\) Choice of PTA has also some effect on the amount of “successful results” and “unsatisfactory results” according to the AHEPs in our material with more favourable results using the traditional three-frequency PTA at 0.5, 1, and 2 kHz.

Evaluation of hearing results with the AHEPs is a refined method to determine technical success after surgery and to compare the spread in individual results for different populations. However, it must be emphasised that it is not a method to obtain an impression of the benefit a patient derives from surgery as patient’s disability is also dependent on the hearing thresholds of the not operated ear. More disability-oriented methods of data analysis are described by Smyth et al.\(^7\) and Browning et al.\(^8\) as well as by de Bruijn et al.\(^9,10\)

**CONCLUSION**

The AHEPs form an easily understood visual presentation of audiometric results of each individual case after stapes surgery or other middle ear interventions. In our opinion the use of the AHEPs would gain additional information when it is combined with the guidelines of the Committee on Hearing and Equilibrium of the AAO-HNS in reports of audiometric
results. Another advantage of presenting data with the AHEPs is that outliers with extreme values of audiometric results are visualised clearly. These values would influence summary statistics but are not always recognisable when presenting summary data with means and standard deviations.

REFERENCES