Clinical and audiological aspects of stapes surgery otosclerosis

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Chapter 3


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Otolaryngology-Head and Neck Surgery, in press
ABSTRACT

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 after middle ear surgery. One of the proposals was to include the hearing thresholds at 0.5, 1, 2, and 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). The hearing results of 451 stapes operations were evaluated to analyse to what extent the choice of different audiological criteria affects success rates. It appeared that choice of PTA significantly affects postoperative gain in air-conduction (AC) thresholds and ABG levels. If one takes the improvement in speech reception threshold (SRT) as “the golden standard”, the gain in AC correlates best with the gain in SRT if a higher frequency, like 3 or 4 kHz, is included in a four-frequency PTA. Also choice of preoperative BC or postoperative BC in computing postoperative ABG had a significant effect on the mean postoperative ABG levels showing more favourable results with the use of preoperative BC thresholds.

INTRODUCTION

In the last four decades the surgical treatment for hearing losses caused by otosclerosis has evolved extensively and it has, according to many prominent otologists, obtained a position as treatment of first choice. The surgical techniques have been refined and still new developments are going on, especially in the field of stapes replacement prostheses. In this respect, it is a necessity that uniformity exists in reporting hearing results after stapes surgery for a fair comparison between several surgical techniques or between various patient populations.

During review of the literature on stapes surgery it appears unfortunately that a great variation exists in audiologic parameters and criteria used to establish success rates. Often the consequences of using different audiologic criteria on hearing outcome are underestimated and therefore it is difficult to make an accurate comparison of results reported in the literature. Furthermore, it appears that the results from speech audiometry are seldom taken into consideration, whereas one of the most important goals of stapes surgery is improvement of speech reception. Several efforts have been made in the past to advance more uniformity in reporting hearing results. In many proposals for guidelines the pure-tone average (PTA) at 0.5, 1, and 2 kHz was the most important because these frequencies are involved in speech reception. However, in 1994 the Committee on Hearing and Equilibrium of the American Academy of Otolaryngology – Head and Neck Surgery (AAO-HNS) proposed guidelines in which the Committee recommended the use of mean of thresholds at frequencies 0.5, 1, 2 and 3 kHz to form a four frequency PTA in reporting results from stapes surgery or ossiculoplasty. Berliner et al. showed in their material that including a higher frequency, like the 3 or 4 kHz, in a four frequency PTA had a substantial influence on success rate in stapes surgery. Another guideline from the Committee was to use postoperative bone-
Effects of Audiological Parameters and Criteria on Success Rates

conduction (BC) rather than preoperative BC in computing postoperative air-bone gap (ABG). With respect to this point, Berliner et al. found that the use of postoperative BC instead of preoperative BC in computing ABG after surgery had an unfavourable influence on success rates.

The purpose of this study was to get a better understanding to what extent the use of different audiologic criteria affects success rates after stapes surgery in our material in which hearing results of 451 stapes operations were analysed. Our study focuses on the following questions: (1) Does choice of frequencies in accounting PTAs influence reported success rates? (2) How do these results relate to results from speech audiometry? (3) To what extent is ABG reduction affected by the use of postoperative instead of preoperative BC thresholds? (4) To what degree is success rate affected by the choice of success criteria?

Patients and Methods

Data were retrieved from every consecutive patient who underwent stapes surgery for otosclerosis during an eleven year period from January 1987 to December 1997. During this period 473 stapes operations were performed by the second author. Of the total amount of patients we had to exclude 22 cases (4.7 %) from analysis; in 18 cases data were incomplete, in 3 cases the audiologist had indicated that the test was not reliable and in 1 case there was a dead ear caused by an infection two weeks postoperatively. The remaining 451 cases that were considered for analysis concerned 397 patients. In 40 patients the operation was performed on both sides at separate surgical settings. There were 61 patients who underwent revision surgery; 10 patients had their initial surgery performed by the second author, while 51 patients were referred from other physicians. Of the revision cases who had their primary operation performed by the second author, there was 1 patient who needed a second revision operation, while in another patient it was necessary to do a third revision. In the group of 51 patients with primary surgery performed by another surgeon, there was one patient who needed revision surgery at both sides. Furthermore, there were 3 cases who already had one revision operation, 4 cases who had a revision operation twice and there was 1 patient who had a revision operation for the third time prior to surgery in our clinic. The intraoperative findings revealed during revision as well as the postoperative hearing results are described in another study. The patient group consisted of 261 women and 136 men with a mean age of 39.9 years (range 12 – 74) at the time of their operation in our hospital. The distribution between left and right ears was approximately even.

In the majority of patients a small fenestra stapedotomy was performed (98.4 %) and in only a few cases a stapedectomy technique was used (1.6 %). A variety of stapes replacement prostheses was implanted. The most frequently used prostheses were the Causse® Teflon piston (63 %), the gold K®-piston (19 %) and the Cawthorne® Teflon piston (12 %). Several other prostheses were used in a minority of the patients. Although the diversity of prostheses is an influential factor in hearing outcome, we did not subdivide the population on the basis of implanted prostheses, because this study concerns only with the relative differences in
methods of reporting results.
In our clinic the air-conduction (AC) thresholds are routinely measured at the octave intervals from 0.125 to 8 kHz and the BC thresholds at the octave intervals from 0.25 to 4 kHz with adequate masking. For most subjects who were considered for analysis both AC and BC thresholds at the above mentioned frequency ranges were available before and after surgery. However, in some subjects the hearing loss was very severe resulting in hearing thresholds which were beyond the maximum output of the audiometer. In these cases the pure tone thresholds at certain frequencies were impossible to determine and this is marked in the audiogram with an arrow pointing down. It is important to consider these limitations of the capacity of the audiometer, because data of pre- or postoperatively unmeasurable hearing thresholds could wrongly be excluded from analysis. Severe postoperative hearing loss as a consequence of an unfavourable operation would then not be taken into account. Conversely, ears with unmeasurable hearing thresholds before operation as a consequence of severe hearing loss but with measurable hearing thresholds after operation could also be rejected. To avoid this problem in these cases thresholds were assumed to be just beyond the audiometer limitations. If AC or BC was not measurable at a certain frequency a value of 10 dB above the limit for that frequency was given.
The AC and BC thresholds at 3 kHz are not routinely measured in the Dutch audiological centres. To obtain values for the four frequency PTA at 0.5, 1, 2 and 3 kHz, a fictive hearing level at 3 kHz was interpolated by taking the average of the thresholds measured at 2 and 4 kHz.
In 93.8 % (n = 423) of the cases speech audiometry was available before and after surgery. For each subject complete speech audiometry was carried out at different levels, using lists of phonetically-balanced CVC-words. From these tests the pre- and postoperative SRTs could be derived. All audiograms were performed by classified personnel according to the ISO-389 (1975) standard. The mean time of audiometric testing after surgery was 2.1 months (range 0.6-12.1; SD ± 2.4). Ninety-four percent of the subjects had postoperative audiometric testing within 3 months.
All data were entered into a computer database and analysed with a spreadsheet program. In analysing our data the postoperative results are presented using four different PTA combinations at 0.5, 1, and 2 kHz, at 0.5, 1, 2, and 3 kHz, at 0.5, 1, 2, and 4 kHz and at 1, 2 and 4 kHz. The last named frequency combination was also analysed because it is has been suggested to be a sensitive measure of overclosure or cochlear damage to hearing. ABG closure data are reported using postoperative BC thresholds as well as preoperative BC thresholds for the four different PTA combinations in computing postoperative ABG. For speech audiometry, data are presented with regard to improvement in speech reception thresholds (SRTs).
Audiometric data in this study did not show a normal distribution established with normality tests. Therefore nonparametric statistical analyses were performed (GraphPad Prism®). The Wilcoxon signed rank test was used for independent data, whereas the Spearman test was used for correlation analysis. Our criterion for statistical significance was set at p-values of less than 0.05 (two-tailed).
RESULTS

Table 1 shows data with regard to mean pre- and postoperative AC and BC levels (with standard deviations). A statistically significant improvement in AC is reached for every frequency, except at 8 kHz. Postoperatively there was an improvement in the mean BC levels at all frequencies. The most obvious improvement was achieved at 2 kHz which was 6.1 dB. The differences between pre- and postoperative BC thresholds were statistically significant for the individual frequencies at 0.5, 1, and 2 kHz. At 4 kHz there is only a small improvement and it was not statistically significant.

Influence choice of frequencies in computing PTA

Figure 1 shows graphically the gain in AC, BC and ABG for the four PTA combinations. For reasons of comparison also the mean gain in SRT has been reported. Choice of frequencies in computing PTA has a relatively small influence on improvement in BC. However, PTA frequency combination does have a significant ($p < 0.001$) influence on improvements in AC and ABG. The differences between the traditional three-frequency (0.5, 1, 2 kHz) and high-frequency (1, 2, 4 kHz) PTA were the largest being 4.9 dB and 4.5 dB for the gains in AC and ABG, respectively. The high frequency PTA combination gives overall a smaller gain in AC and ABG. The gain in AC for the frequency combination 0.5, 1, 2 and 4 kHz is 21.2 dB (SD ± 12.2) and corresponds on average best with the gain in SRT which is 20.2 dB (SD ± 12.1).

Choice of PTA frequency combination has some influence on the preoperative ABG (Fig. 2). Postoperatively it has little influence on the remaining ABG computed either with pre- or with postoperative BC. These differences are not statistically significant. In addition, Figure 3 shows that PTA frequency combination has also little influence on the percentage ABG closures ≤ 10 and higher categories when using either postoperative BC or preoperative BC. The relations between postoperative improvement in SRT at one side and improvements in AC and ABG for the four different PTA combinations at the other side were explored by correlation analysis (Table 2). As expected a stronger correlation exists between gain in AC and gain in SRT in comparison with gain in ABG and gain in SRT. Furthermore, choice of frequencies in computing PTA does have influence on correlation coefficients. In this respect gain in AC for the two four-frequency combinations at 0.5, 1, 2, and 3 kHz and at 0.5, 1, 2, 4 kHz correlates better with gain in SRT in comparison with the traditional three-frequency or high-frequency combination.

Influence choice of pre- or postoperative BC in computing postoperative ABG

Figure 2 shows that the overall results with regard to postoperative ABG are more favourable using preoperative BC. The differences are 3.5 dB, 3.4 dB, 2.5 dB and 3.0 dB for the PTA combinations at 0.5, 1, 2 kHz, at 0.5, 1, 2, 3 kHz, at 0.5, 1, 2, 4 kHz and at 1, 2, 4 kHz, respectively. These differences are statistically significant ($p < 0.001$) for all four PTA combinations. Using preoperative BC gives also more favourable results with regard to percentage ABG closures ≤ 10 dB (Fig. 3). In this respect the largest differences are 6.6 %, 4.9 % and 3.4 % for the PTA combinations 0.5, 1, 2 kHz, 0.5, 1, 2, 3 kHz and 1, 2, 4 kHz respectively, but only 1.5
% for the PTA combination 0.5, 1, 2, 4 kHz. Using pre- or postoperative BC does not substantially affect the results on percentage ABG closures for the higher categories.

**Table 1.** Pre- and postoperative air-conduction and bone-conduction thresholds.

<table>
<thead>
<tr>
<th>Frequency (kHz)</th>
<th>Preop</th>
<th>SD</th>
<th>Postop</th>
<th>SD</th>
<th>Difference</th>
<th>SD</th>
<th>Statistical sign.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air-conduction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.125</td>
<td>58.7</td>
<td>14.9</td>
<td>31.8</td>
<td>13.5</td>
<td>26.9</td>
<td>16.6</td>
<td>* p &lt; 0.0001</td>
</tr>
<tr>
<td>0.25</td>
<td>57.5</td>
<td>15.2</td>
<td>30.0</td>
<td>13.0</td>
<td>27.5</td>
<td>16.4</td>
<td>* p &lt; 0.0001</td>
</tr>
<tr>
<td>0.5</td>
<td>54.4</td>
<td>14.1</td>
<td>27.4</td>
<td>13.5</td>
<td>27.0</td>
<td>14.9</td>
<td>* p &lt; 0.0001</td>
</tr>
<tr>
<td>1</td>
<td>51.3</td>
<td>14.3</td>
<td>25.4</td>
<td>13.6</td>
<td>25.9</td>
<td>14.4</td>
<td>* p &lt; 0.0001</td>
</tr>
<tr>
<td>2</td>
<td>47.2</td>
<td>15.9</td>
<td>27.0</td>
<td>15.5</td>
<td>20.2</td>
<td>12.3</td>
<td>p &lt; 0.0001</td>
</tr>
<tr>
<td>3*</td>
<td>48.3</td>
<td>17.1</td>
<td>32.1</td>
<td>16.9</td>
<td>16.2</td>
<td>12.8</td>
<td>* p &lt; 0.0001</td>
</tr>
<tr>
<td>4</td>
<td>49.5</td>
<td>21.1</td>
<td>37.2</td>
<td>20.8</td>
<td>12.3</td>
<td>15.4</td>
<td>p &lt; 0.0001</td>
</tr>
<tr>
<td>8</td>
<td>54.9</td>
<td>50.6</td>
<td>53.0</td>
<td>25.3</td>
<td>1.9</td>
<td>46.2</td>
<td>NS</td>
</tr>
<tr>
<td><strong>Bone-conduction</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.25</td>
<td>8.6</td>
<td>9.0</td>
<td>8.1</td>
<td>9.1</td>
<td>0.5</td>
<td>8.1</td>
<td>NS</td>
</tr>
<tr>
<td>0.5</td>
<td>16.5</td>
<td>10.7</td>
<td>15.3</td>
<td>11.3</td>
<td>1.3</td>
<td>9.4</td>
<td>p = 0.001</td>
</tr>
<tr>
<td>1</td>
<td>17.3</td>
<td>10.4</td>
<td>14.3</td>
<td>11.6</td>
<td>3.0</td>
<td>9.5</td>
<td>* p &lt; 0.0001</td>
</tr>
<tr>
<td>2</td>
<td>28.5</td>
<td>12.9</td>
<td>22.4</td>
<td>14.4</td>
<td>6.1</td>
<td>10.3</td>
<td>* p &lt; 0.0001</td>
</tr>
<tr>
<td>3*</td>
<td>27.5</td>
<td>13.0</td>
<td>24.4</td>
<td>14.4</td>
<td>3.1</td>
<td>8.0</td>
<td>* p &lt; 0.0001</td>
</tr>
<tr>
<td>4</td>
<td>26.4</td>
<td>15.8</td>
<td>26.3</td>
<td>16.9</td>
<td>0.1</td>
<td>9.7</td>
<td>NS</td>
</tr>
</tbody>
</table>

For each frequency the preoperative (preop) and postoperative (postop) air-conduction (AC) and bone-conduction (BC) thresholds with standard deviations (SD) are shown. Statistical significance (Wilcoxon test) of the reduction of AC and BC levels are indicated in the right column.

* The hearing level at 3 kHz is an interpolated value by taking the average of the hearing thresholds measured at 2 and 4 kHz.
Effects of Audiological Parameters and Criteria on Success Rates

Fig. 1. Mean gain in air-conduction (AC), bone-conduction (BC) and air-bone gap (ABG) are shown for four different pure-tone average (PTA) combinations. Values for ABG improvement were based on postoperative ABG computed with postoperative BC. For comparison the mean gain in speech reception threshold (SRT) is given as the "golden standard". *** The brackets indicate that for AC and ABG all PTA combinations yield significantly different results (Wilcoxon test, $p < 0.001$).

Table 2. Correlation analysis with gain in speech reception as the "golden standard".

<table>
<thead>
<tr>
<th>Gain in AC</th>
<th>0.5, 1, 2 kHz</th>
<th>0.5, 1, 2, 3 kHz</th>
<th>0.5, 1, 2, 4 kHz</th>
<th>1, 2, 4 kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gain in SRT</td>
<td>R = 0.808; $p &lt; 0.001$</td>
<td>R = 0.888; $p &lt; 0.001$</td>
<td>R = 0.884; $p &lt; 0.001$</td>
<td>R = 0.796; $p &lt; 0.001$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gain in ABG²</th>
<th>0.5, 1, 2 kHz</th>
<th>0.5, 1, 2, 3 kHz</th>
<th>0.5, 1, 2, 4 kHz</th>
<th>1, 2, 4 kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gain in SRT</td>
<td>R = 0.608; $p &lt; 0.001$</td>
<td>R = 0.637; $p &lt; 0.001$</td>
<td>R = 0.653; $p &lt; 0.001$</td>
<td>R = 0.642; $p &lt; 0.001$</td>
</tr>
</tbody>
</table>

Gain in speech reception threshold (SRT) vs. gain in air-conduction (AC) and air-bone gap (ABG) explored by correlation analysis (Spearman test) for four different frequency combinations.

*Values based on postoperative air-bone gap computed with postoperative bone-conduction.
Fig. 2. Preoperative mean air-bone gap (preop ABG) and postoperative mean air-bone gap (postop ABG) are shown for four different pure-tone average (PTA) combinations. Postoperative BC (postop BC) values and preoperative BC (preop BC) values are used in accounting postoperative air-bone gap.

Fig. 3. Cumulative percentage of postoperative air-bone gap (ABG) for four different pure-tone average (PTA) combinations. Postoperative bone-conduction (postop BC) values and preoperative bone-conduction (preop BC) values are used in accounting postoperative ABG.
Influence choice of success criteria
Figure 4 shows graphically the success-rates according to different success-criteria. The percentages AC thresholds and the percentages ABG closures within several levels are calculated for the four different PTA combinations. Postoperative ABG has been computed with postoperative BC. Also the percentages of ears with SRTs within several levels are presented. The curve from AC thresholds for the traditional three-frequency PTA at 0.5, 1, and 2 kHz corresponds best with the curve from SRTs. Fig. 4 shows clearly the effect of the choice of PTA on success rate with regard to percentages ears with AC levels within different categories. If normal hearing, defined as an AC threshold ≤ 20 dB, is taken as a measure of success, the success rate will be ~ 8% higher for the traditional three-frequency PTA at 0.5, 1, and 2 kHz than for the four-frequency PTA at 0.5, 1, 2 and 4 kHz. This difference will be even more (~ 10%) if one defines success as “socially acceptable” hearing with an AC level ≤ 30 dB.

Fig. 4. Success rates are shown for air-conduction (AC) thresholds and air-bone gap (ABG) values within several categories for four different pure-tone average (PTA) combinations. Postoperative ABG was computed with postoperative bone-conduction. In addition, success rates are shown for speech reception threshold (SRT) levels within several categories.

The most important differences are between the percentages ABG closures and AC or SRT levels within certain criteria. A much higher success rate (~ 30%) will be achieved if one considers the percentage of ears with ABG closure ≤ 10 dB as criterion for success in stead of
the percentage of normal hearing ears with AC or SRT levels ≤ 20 dB. However, less striking differences will be obtained if one compares ABG closure ≤ 10 dB with AC or SRT levels ≤ 30 dB as criteria for "socially acceptable" hearing.

**DISCUSSION**

In the evolution of surgical treatment of hearing loss caused by otosclerosis initially the frequencies 0.5, 1, and 2 kHz were considered for accounting PTAs in evaluation of hearing results, because they were mostly involved with conversational speech reception. During development of speech audiometry it appeared that the traditional three-frequency PTA (the so called "Fletcherian index") for AC thresholds correlate well with SRTs. Also later, after introduction of the stapedectomy technique by Shea, the hearing thresholds at 0.5, 1, and 2 kHz remained the most important in evaluation of hearing results. Hearing levels at the same frequencies were also recommended in the guidelines of reporting hearing results after surgery of chronic ear infections by the Committee on Conservation of Hearing of the American Academy of Ophthalmology and Otolaryngology in 1965. More recently the above mentioned frequencies were recommended according to the guidelines drafted by the Committee on Nomenclature of the Japan Society of Clinical Otology. To stress the importance of the hearing threshold at 1 kHz in SRT, this Committee recommended additionally a “dividing by four method” in which the hearing threshold at 1 kHz is counted twice.

In 1994 new guidelines were proposed by the Committee on Hearing and Equilibrium of the AAO-HNS to report hearing data in a simple and uniform way after tympanoplasty and stapes surgery. One of the guidelines was to include also the hearing threshold at 3 kHz in a four-frequency PTA. Another guideline was to use AC and BC thresholds of the same postoperative audiogram rather than using postoperative AC and preoperative BC levels in computing postoperative ABG. Goldenberg and Berliner found in their material that when a higher frequency (3 or 4 kHz) was used in a four-frequency PTA, it had not a significant influence on success rate after tympanoplasty surgery in comparison with the traditional three-frequency PTA. A year later Berliner et al. showed that including the hearing thresholds at 3 or 4 kHz in a four-frequency PTA had a significant effect on success rate after stapes surgery.

Our results confirm the findings of Berliner et al. that choice of PTA does affect the percentage of normal hearing ears with AC levels ≤ 20 dB; in this study the differences were 6.0 % and 8.0 % in the advantage of the traditional three-frequency PTA at 0.5, 1, and 2 kHz in comparison with the four-frequency PTAs at 0.5, 1, 2, 3 kHz and 0.5, 1, 2, 4 kHz, respectively. Choice of PTA had little effect on postoperative ABG levels (Fig. 2) which is also in agreement with the findings of Berliner et al. Furthermore, it appeared that it had also little effect on the percentage of ears with ABG closure ≤ 10 dB or higher categories (Figs. 3 and 4).

The most important goal of stapes surgery is improvement of hearing and consequently improvement of the ability for reception of conversational speech. In this perspective we also
analysed the improvements in SRTs and used it as the “golden standard” for comparison with gains in AC and ABG for the four different PTAs examined (Fig. 1). It appeared that the mean postoperative gain in SRT corresponds on average best with the mean gain in AC for the PTA combination 0.5, 1, 2, and 4 kHz, although there are no significant differences with the other PTA combinations after correlation analysis (Table 2). To our surprise, it appeared that after comparison between the percentages ears with a SRT within a certain level (for example 20 dB or 30 dB) and the percentages ears with an AC threshold within a certain level, these success percentages are best in agreement with the traditional PTA combination at 0.5, 1, and 2 kHz (Fig. 4). This may be caused by the fact that SRTs have been measured in quiet and not with background noise. For speech reception in noise the higher frequencies have been shown to be more important.

It is logical that in many studies the surgical success is related to the improvement of ABG, because it is supposed that gap reduction represents repair of the conductive system of the middle ear which shows the technical success of surgery. In establishing postoperative ABG often studies using the method by taking the differences between postoperative AC and preoperative BC levels while more recently published studies are using the method in which the differences between postoperative AC and BC thresholds are taken into account. In some studies it is not possible to trace which method has been used. Occasionally, postoperative ABG is computed by taking the best BC level. Initially, the first mentioned method by using preoperative BC levels was, according to the literature, used more often and an ABG closure within 10 dB was considered as a technical success. This method of computing postoperative ABG was also recommended by the Committee on Nomenclature in Chronic Ear Disease and the Otosclerosis Study Group in 1971. It is however well known that BC thresholds can substantially improve after surgery as already described after fenestration surgery by Carhart in 1950 and is known as the Carhart effect. Postoperatively the inertial component of bone conducted sound transmission is restored and therefore postoperative BC thresholds may correspond better with the true function of the cochlea. This supports the use of postoperative BC thresholds for computing postoperative ABG. Harder found in his study that the gap between postoperative AC and preoperative BC was dependent on the level of preoperative BC thresholds but the gap to postoperative BC seemed to be independent of the preoperative BC thresholds level. Furthermore, he found that gaps to postoperative BC showed less variation than the gaps to preoperative BC and it was stated that postoperative BC thresholds may serve as a more stable and natural reference when calculating postoperative ABG.

In our results choice of preoperative or postoperative BC most obviously affected the mean postoperative ABG levels for all four PTAs with larger improvements relative to preoperative BC (Fig. 2). It had also an effect on the percentage ABG closure ≤ 10 dB with the largest difference for the PTA combination 0.5, 1, and 2 kHz which was 6.6 % more favourable when using preoperative BC. The use of pre- or postoperative BC did not have a substantial influence on the percentage ABG closure ≤ 20 dB or higher levels for all four PTAs (Fig. 3). Berliner et al. did not find large differences in percentages ABG closures ≤ 10 dB and several higher levels by using preoperative or postoperative BC in computing postoperative ABG.
During review of the literature, it appears that several criteria are used to establish success. Studies which report results with regard to improvement of AC thresholds, often take the traditional speech frequencies (PTA 0.5, 1, 2 kHz) into account,\textsuperscript{18,19} although sometimes the gain for individual frequencies are reported as well.\textsuperscript{19,20} Less often results with regard to improvement of AC thresholds are reported with four-frequency PTAs as recommended by the AAO-HNS.\textsuperscript{1} Sometimes authors\textsuperscript{12} are relating surgical success with the percentage ears with AC thresholds within a certain level like 20 dB or 30 dB. Only a few studies\textsuperscript{12,19} have analysed speech audiograms and report results with regard to improvement in SRTs. Just because a variety of success criteria are being used in the literature, it is difficult to compare studies with regard to hearing improvement after surgery. In our material it makes, as expected, a big difference when taking the percentages of ears with ABG closure within a certain level as a measure of success, or when taking the percentages of ears with an AC threshold within a certain level. If one takes the percentage of ears in which normal hearing was obtained after surgery, defined as an AC threshold ≤ 20 dB as a measure of success, there will be a difference of ~35 % from the percentage of ears with an ABG closure ≤ 10 dB postoperatively. The difference will be less when success is defined as the percentage of ears with “socially acceptable” hearing (AC threshold ≤ 30 dB). The effects of choice of PTA on the extent of this difference has been clearly illustrated in this study (Fig. 4).

Although it was not strictly necessary for this study to subdivide the cases with primary surgery from revision surgery, it is well known from the literature\textsuperscript{3} that revision surgery yields less favourable results with regard to hearing improvement as is the case in this study: success rates, defined as an ABG closure ≤ 10 dB (postoperative ABG computed with postoperative BC for the four-frequency PTA at 0.5, 1, 2, and 4 kHz), was 71 % for the primary cases while it was 58 % for the revision group.

**CONCLUSIONS**

The aim of this study was to establish to what extent choice of different audiological criteria affects success rates following stapes surgery. This study provides the following answers to the questions mentioned in the introduction:

1. Choice of PTA significantly affects postoperative gain in AC thresholds and ABG levels (Fig. 2). It has however little influence on the remaining postoperative ABG and on the percentage of ears with ABG closures ≤ 10 dB or higher categories.

2. If the improvement in SRT is regarded as the “golden standard”, the gain in AC does correlate best with the gain in SRT if a higher frequency, like the 3 or 4 kHz, is included in a four frequency PTA.

3. Choice of pre- or postoperative BC in computing postoperative ABG had a significant effect on the mean postoperative ABG levels showing more favourable results when preoperative BC thresholds were used. In our results using preoperative BC levels gives also more favourable results with regard to ABG closure ≤ 10 dB with the largest difference for the PTA combination 0.5, 1, and 2 kHz which was 6.6 %. It has less effect on the percentage of ears with an ABG closure to higher categories.
4. Success rate is mainly dependent on definition and criteria as a measure of success (Fig. 4). In this perspective, the percentage ears with “socially adequate” hearing, defined as an AC threshold $\leq 30$ dB, does compare best with the percentage ears with ABG closure $\leq 10$ dB. In our opinion the achievement of “socially adequate” hearing is a more realistic measure of success than the achievement of “normal” hearing defined as an AC level $\leq 20$ dB.

On the basis of our results we agree with the conclusions of Berliner et al. and the AAO-HNS recommendations to use AC and BC levels from the same audiogram in computing ABG. Because in many audiology departments in Europe the 3 kHz is not routinely measured, a four-frequency PTA will be an average at 0.5, 1, 2 and 4 kHz in most situations and is preferred for reporting results after stapes surgery with regard to mean values of audiological parameters.

REFERENCES