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Surgical Findings and Long-Term Hearing Results in 3,050 Stapedotomies for Primary Otosclerosis: A Prospective Study with the Otology-Neurotology Database

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Objective: To evaluate with a new otologic database the results of primary stapes surgery for otosclerosis with up to 14 years of follow-up in a consecutive series of 2,525 patients operated on by the same surgeon with the same technique (stapedotomy and vein graft interposition) and to provide online access to the complete data of this study for the reviewers. To study the effect of specific operative findings (obliterative otosclerosis and simultaneous malleus ankylosis) and age at the time of surgery on the long-term outcome.
Study Design: Prospective clinical study using a new computerized otologic database.
Setting: Tertiary referral center.
Patients: Two thousand five hundred twenty-five patients who underwent 3,050 stapedotomies for otosclerotic stapes fixation were enrolled in this study from January 1991 to December 2004. Separate analyses were made for two unique pathologies (92 cases of obliterative otosclerosis and 19 cases of simultaneous malleus ankylosis) diagnosed during surgery and for patients in two age brackets (≤18 yr [28 patients] and ≥65 yr [302 patients]).
Intervention: Stapedotomy with vein graft interposition and reconstruction with either a Teflon piston, a bucket handle prosthesis, or a total prosthesis.
Main Outcome Measures: Preoperative and postoperative audiometric evaluation using conventional audiometry. Air-bone gap (ABG), bone-conduction thresholds, and air-conduction thresholds were all assessed. Postoperative audiometry was performed at 3, 6, 9, 12, 18, and 24 months and then annually for 14 years.
Results: Overall, the postoperative ABG was closed to 10 dB in 94.2% of cases. The mean four-frequency postoperative ABG was 1.7 dB compared with 25.6 dB preoperatively. The mean four-frequency bone-conduction thresholds were unchanged postoperatively. A significant postoperative sensorineural hearing loss (SNHL; >15 dB) was seen in 0.5% of cases in this series. Postoperative ABG was achieved to within 10 dB in 95% of cases of obliterative otosclerosis and in 64.7% of cases of simultaneous malleus ankylosis. A significant postoperative SNHL (>15 dB) was seen in 4.8% of cases of obliterative otosclerosis and was not observed in any cases of simultaneous malleus ankylosis. Postoperative ABG was achieved to within 10 dB in 93.5% of cases in the pediatric series and in 94.5% of cases in the senior series. A significant postoperative SNHL (>15 dB) was seen in 0.7% of cases in the senior group but was not observed in the children.
Conclusion: Using a new otologic database, our series confirms that stapedotomy with vein graft interposition for otosclerotic stapes fixation is a safe and successful treatment for long-term hearing improvement. The deterioration in hearing with time after stapedotomy did not exceed the rate of hearing loss because of presbyacusis. Therefore, argon laser stapedotomy with vein graft interposition is our preferred surgical technique in the treatment of otosclerosis. Obliterative otosclerosis and simultaneous malleus ankylosis may be encountered during stapedotomy. Our study shows that reasonable success rates can still be expected in these situations. Stapedotomy results in the elderly and in children are comparable to those obtained in patients of other groups of age undergoing surgery for otosclerosis without an increased risk for complications. **Key Words:** Hearing results—Middle ear—Otology neurotology database—Otosclerosis—Stapedotomy—Stapes surgery.
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The authors of this article confirm that they are not in receipt of any remuneration or fee and have no pecuniary interest resulting from their use of ONDB, the commercial product presented in this article.

Since the first stapedectomy with vein graft interposition described by Shea in 1956 (1), the surgical technique for otosclerotic stapes fixation has undergone many modifications. During the last two decades, the technique has evolved from stapedectomy to stapedotomy

with or without tissue interposition. Previous reports of otosclerosis surgery have shown that stapedotomy gives better high-frequency gain and reduces the risk for sensorineural hearing loss (SNHL) (2,3), whereas stapedectomy is thought to give better hearing gain in the low frequencies (4,5). The aims of this prospective study were to evaluate the results of stapedotomy having 14 years of follow-up in a consecutive series of 2,525 patients operated on by the same surgeon with the same technique (stapedotomy and vein graft interposition) and to determine whether patient age and two specific surgical presentations (obliterative otosclerosis and simultaneous malleus ankylosis) altered the success rate of stapedotomy within the same group of patients. This long-term prospective audiometric evaluation of hearing changes after surgical treatment of stapedial otosclerosis was made with a computerized otologic database developed in our center.

MATERIALS AND METHODS

Patients

This is a prospective study of 2,525 patients who underwent 3,050 stapedotomies for otosclerosis with stapes fixation. All patients treated between January 1991 and December 2004 were included in this study and were operated on by the same surgeon. A serial assessment of hearing status was conducted before and at regular intervals after surgery. All patients had at least 3 months of audiologic follow-up after the operation. Sex ratio was 67% female and 33% male with a mean age of 47.3 years, ranging from 8 to 91 years. There were 28 children (age, ≤18 yr) who underwent 34 stapedotomies and 302 senior patients age ≥65 yr) who underwent 340 stapedotomies. Included in this study were 56 ears that underwent a first revision stapedotomy and 22 ears that underwent a second revision stapedotomy.

Otology-Neurotology Database

An ideal computerized medical record should allow efficient data storage, easy retrieval, and comprehensive documentation of patient care (6). It should possess the following important features (7): 1—a natural, intuitive interface; 2—ease of entry for large volumes of appropriate data; 3—efficient retrieval and review of data in multiple formats; 4—prospective coding of appropriate information; and 5—support for all types of clinical work including the office and the inpatient environment.

The Otology-Neurotology Database (ONDB) (AS Multimedia Inc, Cassagne, France) is a commercially available software package developed at our center, designed to comply with the American Academy of Otolaryngology guidelines of reporting audiometry results (8). It is based on Fourth Dimension Database Software. (4D Inc, San Jose, CA, U.S.A.). The program uses a relational database and template-based graphical user interface to enable the entry and study of patient data (Figs. 1 and 2). ONDB is well suited to use for multicenter studies by virtue of its technical tools which allow the merging and study of large amounts of data collected from different surgeons and institutions, while still ensuring patient confidentiality. At the current time, this program is available to assess results in patients undergoing surgery for otosclerosis (primary and revision surgery), osteogenesis imperfecta, congenital malformations of the ossicular chain, chronic suppurative otitis media with or without cholesteatoma, and implantable hearing aids according to exhaustive criteria and in multiple combinations.

We plan to expand ONDB's capabilities to apply to neurotology and expect that its easily adaptable format can be used to store and retrieve data pertaining to head and neck surgery, rhinology, and, indeed, any other medical or surgical specialty.

ONDB is currently being studied and continually updated and refined by an international scientific committee[1] including respected otologists from the United States, United Kingdom, France, Turkey, South Africa, Israel, India, Tunisia, Croatia, and Brazil.

According to Berman (9), without access to the original data, it is impossible to validate or improve upon a researcher's conclusions. The original data are available online at ondb.kletel.net for reviewers and readers of this article via a client-server network (Fig. 3). Appropriate safeguards have been taken to ensure the anonymity of individual patients (6,10,11). The relevant data are situated in a distant computer known as the «Host Computer». By using Remote Desktop Connection (Microsoft Corp., Redmond, WA, U.S.A.), free access to database of this series of primary otosclerosis is possible using the ONDB program that is on the «Host Computer».

The Remote Desktop Connection software allows the computer of the reader (either PC or Mac) to control the «Host Computer» and work with programs and files on that computer. It is not possible to make any modification to the data of this series.

Gaining Access to the «Host Computer»

Remote Desktop Connection software is installed by default on computers running Windows XP. For Mac users and for earlier versions of Windows, it is necessary to download this software from Microsoft Web site or directly from the following sites:

for PC, www.ondb.org/MSRDPCLI.exe

for Mac, www.ondb.org/RDC103EN.dmg

Once the software has been downloaded, it must be installed on the reader's computer.

1. To run the ONDB program, double-click on «Remote Desktop Connection».
2. Enter the following address: ondb.kletel.net into the window «Computer»
3. Open «Options», select «Display», choose resolution: 1,280 × 1,024.
4. Click on «Connect».
5. One of 10 available log-ins must be entered: Readers 1 to 10, respectively.
6. Enter the following password: ondb.
7. On access to the desktop of the «Host Computer», click on «ondb»; it will open the «Results» section of ONDB.

It is recommended to download ONDB User's Guide from the desktop of the «Host Computer» to use the program.

[1]Members of the Otology-Neurotology Database International Scientific Committee: Robert Jackler (U.S.A.), Neil Sperling (U.S.A.), Mohamed Hamid (U.S.A.), Chris Aldren (U.K.), Leon Lindsay (U.K.), David Luff (U.K.), John Oates (U.K.), Jonathan Osborne (U.K.), Christopher Raine (U.K.), Jacques Magnan (France), Patrice Tran Ba Huy (France), Christian Dubreuil (France), Thibaut Dumon (France), Benoit Gratacap (France), Robert Vincent (France), Mislav Gjuric (Croatia), Nuri Ozgirgin (Turkey), Peter Friedland (South Africa), Duane Mol (South Africa), Jacob Sade (Israël), Ashesh Bhumpar (India), Anand Shah (India), Sady Da Costa (Brazil), and Mounir Marrakchi (Tunisia).

FIG. 1. Computer screen showing template used for data entry in a patient operated on for otosclerosis.

Please note that only 10 readers at any one time can have access to the data. Therefore, a reader can inadvertently be disconnected by another reader who has connected using the same log-in. It will then be necessary to try again later with another log-in.

Surgery

A transcanal procedure was used in all cases in this series. The stapes tendon was cut routinely, and reconstruction of the stapes tendon was performed in 600 cases (19.7%) but was abandoned in 1997 after the data suggested no benefit (12).

In all cases, argon laser stapedotomy was performed (setting: 1 W, 0.2 s) followed by vein graft interposition.

A 0.4-mm-diameter Teflon piston of appropriate length was routinely used when the incus was of normal length (2,843 cases [93.3%]). A bucket-handle (cup)–type prosthesis made of Teflon was used when the incus was short or the facial nerve was dehiscent (175 cases [5.7%]). A total prosthesis (total ossicular replacement prosthesis [TORP]—incus and stapes replacement) comprising a hydroxyapatite head and a 0.4-mm Teflon shaft was used in 32 cases (1%) when stapes fixation and malleus ankylosis occurred simultaneously (19 cases) or when the incus was eroded or dislocated (13 cases).

Surgical Technique for Obliterative Otosclerosis (92 Cases)

Drilling the stapedotomy in cases of obliterative otosclerosis is widely accepted to be more difficult. Using a combination of sequential laser vaporization and drilling, the area being drilled should be progressively enlarged. This helps the placement of the vein graft. Because of the depth of drilling required, it is necessary to measure the distance from the incus or malleus to the stapedotomy with a stapes-measuring rod after drilling has been completed. Ossicular chain reconstruction was performed by use of a 0.4-mm-diameter Teflon piston in 80 cases (87%), a bucket-handle (cup)–type prosthesis in 11 cases (12%), and a total prosthesis (TORP) in 1 case (1%) where malleus ankylosis was also associated with obliterative otosclerosis.

Surgical Technique for Simultaneous Malleus Ankylosis (19 Cases)

Initially, the problem of simultaneous malleus ankylosis was managed in our center by the commonly reported method of removal of the head of the malleus (13). In 1999, the technique of removing the malleus head was abandoned in favor of the technique of malleus relocation (14), allowing for better placement of the TORP. The malleus is dissected free from the tympanic membrane and the tensor tympani sectioned close to its insertion. The incus is then removed. The anterior malleal ligament is stretched by placing a hook anterior to the neck of the malleus which is then pulled posteriorly, repositioning it so that it lies directly over the footplate. The position of the malleus is maintained by its superior ligament which is preserved. The final position of the malleus allows easier placement of TORP. Malleus relocation was

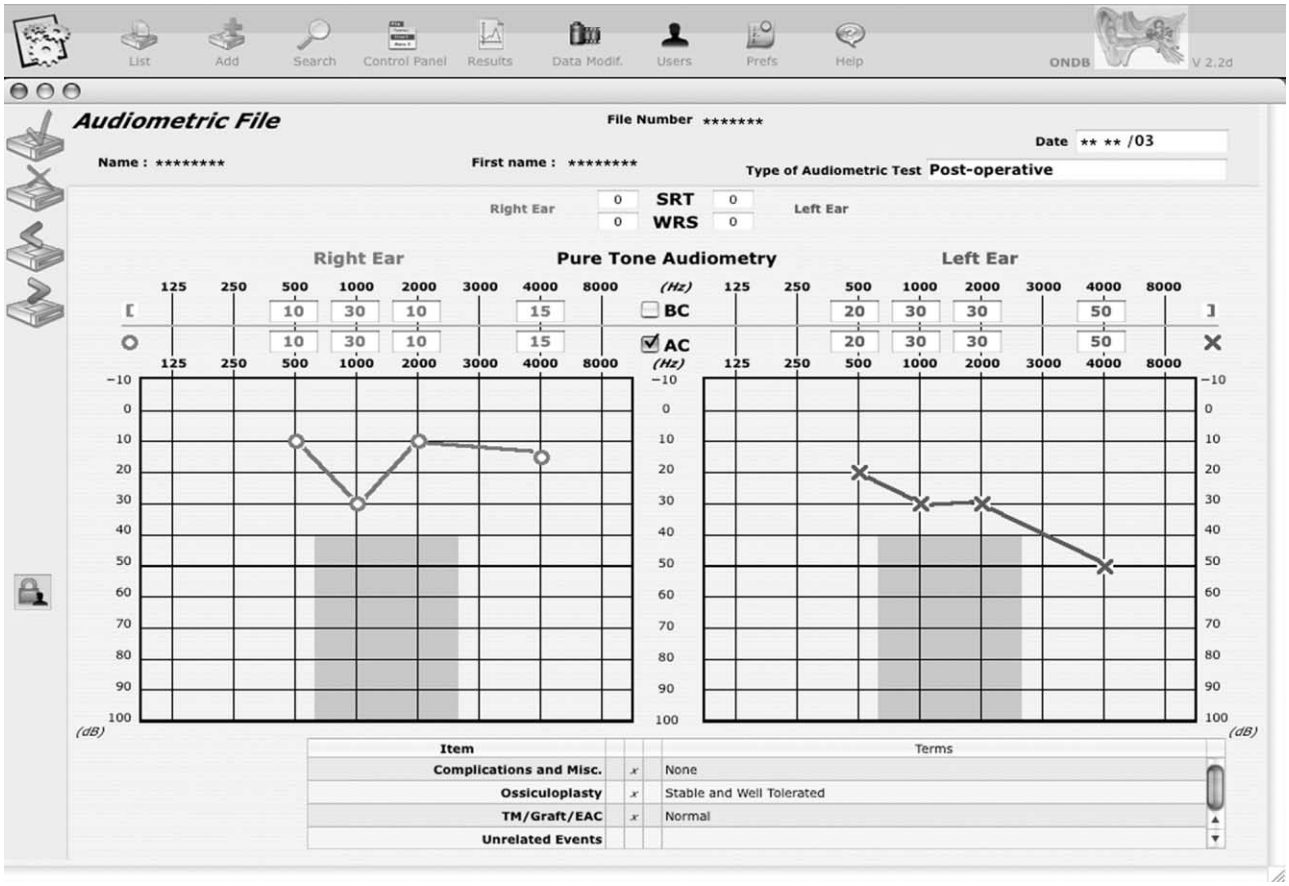

FIG. 2. Computer screen showing template used for audiometric data entry in the same patient operated on for otosclerosis.

used in four cases of simultaneous malleus ankylosis. Ossicular chain reconstruction was performed by use of a total prosthesis in all cases (Figs. 4–11).

In the pediatric series (34 ears), ossicular chain reconstruction was performed by use of a Teflon piston in 30 cases (88.2%), a bucket-handle (cup)–type prosthesis in 2 cases (5.9%), and a total prosthesis in 2 cases of simultaneous malleus ankylosis (5.9%). In the series of seniors (340 ears), a Teflon piston was used in 314 cases (92.3%), a bucket-handle (cup)–type prosthesis in 17 cases (5%), and a total prosthesis in 4 cases of simultaneous malleus ankylosis (1.2%) and in 5 cases of an eroded or dislocated incus (1.5%).

Audiometric Assessment

Audiometric evaluation included the preoperative and postoperative air-bone gap (ABG), air-conduction (AC) thresholds, and postoperative bone-conduction (BC) thresholds. Only AC and BC results that were obtained at the same time postoperatively were used for calculation of ABG and pure-tone averages (PTAs). We used a four-frequency PTA for AC and BC thresholds (0.5, 1, 2, and 4 kHz) obtained at the last follow-up visit. The preoperative and postoperative BC and AC levels at 4 kHz were also assessed. All patients had at least 3 months of audiologic follow-up. Audiometry was reported according to American Academy of Otolaryngology–Head and Neck Surgery guidelines (8) except for thresholds at 3 kHz which were substituted in all cases with those at 4 kHz. This was necessary because of the fact that 3-kHz measurements were not undertaken at the beginning of this study in 1991.

RESULTS

Specific Operative Findings

Obliterative otosclerosis with hard new bone filling the fossa, requiring an oval window drillout for an excessively thick footplate, was seen in 92 (3%) of the 3,050 cases, in 82 patients. Of these 82 patients, 25 were operated on bilaterally. Of these 25 patients, 10 (40%) had obliterative otosclerosis in both ears. The incidence of obliterative otosclerosis was 14.7% (5/34 cases) in our children series and 2.6% (9/340 cases) in our elderly series.

The presence of a simultaneous malleus fixation was found in 19 (0.6%) of the 3,050 cases compared with 2 (6%) of the 34 cases in the children and to 4 (1.2%) of the 340 cases in the elderly series. Of these 19 patients, 3 were operated on bilaterally, but none of them had malleus ankylosis in both ears.

Audiometric Results

Part I: Overall Results

Hearing results in 2,527 cases. Of the 3,050 cases in which surgical data were compiled, 2,527 had audiologic

data available (82.8%). Due to the fact that many of our patients travel long distances for care at our center, follow-up care is sometimes not possible. Mean follow-up was 46.1 months (range, 3–164 mo) (Table 1).

Postoperative hearing results at 12 months or later were available in 1,672 cases (66.2% of 2,527 cases) (8). The mean follow-up for this group was 66.2 months (range, 12–164 mo). A separate analysis was made for the entire series (2,527 cases) and for the group of patients with 1 or more years of follow-up (1,672 cases).

There were 13 cases of postoperative SNHL in the entire series (0.5%), defined as a change in the BC PTA of 15 dB or more. These 13 cases were not included in the assessment of the postoperative ABG (n = 2,514 cases) but were included in the assessment of the postoperative AC and BC thresholds (n = 2,527 cases). The postoperative four-frequency ABG was closed to 10 dB or less in 2,368 (94.2%). The postoperative four-frequency average ABG was 1.7 dB compared with 25.6 dB preoperatively. The postoperative four-frequency AC threshold was 27.2 dB compared with 51.4 dB preoperatively. Postoperatively, the four-frequency average BC threshold was 25.5 dB compared with 25.8 dB preoperatively, and overclosure (postoperative improvement of BC >10 dB) occurred in 98 cases (4%).

At 4 kHz, the mean postoperative AC threshold was 35.8 dB compared with 50.8 dB preoperatively, and the mean postoperative BC threshold was 34 dB compared with 31.4 dB preoperatively.

Hearing results in 1,672 cases with at least 1-year results (Table 2). As outlined above, there were 13 cases of postoperative SNHL in our entire series. One year or later after surgery, 4 of these 13 cases were still being followed up. These four cases were not included in the assessment of the postoperative ABG (n = 1,668 cases) but were included in the assessment of the postoperative AC and BC thresholds (n = 1,672 cases). The postoperative four-frequency ABG was closed to 10 dB or less in 1,570 (94.2%). The postoperative four-frequency average ABG was 1.5 dB compared with 25 dB preoperatively. The postoperative four-frequency average AC threshold was 27.5 dB compared with 51 dB preoperatively. The postoperative four-frequency average BC threshold was unchanged (26 dB), and overclosure occurred in 72 cases (4.3%). At 4 kHz, the average postoperative AC threshold was 36.5 dB compared with 50.3 dB preoperatively, and the average postoperative BC threshold was 34.8 dB compared with 31.7 dB preoperatively (Table 2).

Long-term hearing results in the entire series of available data (2,527 cases). Table 3 shows the

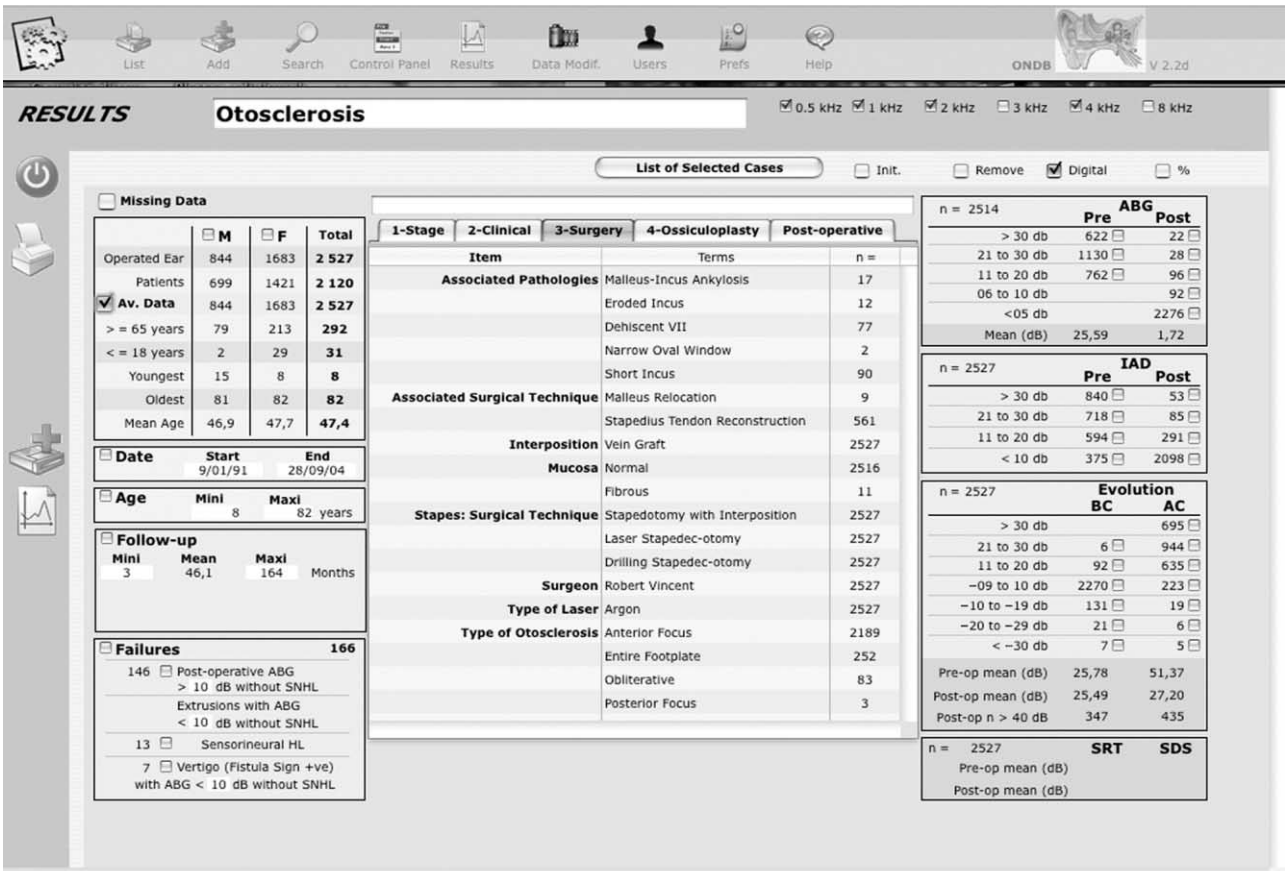

FIG. 3. Computer screen showing template used for presentation of results of primary stapes surgery for otosclerosis in the current series of 3,050 cases.

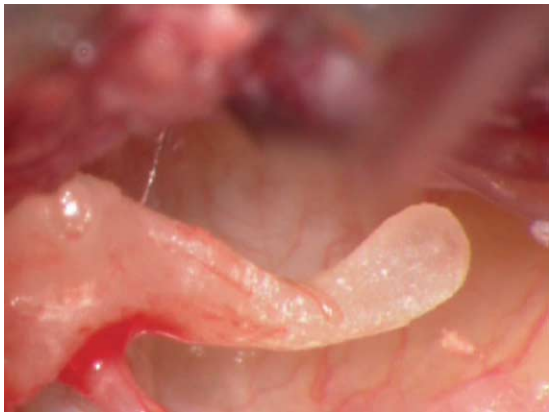

FIG. 4. The malleus handle is dissected from the tympanic membrane. It should be entirely separated from the tympanic membrane.

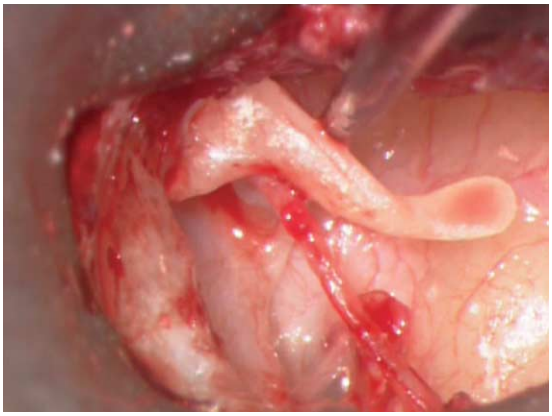

FIG. 6. Malleus relocation: the anterior tympanomallear ligament is stretched with a hook.

audiometric results of the entire series from 1 to 10 years of follow-up. Not all data were available for every case. Many of our patients travel long distances for care at our center, and follow-up is sometimes not possible. Eight hundred patients were tested at 1 year postoperatively, 346 were assessed at 5 years postoperatively, and 180 cases had follow-up data for 10 years. Mean values of the postoperative ABG show a stable long-term hearing improvement. At 10 years, successful closure of the ABG to 10 dB was still present in 96.7% of cases compared with 95.6% of cases at 1 year. No significant progression in hearing loss was observed with time as the average four-frequency postoperative gain in AC was 25.3 dB after 10 years of follow-up compared with 26.2 dB after 1 year. The average four-frequency BC threshold was 25.2 dB at 10 years compared with 24 dB at 1 year. However, assessment of AC and BC thresholds at 4 kHz showed a slight progression of hearing loss with time as the average gain in AC at 4 kHz was 13.9 dB after 10 years of follow-up compared with 17.2 dB after 1 year. Postoperatively, a continuous progression of sensorineural component was observed over years as the mean postoperative BC threshold at 4 kHz was 35.2 dB after 10 years of follow-up compared with 32 dB after 1 year. The average gain in AC at 4 kHz was 13.9 dB after 10 years of follow-up compared with 17.2 dB after 1 year.

Long-term hearing results of a series of 180 cases with data available after 10 years' follow-up. Of the entire series of cases, 180 cases had audiologic data available at 10 years of follow-up. Table 4 shows the audiometric results of these 180 cases which were followed over 10 years. A slight progression of hearing loss with time was observed as the average postoperative gain in AC at 10 years diminished by 3.9 dB as compared with the 1-year results. The average annual deterioration in postoperative gain in AC was mainly observed after 5 years. Average deterioration was 0.35 dB/yr before 5 years and 0.5 dB/yr after 5 years.

To assess deterioration of early results, we compared the results at 1 year with the results of the same cases at 10 years of follow-up. Eighty-two cases had audiologic data available at the 1- and 10-year marks. Table 5 presents the long-term results of these 82 cases showing the

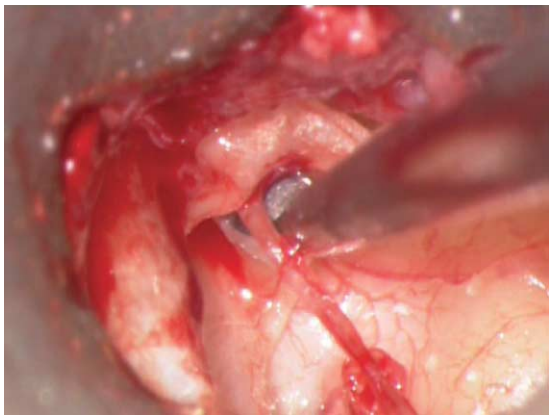

FIG. 5. The tensor tympani is sectioned close to its insertion to the malleus neck.

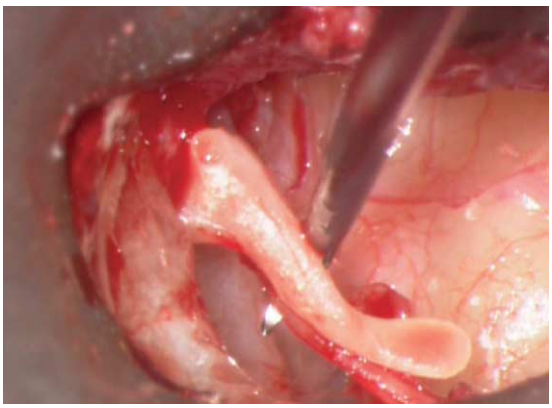

FIG. 7. After the relocation has been completed, the malleus lies directly above the stapes footplate.

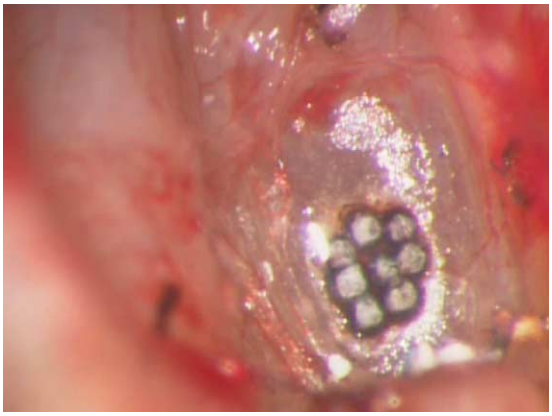

FIG. 8. Argon laser vaporization of the stapes footplate (setting 1 W, 0.2 s).

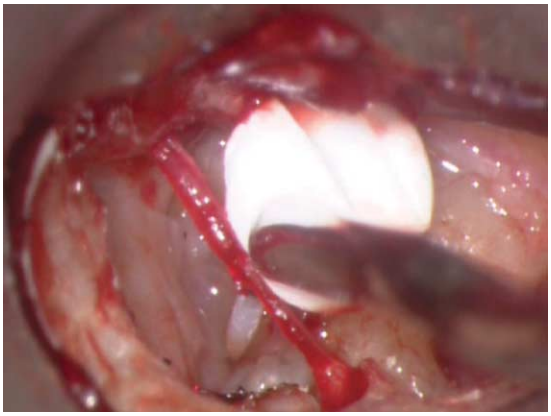

FIG. 10. An hydroxyapatite-Teflon TORP is positioned. The shaft is introduced within the stapedotomy.

annual AC and BC deterioration (in decibels per year) during 10 years of follow-up. The average annual deterioration was 0.4 dB/yr for AC and 0.36 dB/yr for BC. At 4 kHz, the annual deterioration was 0.69 dB/yr for AC and 0.59 dB/yr for BC.

ONDB allowed study of results of these 82 cases depending on each of the four measured frequencies. Table 6 shows AC and BC change by frequency during 10 years. The rate of decline in the AC threshold over the four frequencies ranged from 0.23 to 0.69 dB/yr. The decline observed in the BC threshold over the same four frequencies ranged from 0.25 to 0.59 dB/yr. The minimum loss was observed at 0.5 kHz for AC and BC, and the maximum loss in AC and BC was seen at 4 kHz. A similar deterioration was seen in both AC and BC with time except for frequency at 4 kHz. The annual deterioration in postoperative gain in AC was negligible for 0.5 kHz and was 0.35, 0.29, and 0.7 dB/yr for 1, 2, and 4 kHz, respectively.

Hearing results related to year of surgery (1991–2004). ONDB allowed us to study results according to the date of surgery. This permitted an assessment of ones learning curve (15). Table 7 shows the audiometric results of the entire series of cases according to each year of surgery from 1991 to 2004. Each year represents a different data set. The highest rate of postoperative severe SNHL was seen during Year 8 (1.7% of 174 cases) compared with 0.5% for the entire series of 2,527 cases. Currently, no postoperative SNHL was seen during the last 4-year period (2001–2004); however, the mean follow-up period remains short. It is assumed that, with experience, more difficult cases were attempted, which may account for the unusual pattern in Year 8.

Part II: Results According to Specific Surgical Findings

Obliterative otosclerosis. Of the 92 cases in which obliterative otosclerosis was seen, 83 had audiologic data available (90.2%). Mean follow-up was 53.4 months (range, 3–162.3 mo). There were four cases of postoperative SNHL in this group (4.8%), which were not included in the assessment of the postoperative ABG (n = 79 cases) but were included in the assessment of the postoperative AC and BC thresholds (n = 83 cases). As stated, the incidence of postoperative SNHL was 4.8% in the 83 cases of obliterative otosclerosis. This compares to a rate of 0.4% in the 2,444 cases with available

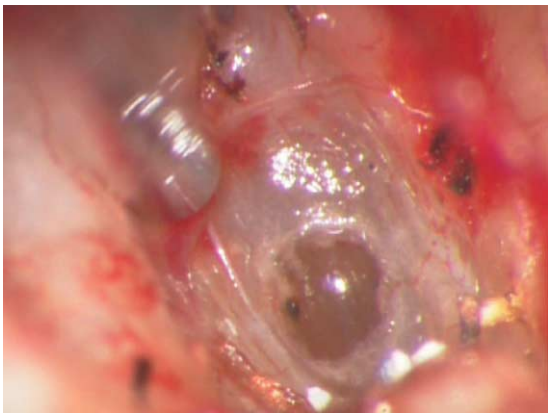

FIG. 9. Stapedotomy.

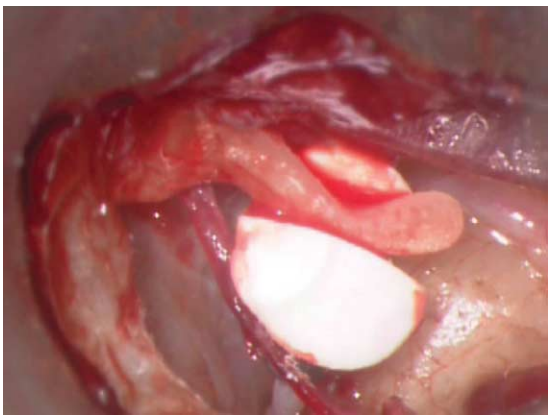

FIG. 11. The relocated malleus is easily positioned within the groove of the prosthesis' head.

TABLE 1. *Hearing results in 2,527 cases*

SNHL (%)	Mean ABG (dB)		Postop ABG (%)			Mean AC (dB)		Mean BC (dB)		Mean AC (dB) at 4 kHz		Mean BC (dB) at 4 kHz	
Postop	Preop	Postop	≤10 dB	11–20 dB	>20 dB	Preop	Postop	Preop	Postop	Preop	Postop	Preop	Postop
0.5	25.6	1.7	94.2	3.8	2	51.4	27.2	25.8	25.5	50.8	35.8	31.4	34

SNHL, sensorineural hearing loss; ABG, air-bone gap; AC, air conduction; BC, bone conduction.

postoperative data who did not have obliterative otosclerosis. The postoperative four-frequency ABG was closed to 10 dB or less in 75 (95%) of 79 cases compared with 94.2% in the 2,444 cases with available postoperative data who did not have obliterative otosclerosis. The postoperative average four-frequency ABG was 2.1 dB compared with 28.7 dB preoperatively. The average postoperative four-frequency hearing threshold was 32 dB compared with 57.3 dB preoperatively. Postoperatively, the mean four-frequency BC threshold was 30 dB compared with 28.8 dB preoperatively. At 4 kHz, the average postoperative hearing threshold was 41.8 dB compared with 57.8 dB preoperatively, and the mean postoperative BC threshold was 40 dB compared with 36.7 dB preoperatively (Table 8). Obliterative otosclerosis was found in 82 patients (92 ears). Of these patients, 25 underwent bilateral surgery, and 10 patients (40%) had obliterative otosclerosis in both ears. Therefore, there were 10 patients (20 ears) with a bilateral obliterative footplate and 72 patients (72 ears) with a unilateral obliterative footplate. Of these 20 cases of bilateral obliterative otosclerosis, 19 had audiologic data available, and of the 72 cases of unilateral obliterative otosclerosis, 64 had audiologic data available. The rate of postoperative four-frequency ABG of less than 10 dB was 96.8% for a unilateral obliterated footplate and 88.8% for a bilateral obliterated footplate. Postoperative SNHL occurred in 5.3% of cases with a bilateral obliterated footplate (1/19 cases) compared with 4.7% of cases with a unilateral obliterated footplate (3/64 cases).

Postoperative hearing results at 12 months or later were available in 62 cases (74.7%) and are presented in Table 9. Mean follow-up was 67.6 months (range, 12–162.3 mo). As previously stated, there were four cases of postoperative SNHL in the entire subset of obliterative otosclerosis cases. One year after surgery, one of these four cases was still being followed. This case was not included in the assessment of the postoperative ABG (n = 61 cases) but was included in the assessment of AC and BC thresholds (n = 62 cases). The postoperative four-frequency ABG was closed to 10 dB or less in 59 (96.7%). The postoperative average four-frequency ABG was 1.7 dB compared with 28.2 dB preoperatively. The average postoperative four-frequency AC threshold was 31 dB compared with 56.6 dB preoperatively. The average postoperative four-frequency BC threshold was 29.2 dB compared with 28.4 dB preoperatively. At 4 kHz, the average postoperative hearing threshold was 41.3 dB compared with 57.7 dB preoperatively, and the mean postoperative BC threshold was 39.5 dB compared with 36.3 dB preoperatively.

Simultaneous Malleus Ankylosis

Of the 19 cases in which simultaneous stapes fixation and malleus ankylosis were identified, 17 (89.5%) had audiologic data available. Mean follow-up was 41.2 months (range, 3.7–133.7 mo). There were no cases of postoperative SNHL in this series. The postoperative ABG (averaged over 0.5, 1, 2, and 4 kHz) was closed to 10 dB or less in 11 (64.7%) compared with 94.3% in the 2,510 cases that did not have simultaneous malleus ankylosis. The postoperative average four-frequency ABG was 9.8 dB compared with 28.6 dB preoperatively. The average four-frequency postoperative hearing threshold was 32.7 dB compared with 52 dB preoperatively. Postoperatively, the average four-frequency BC threshold was 22.8 dB compared with 23.5 dB preoperatively. At 4 kHz, the average postoperative hearing threshold was 48.2 dB compared with 48.8 dB preoperatively, and the mean postoperative BC threshold was 34.4 dB compared with 28 dB preoperatively.

Postoperative hearing results at 12 months or later were available in 12 cases (70.6%) and are presented in Table 9. Mean follow-up was 51.8 months (range, 12.1–120.7 mo). The postoperative ABG was closed to 10 dB or less in 10 (83.3%). The postoperative mean ABG was 3.4 dB compared with 26.3 dB preoperatively. The average postoperative AC threshold was 24 dB

TABLE 2. *Hearing results in 1,672 cases with at least 1-year follow-up*

SNHL (%)	Mean ABG (dB)		Postop ABG (%)			Mean AC (dB)		Mean BC (dB)		Mean AC (dB) at 4 kHz		Mean BC (dB) at 4 kHz	
Postop	Preop	Postop	≤10 dB	11–20 dB	>20 dB	Preop	Postop	Preop	Postop	Preop	Postop	Preop	Postop
0.8	25	1.5	94.2	3.8	2	51	27.5	26	26	50.3	36.5	31.7	34.8

SNHL, sensorineural hearing loss; ABG, air-bone gap; AC, air conduction; BC, bone conduction.

TABLE 3. *Long-term hearing results in the entire series of 2,527 cases*

		<1 yr (3–11 mo)	1 yr (12–18 mo)	2 yr (19–24 mo)	3 yr (25–42 mo)	4 yr (43–52 mo)	5 yr (53–66 mo)	6 yr (67–78 mo)	7 yr (79–90 mo)	8 yr (91–104 mo)	9 yr (105–114 mo)	10 yr (115–126 mo)
Available data		1,838	800	354	677	285	346	223	165	190	154	180
Postop ABG ≤ 10 dB (%)		95.5	95.6	93	95.8	96.4	96.8	96	98.2	99.5	94.2	96.7
Mean ABG (dB)	Preop	25.8	25	25.2	24.6	24	24.3	24.6	25	23.7	24.6	24.8
	Postop	1.6	1	2	1.2	1	1	1	0.6	0.3	1	0.5
Mean AC (dB)	Preop	51.3	51.2	52	51.6	49.6	50.4	50.6	52.6	50.8	50.2	51
	Postop	25.8	25	27	26.5	25.8	26.5	26	27.6	25.8	26.6	25.7
Mean BC (dB)	Preop	25.6	26	26.8	27	25.6	26	26	27.5	27.2	25.6	26.2
	Postop	24.2	24	25	25.2	25	25.5	25	27	25.5	25.5	25.2
Average gain in AC (dB)		25.5	26.2	25	25.1	23.8	23.9	24.6	25	25	23.6	25.3
Mean AC at 4 kHz (dB)	Preop	51	50.2	50.7	50.8	48.3	48.7	49.4	52	50.6	48.2	49.7
	Postop	34.2	33	35.2	34.8	34.3	35.3	35	36.5	36	35.8	35.8
Mean BC at 4 kHz (dB)	Preop	31.3	31.4	32.2	32.6	30.8	31	31.6	33.8	32.6	30	31.2
	Postop	32.5	32	33	33.7	33.5	34.4	34	36	35.4	34.7	35.2

ABG, air-bone gap; AC, air conduction; BC, bone conduction.

compared with 47.8 dB preoperatively. The average postoperative BC threshold was 20.6 dB compared with 21.4 dB preoperatively. Overclosure occurred in one case (8.3%). At 4 kHz, the average postoperative hearing threshold was 40 dB compared with 44.2 dB preoperatively, and the mean postoperative BC threshold was 33.3 dB compared with 24.2 dB preoperatively.

Long-term hearing results according to surgical presentations. Table 10 shows the audiometric results over time of the entire series of cases according to surgical presentation after 1, 5 and 10 years of follow-up. Very few cases were available at 10 years: six cases from the obliterative otosclerosis series and one from the simultaneous malleus ankylosis series. Thus no significant conclusions may be drawn.

Long-term hearing results of a series of cases available at 10 years' follow-up. Of the entire series, 180 cases had audiologic data available at 10 years of follow-up. Of these 180 cases, 82 had audiologic data available at the 1- and 10-year marks. Of these 82 cases, there were four cases of obliterative otosclerosis and one case of simultaneous malleus ankylosis. Table 11 shows the results of these 82 cases during this 10-year period according to surgical presentation. The annual deterioration in AC threshold was 0.27 dB/yr for the obliterative otosclerosis series (four cases) and was 0.4 dB/yr for the 78 cases that did not have obliterative otosclerosis. The annual deterioration in BC threshold was 0.27 dB/yr for the obliterative otosclerosis series compared with 0.38 dB/yr for the 78 cases that did not have obliterative otosclerosis. At 4 kHz, the annual deterioration in AC threshold was 0.42 dB/yr for the obliterative otosclerosis series and was 0.7 dB/yr for the 78 cases that did not have obliterative

TABLE 4. *Long-term hearing results of a series of 180 cases with available data at 10 years' follow-up*

		1 yr (12–18 mo)	5 yr (53–66 mo)	10 yr (115–126 mo)
Available data		82	58	180
Postop ABG ≤10 dB (%)		98.8	98.3	96.7
Mean ABG (dB)	Preop	24.8	24.3	24.8
	Postop	0.3	0.2	0.5
Mean AC (dB)	Preop	52.8	50.8	51
	Postop	23.6	23	25.7
Mean BC (dB)	Preop	28	26.5	26.2
	Postop	23.3	22.8	25.2
Average gain in AC (dB)		29.2	27.8	25.3
Mean AC at 4 kHz (dB)	Preop	51.2	47.8	49.7
	Postop	31	31.5	35.8
Mean BC at 4 kHz (dB)	Preop	32.8	30.2	31.2
	Postop	30.8	31.5	35.2

ABG, air-bone gap; AC, air conduction; BC, bone conduction.

TABLE 5. *Long-term hearing results of a series of 82 cases during 10 years*

		1 yr (12–18 mo)	10 yr (115–126 mo)
Available data		82	82
Postop ABG ≤10 dB (%)		98.8	96.3
Mean ABG (dB)	Preop	24.8	24.8
	Postop	0.3	0.6
Mean AC (dB)	Preop	52.8	52.8
	Postop	23.6	27.2
Mean BC (dB)	Preop	28	28
	Postop	23.3	26.6
Average gain in AC (dB)		29.2	25.6
Mean AC at 4 kHz (dB)	Preop	51.2	51.2
	Postop	30.9	37.1
Mean BC at 4 kHz (dB)	Preop	32.8	32.8
	Postop	30.8	36.1

ABG, air-bone gap; AC, air conduction; BC, bone conduction.

TABLE 6. *Air conduction and bone conduction threshold change by frequency during 10 years (82 cases)*

Frequency (kHz)		AC threshold					BC threshold				
		0.5 kHz	1 kHz	2 kHz	4 kHz	Average	0.5 kHz	1 kHz	2 kHz	4 kHz	Average
1 yr postop (12–18 mo)	Mean (dB)	15.7	21.7	26.3	30.9	23.6	15.1	21.5	26	30.8	23.3
	Change (dB)	+35.6	+33.6	+27.2	+20.3	+21.2	+5	+4.4	+6.9	+2	+4.6
10 yr postop (115–126 mo)	Mean (dB)	17.8	24.8	29	37.1	27.2	17.4	24.3	28.5	36.1	26.6
	Change (dB)	+33.5	+30.4	+24.6	+14	+25.6	+2.8	+1.6	+4.4	−3.3	+1.3
	Deterioration (dB/yr)	0.23	0.34	0.3	0.69	0.40	0.25	0.31	0.28	0.59	0.36

AC, air conduction; BC, bone conduction.

otosclerosis. The annual deterioration in BC threshold at 4 kHz was 0.42 dB/yr for the obliterative otosclerosis series and was 0.6 dB/yr for the 78 cases that did not have obliterative otosclerosis. The unique case of simultaneous malleus ankylosis remained stable with time.

Table 12 shows AC and BC deterioration by frequency during 10 years of these 82 cases according to surgical presentation. The rate of decline in the AC threshold over the four frequencies ranged from 0 to 0.55 dB/yr in the obliterative otosclerosis series compared with 0.25 to 0.7 dB/yr in the 78 cases that did not have obliterative otosclerosis. The decline observed in the BC threshold over the same four frequencies ranged from 0 to 0.55 dB/yr in the obliterative otosclerosis series and ranged to 0.26 to 0.6 dB/yr for the 78 cases that did not have obliterative otosclerosis. In the obliterative otosclerosis series, the greatest loss in AC and BC was seen at 2 kHz, and similar deterioration was observed in both AC and BC.

Part III: Results Related to Age

Children (≤18 Yr Old)

Surgery was performed on 34 ears in 28 children. The sex ratio was 89% female and 11% male. The mean age was 14.8 years, ranging from 8 to 18 years. Of the 34 cases that underwent stapedotomy, 31 (91.2%) had audiologic data available. Results are presented in Table 13. Mean follow-up was 79.5 months (range, 3.9–159.6 mo). There were no cases of postoperative SNHL in this subset. The postoperative four-frequency ABG was closed to 10 dB or less in 29 (93.5%). The postoperative average four-frequency ABG was 1.6 dB compared with 26 dB preoperatively. The average postoperative four-frequency hearing threshold was 17 dB compared with 42.7 dB preoperatively. The mean postoperative four-frequency BC threshold was 15.5 dB compared with 16.7 dB preoperatively. At 4 kHz, the average postoperative hearing threshold was 20.3 dB compared with 34.5 dB preoperatively, and the mean postoperative BC threshold was 19.2 dB compared with 17.4 dB preoperatively.

Postoperative hearing results at 12 months or later were available for 30 cases (100%) and are presented in Table 14. Mean follow-up was 82 months (range, 14.4–159 mo). The postoperative four-frequency ABG was closed to 10 dB or less in 29 cases (96.7%). The postoperative average four-frequency ABG was 1.2 dB compared with 25.5 dB preoperatively. The average postoperative hearing threshold was 16.6 dB compared with 42.3 dB preoperatively. The average four-frequency postoperative BC threshold was 15.4 dB compared with 16.7 dB preoperatively. At 4 kHz, the average postoperative hearing threshold was 20 dB compared with 34 dB preoperatively, and the mean postoperative BC threshold was 19.2 dB compared with 17.3 dB preoperatively.

Obliterative otosclerosis was identified in five cases (14.7%) of the children series, and data were available in all cases. Mean follow-up was 96.6 months (range, 58.4–137.6 mo). There were no cases of postoperative SNHL, and the postoperative four-frequency ABG was closed to 10 dB or less in all cases (100%). The postoperative average four-frequency ABG was 0.7 dB compared

TABLE 7. *Assessment of results related to years of surgery from 1991 to 2004*

Year of surgery	1 (1991)	2 (1992)	3 (1993)	4 (1994)	5 (1995)	6 (1996)	7 (1997)	8 (1998)	9 (1999)	10 (2000)	11 (2001)	12 (2002)	13 (2003)	14 (2004)
Total no. operated cases	96	159	156	220	202	207	194	236	329	236	278	249	248	240
Available data	95	154	151	217	187	182	168	174	267	186	223	187	196	140
Mean follow-up (mo)	112.6	116.1	106.2	86.6	74.6	42.6	32.1	35.6	24.4	22.6	17.2	14.1	9.7	5.8
Postop SNHL (%)	—	0.6	—	1.4	0.5	0.5	0.6	1.7	0.4	1	—	—	—	—
Postop ABG ≤10 dB (%)	87.3	94	95.3	95.3	95	93.4	94.6	91.2	93.6	97.3	94.2	97.3	94	92
Average gain in AC (dB)	23.2	24.5	23.8	24	23.8	23	23.2	21.7	24.4	24.6	23.5	27.5	24.8	24.8
Average change in BC (dB)	−0.8	+1.3	+0.7	+0.3	+1	+1	0	−2	+0.4	+0.4	+0.8	+0.6	−1	+0.5
Average change in BC at 4 kHz (dB)	−4.7	−2.7	−3.4	−4.3	−3.2	−1.6	−2.2	−4.6	−2.4	−1.3	−0.9	−1.5	−3.5	−3

SNHL, sensorineural hearing loss; ABG, air-bone gap; AC, air conduction; BC, bone conduction.

TABLE 8. *Results related to specific surgical findings in 2,527 cases (0.5, 1, 2, and 4 kHz)*

		SNHL (%)	Mean ABG (dB)		Postop ABG (%)			Mean AC (dB)		Mean BC (dB)		Mean AC (dB) at 4 kHz		Mean BC (dB) at 4 kHz	
	Cases	Postop	Preop	Postop	≤10 dB	11–20 dB	>20 dB	Preop	Postop	Preop	Postop	Preop	Postop	Preop	Postop
Obliterative otosclerosis	83	4.8	28.7	2.1	95	1.2	3.8	57.3	32	28.8	30	57.8	41.8	36.7	40
Absence of obliterative otosclerosis	2,444	0.4	25.5	1.7	94.2	4	1.8	51.2	27	25.6	25.3	50.5	35.7	31.2	34
Malleus ankylosis	17	—	28.6	9.8	64.7	11.8	23.5	52	32.7	23.5	22.8	48.8	48.2	28	34.4
Absence of malleus ankylosis	2,510	0.5	25.6	1.6	94.4	3.8	1.8	51.4	27.2	25.8	25.5	50.8	35.8	31.4	34

SNHL, sensorineural hearing loss; ABG, air-bone gap; AC, air conduction; BC, bone conduction.

with 26.2 dB preoperatively. The average postoperative four-frequency hearing threshold was 16.5 dB compared with 44.2 dB preoperatively. The average four-frequency postoperative BC threshold was 15.7 dB compared with 18 dB preoperatively. At 4 kHz, the average postoperative hearing threshold was 20 dB compared with 36 dB preoperatively, and the mean postoperative BC threshold was 20 dB compared with 18 dB preoperatively.

Malleus ankylosis was identified in two cases (6%) of the children series, and data were available in both cases. Mean follow-up was 112.3 months (range, 104–120.7 mo). There were no cases of postoperative SNHL, and the postoperative four-frequency ABG was closed to 10 dB or less in both cases (100%). The postoperative average four-frequency ABG was 0 dB compared with 23.1 dB preoperatively. The average postoperative four-frequency hearing threshold was 16.2 dB compared with 45.6 dB preoperatively. The average postoperative four-frequency BC threshold was 16.2 dB compared with 22.5 dB preoperatively. At 4 kHz, the average postoperative hearing threshold was 30 dB compared with 37.5 dB preoperatively, and the mean postoperative BC threshold was 30 dB compared with 17.5 dB preoperatively.

Seniors (≥65 Yr Old)

Surgery was performed on 340 ears in 302 patients 65 years or older. The sex ratio was 72.5% female and 27.5% male. The mean age was 70 years, ranging from 68 to 91 years. Of the 340 cases that underwent stapedotomy, 292 had audiologic data available (86%). Results are presented in Table 13. Mean follow-up was 39.7 months (range, 3–157.4 mo). There were two cases of severe postoperative SNHL in this series (0.7%) which were not included in the assessment of the postoperative ABG (n = 290 cases) but were included in the assessment of the postoperative AC and BC thresholds (n = 292 cases). The postoperative four-frequency ABG was closed to 10 dB or less in 274 cases (94.5%). The postoperative mean ABG was 1.7 dB compared with 28.4 dB preoperatively. The average postoperative hearing threshold was 40 dB compared with 66.6 dB preoperatively. Postoperatively, the mean postoperative BC threshold was unchanged (38 dB), and overclosure occurred in 20 cases (6.8%). At 4 kHz, the average postoperative hearing threshold was 54.2 dB compared with 71.8 dB preoperatively, and the mean postoperative BC threshold was 52.8 dB compared with 49.3 dB preoperatively.

Postoperative hearing results at 12 months or later were available in 178 cases (61%) and are presented in Table 14. Mean follow-up was 60.4 months (range, 12–157.4 mo). As outlined earlier, there were two cases of postoperative SNHL in the entire senior subset. These two cases were not available for follow-up after 1 year. The postoperative four-frequency ABG was closed to 10 dB or less in 171 (96%). The postoperative mean ABG was 1 dB compared with 27.7 dB preoperatively. The average postoperative AC threshold was 39.3 dB compared with 65.4 dB preoperatively. The average postoperative BC threshold was 38.2 dB compared with 37.6 dB preoperatively. Overclosure occurred in 10

TABLE 9. *Results with at least 1-year follow-up related to specific surgical findings (0.5, 1, 2, and 4 kHz)*

		SNHL (%)	Mean ABG (dB)		Postop ABG (%)			Mean AC (dB)		Mean BC (dB)		Mean AC (dB) at 4 kHz		Mean BC (dB) at 4 kHz	
	Cases	Postop	Preop	Postop	≤10 dB	11–20 dB	>20 dB	Preop	Postop	Preop	Postop	Preop	Postop	Preop	Postop
Obliterative otosclerosis	62	6.4	28.2	1.7	96.7	—	3.3	56.6	31	28.4	29.2	57.7	41.3	36.3	39.5
Malleus ankylosis	12	—	26.3	3.4	83.3	16.7	—	47.8	24	21.4	20.6	44.2	40	24.2	33.3

SNHL, sensorineural hearing loss; ABG, air-bone gap; AC, air conduction; BC, bone conduction.

TABLE 10. *Long-term hearing results related to surgical presentations (0.5, 1, 2, and 4 kHz)*

		Obliterative otosclerosis (83 cases)			Absence of obliterative otosclerosis (2,444 cases)			Simultaneous malleus ankylosis (17 cases)			Absence of malleus ankylosis (2,510 cases)		
Follow-up		1 yr (12–18 mo)	5 yr (53–66 mo)	10 yr (115–126 mo)	1 yr (12–18 mo)	5 yr (53–66 mo)	10 yr (115–126 mo)	1 yr (12–18 mo)	5 yr (53–66 mo)	10 yr (115–126 mo)	1 yr (12–18 mo)	5 yr (53–66 mo)	10 yr (115–126 mo)
Available data		36	18	6	764	328	174	7	2	1	793	344	179
Postop ABG ≤10 dB (%)		100	94.4	100	95.4	97	96.5	100	50	100	95.6	97	96.6
Mean ABG (dB)	Preop	29.8	28	28	25	24	24.6	30.3	24.4	23.7	25	24.3	24.8
	Postop	0.3	2.8	0	1	1	0.5	1.8	6.8	0	1	1	0.5
Mean AC (dB)	Preop	57.5	56.3	55.4	50.8	50	50.8	47.6	49.4	57.5	51.2	50.4	51
	Postop	26.2	29.5	25.6	25	26.3	25.7	18.2	30	18.7	25.2	26.4	25.8
Mean BC (dB)	Preop	27.7	28.2	27.3	26	26	26.2	17.3	25	33.7	26	26	26.2
	Postop	26	26.6	25.6	24	25.4	25.2	16.4	23	18.7	24	25.4	25.2
Average gain in AC (dB)		31.3	26.8	29.8	25.8	23.7	25.1	29.4	19.4	38.8	26	24	25.2
Mean AC at 4 kHz (dB)	Preop	60	56.6	59.2	49.8	48.3	49.4	42.8	50	60	50.3	48.7	49.6
	Postop	37.2	39.7	40	33	35	35.7	30	50	30	33.2	35.2	36
Mean BC at 4 kHz (dB)	Preop	36	35.3	40	31.2	30.7	31	18.6	30	30	31.5	31	31.2
	Postop	37	37.2	40	31.8	34.2	35	27	30	30	32	34.4	35.2

ABG, air-bone gap; AC, air conduction; BC, bone conduction.

TABLE 11. *Long-term hearing results of a series of 82 cases available at 10 years' follow-up related to surgical presentations (0.5, 1, 2, and 4 kHz)*

		Obliterative otosclerosis (4 cases)		Absence of obliterative otosclerosis (78 cases)		Simultaneous malleus ankylosis (1 case)		Absence of malleus ankylosis (81 cases)	
Follow-up		1 yr (12–18 mo)	10 yr (115–126 mo)	1 yr (12–18 mo)	10 yr (115–126 mo)	1 yr (12–18 mo)	10 yr (115–126 mo)	1 yr (12–18 mo)	10 yr (115–126 mo)
Available data		4	4	78	78	1	1	81	81
Postop ABG ≤10 dB (%)		100	100	98.7	96	100	100	98.7	96.3
Mean ABG (dB)	Preop	32.8	32.8	24.5	24.5	23.7	23.7	24.9	24.9
	Postop	0	0	0.3	0.6	0	0	0.3	0.6
Mean AC (dB)	Preop	60	60	52.5	52.5	57.5	57.5	52.8	52.8
	Postop	24.4	26.9	23.6	27.2	18.7	18.7	23.7	27.3
Mean BC (dB)	Preop	27.2	27.2	28	28	33.7	33.7	27.9	27.9
	Postop	24.4	26.9	23.3	26.8	18.7	18.7	23.4	26.7
Average gain in AC (dB)		35.6	33.1	28.9	25.3	38.8	38.8	29.1	25.5
Mean AC at 4 kHz (dB)	Preop	66.2	66.2	50.4	50.4	60	60	51.1	51.1
	Postop	38.7	42.5	30.5	36.8	30	30	30.9	37.2
Mean BC at 4 kHz (dB)	Preop	40	40	32.5	32.5	32.5	30	32.9	32.9
	Postop	38.7	42.5	30.4	35.8	30	30	30.8	36.2

ABG, air-bone gap; AC, air conduction; BC, bone conduction.

cases (5.6%). At 4 kHz, the average postoperative hearing threshold was 53.3 dB compared with 69.6 dB preoperatively, and the mean postoperative BC threshold was 52.5 dB compared with 47.4 dB preoperatively.

Obliterative otosclerosis was identified in nine seniors (2.6%), and data were available in all cases. Mean follow-up was 27.5 months (range, 3–133.4 mo). There were no cases of postoperative SNHL. The postoperative ABG, averaged over 0.5, 1, 2, and 4 kHz, was closed to 10 dB or less in eight cases (89%). The postoperative mean ABG was 4.6 dB compared with 37.6 dB preoperatively. The average postoperative hearing threshold was 44.4 dB compared with 79 dB preoperatively. The mean postoperative BC threshold was 39.8 dB compared with 41.2 dB preoperatively. At 4 kHz, the average postoperative hearing threshold was 63.3 dB compared with 83.3 dB preoperatively, and the mean postoperative BC threshold was 59.4 dB compared with 57.8 dB preoperatively.

Long-term hearing results according to age of patients. Table 15 shows the audiometric results over time of the entire series of cases according to age of patients after 1, 5, and 10 years of follow-up. Only 5 children and 16 seniors were available at 10 years. Thus, no significant conclusions may be drawn. At 10 years, the average gain in AC ranged from 22.8 to 29.3 dB. The greater gain was observed in the children series.

Long-term hearing results of a series of cases available at 10 years' follow-up. Of the entire series, 180 cases had audiologic data available at 10 years of follow-up. Eighty-two cases had audiologic data available at the 1- and 10-year marks. Of these 82 cases, there were 3 cases of children (≤18 yr), 10 patients of 19 to 30 years, 13 patients of 31 to 40 years, 24 patients of 41 to 50 years, 24 patients of 51 to 64 years, and 8 seniors (≥65 yr). Table 16 shows the results of these 82 cases during this 10-year period grouped by age. The annual deterioration in AC threshold ranged from 0.15 to 0.66 dB/yr, and no deterioration was observed in our children series. Patients older than 50 years compared with those younger than 50 years showed greater deterioration in their AC levels during the 10 years of follow-up. The annual deterioration in BC threshold ranged from 0.19 to 0.55 dB/yr, and no BC deterioration was observed in the children series. Again, the greatest BC deterioration was observed with patients older than 50 years.

Table 17 shows AC and BC deterioration by frequency during 10 years of these 82 cases grouped by age. The highest rate of decline in AC and BC thresholds

TABLE 12. *Air conduction and bone conduction thresholds deterioration (dB/yr) by frequency during 10 years in 82 cases related to surgical presentations*

	AC threshold					BC threshold				
	0.5 kHz	1 kHz	2 kHz	4 kHz	Average	0.5 kHz	1 kHz	2 kHz	4 kHz	Average
Obliterative otosclerosis (4 cases)	0	0.14	0.55	0.42	0.27	0	0.14	0.55	0.42	0.27
Absence of obliterative otosclerosis (78 cases)	0.25	0.36	0.29	0.7	0.4	0.27	0.35	0.28	0.6	0.38
Simultaneous malleus ankylosis (1 case)	0	0	0	0	0	0	0	0	0	0
Absence of malleus ankylosis (81 cases)	0.24	0.35	0.3	0.7	0.4	0.26	0.32	0.27	0.6	0.3

AC, air conduction; BC, bone conduction.

TABLE 13. *Results related to age in 2,527 cases (0.5, 1, 2, and 4 kHz)*

		SNHL (%)	Mean ABG (dB)		Postop ABG (%)			Mean AC (dB)		Mean BC (dB)		Mean AC (dB) at 4 kHz		Mean BC (dB) at 4 kHz	
Age (yr)	Cases	Postop	Preop	Postop	≤10 dB	11–20 dB	>20 dB	Preop	Postop	Preop	Postop	Preop	Postop	Preop	Postop
Children ≤18	31	—	26	1.6	93.5	6.5	—	42.7	17	16.7	15.5	34.5	20.3	17.4	19.2
19–30	176	0.5	26	1.6	93.7	5	1.3	44.6	20.6	18.5	19	39.4	25.4	20.5	23.4
31–40	591	0.3	24.7	1.6	94.5	3.7	1.8	46	22.2	21.3	20.5	42.5	27.8	24.6	26.2
41–50	751	0.6	25	1.8	94.2	3.6	2.2	49.4	26	24.4	24.2	47.8	34	29	32
51–64	686	0.4	25.5	1.7	93.8	4.2	2	53.7	29.6	28	27.8	56	40.4	35.7	38.5
Elderly ≥65	292	0.7	28.4	1.7	94.5	2.7	2.8	66.6	40	38	38	71.8	54.2	49.3	52.8

SNHL, sensorineural hearing loss; ABG, air-bone gap; AC, air conduction; BC, bone conduction.

was observed at 2 and 4 kHz and was more important for patients older than 50 years. However, an important decline of AC and BC at 4 kHz was also observed for patients of 19 to 30 years.

Failures

Failures were reported for the entire series (2,527 cases) and included postoperative ABG of more than 10 dB, severe SNHL, prosthesis extrusion with postoperative ABG of 10 dB or less, and perilymph fistula without severe SNHL and postoperative ABG of 10 dB or less. A perilymph fistula was diagnosed based on the presence of vertigo and a positive fistula sign, as well as clear visualization with revision surgery.

The overall rate of failures was 6.6% (166 of 2,527 cases). There were 146 cases of postoperative ABG of more than 10 dB (88% of failures), which includes 1 case of prosthesis extrusion. There were 13 cases of severe postoperative SNHL (7.8%) including 1 case of perilymph fistula. There were seven cases (4.2%) of perilymph fistula without severe SNHL and ABG of 10 dB or less. Therefore, the total number of postoperative perilymph fistula for the entire series was eight cases (0.3%).

Of these 166 failed cases, at the time of initial surgery, there were 10 cases of obliterative otosclerosis (6%), 6 cases of simultaneous malleus ankylosis (3.6%), and 8 cases of simultaneous eroded incus (4.8%). There were 2 children (age, ≤18 yr; 1.2%) and 18 senior patients (age, ≥65 yr; 10.8%). Fourteen TORPs were used for either a simultaneous malleus ankylosis (six cases) or an eroded incus (eight cases).

Table 18 presents the incidence of surgical presentations in the rate of failure. Of these 166 failed cases, at the time of initial surgery, there were 10 cases of obliterative otosclerosis and 6 cases of simultaneous malleus ankylosis. A higher rate of failure was therefore observed in cases of simultaneous malleus ankylosis (35.3% of 17 cases) and obliterative otosclerosis (12% of 83 cases). A greater incidence of postoperative SNHL was seen in cases of obliterative otosclerosis (4.8) compared with 0.4% in the cases that did not have obliterative otosclerosis (9/2,444 cases). Of the four cases of postoperative SNHL in the obliterative otosclerosis series, two occurred immediately after surgery—one patient had a dead ear and the other patient developed an SNHL of 23.7 dB—and at 9 months and 1 year, two patients developed an SNHL of 22.5 and 23.7 dB. The incidence of postoperative perilymph fistula was also greater in case of obliterative otosclerosis (2.4%) compared with 0.2% in the cases that did not have obliterative otosclerosis. One of these two cases of perilymphatic fistula in the obliterative otosclerosis series occurred immediately after surgery and the second case at 3 years postoperatively. Postoperative perilymph fistula and SNHL were not observed in the malleus ankylosis series.

Table 19 summarizes these 166 failures according to patient's age. Of these 166 failed cases, at the time of initial surgery, there were 2 children and 18 seniors. The highest incidence of postoperative SNHL (0.7%) was observed in the series of seniors and fourth-decade patients compared with 0.4 to 0.5% in the other groups

TABLE 14. *Results with at least 1-year follow-up related to age (0.5, 1, 2, and 4 kHz)*

		SNHL (%)	Mean ABG (dB)		Postop ABG (%)			Mean AC (dB)		Mean BC (dB)		Mean AC (dB) at 4 kHz		Mean BC (dB) at 4 kHz	
Age (yr)	Cases	Postop	Preop	Postop	≤10 dB	11–20 dB	>20 dB	Preop	Postop	Preop	Postop	Preop	Postop	Preop	Postop
Children ≤18	30	—	25.5	1.2	96.7	3.3	—	42.3	16.6	16.7	15.4	34	20	17.3	19.2
19–30	128	0.8	25.6	1.4	93.7	5.5	0.8	45	21.3	19.3	19.8	39.8	26.4	21.4	24.7
31–40	409	0.5	24.4	1.5	94.3	3.7	2	47	23	22.6	21.6	43.8	29.7	26.3	28.2
41–50	488	1	24.3	2	93	4	3	49.4	27	25	25	47.7	35.6	30	33.4
51–64	439	0.7	25	1.4	94.3	3.8	1.9	53.5	30	28.5	28.5	55.5	41	36	39.6
Elderly ≥65	178	1	27.7	1	96	1.7	2.3	65.4	39.3	37.6	38.2	69.6	53.3	47.4	52.5

SNHL, sensorineural hearing loss; ABG, air-bone gap; AC, air conduction; BC, bone conduction.

TABLE 15. *Long-term hearing results in 2,527 cases related to age of patients (0.5, 1, 2, and 4 kHz)*

Age (yr)		Children ≤18 (31 cases)			19–30 (176 cases)			31–40 (591 cases)			41–50 (751 cases)			51–64 (686 cases)			Elderly ≥65 (292 cases)		
Follow-up		1 yr	5 yr	10 yr	1 yr	5 yr	10 yr	1 yr	5 yr	10 yr	1 yr	5 yr	10 yr	1 yr	5 yr	10 yr	1 yr	5 yr	10 yr
Available data		17	11	5	60	21	17	195	91	39	242	94	50	201	90	53	85	39	16
Postop ABG ≤10 dB (%)		100	91	100	96.6	85.7	94	97.4	98.9	97.4	94.6	96.8	100	94	97.8	92.4	96.5	97.4	100
Mean ABG (dB)	Preop	25.9	28.2	27.7	26	24.4	24.1	24.4	23.5	24.2	24	23.3	24.8	25.3	23.5	24.7	28.6	29	26
	Postop	0.3	2.7	0	1	2.2	1.1	0.8	0.8	0.3	1.2	1.3	0	1.3	0.6	1.2	1	0.5	0.2
Mean AC (dB)	Preop	43.8	44.7	47.5	44.6	43.6	43.2	46.9	46.6	47.5	49.2	48.4	51.5	53.8	51	52.6	66.7	67.6	62
	Postop	15.6	17.2	18.2	17.3	21	20.4	20.8	22.8	21.5	24.8	26.3	25	27.5	26.8	29.7	37.5	40.3	33.3
Mean BC (dB)	Preop	17.9	16.6	19.7	18.5	19.2	19.1	22.5	23	23.4	25	25	26.6	28.5	27.5	27.9	38	38.6	36
	Postop	15.3	14.4	18.2	16.3	18.8	19.3	20	22	21.2	23.6	25	25	26.2	26.2	28.5	36.6	39.7	33.2
Average gain in AC (dB)		28.2	27.5	29.3	27.3	22.6	22.8	26.1	23.8	26	24.4	22.1	26.5	26.3	24.2	22.9	29.2	27.3	28.7
Mean AC at 4 kHz (dB)	Preop	34.4	35.4	44	39.6	39.5	36.2	44	43.2	46.2	47.2	45.8	48.2	56	52.1	54.2	70.4	69.1	64.4
	Postop	19.7	19	26	20.8	25.7	26.2	27	30.2	30.5	31.9	35.3	34.1	37.7	37.9	42.2	51.4	51.2	46.9
Mean BC at 4 kHz (dB)	Preop	18.5	17.7	21	20	21.2	19.1	26.7	26.7	28.6	29.7	30	31	35.2	34.2	34.9	48.2	44.6	42.2
	Postop	19.7	17.2	26	19.8	24.3	25	26.2	29.4	30.1	30.5	34.1	34.1	36.3	36.9	40.6	50.5	50.9	46.2

ABG, air-bone gap; AC, air conduction; BC, bone conduction.

of patients. A postoperative SNHL was not observed in the series of children. The group of children did not experience a higher rate of failure after primary surgery (6.4%) despite its greater incidence of simultaneous malleus ankylosis (6% compared with 0.6% in the entire series) and obliterative otosclerosis (14.7% compared with 3% in the entire series). Postoperative perilymph fistula and SNHL were not observed in the children series.

Analysis of the 13 Cases of Postoperative SNHL

Of 13 cases of severe postoperative SNHL, at the time of initial surgery, 4 cases were of obliterative otosclerosis (31%). A piston was used in all 13 cases. The mean age was 49 years, ranging from 27 to 78 years. Two cases (15.4%) were senior patients. Immediately after surgery, one patient (0.04%) had serious complication of a dead ear and four patients (0.16%) developed an SNHL of 16 to 39 dB (four-frequency average). Fifteen days after surgery, one patient (0.04%) developed meningitis and subsequently a total dead ear. Five patients (0.2%) had a sudden hearing loss of between 15 and 55 dB at 1, 6, and 9 months and 1 year after surgery. Three years after surgery, one patient (0.04%) developed a sudden SNHL of 25 dB. Four years postoperatively, one patient (0.04%) developed a severe SNHL of 48.7 dB associated with vertigo. This patient was reexplored, and a perilymph fistula was identified (Table 20).

First Revisions

Operative Findings

Fifty-six of 166 failures underwent revision surgery during the follow-up period for persistent ABG or peri-

TABLE 16. *Long-term hearing results of a series of 82 cases available at 10 years' follow-up related to age of patients (0.5, 1, 2, and 4 kHz)*

Age (yr)		Children ≤18 (3 cases)		19–30 (10 cases)		31–40 (13 cases)		41–50 (24 cases)		51–64 (24 cases)		Elderly ≥65 (8 cases)	
Follow-up		1 yr	10 yr	1 yr	10 yr	1 yr	10 yr	1 yr	10 yr	1 yr	10 yr	1 yr	10 yr
Available data		3	3	10	10	13	13	24	24	24	24	8	8
Postop ABG ≤10 dB (%)		100	100	90	90	100	100	100	100	100	91.6	100	100
Mean ABG (dB)	Preop	29.6	29.6	23.4	23.4	21.7	21.7	25	25	25.8	25.7	27	27
	Postop	0	0	1.4	1.9	0.3	0	0	0	0.3	1.3	0	0
Mean AC (dB)	Preop	50.4	50.4	42.1	42.1	48	48	53.8	53.8	54.5	54.5	66.8	66.8
	Postop	15.8	15	14.9	16.9	23.2	24.6	25.4	28.4	24	30	32	37
Mean BC (dB)	Preop	20.8	20.8	18.7	18.7	26.3	26.3	28.8	28.8	28.7	28.7	39.8	39.8
	Postop	15.8	15	13.5	15	22.9	24.5	25.4	28.4	23.7	28.6	32	37
Average gain in AC (dB)		34.6	35.4	27.2	25.2	24.8	23.4	28.4	25.4	30.5	24.5	34.8	29.8
Mean AC at 4 kHz (dB)	Preop	41.6	41.6	34.5	34.5	46.9	46.9	49.8	49.8	56.8	56.8	70	70
	Postop	20	20	14	20.5	30.7	33.8	33.5	38.1	32.7	42.9	43.1	49.4
Mean BC at 4 kHz (dB)	Preop	20	20	18.5	18.5	32.7	32.7	33.7	33.7	34.6	34.6	48.1	48.1
	Postop	20	20	13	18.5	30.7	33.8	33.5	38.1	32.7	40.4	43.1	49.4

ABG, air-bone gap; AC, air conduction; BC, bone conduction.

TABLE 17. *Air conduction and bone conduction thresholds deterioration (dB/yr) by frequency during 10 years in 82 cases related to age*

	AC threshold					BC threshold				
Frequency (kHz)	0.5	1	2	4	Average	0.5	1	2	4	Average
Children ≤18 yr (5 cases)	+0.18[a]	0	+0.18	0	+0.09[a]	+0.18[a]	0	+0.18[a]	0	+0.09[a]
19–30 yr (10 cases)	0.28	0	0	0.72	0.25	0.28	0	0	0.6	0.22
31–40 yr (13 cases)	0	0.13	0.13	0.34	0.15	0.17	0.13	0.13	0.34	0.19
41–50 yr (24 cases)	0.16	0.34	0.32	0.51	0.33	0.16	0.34	0.34	0.51	0.33
51–64 yr (24 cases)	0.39	0.6	0.51	1.13	0.66	0.39	0.48	0.44	0.85	0.54
Elderly ≥65 yr (8 cases)	0.41	0.62	0.48	0.7	0.55	0.41	0.62	0.48	0.7	0.55

[a]Improvement. AC, air conduction; BC, bone conduction.

lymphatic fistula (55 patients). Prosthesis dislocation, migration out of the oval window fenestra, and complete incus erosion were the most common causes for failure in this series (Table 21).

The 19 cases (34% of 56 first revisions) of incus erosion were observed only when a piston was used during primary surgery. In these 19 cases, a TORP was positioned from malleus to stapedotomy during the first revision operation after vein graft interposition. Prosthesis displacement with a normal incus was seen in 14 cases (25%) and was observed when a piston (11 cases) and a TORP (3 cases) were used during the primary surgery.

In these 14 cases of prosthesis displacement, the initial prosthesis was removed, and a new piston was positioned in 11 cases and a new TORP was used in 3 cases during the first revision operation. In eight cases (14.3%), the prosthesis was found attached to the incus or malleus but too short to reach the stapedotomy. In these eight cases, the short prosthesis was removed, and a slightly longer prosthesis was inserted.

In two cases (3.4%), the piston was found to be slightly too long. During the first revision operation, the length of the piston was reduced from 4.5 to 4 mm in both cases.

An oval window perilymph fistula was identified in eight ears (14.3%). Postoperative dizziness with typical fistula sign was present in all cases and occurred within the first year of surgery in six cases at 18 months in one case and at 3 years in the remaining case. The vein graft which had been interposed during initial surgery was found retracted at the anterior pole of the footplate in all cases. The perilymph membrane between the prosthesis and otic capsule margin was torn, and perilymph was actively leaking from this site in all cases. The surgical technique, as described by Lesinski (16), was used. The previous vein graft was vaporized with an argon laser until the margins of the oval window were precisely identified, and an 0.8-mm stapedotomy was then vaporized through the center of the oval window neomembrane into the perilymph of the vestibule. A vein graft was placed over the oval window, and a prosthesis was positioned. The patients' imbalance was relieved in all cases.

Five ears (9%) were found to have no abnormalities that could explain the failure despite the presence of a persistent ABG of more than 16 dB in all cases after primary operation. In these five cases, the prosthesis was found firmly attached to the incus, with a correct position within the stapedotomy and good mobility as demonstrated by the presence of the round window sign in all cases. Despite the absence of an abnormality, the prosthesis was removed, and a new piston was positioned in four cases and bucket handle prosthesis in the other case. Results are reported in Tables 22 and 23 and discussed below.

Of the 56 revised cases, 29 cases were early failures which occurred within the first year after the primary surgery, and 27 were late failures which occurred 1 year or later after the primary operation. Of the 29 early failures, the 2 major causes of failures were short prosthesis in 6 cases (24%) and perilymph fistula in 6 cases (20.7%). Of the 27 late failures, the 2 major causes of failures were incus erosion in 14 cases (51.8%) and displaced prosthesis in 9 cases (33.3%). Of the total of 56 failed cases, incus erosion occurred in 19 cases. Five

TABLE 18. *Failures in 2,527 cases (166 cases) (incidence of surgical presentation in the rate of failure [0.5, 1, 2, and 4 kHz])*

	Obliterative otosclerosis	Absence of obliterative otosclerosis	Simultaneous malleus ankylosis	Absence of malleus ankylosis
Available data	83	2,444	17	2,510
Rate of failure (%)	12	6.4	35.3	6.4
Postop SNHL (%)	4.8	0.4	—	0.5
Postop ABG >10 dB (%)	5	5.8	35.3	5.6
Postop perilymph fistula (%)	2.4	0.2	—	0.3

SNHL, sensorineural hearing loss; ABG, air-bone gap.

TABLE 19. *Failures in 2,527 cases (166 cases) (incidence of age of patients in the rate of failure [0.5, 1, 2, and 4 kHz])*

		Age of patients (yr)					
	Entire series	Children ≤18	19–30	31–40	41–50	51–64	Elderly ≥65
Available data	2,527	31	176	591	751	686	292
Rate of failure (%)	6.6	6.4	6.8	6.2	6.8	6.7	6.2
Postop SNHL (%)	0.5	—	0.5	0.3	0.7	0.4	0.7
Postop ABG >10 dB (%)	5.8	6.4	6.3	5.4	5.7	6.2	5.5
Postop perilymph fistula (%)	0.3	—	—	0.5	0.4	0.1	—

SNHL, sensorineural hearing loss; ABG, air-bone gap.

(26.3%) of these erosions occurred within 1 year of the initial surgery and fourteen (73.7%) at 1 year or later after the primary operation.

Of the total of 56 first revisions, at the time of initial surgery, there were four cases of obliterative otosclerosis and two cases of simultaneous malleus ankylosis. Of the four first revision cases of obliterative otosclerosis, the cause of failure was identified as incus erosion in two cases and oval window perilymph fistula in two cases. Of the two first revision cases of associated malleus ankylosis, the cause of failure was identified as a displaced prosthesis in one case and a short prosthesis in the other case.

Of the total of 55 first revisions, at the time of initial surgery, four cases were seniors. No children were reexplored. Of the four first revision cases in seniors, the cause of failure was identified as incus erosion in three cases, whereas one case was found to have no abnormalities to explain the failure.

Hearing Results

Of the 56 cases undergoing revision surgery, audiometric data were available in 49 cases (Table 22). The mean follow-up was 23.4 months (range, 0.8–95.7 mo). There was no case of a postoperative SNHL in this series. Postoperative closure of four-frequency ABG within 10 dB was achieved in 27 (55%) of 49 cases and was not achieved in 22 cases (45%). After the first revision surgery, the average four-frequency ABG was 12 dB compared with 25.8 dB prerevision. The average postrevision four-frequency AC threshold was 40.8 dB compared with 53.4 dB prerevision, and the average postrevision four-frequency BC threshold was 29 dB compared with 27.6 dB prerevision. At 4 kHz, BC deteriorated to 3.8 dB as the mean postrevision BC threshold was 41.2 dB compared with 37.4 dB prerevision. Hearing results according to cause of failure are presented in Table 23. Given the fact that many of our patients travel long distances for care at our center, follow-up is sometimes impossible. Less successful results were observed in cases where no abnormality was found to explain the failure.

Obliterative otosclerosis. Of the four first revision cases of obliterative otosclerosis, postoperative audiometric data were available in three cases. Mean of follow-up was 64.8 months (range, 15.7–114 mo). After the first revision surgery, the postoperative closure of the four-frequency ABG to within 10 dB was achieved in two of three cases but was not achieved in the other. The average four-frequency postoperative ABG was 7.5 dB compared with 25 dB prerevision. The average postrevision four-frequency hearing threshold was 41.6 dB compared with 54.3 dB prerevision, and the average postrevision four-frequency BC threshold was 34 dB compared with 25 dB prerevision. At 4 kHz, the average postrevision BC threshold was 63.3 dB compared with 38.3 dB prerevision.

Simultaneous malleus ankylosis. Of the two first revision cases of simultaneous malleus ankylosis, postoperative data were available in both cases. Mean follow-up was 30.6 months (range, 15–46.3 mo). After the first revision, the postoperative closure of the four-frequency ABG to within 10 dB was achieved in one case. The mean postoperative four-frequency ABG was 27.5 dB compared with 29.4 dB prerevision. The average postrevision four-frequency hearing threshold was 47.5 dB compared with 50 dB prerevision, and the average postrevision four-frequency BC threshold was 20 dB compared with 20.6 dB prerevision. The average postrevision BC threshold at 4 kHz was 30 dB compared with 25 dB preoperatively.

Seniors. Of the four first revision cases in seniors, postoperative data were available in all cases. Mean follow-up was 25.2 months (range, 3.8–65.9 mo). After the first

TABLE 20. *Surgical presentations and age in the 13 cases of postoperative SNHL*

Surgical presentations		Age (yr)					
Obliterative otosclerosis	Simultaneous malleus ankylosis	Children ≤18	19–30	31–40	41–50	51–64	Elderly ≥65
4 (31%)	—	—	1 (7.7%)	2 (15.4%)	5 (38.5%)	3 (23%)	2 (15.4%)

TABLE 21. *Causes of failures in the first revision series (56 cases)*

Prosthesis used (primary operation)	Prosthesis-related problems					
	Eroded incus	Displaced	Short	Long	Perilymph fistula	Unknown
Piston (n = 49)	19 (38.8%)	11 (22.4%)	4 (8.2%)	2 (4.1%)	8 (16.3%)	5 (10.2%)
Bucket (n = 1)	—	—	1 (100%)	—	—	—
TORP (n = 6)	—	3 (50%)	3 (50%)			
Total (n = 56)	19 (34%)	14 (25%)	8 (14.3%)	2 (3.4%)	8 (14.3%)	5 (9%)

TORP, total ossicular replacement prosthesis.

revision, the postoperative closure of the four-frequency ABG to within 10 dB was achieved in three cases. The average postoperative four-frequency ABG was 4.7 dB compared with 39 dB prerevision. The average postrevision four-frequency hearing threshold was 49.8 dB compared with 80.6 dB prerevision, and the average postrevision four-frequency BC threshold was 44.4 dB compared with 41.6 dB prerevision. The average postrevision BC threshold at 4 kHz was 65 dB compared with 57.5 dB prerevision.

Second Revisions

Of the 22 revised cases with an ABG of more than 10 dB, 7 cases underwent second revision for persistent conductive hearing loss. After the second revision, the cause of failure was identified as incus erosion in five cases, and a TORP was positioned in all cases. A short prosthesis was the cause of failure in two cases where a TORP had been used during the first revision operation (Table 24). A new TORP was used in these two cases with lengths of 6 and 7 mm rather than 5 and 5.75 mm, respectively.

Preliminary results for this second series of revision cases were available in six of seven cases (Table 22). Mean follow-up was 42.1 months (range, 3.6–104 mo). There was no case of postoperative SNHL in this series. Postoperative closure of the ABG to within 10 dB was achieved in five (83.3%) of six cases and was not achieved in one case (16.7%). After the second revision surgery, the mean ABG was 4.6 dB compared with 27.7 dB before first revision. The average AC threshold after the second revision was 36.2 dB compared with 52.3 dB before first revision. The average BC threshold after the second revision was 31.7 dB compared with 24.6 dB before first revision. At 4 kHz, the mean BC was 51.7 dB postoperatively compared with 36.7 dB preoperatively.

Obliterative Otosclerosis

In the obliterative otosclerosis series, the revised cases where a TORP was used during first revision with an ABG of more than 10 dB underwent second revision. After the second revision, the cause of failure was a short prosthesis. A new TORP was used during second revision, and the new prosthesis length was 7 mm rather than 5 mm. Preliminary results for this second revision case were available only at 3.6 months' follow-up. The postoperative four-frequency ABG was 10 dB compared with 22.5 dB preoperatively. The postoperative four-frequency hearing threshold was 42.5 dB compared with 55 dB preoperatively, and the postoperative four-frequency BC threshold was unchanged (32.5 dB). The postoperative BC threshold at 4 kHz was also unchanged (50 dB).

No second revision was undertaken for the failed cases of the first revision in the simultaneous malleus ankylosis series.

DISCUSSION

The success of otosclerosis surgery must be judged not only by the short-term results, but by the longevity of the hearing gain and, thus, benefit during the course of the patient's life (17).

Several studies (3,4,17,19–23) have described long-term results after stapes surgery, and the average deterioration in the AC threshold has been shown to vary between 0.6 and 1.2 dB per year (Table 25). Osterhammel and Osterhammel (18) calculated 0.4-dB hearing loss per year at the frequency 500 to 2,000 Hz and 0.8-dB hearing loss per year at 4 kHz for a normal population from 45 to 65 years of age. Kürsten et al. (19) calculated that the yearly change was 1.1 dB after stapedectomy and 0.7 dB after stapedotomy. Similar results were

TABLE 22. *Hearing results of first (49 cases) and second (6 cases) revisions*

	SNHL (%)	Mean ABG (dB)		Postop ABG (%)			Mean AC (dB)		Mean BC (dB)		Mean BC at 4 kHz (dB)	
	Postop	Preop	Postop	≤10 dB	11–20 dB	>20 dB	Preop	Postop	Preop	Postop	Preop	Postop
First revisions (49 cases)	—	25.8	12	55	16.5	28.5	53.4	40.8	27.6	29	37.4	41.2
Second revisions (6 cases)	—	27.7	4.6	83.3	16.7	—	52.3	36.2	24.6	31.7	36.7	51.7

SNHL, sensorineural hearing loss; ABG, air-bone gap; AC, air conduction; BC, bone conduction.

TABLE 23. *Hearing results of first revisions (49 cases) related to cause of failure*

Cause of failure	Available data	SNHL	Mean ABG (dB)		ABG ≤10 dB	Mean AC (dB)		Mean BC (dB)	
		Postop	Preop	Postop	Postop	Preop	Postop	Preop	Postop
Eroded incus	16	—	34	10.8	9 (56.2%)	66	45	32	34.2
Displaced prosthesis	14	—	31.8	11.7	9 (64.3%)	55.8	34	24	22.2
Short prosthesis	8	—	22.2	12.5	4 (50%)	44.5	36	22.3	23.6
Long prosthesis	2	—	15.6	19.4	—	38	41.2	22.5	21.8
Perilymphatic fistula	6	—	0	12.5	4 (66.6%)	25.2	41.6	25.2	29
Unknown	3	—	20.8	10.8	1 (33.3%)	65.8	60.8	45	50

SNHL, sensorineural hearing loss; ABG, air-bone gap; AC, air conduction; BC, bone conduction.

reported by Birch et al. (20) on a group with a 15-year mean follow-up; in their entire series, a similar deterioration in both AC and BC levels of 0.9 dB/yr was observed with time, but the deterioration for patients younger than 30 years was 0.67 dB/yr. In the series of Smyth et al. (21), a more rapid decline of AC levels during a 15-year period was noted in the group operated on before the age 50 years (0.8d B/yr) compared with the group older than 50 years (0.4 dB/yr). Langman et al. (17) reported a series of patients with a minimum of 18-year follow-up after surgery. They found an annual deterioration in BC levels of 0.4 dB/yr at 500 Hz, to a maximum of 1.1 dB/yr at 2,000 Hz. and a reduction of 0.6 dB/yr at 4 kHz. They also noted an annual fall in the mean AC threshold of 1.1 dB/yr. In their series, patients older than 50 years, compared with those younger than 50 years, showed no significantly greater deterioration in their AC levels during the long term. Kürsten et al. (19) also showed that, at 4 kHz, the difference between stapedectomy and stapedotomy was more pronounced. Aarnisalo et al. (22) observed that although there was an average reduction of 0.9 dB per year in both AC and BC thresholds during 20 years after stapes surgery (either with stapedotomy or stapedectomy), the ABG only increased by 2 to 4 dB during this period.

Vartiainen et al. (24) noted that the mean BC thresholds of otosclerotic ears that were surgically treated deteriorated during 10 years of follow-up. The study of Spandow et al. (3) did not support these findings of a deterioration of BC thresholds. Their study showed that BC in patients operated on with stapedectomy after 5 years, had deteriorated only to 2 to 4 dB and to 6 dB 10 years after surgery but was still better than the preoperative BC. In their study (3), the ABG decreased from 36 dB before surgery to 11 dB after 1 year and was 17 dB after 10 years. Both Smyth et al. (21) and Birch et al. (20) noted that their long-term results seemed to be better with the stapedotomy technique.

In their long-term evaluation of data of stapedotomy and stapedectomy, Kos et al. (4) found that the percentage of cases with a postoperative ABG of less than 10 dB was similar to that observed in the early postoperative period, irrespective of the size of the oval window fenestration. Our results are consistent with these findings. As age-related hearing loss reduces both AC and BC postoperatively, the residual true ABG should remain stable. This feature can be seen in our 10-year follow-up of 82 cases (Table 5): The mean postoperative ABG has remained stable in our long-term follow-up patients, while there has been a slight progression of hearing loss over time (Table 5). We found a 0.4-dB/yr AC decrement and a 0.36-dB/yr BC decrement. This was mainly observed at 4 kHz with a 0.69-dB/yr AC decrement and a 0.59-dB/yr BC decrement. Langman et al. (17) observed a progressively enlarging conductive gap in the speech frequencies which could be related to further growth of the otosclerotic focus. For them, sodium fluoride (NaFl), which has been used to arrest cochlear otosclerosis, may also have a beneficial role in reducing the bone remodeling activity of the otospongiotic focus (25,26). A recent study (27) has shown that diastrophic dysplasia sulfate transporter activity, which is increased in bone cells derived from the stapes of otosclerotic patients, is specifically inhibited by NaFl. This progressive enlarging conductive gap was not observed in our series which also show a lower decline in hearing after stapedotomy than that in previously reported series. However, some of these studies (17,20–23) are with longer follow-up (15–21 yr), and it is possible that, with time, the postoperative hearing

TABLE 24. *Causes of failures in the second revision series (seven cases)*

Prosthesis used (first revision operation)	Prosthesis-related problems						
	Eroded incus	Displaced	Short	Long	Perilymph fistula	Reobliteration	Unknown
Piston (n = 5)	5 (100%)	—	—	—	—	—	—
TORP (n = 2)	—	—	2 (100%)	—			
Total (n = 7)	5 (71.4%)	—	2 (28.6%)	—	—	—	—

TORP, total ossicular replacement prosthesis.

TABLE 25. *Long-term hearing results according to literature (AC and BC deterioration with time)*

	No. cases	Mean follow-up (yr)	AC Decrement over time (dB/yr)	BC Decrement over time (dB/yr)
Spandow et al. (3)	60	10	1	0.6
Spandow et al. (3)	55	5	0.4	0.4
Kos et al. (4)	441	7	0.1	—
Langman et al. (17)	49	21	1.1	0.7
Kürsten et al. (19)	22	9.3	1.1	—
Kürsten et al. (19)	35	6.2	0.7	—
Birch et al. (20)	925	15	0.9	0.9
Smyth et al. (21)	715	15	0.6	—
Aarnisalo et al. (22)	80	20	0.9	0.9
Aarnisalo et al. (22)	62	20	0.9	0.8
Del Bo et al. (23)	200	15	1.2	0.7
Present study	82	10	0.4	0.36

AC, air conduction; BC, bone conduction.

deterioration may increase. In our center, NaFl treatment is given at 2 mg/d to our patients for several years after surgery.

Results According to Specific Surgical Findings

Obliterative Otosclerosis

During stapedectomy, drillout of the oval window for an obliterated otosclerotic footplate is widely accepted to be more difficult and is associated with significantly lower rates of ABG closure and higher rates of SNHL, compared with routine stapedectomy (28). Excessive bleeding, acoustic trauma from the burr, and reclosure of the oval window by otosclerosis have contributed to this fear with decreased expectation as a result (29–31). The incidence of obliterative otosclerosis according to the literature varies from 4 to 31% (28,32,33). The incidence of obliterative otosclerosis was 14.7% in our children series (5/34 cases) and 2.6% in our elderly series (9/340 cases). In the series of 1,800 bilateral stapedectomies of Daniel et al. (28), obliterative otosclerosis requiring an oval window drillout for an excessively thick footplate was undertaken in 86 patients (4.7%). Of these 86 patients, 35 had obliterative otosclerosis in both ears (41% of 86 cases). Therefore, there was a 41% chance that the second ear would also need a drillout. Similar findings were demonstrated in our series as obliterative otosclerosis was found in 82 patients (92 ears). Of these 82 patients, 25 were operated on bilaterally. Of these 25 patients, 10 had obliterative otosclerosis in both ears (40% of 25 cases). In their series (28), the rate of successful outcome (postoperative ABG <10 dB) was 73% for a unilateral obliterative footplate and 60% for bilateral obliterated footplates. This success rate was significantly lower than in their normal group of patients (95%). In our entire series of 2,527 cases, higher rates of failure were also observed in cases of obliterative otosclerosis (12%, 10/83 cases; compared with 6.4% for the 2,444 cases that did not have obliterative otosclerosis; Table 18). A greater incidence of postoperative SNHL (4.8%, 4/83 cases; compared with 0.4% of the 2,444 cases that did not have obliterative otosclerosis) and perilymph fistula (2.4%, 2/83 cases; compared with 0.2% for the 2,444 cases that did not have obliterative otosclerosis; Table 18) was also seen in our obliterative otosclerosis series. In our series, the rate of successful outcome (postoperative ABG ≤10 dB) was 96.8% for a unilateral obliterated footplate and 88.8% for a bilateral obliterated footplate; however, a postoperative SNHL occurred in 4.7% of cases of a unilateral obliterated footplate and in 5.3% in our bilateral obliterated footplate group. Several authors have reported that because of abnormally thick footplate in obliterative otosclerosis, it is more difficult to perform a stapedotomy, and therefore, their conversion to partial or total stapedectomy is much higher (28,34). In our series, it was possible to perform a stapedotomy in all cases of obliterative otosclerosis, using our routine surgical technique of a combination of argon laser and microdrill. This also resulted in a more favorable closure of ABG

TABLE 26. *Stapes surgery in children (results according to other series)*

	Cases	Mean age (yr)	Follow-up (mo)	Obliterative otosclerosis (%)	Malleus ankylosis (%)	SNHL (%)	ABG ≤10 dB (%)
House (46)	24	14 (9–18)	NC	NC	NC	4	91.6
Robinson (47)	35	14 (5–18)	4.9	5.6	—	—	100
Von Haacke (48)	19	16 (6–21)	27 (3–180)	NC	NC	—	73.7
Cole (49)	62	13 (6–20)	82 (2–264)	42	—	1.6	77.4
Millman et al. (50)	40	16 (7–21)	304 (204–408)	17	—	2.5	58
Present study	33	14 (8–18)	79.5 (3.6–159)	14.7	6	—	93.5

SNHL, sensorineural hearing loss; ABG, air-bone gap; NC, not communicated.

TABLE 27. *Stapes surgery in elderly (results according to other series)*

	Cases	Mean age (yr)	Mean follow-up (mo)	SNHL (%)	ABG ≤10 dB (%)
Salvinelli et al. (53)	32	74.5 (61–81)	2	0	NC
Ayache et al. (54)	16	70.1 (65–87)	19.5	0	81.8
Vartiainen (57)	46	NC (60–NC)	96	2.1	61.4
Awengen et al. (58)	38	NC (60–NC)	NC	0	61
Proschel and Jahnke (59)	105	71.4 (65–75)	38		
Ferrario et al. (60)	106	67.1 (65–79)	12	2.8	49
Lippy et al. (61)	143	76.3 (70–92)	6	0	91
Present study	340	70 (68–91)	39.7	0.7	94.5

when comparing hearing results. Daniel et al. (28) performed partial stapedectomy using a Robinson prosthesis with vein graft interposition. They observed a 73% closure of ABG to less than 10 dB, and their overclosure rate was 37%. However, in their study, Daniel et al. compared preoperative BC with postoperative AC for ABG calculation. Shea et al. (35) described a group of 78 ears with "far advanced otosclerosis" (AC level ≥90 dB or and BC level ≥60 dB). In their series, there were 33 cases (42.3%) of obliterative otosclerosis, which underwent partial or total stapedectomy with vein graft using Teflon with or without platinum cup prosthesis. Their success rate after surgery was 54.6% for this group with 42% remaining unchanged. In this group of "far advanced otosclerosis," there is a much greater preexisting SNHL caused by degenerative changes involving the organ of Corti and peripheral cochlear neurones (34,36).

Simultaneous Malleus Ankylosis

In the literature, the incidence of simultaneous malleus ankylosis in primary surgery for otosclerosis seems to be in the region of 0.4 to 2.4% of cases (28,37–40). In the series of 1,800 bilateral stapedectomies of Daniel et al. (28), the presence of malleus fixation was observed in 44 cases (2.4%). This abnormality did affect their success rate as a successful result (postoperative ABG ≤10 dB) was obtained in 85% of cases of simultaneous malleus fixation compared with 95% for their normal patients. Daniel et al. also observed a 23% incidence of bilateral malleus fixation, and when fixation coexisted bilaterally, the success rate dropped to 60%. In our series, malleus ankylosis was found in 0.6% of cases (19/3,050 cases) and was never observed bilaterally. The presence of an simultaneous malleus fixation was found in 2 of the 34 cases (6%) in our children series and in 4 (1.2%) of the 340 cases in our elderly series compared with 0.6% in our entire series of 3,050 cases (19 cases). Numerous etiopathogenic hypotheses of malleus ankylosis have been suggested in the literature. In 1999, we reported a series of 123 cases of malleus ankylosis (13) with associated otosclerotic stapes fixation in 6% of these cases. The presence of otosclerosis of the malleus was seen in one case and of the incus in another and was thought to be responsible for the fixation of the ossicle in the second case. Congenital abnormalities have a significant part to play in the etiopathogenic hypotheses of malleus ankylosis because of a lack of full development of the epitympanic space (40–42). For Dietzel (43) and Sleecks et al. (37), an abnormally high position of the head of the malleus is frequently observed in otosclerotic ears. Therefore, the high incidence of malleus ankylosis in otosclerotic stapedial fixation would occur as a result of "leverage" by the otosclerotic foci (41). Although simultaneous malleus otosclerosis is uncommon, failure to diagnose during routine stapes surgery results in its inevitable failure. Huber et al. (44) found a much higher failure rate of 37.5% caused by malleus fixation. This seems to be a much higher incidence as other authors have observed a rate of 3 to 13.5% in revision surgery after stapes surgery (13,16,37). In our series, although no cases of postoperative SNHL were seen in the simultaneous malleus ankylosis group, this same group did possess the worst results of postoperative closure of the ABG to within 10 dB—it was achieved in 64.7% of cases compared with 94.4% in the 2,510 cases that did not have simultaneous malleus ankylosis.

Results According to Age

Stapes Surgery in Children

Otosclerosis is a common cause of conductive hearing loss, usually presenting in young and middle-aged adults. It is an uncommon pathology in children, and therefore, stapes surgery is not routinely performed in this age group. In a large study of temporal bone sections, Guild (45) described one case of histological otosclerosis of 161 temporal bones in children younger than 5 years. Several studies have demonstrated good results in children after stapes surgery (46–51) and are presented in Table 26. Like Millman et al. (50) and Cole (49), we also found a higher prevalence of obliterative otosclerosis in children. Gristwood and Venable (52) studied histological findings in light of clinical symptoms. They concluded that an early onset of clinical otosclerosis dramatically increases the chance of fulminating lesions with severe and diffuse involvement of the stapes footplate. A late onset of clinical symptoms tend to be associated with more stable localized lesions at the anterior pole of the footplate. Two cases of simultaneous malleus ankylosis were identified in our children series. To our knowledge, this has not been previously described in other series of children. Millman et al. (50) found no significant change

in ABG closure over time. Their long-term results of stapedectomy in this population remain satisfactory with a mean ABG at the last follow-up (mean, 25.4 yr) only 2 dB more than the immediate postoperative evaluation (mean, 2 mo). However, in their series, otosclerosis at the footplates annulus had a higher rate of successful ABG closure to within 10 dB at last follow-up (72%) compared with the obliterative type (32%). This was in contrast to our series of juvenile obliterative otosclerosis which demonstrated excellent results. Our long-term results of stapedotomy in this population remained satisfactory. However, the authors would wish to point out that the period of follow-up is insufficient to be able to predict the long-term results, although in those cases with a follow-up of 10 years (five cases), there were no late failures. Robinson (47) and Millman et al. (50) found that juvenile otosclerosis did not demonstrate a greater BC deterioration over time. In our series of children, no deterioration in AC or BC thresholds was observed (Table 17).

Stapes Surgery in the Elderly

Several studies have commented on the variable of patient age at the time of stapes surgery (17,21, 52–54). Stapedectomy in seniors is controversial. It is indicated to avoid the use of a hearing aid or to facilitate hearing aid fitting, when the association of otosclerosis and presbyacusis makes hearing aid provision unsatisfactory (54). Whereas some authors have reported lower success rates in the elderly than in younger patients (55,56), others, however, think that old age does not preclude stapes surgery (53,54,57–60). Some authors have also reported an increased risk for labyrinthine fistula and postoperative vestibular symptoms in elderly patients (56). This was not the case in our series as all eight cases of postoperative fistula in the entire series were encountered in patients younger than 55 years (mean, 43 yr; range, 30–52 yr). Smyth et al. (21) reported that patients older than 50 years had poorer hearing results compared with younger patients. However, the younger group had a more rapid deterioration in hearing over time. In the report of Langman et al. (17), preoperative and postoperative AC and BC thresholds were similar in the two groups of patients (>50 and <50 years). There was no significant difference in the deterioration of AC after an 18-year follow-up. In a series of 154 cases of stapedectomy in the elderly, Lippy et al. (61) stated that the percentage of patients (90.9%) having a successful surgical result (postoperative ABG within 10 dB) was similar to younger patients in the comparison group with a successful surgical result (90%). There were no cases of postoperative SNHL in their series, and the improved hearing levels after stapedectomy seemed fairly stable for elderly patients who returned for their 1-year and 5-year follow-up. In the study of 473 patients of Ayache et al. (54) (16 patients were older than 65 years, and 10 stapedectomies and 6 stapedotomies were performed), similar postoperative hearing improvements were noticed both in elderly (≥65) and younger patients (<65) with no significant difference seen between these two groups in terms of postoperative ABG, hearing gain, and overclosure. There were no dead ears in their series of elderly subjects; however, one patient experienced a high-frequency BC loss of 28.3 dB which was directly related to acoustic trauma that occurred 3 months postoperatively. The study of 40 patients older than 60 years of Salvinelli et al. (53) confirmed similar findings after stapedotomies. In their series, the reduction in ABG was higher in patients older than 50 years as compared with younger patients.

Our results compare favorably with previous series (Table 27), and our low rate of complications confirms that advanced age is not a contraindication to stapedectomy. Moreover, surgery will stop the progression of the disease and allow the patient better use of a hearing aid with an important improvement in sound discrimination (59). We also agree with Lippy et al. (61) that elderly patients who had severe losses before surgery and could not wear an aid could successfully use an aid after surgery. With increases in average life expectancy, the number of patients seen with untreated otosclerosis in their later years may increase. Longer life expectancy also increases the number of years that patients will benefit from improvements in hearing after stapedectomy (61).

CONCLUSION

This series demonstrates that stapedotomy with vein graft interposition for otosclerotic stapes fixation is a safe and successful treatment with sustained long-term hearing improvement. Our series also shows that a revision operation is possible with encouraging results despite a slight tendency toward sensorineural deterioration. Obliterative otosclerosis and simultaneous malleus ankylosis may be encountered during stapedotomy. A successful outcome may still be expected, although our study confirmed an effect from these two middle ear abnormalities on the success rate of stapedotomy. This series also demonstrated that stapedotomy in children is a safe and effective treatment for otosclerosis. Our long-term hearing results of stapedotomy in children were good as demonstrated by the maintenance of the ABG closure and stable AC and BC thresholds over time. Our series also ascertained that stapedotomy is a safe and effective procedure for otosclerosis in the seventh and eighth decades of life, and we therefore recommend surgery for otosclerosis in older adults to recover social hearing and thus improve their independence and quality of life. This article also described a new otologic database (ONDB) that may be used in the future as a standard system by otologists for personal or multicentric studies. Our intention is to continue the use of ONDB for the long-term prospective evaluation of our results in otosclerosis surgery as well as in other fields of otologic surgery.

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