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The use of cortical bone grafts in ossiculoplasty II: Graft mass and hearing change at different frequencies

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Abstract

The masses of preserved ossicles and cortical bone grafts have been studied *in vitro* using a Stanton Unimatic CL41 balance. The cortical bone grafts prepared for use in malleus–stapes assemblies had a mean mass 28 per cent greater than that for an incus, while those prepared for use in a malleus–footplate or drum–footplate assembly had a mean mass 58 per cent greater. Analysis of the hearing results for the first 20 ossiculoplasty operations performed by the author using cortical bone grafts revealed no significant differences in outcome attributable to increased mass. However, large grafts did become fixed to surrounding structures in some cases.

Key words: Ossicular replacement prosthesis, cortical bone mass; Hearing tests

Introduction

The author has been using cortical bone grafts routinely in tympanoplasty operations for more than three years. The results of animal experiments (Hoffman and Zollner, 1969; Plester and Steinbach, 1977) and the clinical experience of some surgeons (Pulec and Sheehy, 1973) indicate that some re-absorption of cortical bone grafts may be expected following their introduction into the middle ear. In view of this, relatively large grafts were used in the early operations. It was felt that, because ossicles are made of denser bone than grafts harvested from Henle's spine, there would not be a significant increase in mass. The results of animal and other experiments suggest that increasing the mass of ossicular grafts can result in a high frequency hearing loss (Kirkae *et al.*, 1964; Green and Lee, 1973; Pickles, 1987). This study was therefore carried out to obtain normative data concerning the mass of human ossicles and to compare this with those for cortical bone grafts of the type used in ossicular reconstruction. In addition, the hearing results for the first 20 cases to have ossiculoplasties using cortical bone have been examined in detail to see if there was any difference in the degree of hearing improvement obtained at different frequencies.

Materials and methods

Measurements of mass

Preserved human incudes and malleuses were weighed using a Stanton Unimatic CL41 balance. A number of cortical bone grafts were prepared from preserved temporal bones and weighed using the same apparatus. These were prepared to closely simulate grafts used in middle ear surgery. The grafts were measured and were introduced into the middle ears of the temporal bones from which they had been harvested to ensure that they could be used to reconstruct the ossicular chain in a satisfactory manner, without contact with the tympanic ring or other areas to which fixation might occur. One composite prosthesis using a Schuring Ossicle Columella Prosthesis was included (Schuring and Lippy, 1983). The prosthesis used was one which had been cut to size and used in a previous tympanoplasty operation. It had been removed at revision surgery and the bone graft which had been used with it was sent for histological examination. A new bone graft was harvested for this study.

Patient study

Pure tone audiograms recorded one year after ossiculoplasty operations using cortical bone grafts were studied (Group A). The pre- and post-operative air conduction thresholds for 250, 500, 1000, 2000, 4000 and 8000 Hz and the bone conduction thresholds for 250, 500, 1000, 2000 and 4000 Hz were entered onto a computer spreadsheet (Lotus 123). The pre- and post-operative air–bone gaps for 250, 500, 1000, 2000 and 4000 Hz and the post-operative changes in air conduction thresholds for 250, 500, 1000, 2000, 4000 and 8000 Hz were calculated. The group mean hearing losses for all six frequencies and air–

TABLE I
VARIATIONS IN MASS OF HUMAN OSSICLES

Ossicle	Mean mass (mg)	Range	SD
Incus	31.3	22.5–36.4	2.8
Malleus	27.3	25.2–31.6	1.6

SD = Standard deviation.

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TABLE II
MASSES OF OSSICLES, CORTICAL BONE GRAFTS AND PROSTHESES

Ossicle/Graft/Prosthesis	Mass (mg)	Relative to incus Proportion	Percentage
Incus (mean)	31.3		
Malleus (mean)	27.3		
Modified incus	27.5	0.9	−12
Cortical bone PORG (mean)	40.2	1.3	+28
Cortical bone TORG (mean)	49.3	1.6	+57

PORG = Partial ossicular replacement graft.
TORG = Total ossicular replacement graft.

bone gaps for five frequencies were calculated. The whole process was repeated for a group of patients who had undergone reconstructions using ossicular grafts (Group B). These two groups were not matched pairs but were broadly comparable. Similar surgical techniques had been used in both and there was a similar mixture of ossicular defects. The patterns of residual hearing losses and air–bone gaps for the two groups were compared.

Statistical analysis

The group means for air–bone gaps and post-operative hearing changes for each frequency in the two groups were compared using a *t*-test.

Results

Measurements of mass

A total of 28 incudes and 15 malleuses were available for study. The results for these specimens are summarized in Table I. A total of eight cortical bone grafts were prepared, four of these being designed to reconstruct ears with loss of the incus but an intact stapes arch (partial ossicular replacement graft, PORG) while the remainder were designed for ears with an absent stapes arch (total ossicular replacement graft, TORG). The results for these, together with the mean values for the ossicles and the result for an incus modified for use in ossiculoplasty, are presented in Table II.

Patient study

The first 20 ossiculoplasties using cortical bone grafts constituted the study group (Group A). All the operations had been carried out before the data presented above became available. The mean pre- and post-operative hearing losses for the study group and controls are presented in Figures 1 and 2, while the mean air–bone gaps are presented in Figures 3 and 4. There were no statistically significant differences between the two groups. The mean hearing changes for each frequency tested are summarized in Table III. Review of individual audiograms revealed that a total of seven patients in Group A had conductive hearing losses involving 250, 500 and 1000 Hz. A similar pattern was seen in two patients in Group B. Representative audiograms are displayed in Figures 5 and 6. Four of the affected patients in Group A had previous open cavity mastoidectomies. However, the remaining three patients in Group A and the two patients in Group B had not had this type of surgery previously. Similarly, while three patients had an absent stapes arch, the rest had an intact stapes. There was no relationship between this pattern of hearing loss and the presence or absence of a tympanic membrane perforation. Comparison of pre- and post-operative air–bone gaps indicates that a similar low tone conductive hearing loss was present pre-operatively in all but one of the cases. This patient's hearing data is presented in Figure 7.

Discussion

The results presented above indicate that the use of a cortical bone graft in ossiculoplasty is likely to be associated with an increase in the system mass. Kirkae *et al.*

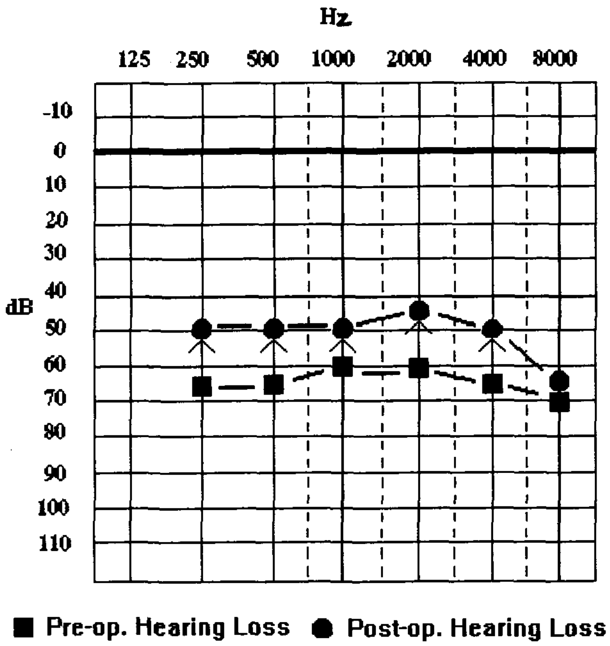

FIG. 1
Mean pre- and post-operative hearing losses for Group A. (cortical bone grafts).

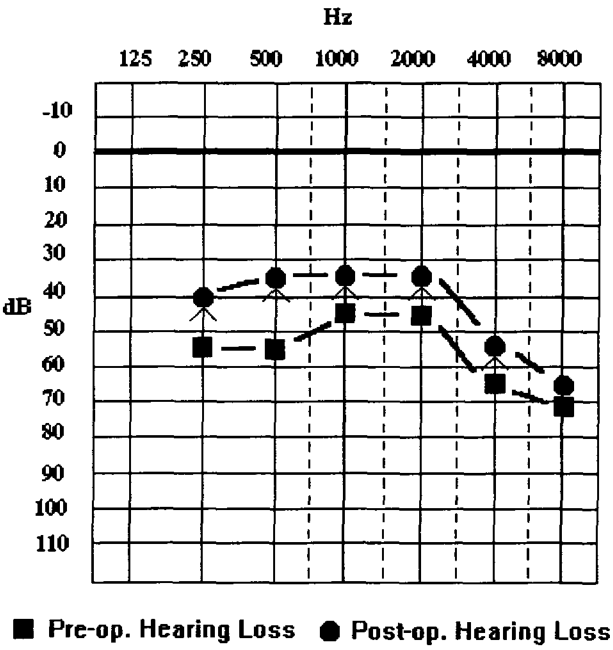

FIG. 2
Mean pre- and post-operative hearing losses for Group B. (ossicular grafts).

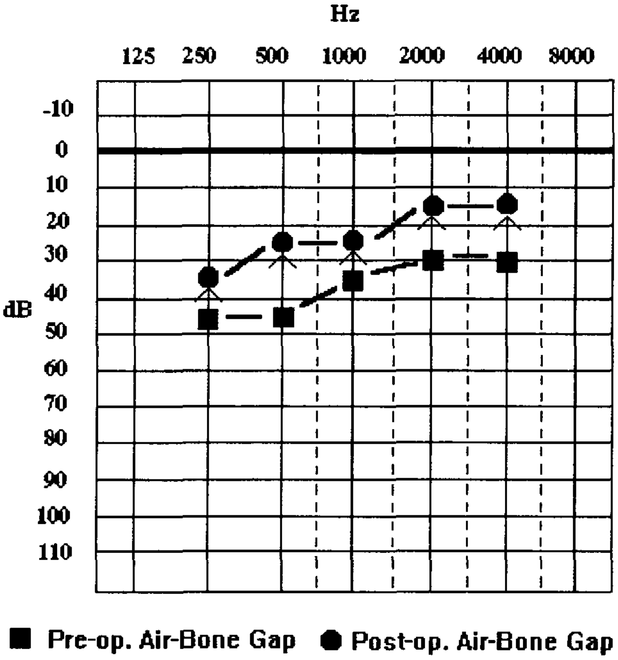

Fig. 3

Mean pre- and post-operative air–bone gaps for Group A (cortical bone grafts).

TABLE III

MEAN HEARING CHANGES (dB, ISO) FOR THE FREQUENCIES 250 TO 8000 Hz FOR GROUP A (CORTICAL BONE GRAFTS) AND GROUP B (OSSICULAR GRAFTS)

	Hearing change (dB)			
	Cortical bone		Ossicular graft	
Frequency (Hz)	Mean	SD	Mean	SD
250	13	11.5	11	19.9
500	11	15.3	13	14.9
1000	10	18.6	13	20.5
2000	14	15.7	12	18.9
4000	7	18.2	9	13.3
8000	1	15.9	1	14.9

(1964) studied a model of the middle ear. They found that when 250 mg of lead was added to the bamboo ossicular chain, leading to a 25-fold increase in its mass, there was an overall decrease in sound transmission, especially at the high frequencies. The same authors added 28 mg to the ossicular chain of a cat without producing any change. However, these experiments did not involve ossicular reconstructions, so the results do not necessarily apply to them. The use of a PORG would have resulted in a mean increase of 9 mg, while the corresponding increase for a TORG would have been 18 mg. These figures assume that an unmodified incus was used in the same circumstances and so the difference would be even greater if the comparison was made with a modified incus (see Table II). It should be pointed out that TORGs are used in cases with extensive destruction of the ossicular chain and so the mass of the system is not as greatly increased by such a graft as the figures quoted above suggest. Clarke and Dunlop (1968) studied the hearing in cats undergoing stapedectomy using different prostheses. They reported that an eight-fold increase in the mass of the piston was not associated with any adverse effect on hearing. The ossicular arrangement created by stapedectomy is closer to the original than that created by ossiculoplasty, so the effect may be different.

The present study was carried out because it was thought that the use of cortical bone grafts with a mass greater than that of an incus might result in a high frequency hearing loss. No such effect is evident in the results, but lower hearing gains were made at 4000 and 8000 Hz than at lower frequencies in both groups. However, many of the patients heard better at 2000 and 4000 Hz post-operatively than at lower frequencies because their pre-operative thresholds were better at these frequencies. From the results of previous studies, dis-

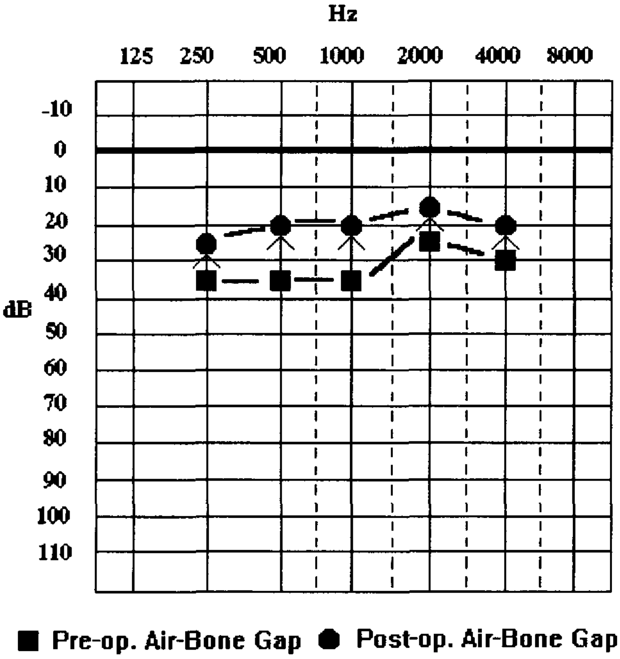

Fig. 4

Mean pre- and post-operative air–bone gaps for Group B (ossicular grafts).

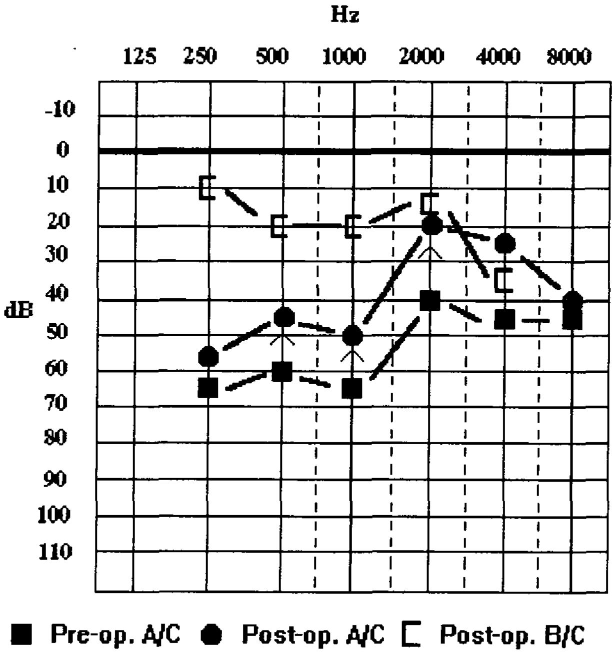

Fig. 5

Summary of hearing data for a representative case with a low tone conductive hearing loss from Group A (cortical bone grafts).

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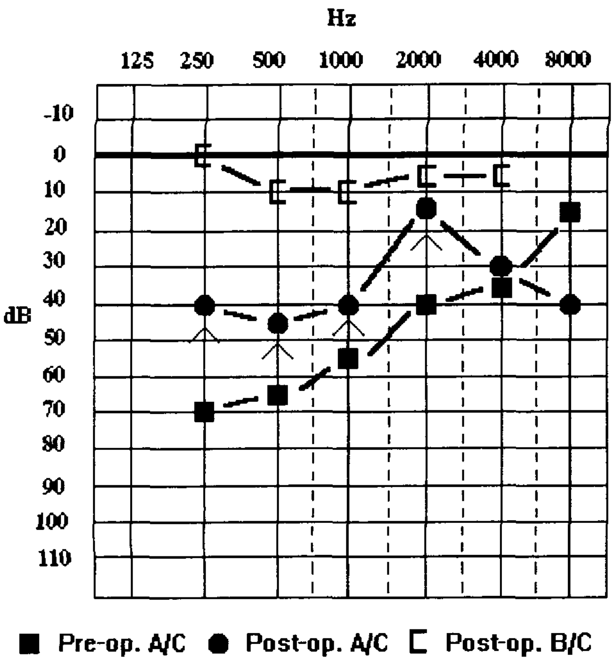

FIG. 6

Summary of hearing data from a representative case with a low tone conductive hearing loss from Group B (ossicular grafts).

cussed above, it appears likely that this is because the changes in mass were not sufficient to impair the transmission of high frequencies, at least in the context of a non-physiological reconstruction.

On the contrary, there appears to be a tendency for patients with cortical bone grafts to have a low frequency conductive hearing loss. However, further analysis of the data indicates that this pattern of hearing loss was present pre-operatively in all but one case. Since this study was

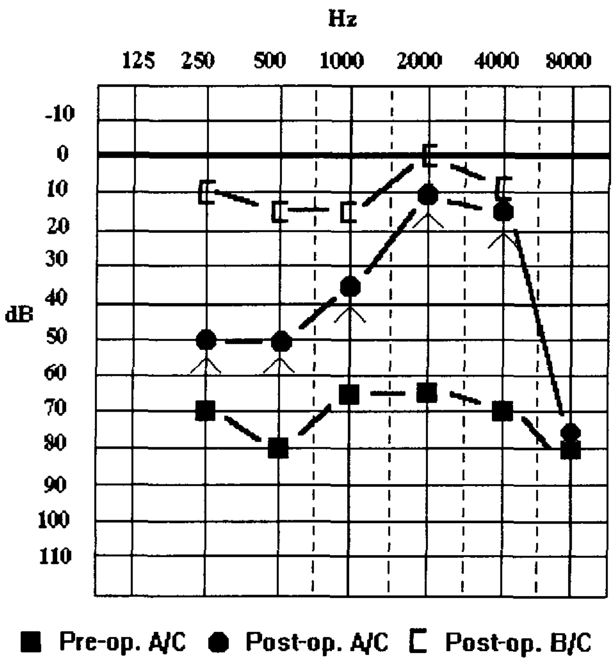

FIG. 7

Summary of hearing data from the case in Group A with a low tone conductive hearing loss post-operatively, but not pre-operatively. The patient had undergone a previous modified radical mastoidectomy.

carried out the author has noted quite a number of patients who have subsequently presented with ossicular defects and who have had the same pattern of hearing loss. The reasons for this are not entirely clear. Clark and Dunlop (1968) reported that, in experimental stapedectomy operations on cats, a low frequency hearing loss resulted when the piston was not crimped onto the incus. In patients undergoing surgery for ossicular defects it is not uncommon to find soft tissue attachments between the ossicles and/or the tympanic membrane. These are inadequate to transmit sound efficiently, but might constitute a loose connection analogous to the uncrimped piston. However, Elbrond and Elpern (1965), who studied the performance of ossicular reconstructions in human temporal bones, reported that an excessive increase in the tension of the system resulted in depressed transmission, particularly at low frequencies. The same authors reported that drum–stapes assemblies transmitted low frequencies better than high frequencies, while malleus–stapes assemblies transmitted high frequencies more efficiently. Anthony *et al.* (1972) reported that a low tone conductive hearing loss, of a pattern similar to that observed in the present study, was characteristic of ears with tympanic membrane perforation with an intact ossicular chain. In some cases this pattern persisted after successful closure of the perforation. In the present study low tone conductive losses were found in patients with an intact tympanic membrane.

Although the results of operations which have produced the pattern of low frequency residual hearing loss described above cannot be viewed as satisfactory, a number of the patients are happy with the outcome. This is presumably because of their relatively good hearing at 2000 and 4000 Hz. Another factor is the hearing in the other ear. The patient whose hearing data is shown in Figure 5 was very pleased with the outcome because the operated side became her better hearing ear. On the assumption that low tone losses result from loosely joined reconstructions, better results might be expected if a technique in which the graft is more firmly attached to the residual ossicular chain is carried out.

Analysis of the reasons for failure in some of the early cases indicates that fixation of the graft to surrounding structures, particularly the tympanic ring, has been a problem. This relates to the size of the graft used and therefore, although the mass effect does not seem to be significant, smaller, more extensively modified grafts are now used. In the case of TORGs, the composite prosthesis using a teflon strut is now preferred, as it is difficult to create a strut slender enough to fit into a narrow oval window niche without risking fixation. The use of the composite prosthesis does of course reduce the mass of the system. In the present study the mass of the composite TORG was only 22 per cent greater than that of an incus and this difference can be further reduced by using a smaller bone graft. Analysis of early failures with the composite prosthesis indicates that these were due either to making the columella too short, and therefore vulnerable to drum lateralization, or to the use of an oversized bone graft leading to fixation.

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