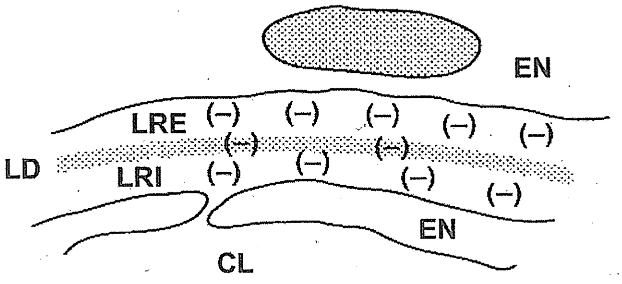

Fig 1. Schematic drawing of capillary basement membrane anionic sites. Anionic sites (–) are mainly located along lamina rara interna (LRI) and lamina rara externa (LRE) in capillary basement membrane. LD — lamina densa; EN — endothelial cell; CL — capillary lumen.

ers, the changes in the PEI distribution needed to be evaluated in all of these layers.

To analyze the changes in the PEI distribution in each area as accurately as possible, we evaluated both the number and size of the PEI particles located in the 3 layers. A tissue block was randomly selected, and the capillary BM in the stria vascularis was examined. Several photographs (×12,000) were taken of each ear, and 2 films were randomly selected for determining the number and size of PEI particles on a 1-μm BM segment. Each electron micrograph (×48,000) was enlarged 4 times for each film (×12,000). The number and size of the PEI particles were measured on the micrograph by use of a magnifying glass with a ruler. Small particles (diameter greater than 0.4 mm) that were located along the BM were counted as PEI particles on the micrographs. To obtain a measure reflecting the number and size of the PEI particles in a given area of the BM, we used the formula $\sum$[(PEI particle radius)$^2\pi$ × number of PEI particles]/1 μm BM = PEI area.

SigmaStat software (SPSS, Chicago, Illinois) was used for statistical analysis. One-way analysis of variance was used to compare the ABR threshold shifts at each frequency and the changes in the area of the PEI particles between the control and experimental groups. When the analysis of variance results showed significant differences, multiple pairwise comparisons were performed by Dunnett's method. A p value of less than 0.05 was considered statistically significant.

RESULTS

After operation, all of the experimental animals demonstrated a temporary head tilt toward the side of the surgery, with paretic nystagmus. Further, each animal walked in a counterclockwise direction. In all experimental animals, neither head tilt nor paretic nystagmus was observed the day after surgery.

The ABR threshold shifts that were observed at 4, 8, and 20 kHz in the animals decapitated immediately after surgery (group 1) were significantly greater than those observed in the control animals (Fig 2).

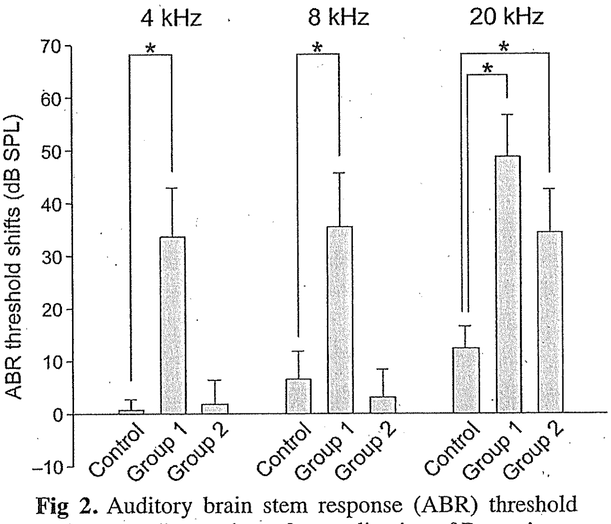

Fig 2. Auditory brain stem response (ABR) threshold shifts, according to time after application of Burow's solution, at 4, 8, and 20 kHz in experimental and control animals. At 4, 8, and 20 kHz, ABR threshold shifts were significantly greater in experimental group 1 than in control group. ABR threshold shifts at 4 and 8 kHz, but not at 20 kHz, had recovered by 2 days after surgery. Asterisk — $p < 0.05$, Dunnett's method.

No significant differences in the ABR threshold shifts at 4 and 8 kHz were observed between the animals decapitated 2 days after surgery (group 2) and the control animals. The ABR threshold shifts at 20 kHz in group 2 were significantly greater than those in the control group (Fig 2). No marked degeneration was observed in the stria vascularis of the basal or third turns in either the control or experimental animals. In the control animals, the PEI particles were evenly distributed in the lamina rara externa and the lamina rara interna of the capillary BM (Fig 3). No difference was observed in the PEI distribution between the basal and third turns. The number and size of the PEI particles in group 1 were lower than those in the control group (Fig 3). The PEI distribution in group 2 was similar to that in the control group (Fig 3). In both groups 1 and 2, no difference was observed in the PEI distribution between the basal and third turns of the cochlea. The area containing PEI particles in the basal and third turns of the cochlea was significantly smaller in group 1 than in the control group (Fig 4). However, in group 2, this area did not significantly differ in size from that in the control group (Fig 4).

DISCUSSION

Our current findings revealed changes in the ABR threshold shifts and in the anionic sites on the capillary BM in the stria vascularis in relation to the short time course that Burow's solution was retained on the RWM. In our previous study, we found that a

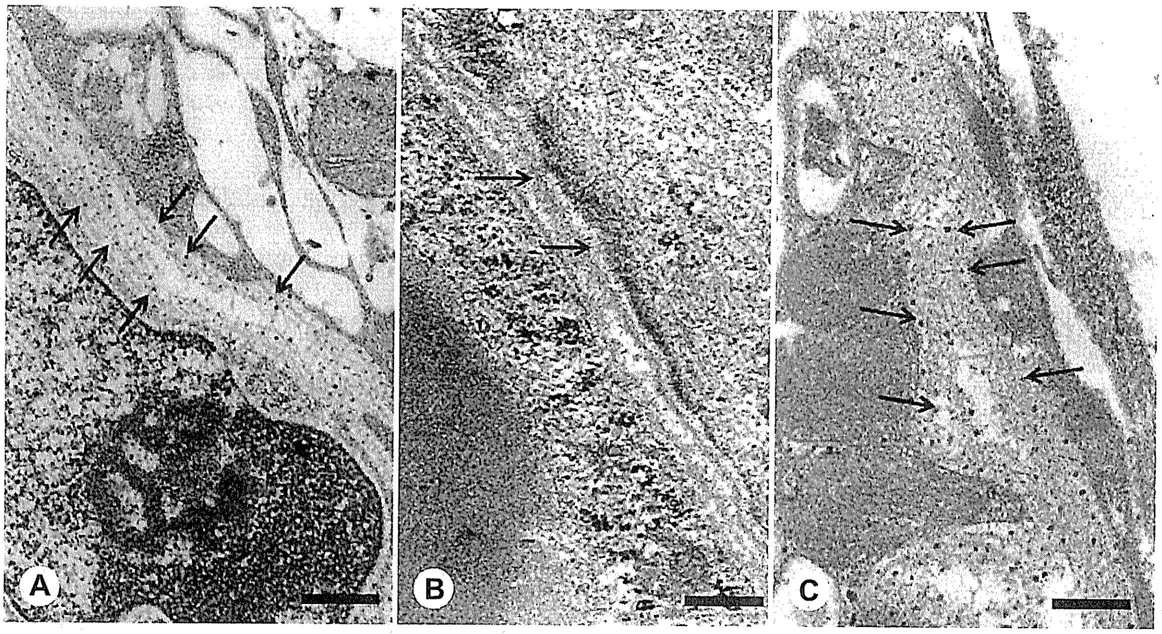

Fig 3. Polyethylenimine (PEI) distribution (arrows) on capillary basement membrane in stria vascularis in basal turn. Bars — 0.2 μm. **A)** Control group. **B)** Experimental group 1. **C)** Experimental group 2. In control group and experimental group 2, PEI particles were evenly distributed in lamina rara externa and lamina rara interna of capillary basement membrane. Compared to control group, experimental group 1 had markedly decreased number and size of PEI particles.

significant amount of outer hair cell loss occurs in the basal turn of the cochlea after Burow's solution has been applied to the RWM for 2 hours.[3] Therefore, in the current study, we used the time window of 2 hours for applying Burow's solution onto the RWM.

In the current study, all experimental animals temporarily demonstrated a head tilt toward the side of the surgery, with paretic nystagmus, and walked in a counterclockwise direction — similar to behavior

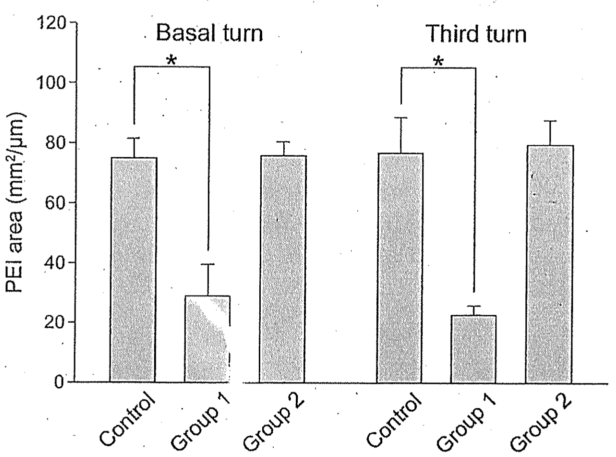

Fig 4. PEI area on capillary basement membrane in stria vascularis in basal and third turns. In both turns, number and size of PEI particles in group 1 differed significantly from those in control group. Number and size of PEI particles in group 2 was similar to those in control group. Asterisk — $p < 0.05$, Dunnett's method.

observed in a previous report.[3] This result suggests that Burow's solution penetrated to all parts of the inner ear, including the vestibular labyrinth passing through the scala tympani.

In the current study, the ABR threshold shifts that were observed at 4, 8, and 20 kHz in the experimental animals that were decapitated immediately after surgery were significantly greater than those observed in the control animals. These findings suggest that hearing rapidly deteriorates after Burow's solution is applied and retained on the RWM for 2 hours. In addition, the area containing PEI particles in the basal and third turns of the cochlea decreased significantly immediately after surgery. It has been demonstrated that the distribution of PEI particles present at the anionic sites undergoes a decrease on the capillary BM in the stria vascularis under the condition of acidosis.[5] Therefore, a decrease in the area containing PEI particles in the BM suggests that the pH of the tissue in the stria vascularis, especially the intermediate cell layer, became acidic after the application of Burow's solution. It has been reported that the application of acetic acid to the RWM rapidly suppresses sodium-potassium adenosine triphosphatase activity and decreases the pH of the perilymph and endolymph, with a subsequent persistent decline in the endocochlear potentials.[4] In addition, it has been reported that adenosine triphosphatase is particularly sensitive to aluminum acetate.[8] One hypothesis is that the application of Burow's solution to the RWM decreases the pH of the tissue in the stria vascularis, especially the intermediate cell layer, and rapidly suppresses sodium-potassium adenosine triphosphatase activity, thereby inducing hearing impairment. In this study, all of the experimental animals demonstrated a temporary head tilt toward the side of the surgery, with paretic nystagmus, immediately after application of Burow's solution. Therefore, another hypothesis is that the cochlear hair cells are directly influenced by the low pH of Burow's solution. In this study, the ABR thresholds at 4, 8, and 20 kHz significantly increased immediately after surgery; the thresholds at 4 and 8 kHz, but not at 20 kHz, recovered 2 days after surgery. Tanaka et al[9] recorded no significant ABR threshold shifts at 1, 2, 4, 8, or 16 kHz 3 days after acidic phosphate-buffered saline solution was placed on the round window membrane. These data suggest that the direct effect of low pH on the cochlear hair cells is not permanent. Therefore, the ABR threshold shift at 20 kHz in the current study cannot be attributed to the low pH.

In the experimental animals decapitated 2 days after surgery, the ABR threshold shifts at 4 and 8 kHz were the same as those in the control animals. In addition, the area containing PEI particles in the basal and third turns in these animals was not significantly different from that in the control animals. These findings suggest that the ABR threshold shifts at 4 and 8 kHz caused by the application of Burow's solution to the RWM were temporary and that the changes in the BM anionic sites induced by a decrease of pH were completely reversed within 2 days after surgery. In the cochlea, the BM consists of 4 components: laminin, entactin/nidogen, type IV collagen, and heparan sulfate proteoglycans.[10] In glomeruli, it has been demonstrated that the turnover of proteoglycans — the principal component of BM anionic sites — is fairly rapid.[11,12] Yoshimura et al[13] reported that the anionic sites of the glomerular BM generally begin to recover 3 hours after their disappearance following treatment with cationic probe molecules. However, the BM anionic sites in the stria vascularis may not recover when the cochlea undergoes severe degeneration after exposure to an ototoxic drug.[14] The recovery of the BM anionic sites noted in the current study suggests that the cochlear damage subsequent to the pH change was not severe enough to prevent regeneration, and that normal proteoglycan turnover continued.

In the current study, the ABR threshold shifts at 20 kHz continued to increase even 2 days after surgery, despite the reversal in the acetic pH changes in the stria vascularis. Therefore, the ABR threshold shifts at 20 kHz cannot be attributed to the pH changes induced by the acetic acid present in Burow's solution. Recently, we demonstrated that degeneration of the outer epithelium and extensive erythrocyte infiltration appear in the scala tympani, adjacent to the RWM, immediately after Burow's solution is retained on the RWM for 2 hours.[3] These findings suggest that the inflammatory changes occur mainly in the lower basal turn. Aluminum sulfate, the other principal component of Burow's solution, is known to have an astringent effect that causes decomposition of proteins, constriction of blood vessels, tightening of the skin or mucosa, and induction of inflammation. Therefore, the ABR threshold shift at 20 kHz may be attributable to the inflammation caused by the aluminum sulfate entering the scala tympani through the RWM.

Recently, Oishi et al[15] reported 2 cases of acute sensorineural hearing loss that occurred after the administration of 8% Burow's solution into the tympanic cavities. Because a previous study reported that the application of an artificial perilymph of pH 4 titrated with hydrochloric acid induced no significant changes in the endocochlear potentials,[4] the low pH of Burow's solution would not be a risk factor for permanent ototoxicity. Possibly, the most effective method for preventing permanent hearing loss may be to decrease the concentration of aluminum sulfate in Burow's solution. Alternatively, intratympanic irrigation with physiological saline solution is also recommended for removing or diluting the remnants of Burow's solution, especially the aluminum sulfate component, in the round window niche.

Thus, our findings demonstrated that although the changes in pH caused by application of Burow's solution to the RWM led to ABR shifts at 4 and 8 kHz, along with a decrease in the PEI distribution area in the basal and third turns signifying damage to the BM anionic sites, these changes were temporary and were reversed by 2 days after the application. This finding indicated that the hearing loss and ototoxicity caused by the acetic acid in Burow's solution was unlikely to be permanent; however, it may be advisable to reduce the aluminum sulfate concentration administered in order to decrease the incidence of ototoxicity.

CONCLUSIONS

The ABR threshold shifts and the area of the anionic sites on the capillary BM in the stria vascularis were changed in relation to the time that Burow's solution was retained on the RWM. Although Burow's solution may cause an acetic low pH in the stria vascularis and a temporary ABR threshold shift at 4 and 8 kHz, a permanent ABR threshold shift at 20 kHz cannot be attributed to the acetic low pH.

Acknowledgments: We thank Yoshiro Mori, Yukari Kurasawa, and Atsuko Tsuyuzaki for their technical assistance in light microscopic examination.

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ORIGINAL ARTICLE

Carhart Notch 2-kHz Bone Conduction Threshold Dip

A Nondefinitive Predictor of Stapes Fixation in Conductive Hearing Loss With Normal Tympanic Membrane

Akinori Kashio, MD; Ken Ito, MD; Akinobu Kakigi, MD; Shotaro Karino, MD; Shin-ichi Iwasaki, MD; Takashi Sakamoto, MD; Takuya Yasui, MD; Mitsuya Suzuki, MD; Tatsuya Yamasoba, MD

Objective: To evaluate the significance of the Carhart notch (a 2-kHz bone conduction threshold dip [2KBD]) in the diagnosis of stapes fixation by comparing its incidence among ears with various ossicular chain abnormalities.

Design: Retrospective study.

Setting: University hospital.

Patients: A total of 153 ears among 127 consecutive patients with a congenital ossicular anomaly or otosclerosis.

Main Outcome Measures: The 2KBD depth was defined as the threshold at 2 kHz minus the mean of thresholds at 1 and 4 kHz. The presence of 2KBD (depth, ≥10 dB), 2KBD depth, relationship between 2KBD depth and air-bone gap, and 2-kHz bone conduction recovery after operation were evaluated in a stapes fixation group (which included cases of otosclerosis and congenital stapes fixation), an incudostapedial joint detachment group, and a malleus or incus fixation group.

Results: A 2KBD was present in 32 of 102 stapes fixation ears (31.4%), 5 of 19 incudostapedial joint detachment ears (26.3%), and 6 of 20 malleus or incus fixation ears (30.0%) (12 ears had other diagnoses). The mean (SD) 2KBD depths were 17.3 (5.2) dB in the stapes fixation group, 18.5 (2.2) dB in the incudostapedial joint detachment group, and 16.3 (2.1) dB in the malleus or incus fixation group. No statistically significant differences were noted among these 3 groups. No correlation was noted between 2KBD depth and air-bone gap extent. Recovery of 2-kHz bone conduction threshold in the stapes fixation group was less than that in the other 2 groups.

Conclusion: Incidence of 2KBD was similar among the stapes fixation, incudostapedial joint detachment, and malleus or incus fixation groups, implying that 2KBD is not a useful predictor of stapes fixation.

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In 1950, Carhart[1] reported bone conduction threshold elevation of approximately 2 kHz among patients with otosclerotic lesion–induced stapes ankylosis that disappeared after stapes surgery. Since then, this deceptive 2-kHz bone conduction threshold dip (2KBD) without inner ear damage has become a well-known indicator of stapes fixation (Carhart notch). However, results of studies[2-9] have suggested that elevation in bone conduction thresholds between 1 and 4 kHz can be caused by various factors that affect the conductive mechanism of the middle ear. In fact, it is not uncommon to encounter cases of Carhart notch in which hearing loss is caused by detachment of the incudostapedial joint. For Carhart notch to be used as a preoperative predictor of stapes fixation, it should be shown that the notch exists with stapes fixation but not with other ossicular chain disorders, such as disconnection; however, few clinical investigations have assessed this issue. In the present study, we evaluated the significance of 2KBD depth, defined as the threshold at 2 kHz minus the mean of thresholds at 1 and 4 kHz, in diagnosing various ossicular chain abnormalities in the setting of a normal tympanic membrane.

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METHODS

We studied 153 ears among 127 consecutive patients who had a congenital ossicular anomaly or otosclerosis that was confirmed during surgery between January 1997 and December 2007 at the University of Tokyo Hospital, Tokyo, Japan. On the basis of the diagnosis made during surgery, we assigned these ears to the following 3 groups:

Table 1. Postoperative Diagnosis, Age, and Preoperative Air and Bone Conduction Thresholds Among Patients With the Various Pathologic Conditions

Postoperative Diagnosis	No. of Ears	Mean (SD)		
		Patient Age, y	ACT, dB	BCT, dB
Stapes fixation	102	48 (15)	58.3 (15.1)	26.3 (11.0)
Incudostapedial joint detachment	19	26 (17)	54.0 (11.9)	15.8 (7.0)
Malleus or incus fixation	20	24 (22)	56.8 (13.5)	19.2 (12.4)
Other	12	22 (16)	65.1 (8.4)	17.2 (12.5)

Abbreviations: ACT, air conduction threshold; BCT, bone conduction threshold.

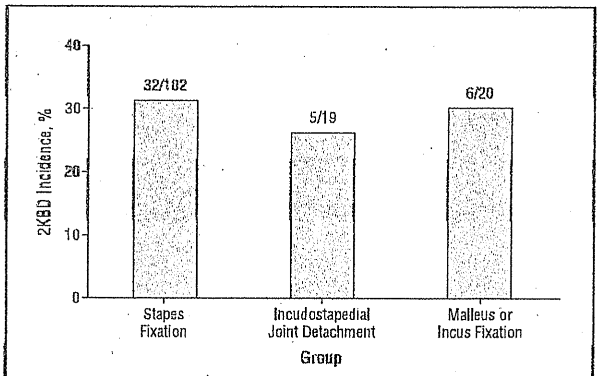

Figure 1. Incidence of 2-kHz bone conduction threshold dip (2KBD) among various pathologic conditions.

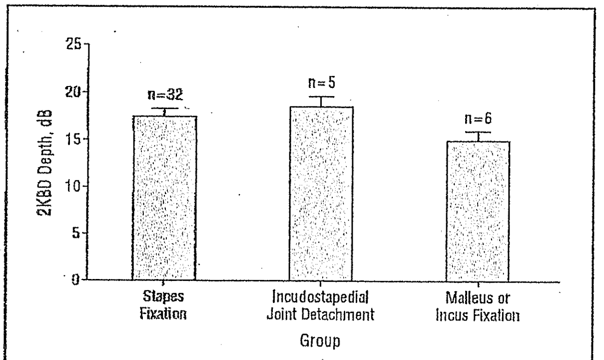

Figure 2. Depth of 2-kHz bone conduction threshold dip (2KBD) among various pathologic conditions. Error bars indicate standard error.

Table 2. Age-Related 2-kHz Bone Conduction Threshold Dip (2KBD)–Positive Rates

Age Group, y	Postoperative Diagnosis	No.	2KBD Positive
0-29	Stapes fixation	8	1
	Incudostapedial joint detachment	12	2
	Malleus or incus fixation	15	5
	Total, No. (%)	**35**	**8** (22.9)
30-59	Stapes fixation	70	20
	Incudostapedial joint detachment	6	2
	Malleus or incus fixation	2	0
	Total, No. (%)	**78**	**22** (28.2)
≥60	Stapes fixation	24	11
	Incudostapedial joint detachment	1	1
	Malleus or incus fixation	3	1
	Total, No. (%)	**28**	**13** (46.4)

a stapes fixation group (which included cases of otosclerosis and congenital stapes fixation), an incudostapedial joint detachment group, and a malleus or incus fixation group. The medical records of these patients were retrospectively reviewed. Stapes fixation was observed in 102 ears (including 15 ears with congenital fixation), incudostapedial joint detachment without stapes fixation in 19 ears, and malleus or incus fixation without stapes fixation in 20 ears. The other 12 ears (including a combination of incudostapedial joint detachment and malleus or incus fixation or obstruction of the oval window) could not be classified into the aforelisted groups and were excluded from the analysis. The patients ranged in age from 6 to 72 years (mean [SD] age, 40 [20] years). Postoperative diagnoses and the mean age and mean preoperative air and bone conduction thresholds (at 0.5, 1, and 2 kHz) are given in **Table 1**. Patients in the stapes fixation group were significantly older than those in the other 2 groups. No significant differences were noted among the 3 groups in preoperative air or bone conduction thresholds.

For audiometric evaluation, we measured air conduction thresholds at 0.125, 0.25, 0.5, 1, 2, 4, and 8 kHz. Bone conduction thresholds were measured at 0.5, 1, 2, and 4 kHz. Pure-tone audiometry was performed more than once on various days before surgery. The 2KBD was considered present when the bone conduction threshold at 2 kHz exceeded the mean of thresholds at 1 and 4 kHz by at least 10 dB. The 2KBD depth was calculated by subtracting the mean of thresholds at 1 and 4 kHz from the bone conduction threshold at 2 kHz.

Values were recorded as the mean (SD) unless indicated otherwise. Statistical analyses used χ^2 test, Wilcoxon signed rank test, and 1-way analysis of variance with Bonferroni post hoc test.

RESULTS

The 2KBD was detected in 32 of 102 ears (31.4%) in the stapes fixation group, 5 of 19 ears (26.3%) in the incudostapedial joint detachment group, and 6 of 20 ears (30.0%) in the malleus or incus fixation group (**Figure 1**). The mean 2KBD depths were 17.3 (5.2) dB in the stapes fixation group, 18.5 (2.2) dB in the incudostapedial joint detachment group, and 16.3 (2.1) dB in the malleus or incus fixation group (**Figure 2**). No statistically significant differences were noted in 2KBD incidence or 2KBD depth among the 3 groups.

Table 2 gives age-related dip-positive rates. There were no significant differences in percentages of dip-positive cases among the different age groups.

Figure 3 shows the relationship between 2KBD depth and air-bone gap, indicating no correlation between the 2 variables. No apparent differences were observed among the 3 groups.

Table 3 gives 2-kHz bone conduction thresholds before and after surgery, as well as improvements obtained by surgery. Of 102 ears in the stapes fixation group, 3 ears were excluded in which ossicular reconstruction could not be performed. Of 19 ears in the incudostapedial joint detachment group, 1 was excluded because the patient dropped out during the postoperative follow-up period. Improvement in 2-kHz

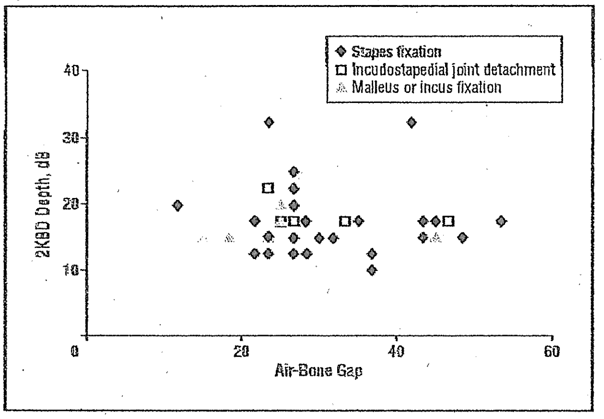

Figure 3. Relationship between 2-kHz bone conduction threshold dip (2KBD) depth and air-bone gap (r=0.34).

Table 3. Preoperative and Postoperative 2-kHz Bone Conduction Thresholds and Recovery

Postoperative Diagnosis	No. of Ears	2-kHz Bone Conduction Threshold, Mean (SD), dB		
		Preoperative	Postoperative	Recovery
Stapes fixation				
Total	99	35.0 (1.3)	31.2 (1.4)	4.6 (1.0)
2KBD positive	30	41.3 (2.0)	37.0 (2.8)	4.3 (1.9)
Incudostapedial joint detachment				
Total	18	22.2 (2.5)	16.9 (2.7)	5.6 (2.9)
2KBD positive	4	35.0 (5.3)	20.0 (6.2)	15.0 (4.7)
Malleus or incus fixation				
Total	20	26.5 (3.9)	20.1 (3.6)	6.3 (3.9)
2KBD positive	6	41.7 (7.8)	22.5 (7.7)	19.2 (4.6)

Abbreviation: 2KBD, 2-kHz bone conduction threshold dip.

bone conduction thresholds among the stapes fixation group was less than that among the other 2 groups; the difference between the 2KBD-positive stapes fixation group and the 2KBD-positive malleus or incus fixation group was statistically significant ($P<.05$, Bonferroni post hoc test) (**Figure 4**).

COMMENT

PREDICTIVE ABILITY OF CARHART NOTCH AND ITS UNDERLYING MECHANISMS

Acute or chronic otitis media associated with perforation of the tympanic membrane and otitis media with effusion can be diagnosed easily; however, in patients with normal tympanic membrane, sufficient information is needed to diagnose the cause of hearing loss. An audiological feature of 2KBD, Carhart notch, is widely known and is traditionally believed to suggest stapes fixation[10]; however, few investigations have verified its usefulness. In the present study, we evaluated the significance of Carhart notch in predicting stapes fixation and found that 2KBD was ineffective as a predictive tool. Incidence of Carhart notch was almost identical among the stapes fixa-

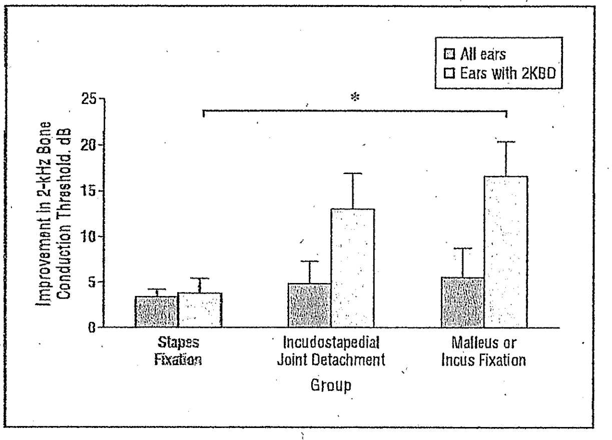

Figure 4. Postoperative recovery of 2-kHz bone conduction thresholds. Error bars indicate standard error, and the asterisk indicates a significant difference ($P<.05$, Bonferroni post hoc test). 2KBD indicates 2-kHz bone conduction threshold dip.

tion, incudostapedial joint detachment, and malleus or incus fixation groups. Otologic surgeons should be aware of this fact and should be ready to adapt their procedures according to pathologic findings during surgery.

Supporting our present findings that Carhart notch is not specific to stapes fixation, bone conduction threshold elevation between 1 and 4 kHz has also been reported in various pathologic conditions that affect the conductive mechanism of the middle ear. This phenomenon has been described in fluctuations of otitis media with effusion,[2,11-13] chronic otitis media,[5,6,14-17] experimental creation of artificial conductive impairment by loading the tympanic membrane,[8,18,19] occlusion of the round window or oval window,[8,9] and disarticulation of the incudostapedial joint.[9,20] Bone conduction threshold elevation has been reported principally between 1 and 4 kHz, with the largest being at 2 kHz.[2,5,7,21]

Bone conduction thresholds do not always represent a pure estimate of cochlear reserve, as many components are involved in bone conduction. The most important physical phenomena are believed to be (1) sound radiation into the ear canal, (2) inertial motion of the middle ear ossicles, and (3) compression and expansion of the bone encapsulating the cochlea.[22,23] Ossicular chain deficiencies are closely related to these components. A change in the ossicular chain may result in less inertial motion energy transmitted into the inner ear and can cause impedance mismatch between the inner ear and the ossicular system, modifying (decreasing or increasing) the loss of bone-conducted sound pressure from the vestibule to the footplate. It is reported that the middle ear does not contribute to perception of bone conduction sound at frequencies lower than 1 kHz.[8,20,24] At higher frequencies, the middle ear can affect bone conduction. Using human cadaver heads, Stenfelt[20] reported that motion of the stapes with bone conduction sounds was decreased by 5 to 10 dB between 1.2 and 2.7 kHz after the incudostapedial joint was severed. Using cats, Kirikae[8] reported a decrease in response at frequencies between 1 and 3 kHz after fixation of the stapes. With an intact ossicular chain, resonance frequency of the ossicular vibration with bone conduction stimulation is close to 1.5

kHz,[20] which explains 2-kHz bone conduction threshold elevation in ossicular deficiency. Therefore, although the underlying mechanisms may differ, 2-kHz bone conduction threshold elevation may well occur in various impairments of the ossicular chain, including stapes fixation, incudostapedial joint detachment, and malleus or incus fixation. The reason for this phenomenon seems complex, but oversimplification is inappropriate; further fundamental studies are needed to clarify its mechanism.

AGE-RELATED EFFECTS OF 2KBD

The mean age of patients in the stapes fixation group was significantly older than that of patients in the incudostapedial joint detachment group and the malleus or incus fixation group. In our cohort, patients in the latter 2 groups with normal tympanic membranes were mainly young adults or children with congenital malformations of the ossicular chain. This may explain the younger mean ages of these groups. Aging raises bone conduction thresholds at high frequencies, and elevation of 4-kHz bone conduction thresholds results in underestimation of potential 2KBD depths in older patients with stapes fixation. However, in our series, no significant differences were noted in 2KBD incidence among age groups. This suggests that age differences among the 3 study groups did not affect 2KBD incidence.

2KBD DEPTH AND 2-KHZ BONE CONDUCTION THRESHOLD RECOVERY AFTER SURGERY

Several investigations have focused on 2KBD, but its definitive criteria have not yet been established. However, previously reported mean 2KBD depths in otosclerosis ranged from 2.4 to 12.5 dB.[20,24,25] These studies included all cases and not just those classified as dip positive by certain criteria. The overall mean 2KBD depth, including dip-negative cases, was 8.5 dB in our stapes fixation group, which is within the range previously reported. For the 2KBD-positive cases, all 3 groups showed similar depths. These results suggest that an apparent elevation in bone conduction thresholds caused by a middle ear deficiency is similar regardless of the cause. Moreover, no correlation was observed between air-bone gap and 2KBD depth, suggesting that the depth may not be influenced by the degree of middle ear deficiency.

Carhart[1] originally reported postoperative bone conduction improvements of 5 dB at 500 Hz, 10 dB at 1 kHz, 15 dB at 2 kHz, and 5 dB at 4 kHz. Ginsberg et al[21] confirmed the finding of optimal bone conduction improvement at 2 kHz. Awengen[25] showed an improvement of 4 to 12 dB for bone conduction at 2 kHz in otosclerosis after stapedectomy. In our series, the mean recovery of 2-kHz bone conduction was 4.6 to 6.3 dB, and the value was 4.3 to 19.2 dB when we limited the analysis to only dip-positive cases. Recovery trends in the stapes fixation group were worse than those in the other 2 groups. Gerard et al[26] proposed that there is less postoperative improvement in bone conduction with increasing age; this suggests that the aging cochlea is more susceptible to surgical damage. Because the mean age of patients was significantly older in the stapes fixation group, this may have influenced their recovery. When we evaluated 33 younger patients (about one-third of the group; mean age, 33 years) from the stapes fixation group, the overall 2KBD recovery was 7.9 (1.8) dB, which was comparable to that of the other 2 groups. Surgical procedures used in stapes surgery are more invasive and involve opening of the inner ear. Cook et al[27] reported a weak ($r=0.28$) but significant ($P<.05$) correlation between bone conduction recovery at 2 kHz and air conduction recovery after stapes surgery. We also investigated this issue and found that bone conduction recovery at 2 kHz had a weak correlation with the mean air conduction recovery ($r=0.38$, $P<.05$) but observed that preoperative air-bone gap and 2-kHz bone conduction threshold recovery had no significant correlation ($r=-0.11$, $P>.05$). These facts imply that air and bone conduction threshold elevations are related somewhat but that the underlying mechanisms of these phenomena may not be simple.

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