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.

Arch Otalaryngol Head Neck Surg. 2011;137(3):236-240

In 1950, Carhart 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 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.

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

<table>
<thead>
<tr>
<th>Postoperative Diagnosis</th>
<th>No. of Ears</th>
<th>Mean (SD) Patient Age, y</th>
<th>ACT, dB</th>
<th>BCT, dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stapes fixation</td>
<td>102</td>
<td>48 (15)</td>
<td>58.3 (15.1)</td>
<td>26.3 (11.0)</td>
</tr>
<tr>
<td>Incudostapedial joint detachment</td>
<td>19</td>
<td>26 (17)</td>
<td>54.0 (11.9)</td>
<td>15.9 (7.0)</td>
</tr>
<tr>
<td>Malleus or incus fixation</td>
<td>20</td>
<td>24 (22)</td>
<td>56.8 (13.5)</td>
<td>19.2 (12.4)</td>
</tr>
<tr>
<td>Other</td>
<td>12</td>
<td>22 (16)</td>
<td>65.1 (8.4)</td>
<td>17.2 (12.5)</td>
</tr>
</tbody>
</table>

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

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

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

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.

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

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.
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; 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 fixation, 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, chronic otitis media, experimental creation of artificial conductive impairment by loading the tympanic membrane, occlusion of the round window or oval window, and disarticulation of the incudostapedial joint. Bone conduction threshold elevation has been reported principally between 1 and 4 kHz, with the largest being at 2 kHz.

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. 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. At higher frequencies, the middle ear can affect bone conduction. Using human cadaver heads, Stenfelt 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 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,\textsuperscript{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.\textsuperscript{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\textsuperscript{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\textsuperscript{21} confirmed the finding of optimal bone conduction improvement at 2 kHz. Awengen\textsuperscript{23} 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\textsuperscript{25} 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\textsuperscript{22} 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.

Submitted for Publication: March 29, 2010; final revision received September 10, 2010; accepted October 18, 2010.

Correspondence: Ken Ito, MD, Department of Otolaryngology, Teikyo University School of Medicine, 2-11-1 Kaga Itabashi-ku, Tokyo, Japan (itoken-1ky@umin.ac.jp).

Author Contributions: Drs Kashio, Ito, Karino, Iwasaki, Sakamoto, Suzuki, and Yamasoba had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. Study concept and design: Kashio and Ito. Acquisition of data: Kashio, Ito, Karino, Iwasaki, Sakamoto, Suzuki, and Yamasoba. Analysis and interpretation of data: Kashio, Ito, Kakigi, Sakamoto, Yasui, and Yamasoba. Drafting of the manuscript: Kashio, Ito, and Yasui. Critical revision of the manuscript for important intellectual content: Kashio, Ito, Kakigi, Karino, Iwasaki, Sakamoto, Suzuki, and Yamasoba. Statistical analysis: Ito and Yasui. Administrative, technical, and material support: Kashio. Study supervision: Ito, Kakigi, Karino, Iwasaki, Sakamoto, Suzuki, and Yamasoba.

Financial Disclosure: None reported.


Call for Photographs

Archives of Otolaryngology—Head & Neck Surgery is always seeking interesting cover photographs. Since many of our readers are excellent amateur photographers, we would appreciate submissions of choice photographs to us. Please e-mail them as an attachment, in .jpg or .tif format, to archoto@jama-archives.org or, if necessary, mail them to Archives of Otolaryngology—Head & Neck Surgery, 183 Tuckahoe Farm Ln, Charlottesville, VA 22901. Contact Susan Levine, Editorial Manager, with any questions at (434) 960-9202.