

Ossicular chain reconstruction improves bone conduction threshold in chronic otitis media

H-S LEE, S-D HONG*, S H HONG*, Y-S CHO*, W-H CHUNG*

Abstract

This study aimed to assess the elevation of bone conduction threshold in patients with chronic otitis media and to investigate the mechanism of this phenomenon. One hundred and six patients with unilateral chronic otitis media who had undergone a tympanomastoidectomy were reviewed retrospectively. The differences in the bone conduction thresholds between the diseased and normal sides were assessed and compared according to the duration of the disease and the presence of cholesteatoma. Post-operative changes in the bone conduction threshold were also assessed. The mean bone conduction thresholds were significantly elevated on the diseased side, ranging from 3.4 to 11.6 dB across frequencies, with a maximal elevation at 2000 Hz. The duration of disease and the presence of cholesteatoma did not affect the degree of the bone conduction elevation. After ossicular reconstruction, bone conduction thresholds improved significantly at all frequencies, with the greatest improvement being observed at 2000 Hz. These results suggest that the elevation in the bone conduction threshold in chronic otitis media is mainly caused by a change in the conductive mechanism in the middle ear.

Key words: Suppurative Otitis Media; Bone Conduction; Otologic Surgical Procedures; Conductive Hearing Loss

Introduction

Sensorineural hearing loss is commonly encountered in patients with uncomplicated chronic otitis media. Even though the patients have no history of labyrinthitis, the bone conduction threshold is elevated. However, the mechanism of bone conduction threshold elevation in cases of chronic otitis media is not completely understood. Such an elevation has been reported to be caused by either cochlear involvement, as a result of an extension of inflammation into the inner ear,^{1,2} or disruption of the middle-ear conductive mechanism of hearing.³ According to Paparella *et al.*,² sensorineural hearing loss in chronic otitis media is the result of toxic substances passing from the middle ear into the inner ear via the round window membrane. Morphological changes in the cochlea have also been demonstrated in patients with chronic otitis media.¹ An elevation in the bone conduction threshold in chronic otitis media is associated with prolonged disease duration^{4–7} and the presence of cholesteatoma,^{5,8,9} which supports the view that toxic inflammatory substances could be the main reason for the elevation in bone conduction threshold seen in chronic otitis media.

On the other hand, an elevation in the bone conduction threshold could be caused by a disruption of the middle-ear mechanism of hearing. The bone conduction response is not always induced by sound conduction from the skull directly to the cochlea.¹⁰ The ossicular chain is also involved in the bone conduction response.¹¹ The Carhart effect refers to a depression of bone conduction in the presence of a conductive hearing loss, particularly otosclerosis. Chronic middle-ear inflammation usually causes perforation of the tympanic membrane and ossicular chain discontinuity. In addition, middle-ear granulations can restrict the motion of the ossicular chain. Browning and Gatehouse suggested that elevated bone conduction thresholds in chronic otitis media were likely to reflect the Carhart effect rather than damage to the inner ear due to disease.¹² In addition, Walby *et al.* reported that there was no evidence that chronic otitis media caused the destruction of hair cells or cochlear neurons.³

The aim of this study was to determine the mechanism of bone conduction change in chronic otitis media. Bone conduction threshold can be restored after ossicular reconstructive surgery if the ossicular chain disruption is the main cause of bone

From the Department of Otorhinolaryngology-Head and Neck Surgery, Pundang Jesaeng Hospital, Daejin Medical Center, Sungnam, and the *Department of Otorhinolaryngology-Head and Neck Surgery, Sungkyunkwan University School of Medicine, Samsung Medical Center, Seoul, Korea.

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conduction threshold elevation. Therefore, this study compared bone conduction thresholds before and after ossicular reconstruction.

Materials and methods

One hundred and six patients with unilateral, chronic otitis media who had undergone tympanomastoidectomy between 1999 and 2003 were reviewed retrospectively. Subjects with a history of labyrinthitis, previous otological surgery, meningitis, head trauma, labyrinthine fistula and ototoxicity that could cause permanent sensorineural hearing loss were excluded. Patients' ages ranged from 10 to 63 years (mean, 40.1 years). The contralateral, unaffected ear was used as the control.

The air conduction and bone conduction thresholds were measured using a clinical audiometer (GSI 61, Grason-Stadler, Milford, NH, USA), which had been calibrated according to International Organization for Standardization (ISO) standards. Bone conduction threshold measurement was performed with appropriate masking of the opposite ear. The differences between the bone conduction thresholds of the diseased and contralateral normal sides were calculated, and these differences were compared according to the presence of cholesteatoma and the disease duration. Audiograms were obtained pre-operatively and six months after surgery in order to compare the level of post-operative hearing.

The role of ossicular continuity in bone conduction response was investigated by dividing the patients into two groups according to surgery type. The first group comprised subjects who had undergone tympanomastoidectomy with ossicular reconstruction ($n = 76$). The second group comprised subjects who had undergone tympanomastoidectomy without ossicular reconstruction for a staged operation ($n = 30$). The post-operative air and bone conduction thresholds were measured in both groups. The patients in the first group were subdivided into successful ($n = 37$) and unsuccessful ($n = 39$) groups, according to the presence or absence, respectively, of a post-operative air conduction improvement of 15 dB or more at the four-frequency (500, 1000, 2000 and 4000 Hz) average. The post-operative changes in bone conduction threshold for these subgroups were compared.

Statistical analysis

A paired *t*-test was used to compare the pre-operative bone conduction threshold for the normal and diseased ears, and to compare the pre- and post-operative bone conduction thresholds in each group. Comparisons between the groups were performed using an independent samples *t*-test. Linear regression was used to analyse the association between the disease duration and the difference in bone conduction. All statistical analyses were performed using the Statistical Package for the Social Sciences version 11.5 software (SPSS, Chicago, Illinois, USA).

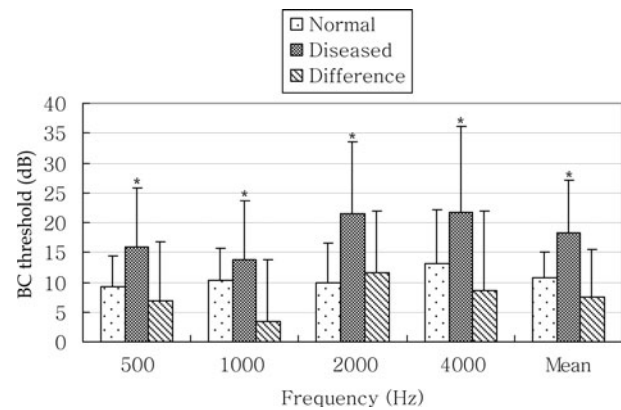


FIG. 1

Mean differences in pre-operative bone conduction thresholds according to frequency, for normal and diseased ears ($n = 106$). These differences ranged from 3.3 to 11.6 dB across the frequency range, with a maximum value at 2000 Hz. ($*p < 0.05$)

Results and analysis

Pre-operative bone conduction threshold

The differences in the bone conduction threshold ranged from 3.3 to 11.6 dB across the frequency range, and were greatest at 2000 Hz (Figure 1).

The presence of cholesteatoma and the disease duration did not affect these differences in bone conduction threshold (Table I, Figure 2).

Post-operative bone conduction change

In patients who had undergone ossicular reconstruction, the post-operative air–bone gap (ABG) improved by an average of 10.0 ± 10.4 dB. However, in those who had not undergone ossicular reconstruction, the post-operative ABG did not significantly improve (range, -1.46 ± 10.2 dB). After ossicular reconstruction ($n = 76$), the mean post-operative bone conduction threshold showed a significant improvement at all frequencies, ranging from 2.3 to 3.9 dB, with the greatest improvement being observed at 2000 Hz (Figure 3a). However, in those who had not undergone ossicular reconstruction ($n = 30$), the mean post-operative bone conduction threshold did not improve (Figure 3b).

Of those who had successfully undergone ossicular reconstruction (i.e. >15 dB improvement in air conduction threshold; $n = 37$), a significant improvement in post-operative bone conduction threshold was

TABLE I

PRE-OPERATIVE BONE CONDUCTION THRESHOLD DIFFERENCES, BY PRESENCE OF CHOLESTEATOMA

	Cholesteatoma*	No cholesteatoma [†]
BC threshold difference (mean \pm SD, dB)	7.7 ± 8.2	$7.5 \pm 7.8^{\ddagger}$

* $n = 52$; [†] $n = 54$; [‡] $p = 0.890$. BC = bone conduction; SD = standard deviation

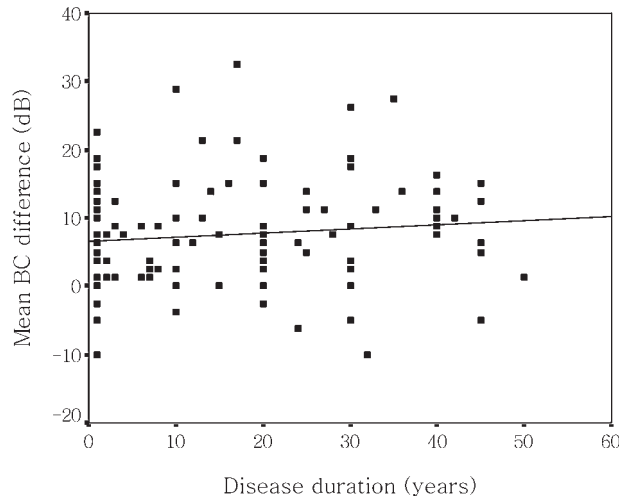


FIG. 2

Correlation between mean pre-operative bone conduction (BC) threshold difference and disease duration. No significant correlation was demonstrated ($p = 0.266$).

observed at 500, 2000 and 4000 Hz, ranging from 3.1 to 6.0 dB, with the greatest improvement being observed at 2000 Hz (Figure 4a). In the unsuccessful group ($n = 39$), the mean post-operative bone conduction changes were smaller and significant only at 1000 Hz (Figure 4b). Post-operative bone conduction change at 2000 Hz was significantly

greater in the successful group compared with the unsuccessful group (Figure 4c).

Discussion

In this study, chronic otitis media was observed to elevate the bone conduction threshold significantly

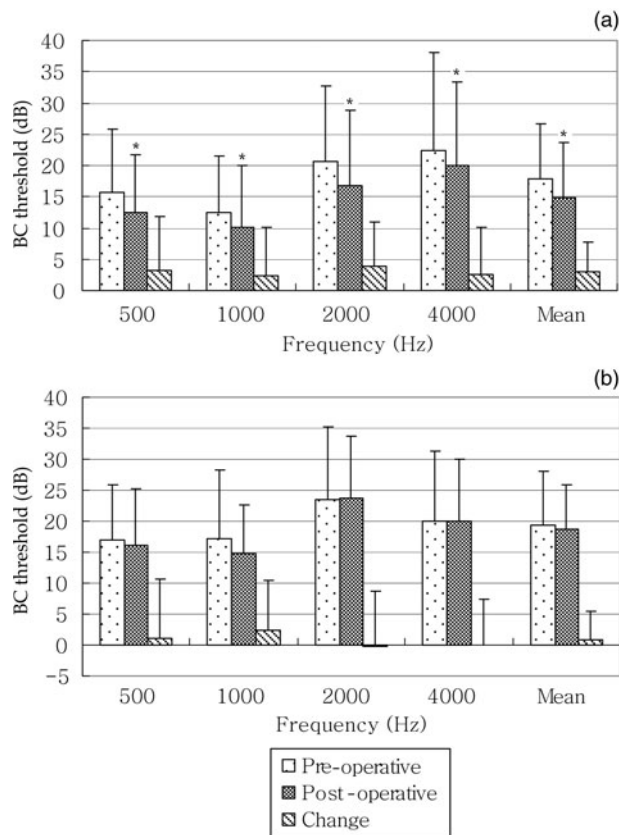


FIG. 3

Mean post-operative bone conduction thresholds according to type of surgery. (a) Tympanomastoidectomy plus ossicular reconstruction ($n = 76$); significant bone conduction threshold improvement at all frequencies (2.3–3.9 dB), greatest at 2000 Hz ($*p < 0.05$). (b) Tympanomastoidectomy without ossicular reconstruction ($n = 30$); no significant bone conduction threshold improvement.

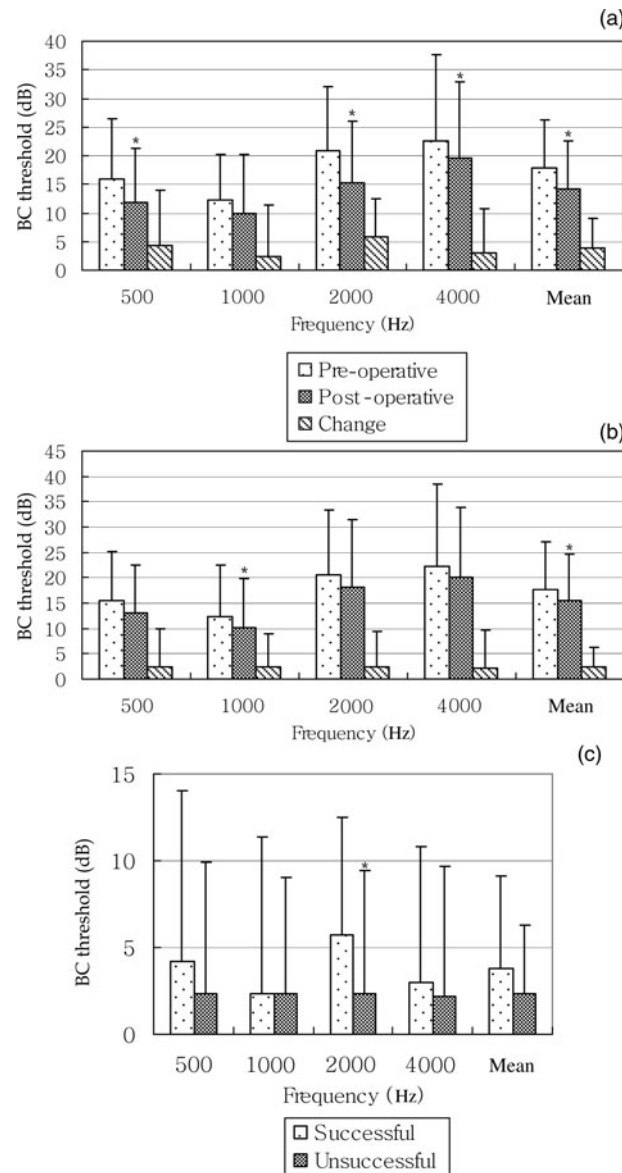


FIG. 4

Mean post-operative bone conduction thresholds in patients undergoing ossicular reconstruction, according to success of surgery (i.e. improvement in air pure tone average of >15 dB). (a) Successful group ($n = 37$); significant bone conduction threshold improvement at 500, 2000 and 4000 Hz (3.1–6.0 dB), greatest at 2000 Hz ($*p < 0.05$). (b) Unsuccessful group ($n = 39$); smaller bone conduction changes, significant only at 1000 Hz ($*p < 0.05$). (c) Mean post-operative bone conduction threshold changes, comparing successful and unsuccessful groups; bone conduction change at 2000 Hz was significantly greater in the successful group ($*p < 0.05$).

at all frequencies (i.e. 500, 1000, 2000 and 4000 Hz). However, disease duration and presence of cholesteatoma were not related to the degree of the bone conduction changes. The bone conduction threshold improved significantly after ossicular reconstruction. In particular, post-operative change of bone conduction threshold was significantly greater in those who showed a hearing gain after the ossicular reconstruction, compared with those who did not. This suggests that disturbances in the middle-ear mechanism as a result of chronic inflammation can increase the bone conduction threshold, an effect which can be reversed by surgery.

The causes of sensorineural hearing loss in chronic otitis media are controversial. In chronic otitis media,

an increase in bone conduction threshold has been reported to be caused by either cochlear involvement, as a result of extension of the inflammation into the inner ear,^{1,2} or disruption of the middle-ear hearing mechanism.³ In order to exclude the involvement of inflammatory toxins in the inner ear, the correlations between bone conduction threshold and disease duration or presence of cholesteatoma were examined. A longer duration of inflammation might produce a greater elevation of bone conduction threshold. Chronic otitis media with cholesteatoma also has a prolonged pathological process,^{1,13} and several inflammatory mediators might be produced that could lead to inner-ear disease during the active process. However, in this

study, the observed bone conduction threshold elevation was not associated with disease duration or presence of cholesteatoma, which is consistent with the results of other studies.^{9,14} These findings suggest that an extension of inflammation into the inner ear is not the main reason for sensorineural hearing loss in chronic otitis media.

The contribution of the middle-ear mechanism to the bone conduction response in patients with chronic otitis media was examined. The bone conduction response employs three different modes: the compressional, inertial and osseotympanic modes. In the compressional mode, skull vibration caused by sound directly causes vibration of the otic capsule. The ossicular chain is not involved in this mode. However, both inertial and osseotympanic motion employ the ossicular chain. The ossicular chain is loosely connected to the skull and otic capsule. Because of inertia in the ossicular chain, skull vibration due to sound causes movement in the ossicular chain. In osseotympanic motion, sound energy is transmitted from the external auditory canal to the tympanic membrane via the vibration of the skull and para-auditory structures (i.e. jaw and soft tissue).¹¹ If the ossicular chain is ankylosed or disrupted, the inertial and osseotympanic motion contributing to the bone conduction response may be hindered. This can cause an increase in the bone conduction threshold.

This effect has been demonstrated by the Carhart notch observed in cases of otosclerosis. Carhart observed a maximal bone conduction threshold elevation at 2000 Hz in patients with stapes ankylosis, a pattern termed the Carhart notch. This effect can also influence patients with chronic otitis media, via mechanical occlusion of the oval window or the round window by granulations, cholesteatoma or exudate, or by ossicular fixation. In our study, in patients with chronic otitis media, bone conduction thresholds were elevated compared with the contralateral, normal ear. The mean bone conduction threshold difference was greatest at 2000 Hz. This result is similar to those of other studies^{5,8} which showed that Carhart effects are also effective in chronic otitis media.

Mean bone conduction thresholds were significantly improved in the ossicular reconstruction group. However, in those cases where the ossicular reconstructions were not performed for a staged operation, the post-operative bone conduction thresholds were similar to the preoperative values. In the ossicular reconstruction group, the mean average post-operative bone conduction threshold change was less than 5 dB (2.3 to 3.9 dB) over the frequencies. However, 23 of 76 patients (30.3 per cent) showed a >5 dB improvement in bone conduction average (500, 1000, 2000 and 4000 Hz), and seven of 76 patients (9.2 per cent) showed a >10 dB improvement (data not shown).

Individual variations in pre-operative bone conduction threshold and post-operative bone conduction change suggest that the severity of middle-ear pathology might influence the ossicular chain mobility and the bone conduction threshold.

In addition, patients undergoing successful ossicular reconstruction (i.e. post-operative air conduction improvement >15 dB) showed better bone conduction improvement than those undergoing the same procedure unsuccessfully. In the unsuccessful group, even though ossicular chain continuity was restored, there may have been middle-ear granulation or other factors which limited the ossicular chain mobility and sound conduction mechanism. These persistent middle-ear problems prevented satisfactory hearing gain or bone conduction improvement.

These results appear similar to those reported by Linstrom *et al.*,¹⁵ who reported bone conduction threshold improvements from 4.0 to 9.3 dB across the frequencies in patients undergoing ossicular reconstruction, with the largest mean improvement being observed at 2000 Hz. Tuz *et al.* reported improved bone conduction thresholds in six of 12 cases following tympanoplasty.¹⁶

- **In patients with chronic otitis media who have no history of labyrinthitis, bone conduction threshold is elevated. However, the mechanism of bone conduction threshold elevation by chronic otitis media is not completely understood**
- **In this study, no significant relationship was found between an increase in bone conduction threshold and the disease duration or the presence of cholesteatoma. The mean pre-operative bone conduction thresholds were significantly elevated on the diseased side across frequencies with greatest at 2000 Hz. In addition, Mean post-operative bone conduction thresholds were significantly improved at all frequencies in ossicular reconstruction group, especially in successful group.**
- **This study suggests that the elevation in bone conduction threshold seen in chronic otitis media is mainly caused by a change in the conductive mechanism of the middle ear**

In contrast, Vartiainen and Seppa reported that nine out of 181 cases showed an improvement in bone conduction threshold after surgery, but this change was not clinically significant.¹⁷ Similarly, El-Sayed noted that post-operative improvement in bone conduction threshold was significant in only nine out of 93 patients.⁵

Our finding of post-operative improvement in bone conduction threshold in those who had undergone ossicular reconstruction, particularly in the successful group, may also support the hypothesis that an elevated bone conduction threshold in chronic otitis media is caused by a loss of the middle-ear mechanism of hearing.

Conclusion

This study demonstrated statistically significant elevations in bone conduction threshold in patients

with chronic otitis media. No significant relationship was found between an increase in the bone conduction threshold and the disease duration or the presence of cholesteatoma. The mean difference in the pre-operative bone conduction between the diseased and normal ears, and the improvement in the post-operative bone conduction, were greatest at 2000 Hz. These results suggest that the elevation in bone conduction threshold observed in chronic otitis media is caused mainly by a change in the conductive mechanism of the middle ear.

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Address for correspondence:
 Won-Ho Chung,
 Department of Otorhinolaryngology-Head and Neck Surgery,
 Samsung Medical Center,
 50 Ilwon-dong Kangnam-ku,
 Seoul 135-710, Korea.

Fax: 82 2 3410 3879
 E-mail: whchung@smc.samsung.co.kr

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