CEO Clinical and Experimental Otorhinolaryngology Vol. 4, No. 3: 126-130, September 2011 http://dx.doi.org/10.3342/ceo.2011.4.3.126

Original Article

Frequency-Specific Hearing Results After Surgery for Chronic Ear Diseases

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Objectives. To analyze frequency-specific hearing results after surgery for chronic ear diseases while considering pathological findings and various surgical factors.

Methods. Patients who underwent surgical management of chronic otitis media were reviewed retrospectively (n=559). Using pure tone audiometry, air conduction (AC), bone conduction (BC), and air bone gap (ABG) change between pre- and post-operative tests were calculated for the frequencies of 250, 500, 1,000, 2,000, 3,000, 4,000 (AC and BC), and 6,000 Hz (AC). Frequency-specific results were investigated, considering various surgical factors, such as type of surgery, type of ossiculoplasty and pathological findings.

Results. AC results in the intact canal wall mastoidectomy showed improvement at each frequency except 4,000, 6,000 Hz. AC results in the tympanoplasty showed improvement at each frequency except 6,000 Hz. AC and ABG results in the open cavity mastoidectomy showed improvement only at the frequencies of 250, 500, 2,000 Hz. AC and ABG improved at low and mid frequencies but not in high frequencies above 3,000 Hz when ossicular reconstruction was conducted. AC and ABG results also improved at low and mid frequencies in the cholesteatoma, and ABG results improved at all frequencies except 3,000 Hz in the non-cholesteatoma.

Conclusion. After chronic ear surgery, AC and ABG changes improved, primarily in the low and mid frequencies. Further evaluation and studies for post-operative hearing loss at high frequencies are recommended for rehabilitation of hearing ability after surgery.

Key Words. *Hearing, Frequency, Otitis media, Chronic, Surgery*

INTRODUCTION

One of the major objectives in surgery for chronic otitis media (COM) is restoration of hearing (1). However, results have varied from one study to the next (2), and surgery for chronic ear disease has shown different results and prognoses according to various factors (e.g., presence and extent of cholesteatoma, severity of mucosal disease, methods of mastoid management, and methods of ossicular reconstruction). Over the past eight years, we have dealt with over 800 cases of chronic ear surgery and have investigated frequency-specific hearing results of the surgery according to the aforementioned factors. Frequency-specific hearing studies are important because the same average pure tone threshold does not always result in the same pattern of hearing perception. This study will be helpful in predicting hearing results and the prognosis after surgical procedures, and in preparing for frequency-specific rehabilitation of hearing after surgery.

MATERIALS AND METHODS

This study was designed as a retrospective chart review of 812

• Received November 18, 2010
Accepted after revision March 27, 2011

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patients with chronic otitis media with or without cholesteatoma, who underwent surgical management between May 2001 and February 2009. This retrospective review was approved by the Institutional Review Board of the Uijeongbu St. Mary's Hospital. A total of 559 patients who had both pre- and post-operative pure tone audiometry data were selected (201 males, 358 female). The patients' ages ranged from 7 to 78 years (mean, 49.6). Indications for surgery other than correcting conductive hearing loss were retraction, drainage, perforation, and cholesteatoma. Exclusion criteria of pre-operative conditions were surgery during acute ear infection, traumatic tympanic membrane perforation within 2 months, a bilateral operation case, and revision surgery. Exclusion criteria of post-operative states were surgical failure of neotympanization, and adhesive otitis media by Eustachian tube dysfunction. Surgical interventions were performed by two otology surgeons. Surgical methods were selected by underlying pathological conditions and by hearing status. Pre-operative pure tone audiometry was done within 2 months before surgery; post-operative audiometry tests were conducted when the tympanic membrane had dried up and no pathological findings were found in the middle ear cavity through microscopic examination at least 3 months after surgery. The average time interval for hearing assessment was 5.2 months. Pure-tone audiometry was conducted in a double-walled sound room using standard procedures. All patients received this test before surgery and were reevaluated when the operated ear had dried up. Audiometric testing of the air conduction threshold (AC) was performed at 250, 500, 1,000, 2,000, 3,000, 4,000, and 6,000 Hz. Bone conduction threshold (BC) was recorded at 250, 500, 1,000, 2,000, 3,000, and 4,000 Hz. BC measurement was performed with appropriate masking of the opposite ear. AC change, BC change, and air-bone gap (ABG) change between pre- and post-operative tests were calculated at every frequency. Frequency-specific changes in these variables were analyzed statistically by comparing pre- and post-operative averages. Tests of significance were done with *t*-tests using a significance level of 0.05. Data were subdivided into the following groups (Table 1): cholesteatoma (Chole) versus non-cholesteatoma (N-Chole), tympanoplasty (Tym) versus mastoidectomy, intact canal wall (IC) versus open cavity (OC), and ossiculoplasty type (partial ossicular replacement prosthesis [PORP] vs. total ossicular replacement prosthesis [TORP] vs. none).

Table 1. Patients numbers included in each group

	Cholesteatoma			Non cholesteatoma			Sum
	PORP	TORP	Non ossi	PORP	TORP	Non ossi	
IC	21	10	28	37	9	117	222
OC	25	12	34	14	5	18	108
Tym	5	4	17	7	3	193	229
Sum	51	26	79	58	17	328	559

PORP: partial ossicular reconstruction prosthesis; TORP: tortal ossicular reconstruction prosthesis; Non ossi: non ossiculoplasty; IC: intact canal wall mastoidectomy; OC: open cavity mastoidectomy; Tym: tympanoplasty.

RESULTS

Frequency-specific hearing changes (559 patients)

In AC tests, hearing at all frequencies except 6,000 Hz significantly improved after surgery (Fig. 1). The hearing at 6,000 Hz was aggravated, by 3.4 dB. BC significantly improved at every frequency except 4,000 Hz. ABG data revealed significantly improved changes at all frequencies.

Analysis by surgical method (IC vs. OC vs. Tym)

In the IC group, AC at all frequencies except 4,000 and 6,000 Hz significantly improved. AC and ABG results in OC group showed improvement only at the frequencies of 250, 500, 2,000 Hz. In the Tym group, AC changes at all frequencies except 6,000 Hz significantly improved. Some significant aggravation was observed at 6,000 Hz in both IC and OC groups (Fig. 2A). BC changes in the IC group were significantly improved at 250, 500, 1,000, 2,000 Hz. In the OC group, BC change statistically improved only at 250 Hz. BC data in the Tym group revealed significant improvements at 2,000 and 3,000 Hz (Fig. 2B).

IC groups significantly improved in ABG changes at every frequency. ABG results in the Tym group showed improvement at every frequency except 500 Hz. However ABG changes in the OC group were statistically improved only at 250, 500, and 2,000 Hz (Fig. 2C).

Analysis by the method of ossiculoplasty (TORP vs. PORP vs. none)

In the PORP group, AC (Fig. 3A), BC (Fig. 3B), and ABG (Fig. 3C) results significantly improved at 250, 500, 1,000, 2,000 Hz. In the TORP group, AC and ABG changes significantly improved at 250, 500, and 2,000 Hz. BC changes were not significant at

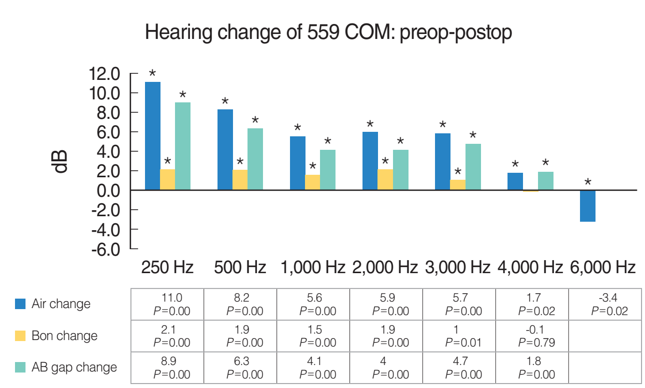

Fig. 1. The results of frequency-specific hearing change of all patients (559 patients). The label marked as '⋆' means statistically significant change; '+' value means 'improvement'; and '–' value means 'aggravation'. COM: chronic otitis media; AB: air-bone.

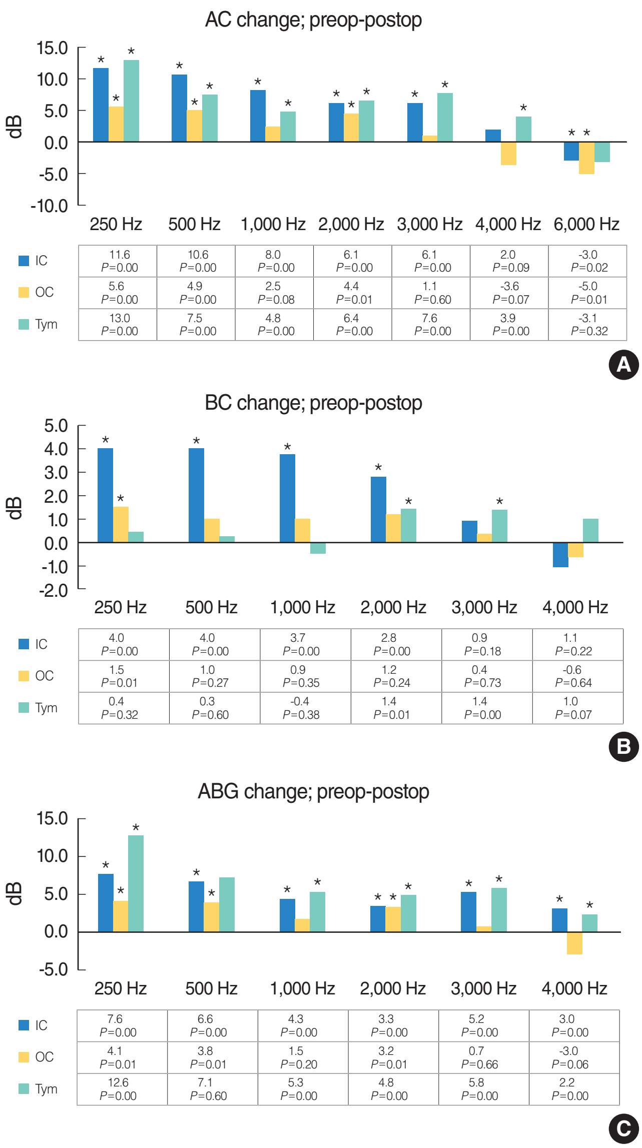

Fig. 2. Analysis by surgical methods. (IC vs. OC vs. Tym). The value marked as '*' means statistically significant change; '+' value means 'improvement'; and '–' value means 'aggravation'. AC: air conduction; BC: bone conduction; ABG: ain-bone gap; IC: intact canal; OC: open cavity; Tym: tympanoplasty.

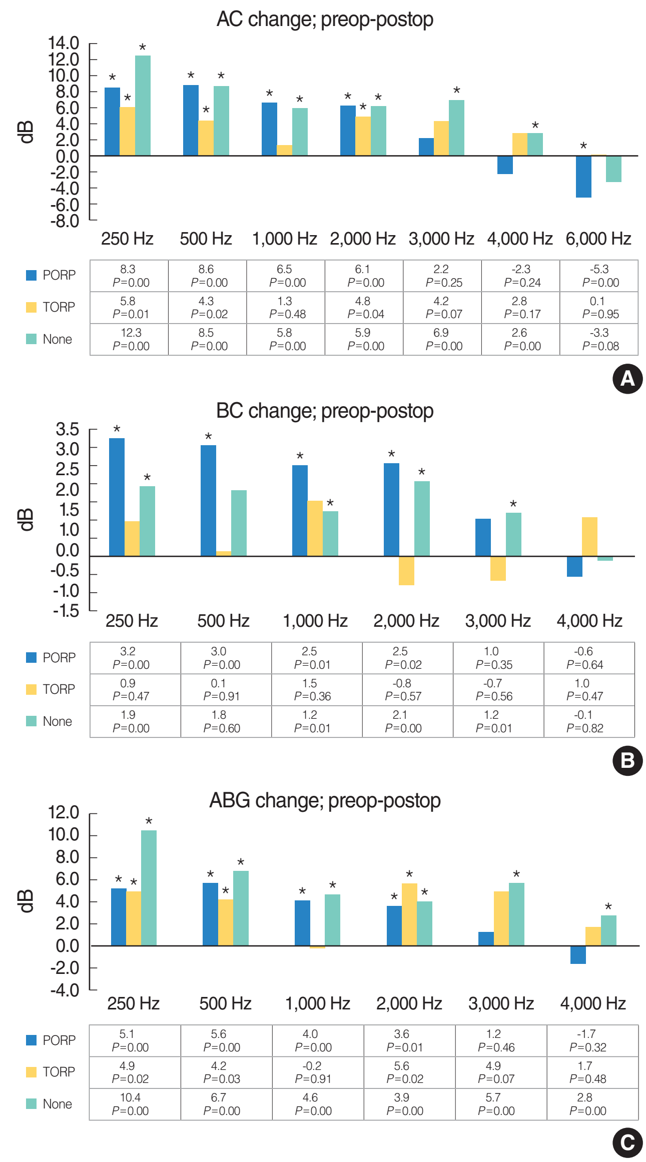

Fig. 3. The analysis by the methods of ossiculoplasty (TORP vs. PORP vs. None). The label marked as '*' means statistically significant change; '+' value means 'improvement' and '–' value means 'aggravation'. AC: air conduction; BC: bone conduction; ABG: ain-bone gap; TORP: total ossicular replacement prosthesis; PORT: partial ossicular replacement prosthesis.

any frequency. In the 'none' group, AC results significantly improved at all frequencies except 6,000 Hz. BC results significantly improved at each frequency except 500, 4,000 Hz. ABG results significantly improved at all frequencies.

Analysis by the presence of Cholesteatoma (Chole vs. N-Chole)

Both the N-Chole and Chole groups, all frequencies except 4,000, 6,000 Hz showed significant improvement in AC (Fig. 4A). BC changes in the N-Chole group significantly improved at 250, 500, 1,000, and 2,000 Hz (1.3-2.1 dB). However, BC changes in the Chole group significantly improved at every frequency (Fig. 4B). ABG changes in the N-Chole group significantly improved at every frequency except 3,000 Hz, but those in the Chole group significantly improved at all frequencies except 3,000 and 4,000 Hz (Fig. 4C).

DISCUSSION

As expected, the best results in hearing improvement were observed in the Tym group, followed by the IC group and the OC group (Fig. 2). AC and ABG changes in the Tym group signifi-

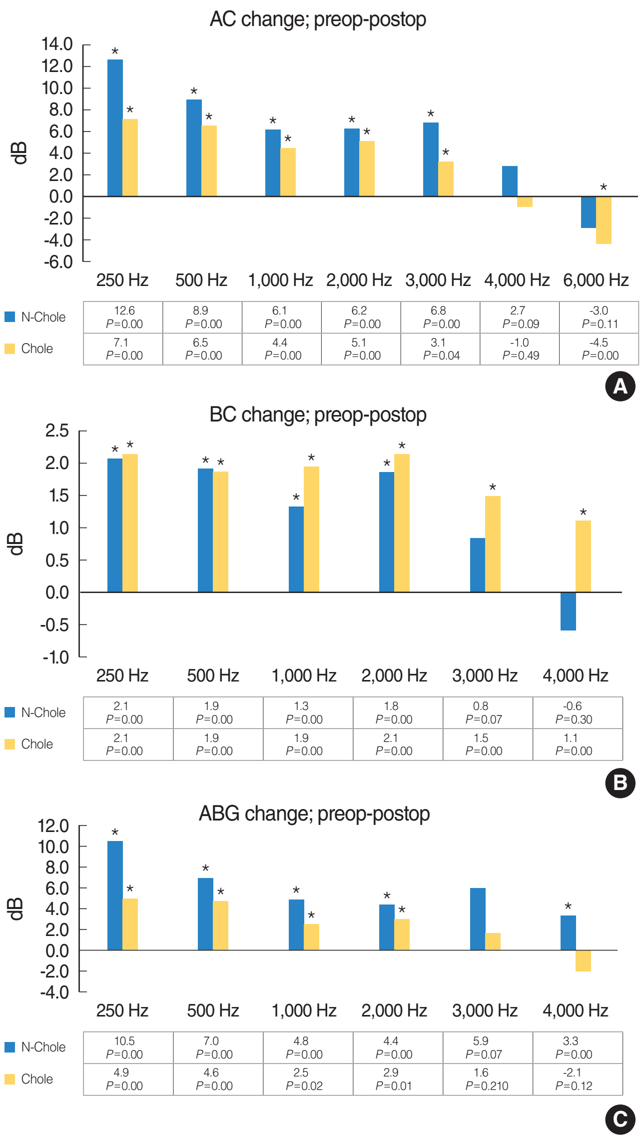

Fig. 4. Analysis by the presence of cholesteatoma (Chole vs. N-Chole). The value marked as '*' means statistically not significant change; '+' value means 'improvement' and '–' value means 'aggravation'. AC: air conduction; BC: bone conduction; ABG: ain-bone gap.

cantly improved at all frequencies except 6,000 Hz. Most cases in the Tym group had only one problem, perforation of the tympanic membrane. With this problem successfully addressed, the impaired ossicular coupling effect could be normalized. Other factors, such as severe disease extent, diseased mucosal condition, and impaired Eustachian tube function, had some influence in the IC and OC groups. The severity of conductive hearing loss after tympanomastoid surgery can be predicted by the degree to which ossicular coupling, acoustic coupling, and stapes-cochlear input impedance are altered (3). The average normal volume of the middle ear air spaces is 6 mL (tympanic cavity=0.6 mL; mastoid=5.4 mL) (4). Canal down mastoidectomy procedures typically result in middle ear air spaces being reduced to that contained behind the tympanic membrane graft, which has a small effect on middle ear sound transmission, with a predicted air-bone gap of less than 10 dB. However, further reduction in the effective middle ear air space, as seen with Eustachian tube dysfunction, can cause relatively large air-bone gaps, especially at low frequencies (4). Rosowski and Merchant (4) suggested that a middle ear air space of 0.1 mL resulted in a 19 dB ABG. An air space of 0.001 mL (the size of a small air bubble) ought to cause an ABG of at least 60 dB (4).

In this study, BC changes in the IC group showed some statistically significant improvement at low and mid frequencies. To explain this, the mechanism of bone conduction threshold elevation in cases of chronic otitis media should be 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 (5-9), or by disruption of the middle-ear conductive mechanism of hearing (10, 11). After surgery, the two situations are reversed or resolved so that BC improvement can occur (11). Browning and Gatehouse (12) suggested that elevated bone conduction thresholds in chronic otitis media were more likely to reflect the Carhart effect rather than damage to the inner ear due to disease. In our study, bone conduction thresholds improved significantly at low and mid frequencies after ossicular reconstruction. These results suggest that the elevation in the bone conduction threshold in chronic ear disease is primarily caused by a change in the conductive mechanism of the middle ear (13).

The IC and OC groups both showed significantly aggravated values of AC change at 6,000 Hz, a problem that remains unsolved. High frequency hearing loss after surgery might be explained by iatrogenic damage; typically OC procedures have more drilling time and more pathology in the middle ear near the stapes and oval window. Middle ear surgery may adversely affect cochlear function, particularly at higher frequencies (14). Hussain (15) noted that tympanic perforation from minor trauma could cause sensorineural hearing loss as well as conductive hearing loss. In contrast to this opinion, there are reports that extended high-frequency air-conduction threshold loss following myringoplasty was due to changes in middle ear transmission and was not indicative of iatrogenic cochlear damage (16). They noted that AC improved through 4,000 Hz but was elevated for frequencies of 6,000-18,000 Hz after myringoplasty. The shape, thickness, and anisotrophy of the tympanic membrane have been shown to be important factors for sound transmission in the middle ear (17, 18). Fat or temporalis fascia was histologically different from highly organized lamina propria of the pars tensa of the tympanic membrane (16). Additionally, a reconstructed tympanic membrane may have a different vibration pattern, which could be changed by the relation of the tympanic membrane with the malleus or incudo-malleolar axis (16, 17). Thus, middle ear surgery, including reconstruction of the tympanic membrane, will likely result in some hearing deterioration at frequencies of 6,000 Hz and higher.

In the PORP and TORP ossiculoplasty groups, AC and ABG changes showed statistically significant improvements, primarily at lower and mid frequencies. At frequencies higher than 3,000 Hz, they were not significantly different or actually worsened (Fig. 3). The normal middle ear pressure gain (a result of ossicular coupling) is frequency-dependent and less than generally believed (3). The mean gain is 20 dB or less between 250 and 500 Hz, with a maximum of 25 dB around 1,000 Hz, and decreases 6 dB or less per octave at higher frequencies. Normal middle ear pressure gain was decreased or absent in the pre-operative state. After reconstructive surgery, such as ossiculoplasty, decreased or absent middle ear pressure gain could be regained. Thus, meaningful AC changes were primarily at lower and mid frequencies with no significant change at higher frequencies (3).

The N-Chole group significantly improved in ABG at all frequencies except 3,000 Hz. The Chole group did not improve in AC at 4,000, 6,000 Hz, but was instead aggravated at 6,000 Hz. The ABG changes were not improved at 3,000, 4,000 Hz in the Chole group (Fig. 4). For complete removal of the lesion in the Chole group, mechanical trauma to the oval window via the stapes could occur. The most dangerous portion may be the basal turn of the cochlear, the nearest portion to the middle ear and associated with high-frequency sound. The worsened hearing at high frequencies may be explained by this mechanism.

There might be some risk of bias by directly comparing the hearing results of each group. Several factors, such as the degree of infection, severity of ossicular injury, surgical experience, and duration of drilling time may affect the results.

Another limitation of this study is lack of the 6,000 Hz BC data. Although BC at 6,000 Hz is not as essential in verbal communication as AC at 6 kHz, it is recommended to check BC at 6,000 Hz to accurately evaluate BC. More controlled studies and long-term follow-ups that evaluate high frequencies pre- and post-operatively are expected in the future.

In conclusion, AC and ABG changes revealed statistically significant improvements, primarily at low and mid frequencies after chronic ear surgery. However, most of the cases showed unfavorable post-operative hearing results at high frequencies. Hearing ability at high frequencies is related to accurate understanding of consonant phonation. Preparation for rehabilitation of hearing ability at high frequencies may be necessary after such surgery.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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