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Frequency-specific analysis of hearing outcomes after surgery for chronic ear diseases

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Abstract

Objective. To examine the relationship between different surgical factors and frequency-specific hearing results following surgery for chronic ear disorders.
Methods. We reviewed retrospectively data of 246 patients with chronic ear diseases who had surgery between January 2019 and December 2020. Seventy-three patients did not fulfil the criteria and were excluded. Air-conduction threshold, bone-conduction threshold and air–-bone gap were tested at 250–4000 Hz, respectively. Frequency-specific results were investigated in relation to various surgical factors.
Results. The radical mastoidectomy group and tympanoplasty group significantly improved in air-conduction threshold changes at every frequency. In the tympanoplasty group, air–bone gap at all frequencies except 4000 significantly improved. Air-conduction threshold improved at low and middle frequencies when ossicular reconstruction was conducted. In all groups, bone-conduction threshold data revealed significant improvements at 500, 1000, and 2000 Hz.
Conclusions. Hearing improved significantly post-operatively in air-conduction threshold and air-bone gap test, mainly at low and middle frequencies. Bone-conduction threshold improved significantly at 500–2000 Hz.

Introduction

The main purposes of chronic otitis media surgery are to re-establish the protective barrier of the middle ear and improve hearing.[1] However, as variations in surgical method, lesion severity, and other factors can alter the comparability of surgical results, the study results that have been reported do not show good agreement.[2] Pure tone audiometry is routinely used to assess pre-and post-operative hearing. Most clinical research, on the other hand, has only assessed average pure tone threshold, rather than frequency-specific hearing results. Frequency-specific hearing studies are important since the same average pure tone threshold does not always lead to the same patterns of hearing perception.[3] Therefore, we conducted a retrospective study in which we assessed frequency-specific hearing results based on potential influencing factors to give evidence for frequency-specific post-operative hearing rehabilitation.

Materials and methods

We reviewed retrospectively data of 246 consecutive patients with chronic otitis media who had surgery at our hospital between January 2019 and December 2020. We included 173 patients with pre- and post-operative pure tone audiometry data in the analysis. Patients with adhesive otitis media, revision surgery and failed surgical procedures were excluded. The surgical procedures were performed by one otology surgeon. The selection of surgical approach was determined by the range of lesion as well as the pre-operative status of hearing and facial nerve function. Canal wall down tympanoplasty refers to canal wall mastoidectomy plus tympanoplasty.

Pure tone audiometry was conducted in a double-chamber anechoic room using standard procedures. All patients had pre-operative pure tone audiometry within one week of surgery. Air-conduction threshold, bone-conduction threshold, and air–bone gap (ABG) were tested at 250, 500, 1000, 2000 and 4000 Hz. Post-operative pure tone audiometry was examined using the same techniques one year after surgery. At these frequencies, changes in air-conduction threshold, bone-conduction threshold, and ABG were calculated between pre- and post-operative examinations. Statistical analysis was performed for each frequency by comparing pre- and post-operative mean values. A positive value indicates improvement, and a negative value indicates deterioration.

According to the different surgical procedures, patients were divided into two subgroups: tympanoplasty versus canal wall down tympanoplasty. The patients also were divided into subgroups according to the type of ossicular replacement: partial ossicular replacement prosthesis (PORP) versus total ossicular replacement prosthesis (TORP) versus none (Table 1).

Table 1. Distribution of cases in different groups; TORP = total ossicular replacement prosthesis, PORP = partial ossicular replacement prosthesis

	Number of patients (%)
Surgical method – Tympanoplasty	127 (73.4)
– Canal wall down tympanoplasty	46 (26.6)
Ossicular replacement – TORP – PORP – None	17 (9.8) 107 (61.8) 49 (28.3)

Statistical analyses were performed using SPSS version 21.0 software (IBM, Armonk, NY, USA). The metering data were expressed as mean ± standard deviation (SD) and the significance analysis was conducted using a *t*-test. The categorical variables were compared using the chi-square test or Fisher's exact test; $p < 0.05$ indicates that the difference is statistically significant.

Results

Among the 173 chronic otitis media patients (173 ears), ages 10–74 years (median = 45 years), there were 66 males and 107 females, with a male:female ratio of 1:1.62, of which 91 (52.6 per cent) were left ears. Of the total cohort, hearing in all frequencies improved significantly post-operatively in air-conduction threshold (Figure 1a) and ABG (Figure 1c) test. Bone-conduction threshold (Figure 1b) significantly improved at 500, 1000 and 2000 Hz.

Hearing results and surgical method

The canal wall down tympanoplasty group and tympanoplasty group significantly improved in air-conduction threshold changes at every frequency. Air–bone gap results in the tympanoplasty group showed improvement at every frequency. In the canal wall down tympanoplasty group, ABG at all frequencies except 4000 Hz ($p = 0.069$) significantly improved. Bone-conduction threshold changes in the canal wall down tympanoplasty group and tympanoplasty group were significantly improved at 500, 1000 and 2000 Hz (Figure 2).

Ossicular replacement comparison

Air-conduction threshold and bone-conduction threshold results significantly improved in the 'None' group at 250, 500, 1000 and 2000 Hz. Air–bone gap changes were significantly improved at 250, 500 and 1000 Hz. Using the TORP replacement, air-conduction threshold and bone-conduction threshold showed significant differences at 250, 500, 1000 and 2000 Hz, and at 1000, 2000 and 4000 Hz, respectively. Air–bone gap change statistically improved only at 500 and 1000 Hz. In the PORP group, air-conduction threshold and ABG significantly improved at every frequency. Bone-conduction threshold data revealed significant improvements at 500, 1000 and 2000 Hz (Figure 3).

Discussion

This study compared pre- and post-operative frequency-specific hearing outcomes in patients with chronic otitis media. As anticipated, all frequencies of the group showed significant post-operative improvement in hearing in the air-conduction threshold and ABG tests. The gain is most prominent at low and middle frequencies. This is consistent with previous studies.[4] The normal middle-ear pressure gain (a result of ossicular coupling) is frequency-dependent.[5] Choi *et al.* noted that the mean gain decreases 6 dB or less per octave for frequencies above 1000 Hz.[3] The low- and middle-frequency improvements may represent a normalisation of the ossicular coupling effect following reconstructive surgery. In addition to air-conduction threshold elevation, some patients with chronic otitis media also have bone-conduction threshold elevation.

An elevation in bone-conduction threshold can result from tympanosclerosis, stapes fixation, round window membrane alteration, tympanic membrane perforation, and ossicular chain disruption or fixation.[6] The current study found that, with the exception of 250 and 4000 Hz, bone-conduction threshold significantly improved in the whole cohort. The ossicular chain has a large resonance effect at 500–2000 Hz. Weakness or disappearance of resonance caused by destruction of the ossicular chain can lead to bone-conduction threshold changes at 500–2000 Hz, and bone-conduction threshold can be improved when the continuity and resonance of the ossicular chain are restored through reconstructive surgery.[5–7]

At all frequencies except 2000 Hz, the hearing improvement of patients who underwent tympanoplasty was better than that of patients who underwent canal wall down tympanoplasty in this study. The difference in efficacy between tympanoplasty and canal wall down tympanoplasty typically has been ascribed to poor Eustachian tube function and greater disease severity in patients requiring canal wall down tympanoplasty.[8] Furthermore, Quaranta *et al.* claimed that an intact posterior canal wall was considered a predictor of the better hearing result in ossiculoplasty.[9]

Hearing improvement at 2000 Hz was significantly better in the canal wall down tympanoplasty group than in the tympanoplasty group in our investigation. This was consistent with results in research by Şevik Eliçora *et al.*[4] It is perhaps relevant that the intact ossicular chain has the greatest effect on hearing at 2000 Hz.[10] The bone-conduction threshold change results were superior in the canal wall down tympanoplasty group compared with the tympanoplasty group at 250–2000 Hz. The canal wall down tympanoplasty group had poorer post-operative bone-conduction threshold outcomes compared to the tympanoplasty group at 4000 Hz. Excessive ossicular chain movement, vibration or noise from drilling, or other inner-ear disruption are all associated with high-frequency sensorineural hearing loss (i.e. strong suction or thermal damage).[11–13] Canal wall down tympanoplasty generally has more drilling time in the middle ear near the stapes and oval window, and the bone-conduction threshold seems to be more susceptible to its adverse effect at 4000 Hz.

Surprisingly, the TORP group had the best hearing improvement, followed by the PORP group and the None group at all frequencies except 1000 Hz. The None group was closer to normal hearing to begin with and had less room for improvement. Most studies assumed that PORP was associated with superior post-operative hearing outcomes when compared with TORP.[3] They suggested that the stapes suprastructure plays an important role in hearing,[14] and the stability between TORP and stapes floor is inadequate and prone to displacement, resulting in the interruption of TORP and stapes footplate connection. But in their studies, post-operative audiometry tests were generally conducted about three months after surgery[3].

It is our opinion that the residual stapes in subsequent recovery may continue to be disrupted and experience adhesion with the surrounding tissue. Furthermore, ossicular coupling of TORP may be superior to that of PORP.[15] Cadaveric temporal bone studies support this viewpoint and considered

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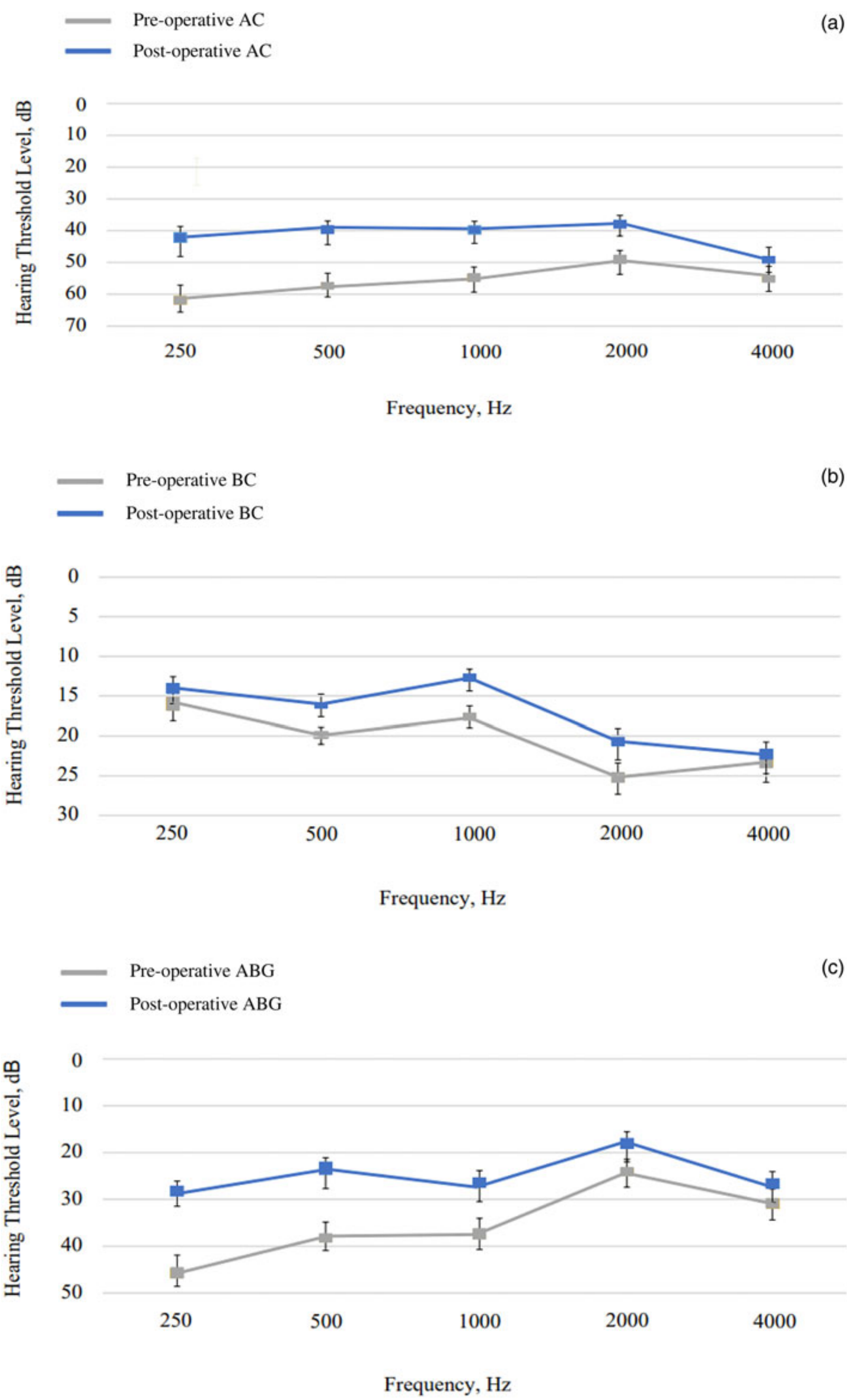

Figure 1. Pre-operative and Post-operative frequency-specific hearing results in air-conduction threshold (AC), bone-conduction threshold (BC), and air–bone gap (ABG). a, Pre-operative and post-operative levels in AC. b, Pre-operative and post-operative levels in BC. c, Pre-operative and post-operative levels in ABG.

that TORP placement to a stapes footplate offers acoustic advantages over other ossiculoplasty techniques. The reduced middle-ear pressure can be restored after ossiculoplasty. Therefore, the results suggest that air-conduction threshold changes occurred principally at lower and middle frequencies, with no substantial changes at higher frequencies. Tonndorf *et al*. thought that the influence of ossicular chain mechanics on bone-conduction threshold is expressed at most as improvement for the frequency of 2000 Hz, which is caused by the reduction or elimination of resonance within the ossicular chain.[16] Similarly, we found that three groups all showed significant improvement at 1000–2000 Hz.

This study is limited by its retrospective nature and small sample size. Other confounding factors, such as infection degree, operator experience and surgery duration, could influence study results. In addition, hearing data at 6000 Hz were lacking in this study. Although 6000 Hz has little effect on the verbal communication, the relevant changes still need to be studied further.

- Most studies only assessed average pure tone threshold after middle-ear surgery, rather than frequency-specific hearing results
- This audit showed that the hearing improved significantly post-operatively in air-conduction threshold and air–bone gap tests, mainly at low and middle frequencies
- Post-operative frequency-specific hearing results were affected by variances in surgical method and ossicular replacement
- This study provides a basis for post-operative frequency-specific hearing rehabilitation

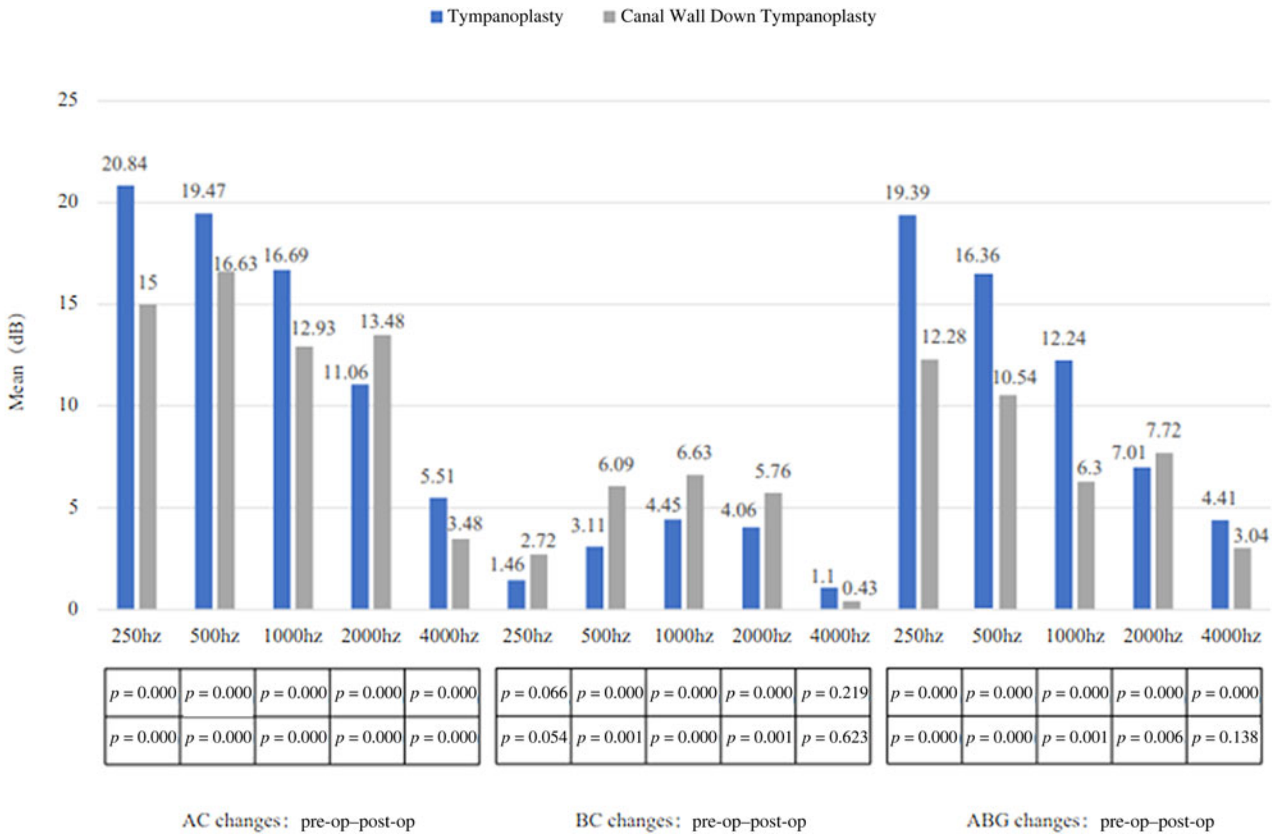

Figure 2. Analysis by surgical methods (tympanoplasty versus canal wall- down tympanoplasty); AC = air-conduction threshold; BC = bone-conduction threshold; ABG = air–bone gap; *p* values represent significance of hearing change from pre-operative to post-operative follow up.

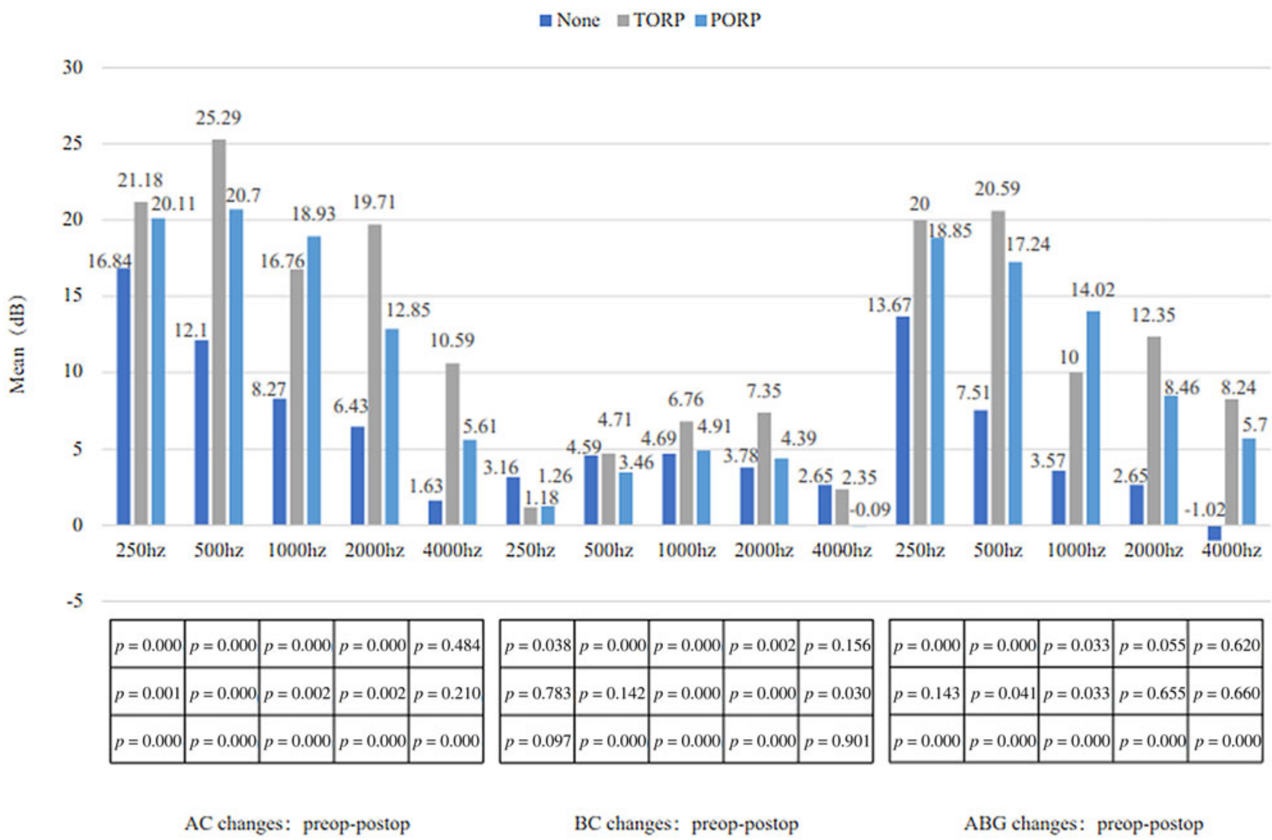

Figure 3. Analysis of the types of ossicular replacement (None versus TORP versus PORP); TORP = total ossicular replacement prosthesis; PORP = partial ossicular replacement prosthesis; *p* values represent significance of hearing change from pre-operative to post-operative follow-up.

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Conclusion

We systematically evaluated the effect of hearing reconstruction at different frequencies after surgery. Hearing improved significantly post-operatively in air-conduction threshold and the ABG test, mainly at low and middle frequencies. Bone-conduction threshold improved significantly at 500–2000 Hz. Post-operative preparation for high-frequency hearing rehabilitation may be needed.

Conflicts of interest. The authors declare that they have no conflicts of interest.

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Authorship. Concept, LXC; design, HHS; supervision, JQQ; resources, LXC; materials, HHS; data collection and processing, JQQ; analysis and interpretation, LXC; literature search, HHS; Writing, JZL; critical review, JZL.

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References

1 Jackson CG, Glasscock ME 3rd, Schwaber MK, Nissen AJ, Christiansen SG, Smith PG. Ossicular chain reconstruction: the TORP and PORP in chronic ear disease. *Laryngoscope* 1983;**93**:981–8
2 Kim HJ. A standardized database management of middle ear surgery in Korea. *Acta Otolaryngol Suppl* 2007;**558**:54–60
3 Choi HG, Lee DH, Chang KH, Yeo SW, Yoon SH, Jun BC. Frequency-specific hearing results after surgery for chronic ear diseases. *Clin Exp Otorhinolaryngol* 2011;**4**:126–30
4 Şevik Eliçora S, Erdem D, Dinç AE, Damar M, Bişkin S. The effects of surgery type and different ossiculoplasty materials on the hearing results in cholesteatoma surgery. *Eur Arch Otorhinolaryngol* 2017;**274**:773–80
5 Merchant SN, Ravicz ME, Puria S, Voss SE, Whittemore KR Jr, Peake WT, Rosowski JJ. Analysis of middle ear mechanics and application to diseased and reconstructed ears. *Am J Otol* 1997;**18**:139–54
6 Yoshida H, Miyamoto I, Takahashi H. Is sensorineural hearing loss with chronic otitis media due to infection or aging in older patients? *Auris Nasus Larynx* 2010;**37**:402–6
7 Tüz M, Doğru H, Uygur K, Gedikli O. Improvement in bone conduction threshold after tympanoplasty. *Otolaryngol Head Neck Surg* 2000;**123**:775–8
8 Lee HS, Hong SD, Hong SH, Cho YS, Chung WH. Ossicular chain reconstruction improves bone conduction threshold in chronic otitis media. *J Laryngol Otol* 2008;**122**:351–6
9 Goldenberg RA, Emmet JR. Current use of implants in middle ear surgery. *Otol Neurotol* 2001;**22**:145–52
10 Quaranta N, Taliente S, Coppola F, Salonna I. Cartilage ossiculoplasty in cholesteatoma surgery: hearing results and prognostic factors. *Acta Otorhinolaryngol Ital* 2015;**35**:338–42
11 Dinç AE, Damar M, Erdem D, Eliçora SŞ, Akyıldız I, Kumbul YÇ. Audiometric correlations with pathologies of ossicular chain in 159 ears with chronic otitis media. *Clin Otolaryngol* 2016;**41**:817–21
12 Kaya I, Turhal G, Ozturk A, Gode S, Bilgen C, Kirazli T. The effect of endoscopic tympanoplasty on cochlear function. *Clin Exp Otorhinolaryngol* 2018;**11**:35–9
13 Gerber MJ, Mason JC, Lambert PR. Hearing results after primary cartilage tympanoplasty. *Laryngoscope* 2000;**110**:1994–9
14 Badr-El-Dine M, James AL, Panetti G, Marchioni D, Presutti L, Nogueira JF. Instrumentation and technologies in endoscopic ear surgery. *Otolaryngol Clin North Am* 2013;**46**:211–25
15 House JW, Teufert KB. Extrusion rates and hearing results in ossicular reconstruction. *Otolaryngol Head Neck Surg* 2001;**125**:135–41
16 Baker AB, O'Connell BP, Nguyen SA, Lambert PR. Ossiculoplasty with titanium prostheses in patients with intact stapes: comparison of TORP versus PORP. *Otol Neurotol* 2015;**36**:1676–82
17 Wiatr M, Składzień J, Wiatr A, Tomik J, Stręk P, Medoń D. Postoperative bone conduction threshold changes in patients operated on for chronic otitis media—analysis. *Otolaryngol Pol* 2015;**69**:1–6