The Journal of International Advanced Otology

J Int Adv Otol 2016; 12(2): 132–6 • DOI: 10.5152/iao.2016.2332

Original Article

Assessment of Mastoid Function with Magnetic Resonance Imaging after Canal Wall Up Cholesteatoma Surgery

William J. Parkes, Sharon L. Cushing, Blake C. Papsin, Susan I. Blaser, Adrian L. James

Department of Otolaryngology-Head and Neck Surgery, The Hospital for Sick Children, University of Toronto, Toronto, ON, Canada (HJP, SLC, BCP, ALJ)
Division of Pediatric Neuroradiology, Department of Diagnostic Imaging, The Hospital for Sick Children, University of Toronto, Toronto, ON, Canada (SIB)

OBJECTIVE: To use magnetic resonance imaging (MRI) to assess the extent of mastoid opacification after canal wall up (CWU) cholesteatoma surgery.

MATERIALS and METHODS: Thirty-five children in whom post-operative MRI had been obtained after CWU surgery. Cholesteatoma confined to the meso- and/or epi-tympanum was removed using a transcanal approach (n=18). More extensive disease required a combined approach tympanomastoidectomy (CAT, n=17). Mastoid opacification was assessed in both ears by a neuroradiologist blind to surgical details using an ordinal scale from 0 (no opacification) to 6 (completely opacified). The primary outcome measure was presence of normal mastoid ventilation, defined by evaluation of non-operative ears as a score ≤2. The presence of normal ventilation, as well as the raw opacification scores, were compared according to type of cholesteatoma surgery: 1) transcanal, with no mastoidectomy and 2) CAT.

RESULTS: Mastoid ventilation was normal in 18 post-operative ears (51%). There was no significant difference in the proportion of normally ventilated mastoids in the CAT (n=17) and transcanal (n=18) groups (p=0.318; Fisher's exact). However, mastoid opacification scores were significantly higher in the CAT group than in the transcanal group (p=0.036; Mann–Whitney U).

CONCLUSION: The mastoid frequently fails to become normally ventilated after cholesteatoma surgery. Subgroup analysis suggests cortical mastoidectomy does not increase the likelihood of normal mastoid ventilation after CWU cholesteatoma surgery. MRI provides a non-invasive tool to assess mastoid function, which contributes to the current debate on optimum surgical strategies for management of the mastoid in cholesteatoma surgery. Further research will determine whether this measure of mastoid health correlates with risk of recurrent cholesteatoma.

KEYWORDS: Mastoid, cholesteatoma, magnetic resonance imaging

INTRODUCTION

The role of the mastoid air cell system in middle ear pressure regulation remains incompletely understood. Given the well-described association of small, poorly pneumatized mastoid systems with the development of tympanic membrane retraction and cholesteatoma, elucidation of this function may be relevant to decisions on how to manage the mastoid surgically in chronic ear disease [1]. Historically, some have proposed that the mastoid functions as an air reservoir capable of buffering middle ear pressure changes [2, 3]. It is also considered that gas exchange across a healthy mastoid mucosa is a part of normal middle ear pressure homeostasis [4]. For these reasons, it can be inferred that a large, well-pneumatized mastoid should help to prevent tympanic membrane retraction and cholesteatoma. In line with these concepts, techniques aimed at improving ventilation pathways between the middle ear and mastoid are advocated in surgery for cholesteatoma [5]. A cortical mastoidectomy can also be drilled with the intention of creating a larger and, hypothetically, more effective buffer against pressure change [6]. Nevertheless, recurrence of cholesteatoma after canal wall up (CWU) surgery can be anticipated in more than 25% of cases with long-term follow-up [7].

Paradoxically, complete obliteration of the mastoid has also long been recommended in the management of cholesteatoma [8, 9]. Recent reports indicate that obliteration of mastoid air spaces is associated with low rates of recurrent cholesteatoma [10], indeed lower than may be expected from CWU surgery without obliteration. For example, recurrent cholesteatoma rates of around 2% at five-year follow-up have been reported with mastoid obliteration after canal wall down (CWD) surgery in both pediatric and adult patients [11-13] and also when obliterating the mastoid as part of CWU surgery [14,15]. Mathematical modeling has led to the hypothesis that obliteration is so effective because removal of gas exchange surfaces in ears with small tympanomastoid volume stabilizes middle ear pressure [16]. Although some comparative case series show no significant difference in outcome with or without

Presented in: This study was presented at the Society for Ear, Nose and Throat Advances in Children Annual Meeting, 3-7 December 2015, Texas, USA.

Corresponding Address: William J. Parkes E-mail: wjparkes@gmail.com

Submitted: 10.03.2016 **Accepted:** 18.07.2016

obliteration [17, 18], it is notable that no contemporary reports indicate that mastoid obliteration has worse outcomes than other intact canal wall surgery (i.e., mastoid sparing trans-canal surgery or combined approach tympanomastoidectomy (CAT)).

One potential explanation for the failure of either CAT or mastoid-sparing surgery to yield demonstrably less cholesteatoma recurrence than mastoid obliteration is that the approaches do not enhance physiological function as expected: either because the physiological hypotheses such as the air volume reservoir are insufficiently accurate [16] or because surgery does not lead to a ventilated mastoid space as intended. To some extent, the post-operative ventilatory capacity of the mastoid can be assessed by exploration when a second stage is indicated after CWU surgery. In ears that do not need a cortical mastoidectomy or do not develop recurrent disease, however, the true ventilatory capacity of the mastoid is difficult to gauge. To provide a more comprehensive assessment of mastoid status after CWU surgery, we reviewed magnetic resonance imaging (MRI) of the temporal bone in a series of children that had CWU surgery for cholesteatoma.

MATERIALS and METHODS

Patient selection

The Institutional Research Ethics Board approved this study (REB # 1000012951). A prospective database of all patients treated surgically for cholesteatoma by a single surgeon since 2005 was searched to identify all patients in whom post-operative MRI had been obtained to screen for occult cases of residual disease after CWU cholesteatoma surgery. Typically, these scans were performed at least 3 years after the last operation or just prior to referral out of the institution at age 18 years.

Surgical technique

CWU surgeries in these patients were all started with a transcanal approach to the middle ear, either via a post-auricular incision or permeatally via endoscopy. Mastoidectomy was performed when transcanal access to the cholesteatoma remained inadequate after removal of the scutum, as would be the case with significant extension of disease into the mastoid antrum. Drilling was typically restricted to the limits of the cholesteatoma, so that mucosalized air cells in the mastoid were preserved when not involved with cholesteatoma. Additionally, mastoidectomy was carried out when needed for access to medial epitympanic cholesteatoma with intact ossicles in an effort to preserve the integrity of the ossicular chain [19].

Analysis

A neuroradiologist, blinded to the surgical histories, subsequently reviewed MRI of both ears of all patients and assessed the degree of mastoid and antrum opacification for each temporal bone according to a predetermined, ordinal scale depicted in Table 1. All images were T2-weighted and reviewed in the axial plane. Images were compared with pre-operative CT to provide a baseline understanding of the bony morphology of each temporal bone. For pragmatic purposes, the level of the lateral semicircular canal was used to delineate antrum from mastoid. A representative image obtained 6 years after tympanomastoidectomy is displayed in Figure 1 and shows the stark contrast between a severely opacified post-operative mastoid and a completely clear contralateral mastoid. Two scans revealing acute rhinosinusitis or middle ear effusion were excluded in order to control for the confounding effect of transient opacification of the mastoid related to upper respiratory illness.

Table 1. Opacification Grading Scale for MRI review

0	100% aerated
1	<5% opacified
2	6-25% opacified
3	26-50% opacified
4	51-75% opacified
5	76-99% opacified
6	100% opacified

MRI: magnetic resonance imaging

Figure 1. T2-weighted magnetic resonance image in the axial plane at the level of the mastoid antrum. Note that on the left (the non-operative ear), the mastoid, antrum, and middle ear are black, indicating complete aeration. On the right (the post-operative ear), extensive fluid signal fills the mastoid air cells and antrum and surrounds the ossicles (which appear gray) within the middle ear.

At the completion of the radiographic review, opacification scores (OS) from the non-operative ears were analyzed in order to define the range of OS consistent with normal mastoid ventilation in such patients. As the otoscopic status of the contralateral ear had been reliably recorded in the database, contralateral ears with known pathology, such as chronic otitis media and persistent retraction, could be identified and were excluded from this portion of the analysis. Patients with a history of bilateral surgery for cholesteatoma were also excluded from the contralateral assessment. After exclusions (5 patients with contralateral chronic otitis media and 2 with bilateral cholesteatoma), 26 contralateral ears were deemed representative of normal. In order to confirm that the group of contralateral ears did indeed represent a different population than the surgical ears, a paired analysis was performed. A Wilcoxon signed rank test demonstrated that the observed difference in OS between paired surgical and contralateral ears was statistically significant ($p<0.01$), so the null hypothesis that the paired samples were from the same population was rejected.

The median mastoid OS in the contralateral group was 1 with a range of 0–2. Thus, a score of ≤2 was defined as the range for normal mastoid ventilation in this sample. The mastoid OS from the post-operative ears were dichotomized as "normal" or "abnormal" based on the range of normal defined by the contralateral assessment. The primary outcome measure for this study was to determine the proportion of normally ventilated mastoids after CWU surgery based on this definition.

Secondarily, a subgroup comparison of mastoid ventilation was made between the two surgical groups: A) those who had undergone mastoid-sparing trans-canal surgery and B) those who underwent combined approach tympanomastoidectomy (CAT). The proportion of normally versus abnormally ventilated mastoids was compared with Fisher's exact test. Raw antrum and mastoid OS were also compared between the two surgical groups using the Mann–Whitney U test. SPSS software (IBM Corporation; New York, USA) was employed for all statistical analysis.

RESULTS

Magnetic resonance imaging studies were obtained after CWU surgery on 35 children (22 male and 13 female). Two scans were excluded secondary to the presence of acute rhinosinusitis. Two patients had a history of bilateral cholesteatoma; therefore, the total number of post-operative mastoids assessed was 35. The average age at the time of the most recent cholesteatoma surgery was 11.4±2.5 years, and the average interval between the last surgery and surveillance MRI was 4.3±1.4 years. Assessment of non-echo planar diffusion-weighted MR images revealed no cases of residual cholesteatoma. None of these ears has developed recurrent cholesteatoma in subsequent follow up (median 1.1 years, range 0–6.2 years).

Regarding the primary outcome for this study, the proportion of ears with normal mastoid ventilation after CWU surgery was 51% (18/35). The median mastoid OS was 2 after cholesteatoma surgery.

Demographic data are categorized by surgical approach in Table 2. A transcanal approach was employed in 18 ears, and 17 ears were treated with CAT. The median Mills stage [20] at the time of initial surgery was 2, representing the number of subsites within the tympanomastoid system that contained cholesteatoma. Eleven ears required second-look procedures, 3 ears required a third-look, and 1 ear underwent a total of 4 surgeries for cholesteatoma; all of these were completed prior to MRI. The decision to perform CAT was generally driven by the extent of disease as evidenced by the higher Mills stages recorded for the CAT group. The more extensive disease in the CAT group also accounts for the higher requirement for subsequent surgery. Of note, there is no difference in the time interval from last surgery to MRI between the two groups.

When looking at the raw OS for antrum and mastoid area separately (Figure 2, 3), it is found that the mastoid area was more likely to be opacified than the antrum after mastoid-sparing transcanal surgery (p=0.002; Mann–Whitney U test), whereas both areas were equally likely to be opacified after CAT (p=0.420; Mann–Whitney U test). Furthermore, the mastoid area was more likely to be opacified after CAT than mastoid-sparing surgery (p=0.036; Mann–Whitney U test). Although these findings are consistent with somewhat better ventilation after mastoid-sparing surgery, overall there is no significant difference in the proportion of ears with normal or abnormal ventilation after CAT or mastoid-sparing surgery (p=0.318; Fisher's exact test) (Table 3).

Table 2. Patient demographics

	Transcanal	CAT
Gender		
Male	8	13
Female	7	5
Median (mode) initial Mills Stage	1 (1)	3 (4)
Second-looks	0	11
Third-looks	0	3
Fourth-looks	0	1
Mean age±SD at last surgery (years)	11.3±2.6	11.8±2.3
Mean interval±SD from last surgery to MRI (years)	4.4±1.6	4.4±1.3

CAT: combined approach tympanomastoidectomy; MRI: magnetic resonance imaging; SD: standard deviation

Table 3. Mastoid ventilation after two CWU approaches

	Transcanal	CAT
Normal (n)	11	7
Abnormal (n)	7	10
	p=0.318 (Fisher's exact test)	

CAT: combined approach tympanomastoidectomy; CWU: canal wall up

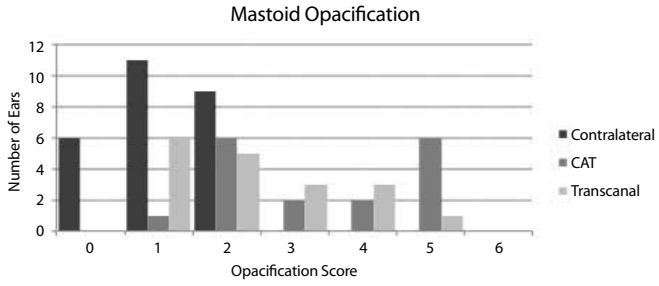

Figure 2. Bin analysis of mastoid opacification scores

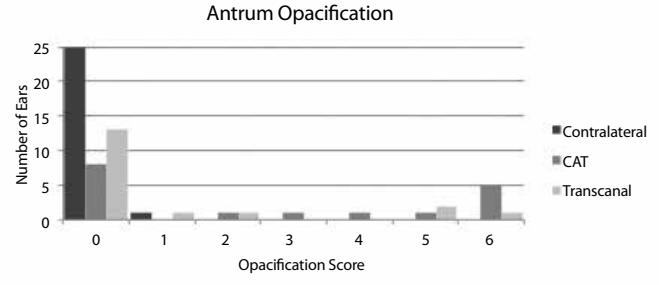

Figure 3. Bin analysis of antrum opacification scores

DISCUSSION

Magnetic resonance imaging can be used to provide insight into post-operative mastoid function. We have found that 50% of mastoids are opacified after CWU cholesteatoma surgery. This demon-

strates that normal ventilatory function cannot be guaranteed after CWU cholesteatoma surgery whether a cortical mastoidectomy is drilled or not. Further research will determine whether this measure of mastoid health can be used to predict risk of recurrent cholesteatoma.

Magnetic resonance imaging is clearly advantageous over other techniques for assessment of mastoid function, such as CT scan, nitrous oxide-induced middle ear pressure change, or exploratory surgery (i.e., second-look surgery) [21] as being totally non-invasive. Although reliable distinction cannot be made between fluid and soft-tissue scarring, at the very least, sufficient information is available from MR images to dichotomize mastoids into those that contain water-rich opacity from those that do not. Another shortcoming of MRI is the inability to distinguish air from bone. However, surgical experience of staged and revision tympanomastoid surgery shows that while some limited cortical regrowth can be expected, osteogenesis resulting in obliteration of the mastoid and antrum does not occur spontaneously. It is therefore realistic to assume that an "empty" antrum on post-operative MRI is pneumatized, especially when pre-operative CT is used for evaluation of antrum morphology as in this study.

The present findings are consistent with our prospectively accrued, as yet unpublished, data collected at the second stage of CAT, which reveal that the mastoid is opacified with mucosal scar tissue in approximately 50% of cases. Similarly, Takahashi et al. [21] has shown with CT evaluation that the potential "air reservoir" created with the first stage of CAT tends to become filled half of the times—sometimes with scar tissue and other times with fluid-filled cysts.

Takahashi et al. [21] also assessed tympanomastoid gas exchange using intra-operative pressure recordings before and after inhalation of nitrous oxide. Nitrous oxide administration failed to elicit a pressure increase within the mastoid in 5 ears, all of which were opacified on CT. This correlation between mastoid opacification and impaired mucosal gas exchange led the authors to conclude that mucosal preservation at the time of mastoidectomy may play an important role in the restoration of mastoid aeration post-operatively. In contrast, our subgroup analysis suggests that preservation of mastoid gas exchange surfaces by a mastoid-sparing transcanal approach does not increase the likelihood of a healthy, well-aerated post-operative mastoid when compared with drilling a cortical mastoidectomy for CAT. Because of our small sample sizes, however, type II error is certainly possible.

In the present series, cortical mastoidectomy was only drilled in ears with more extensive disease. Clearly, disease severity was an uncontrolled variable that might also be expected to contribute to the incidence of post-operative scarring. Consequently, we cannot claim from these observations that cortical mastoidectomy has no beneficial effect on mastoid function. Nevertheless, based on the current findings and those previously reported by Takahashi et al. [21], one should not assume that a surgically enlarged mastoid will always function as an air reservoir. Further research would be required to determine whether or not alterations in technique might increase the likelihood of establishing a healthy mastoid cavity capable of functioning as an air reservoir.

Limited by a retrospective design and small sample size, further subgroup analysis could not be performed in the present study. As such, the relationship between the extent of mucosal preservation in mastoidectomy cases and post-operative aeration proposed by Takahashi et al. [21] was not evaluated. The surgical philosophy followed in this series was to drill the smallest cortical mastoidectomy necessary to safely remove the cholesteatoma, thereby sparing mucosalized air cells whenever possible. While it remains possible that a concerted effort to preserve more mucosa at the time of mastoidectomy could improve post-operative aeration, the dilemma lies in determining just how much mucosa to leave behind. If too much mucosa remains, the surface area/volume ratio within the mastoid can exceed that of the tympanum. When this occurs, modeling predicts that the mastoid can be expected to act as a gas sink, even if adequately aerated [22].

Rather than contend with the predicament of surgically optimizing the surface area/volume ratio within the mastoid and trying to achieve a ventilated space, one might instead opt to dismiss the reservoir theory altogether. Mastoid obliteration has been employed for over a century and represents an alternative approach to the management of chronic ear disease [23]. One purported advantage of obliteration is the removal of the mastoid mucosa from the pressure equation, albeit at the expense of any benefit afforded by mastoid air volume [24]. This alternate theory has recently been supported by a mathematical model demonstrating that gas exchange after obliteration can actually mimic that of a large-volume middle ear cleft [16]. In this context, and in contrast to traditional expectations of healthy mastoid function, it is intriguing to speculate whether a mastoid system that becomes completely opacified by scar tissue after CWU surgery would behave more similarly to an intentionally obliterated mastoid and have a lower rate of cholesteatoma recurrence. Further investigation of this concept is required as other mechanisms could also lead to recurrent disease. Scar contraction after mastoid obliteration with fat has been reported [25], so it could also be speculated that contraction of obliterative scar tissue in the mastoid might contribute to recurrent cholesteatoma by pulling on the reconstructed tympanic membrane or scutum.

This study highlights post-operative MRI as an ideal tool for future investigation of the contribution of these different mechanisms to recurrent cholesteatoma. Longer follow-up than is available with this dataset is required to determine if the risk of recurrent cholesteatoma can be predicted from MRI assessment of mastoid aeration. If a relationship were established, though, MRI could conceivably be used to help guide the frequency and duration of post-operative monitoring for cholesteatoma recurrence. Specifically, in the pediatric population where the risks of ionizing radiation are magnified, future investigation into any correlation between MRI appearance of the mastoid and risk of recurrent cholesteatoma is certainly warranted.

Conclusion

The mastoid frequently fails to become normally ventilated after CWU cholesteatoma surgery. Mastoid-sparing transcanal surgery does not significantly increase the likelihood of normal mastoid ventilation compared with CAT surgery. MRI provides a non-invasive tool to assess mastoid function, which contributes to the current debate on optimum surgical strategies for management of the mastoid in cholesteatoma surgery. Long-term follow-up will ultimately help to

determine whether recurrent cholesteatoma really is more commonly associated with a ventilated or opacified mastoid.

Ethics Committee Approval: Ethics committee approval was received for this study from the ethics committee of The Institutional Research Ethics Board approved this study (REB #1000012951).

Informed Consent: N/A.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept - A.J., W.P.; Design - A.J., S.B., W.P.; Supervision - A.J., S.B., B.P., S.C.; Resources - A.J., S.B., W.P.; Materials - A.J., S.B., W.P.; Data Collection and/or Processing - A.J., S.B., W.P.; Analysis and/or Interpretation - A.J., S.B., B.P., S.C., W.P.; Literature Search - A.J., W.P.; Writing Manuscript - A.J., S.B., B.P., S.C., W.P.; Critical Review - A.J., S.B., B.P., S.C., W.P.

Conflict of Interest: No conflict of interest was declared by the authors.

Financial Disclosure: The authors declared that this study has received no financial support.

REFERENCES

1. Peer S, Papsin BC, James AL. Cholesteatoma and tympanic membrane retraction in children. Paparella's Textbook of Otolaryngology 2015: In press.
2. Sade J. The correlation of middle ear aeration with mastoid pneumatization. The mastoid as a pressure buffer. Eur Arch Otorhinolaryngol 1992; 249: 301-4. [CrossRef]
3. Alper CM, Kitsko DJ, Swarts JD, Martin B, Yuksel S, Cullen Doyle BM, et al. Role of the mastoid in middle ear pressure regulation. Laryngoscope 2011; 121: 404-8. [CrossRef]
4. Gaihede M, Dirckx JJ, Jacobsen H, Aernouts J, Søvsø M, Tveteraås K. Middle ear pressure regulation--complementary active actions of the mastoid and the Eustachian tube. Otol Neurotol 2010; 31: 603-11. [CrossRef]
5. Marchioni D, Alicandri-Ciufelli M, Molteni G, Artioli FL, Genovese E, Presutti L. Selective epitympanic dysventilation syndrome. Laryngoscope 2010; 120: 1028-33. [CrossRef]
6. Holmquist J, Bergstrom B. The mastoid air cell system in ear surgery. Arch Otolaryngol 1978; 104: 127-9. [CrossRef]
7. Stangerup SE, Drozdziewicz D, Tos M. Cholesteatoma in children, predictors and calculation of recurrence rates. Int J Pediatr Otorhinolaryngol 1999; 49(Suppl 1): S69-73. [CrossRef]
8. Elbrond O. Obliteration of Mastoid Cavities in Temporal Bone Surgery. Eighty Cases Operated on According to the Method of Guilford. Arch Otolaryngol 1963; 78: 132-7. [CrossRef]
9. Guilford FR. Obliteration of the cavity and reconstruction of the auditory canal in temporal bone surgery. Trans Am Acad Ophthalmol Otolaryngol 1961; 65: 114-22.
10. Yamamoto Y, Takahashi K, Morita Y, Ohshima S, Takahashi S. Long-term follow-up results of canal wall down tympanoplasty with mastoid obliteration using the bone pate plate for canal wall reconstruction in cholesteatoma surgery. Otol Neurotol 2014; 35: 961-5. [CrossRef]
11. Trinidade A, Skingsley A, Yung MW. Pediatric Cholesteatoma Surgery Using a Single-Staged Canal Wall Down Approach: Results of a 5-Year Longitudinal Study. Otol Neurotol 2015; 36: 82-5.
12. Trinidade A, Skingsley A, Yung MW. Mastoid obliteration surgery for cholesteatoma in 183 adult ears - a 5-year prospective cohort study. Clin Otolaryngol 2015; 40: 721-6. [CrossRef]
13. Walker PC, Mowry SE, Hansen MR, Gantz BJ. Long-term results of canal wall reconstruction tympanomastoidectomy. Otol Neurotol 2014; 35: e24-30. [CrossRef]
14. Vercruysse JP, De Foer B, Somers T, Casselman JW, Officiers E. Mastoid and epitympanic bony obliteration in pediatric cholesteatoma. Otol Neurotol 2008; 29: 953-60. [CrossRef]
15. van Dinther JJ, Vercruysse JP, Camp S, De Foer B, Casselman JW, Somers T, et al. The Bony Obliteration Tympanoplasty in Pediatric Cholesteatoma: Long-term Safety and Hygienic Results. Otol Neurotol 2015; 36: 1504-9. [CrossRef]
16. Csakanyi Z, Katona G, Konya D, Mohos F, Sziklai I. Middle ear gas pressure regulation: the relevance of mastoid obliteration. Otol Neurotol 2014; 35: 944-53. [CrossRef]
17. Vartiainen E, Härmä R. Mastoid obliteration in intact canal wall mastoidectomy. Clin Otolaryngol Allied Sci 1987; 12: 327-9. [CrossRef]
18. Kuo CL, Lien CF, Shiao AS. Mastoid obliteration for pediatric suppurative cholesteatoma: long-term safety and sustained effectiveness after 30 years' experience with cartilage obliteration. Audiol Neurootol 2014; 19: 358-69. [CrossRef]
19. James AL. Approaches to cholesteatoma with an intact ossicular chain: Combined use of microscope, endoscope and laser. In: Takahashi H, ed. Cholesteatoma and Ear Surgery – An Update. Amsterdam, The Netherlands: Kugler Publications, 2013: 333-6.
20. Saleh HA, Mills RP. Classification and staging of cholesteatoma. Clin Otolaryngol Allied Sci 1999; 24: 355-9. [CrossRef]
21. Takahashi H, Honjo I, Naito Y, Miura M, Tanabe M, Hasebe S, et al. Gas exchange function through the mastoid mucosa in ears after surgery. Laryngoscope 1997; 107: 1117-21. [CrossRef]
22. Swarts JD, Cullen Doyle BM, Alper CM, Doyle WJ. Surface area-volume relationships for the mastoid air cell system and tympanum in adult humans: Implications for mastoid function. Acta Otolaryngol 2010; 130: 1230-6. [CrossRef]
23. Yung M, Bennett A. Use of mastoid obliteration techniques in cholesteatoma. Curr Opin Otolaryngol Head Neck Surg 2013; 21: 455-60. [CrossRef]
24. Gantz BJ, Wilkinson EP, Hansen MR. Canal wall reconstruction tympanomastoidectomy with mastoid obliteration. Laryngoscope 2005; 115: 1734-40. [CrossRef]
25. Tos M. Obliteration with a fat graft. Manual of Middle Ear Surgery; Vol 2: Mastoid surgery and reconstructive procedures. New York: Thieme Medical Publishers, Inc., 1995: 414-5.