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ORIGINAL ARTICLE

Effect of mastoid bone pneumatization on the conformation and depth of the sinus tympani, a high-resolution computed tomography study

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Abstract

Purpose To investigate the relationship between mastoid pneumatization and the conformation and depth of the sinus tympani (ST) in patients with chronic otitis media (COM), based on the high-resolution computed tomography (HRCT) scans.
Methods Two hundred and two patients affected by COM were included in the study. The patients were divided into three groups according to the extent of mastoid pneumatization on HRCT scans; pneumatized (group 1), diploic (group 2) or sclerotic (group 3). The variation in the ST area (types A, B, C) was assessed using a radiomorphological classification based on the relationship between the medial boundary of the ST and the third portion of the facial nerve. Depth of the ST was calculated by measuring the distance between the medial boundary of the ST and medial boundary of the third portion of the facial nerve
Results There was a statistically significant difference between the groups in terms of the type of ST ($p < 0.001$). The mean depths of the ST were 1.59 ± 0.82 mm (0.00–2.80 mm) in group 1, 1.10 ± 0.79 mm (0.00–3.00 mm) in group 2 and 0.53 ± 0.63 mm (0.00–2.60 mm) in group 3. The groups were significantly different in terms of the depth of the ST ($p < 0.001$).
Conclusion A well-pneumatized mastoid is highly associated with a deep and posteriorly positioned ST with respect to the facial nerve. The preoperative HRCT scans of patients with cholesteatoma should be carefully evaluated to determine the conformation and depth of the ST.

Keywords Sinus tympani · Mastoid pneumatization · Chronic otitis media · Computed tomography · Middle ear surgery

Introduction

Certain factors affecting pneumatization of the temporal bone have been debated for a long time. The extent of pneumatization of the mastoid portion is controlled by non-genetic factors, such as the incidence of secretory otitis media (SOM) and chronic middle ear infections (otitis media) in childhood, as explained by the environmental theory [7, 14, 22, 24, 26]. Research conducted with healthy children, monitored from babyhood to school age, confirms the hypothesis that as the greater the extent of the past sequel of SOM, the smaller the mastoid air cell system [23]. Animal studies have shown that inflammation occurring in the middle ear cavity restrains normal mastoid pneumatization and development of the mastoid procedure, reducing its length [1, 2]. Conversely, as stated by the genetic theory, mastoid air cell size is genetically determined, and a poorly pneumatized mastoid is a predisposing factor for the development of acute or chronic otitis media (COM) [5, 16, 18, 25]. The extent of mastoid pneumatization brings along important clinical and surgical considerations due to its interrelationships with other structures of the temporal bone; for example, the facial nerve (FN), tegmen mastoideum, sigmoid sinus, jugular bulb, as well as pneumatization of other portions of the temporal bone.

The sinus tympani (ST) is a posterior extension of the mesotympanum. It is located medial to the FN, stapedius

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muscle and pyramidal eminence, and lateral to the posterior semicircular canal and the vestibule. Meckel [12] first described the concept of ST in 1820. The clinical importance of ST due to its noticeable outpouching was first acknowledged by Steinbrugge [21] in 1879. Platzer [15] indicated that the posterior part of the medial wall of the tympanic cavity was separated into three compartments bordered by the ponticulus (superiorly) and the subiculum (inferiorly), between which ST is located. Sinus tympani is of clinical interest to otologists due to its tendency to be invaded by cholesteatoma, the difficulty of visualization, and lack of a direct-access surgical approach. Sinus tympani holds great potential for harboring residual disease; thus, in the surgical removal of cholesteatoma, for the complete evacuation of the disease, maximum exposure of ST is essential. In 2009, Marchioni et al. [10] performed a radiomorphological classification regarding the medial and posterior outpouching of ST and concluded that there was an anatomical relation between FN and the medial boundary of ST. The authors pointed out that it would be impossible to control the disease in cases with a deep ST and posterior extension.

Saito et al. [17] and Donaldson et al. [6] determined that the medial and posterior outpouching of ST varied and might be associated with the overall status of temporal bone pneumatization. However, objective data related to the effect of pneumatization of the mastoid in ST morphology are rare. In this study, we aimed to elucidate the possible relation between pneumatization of the mastoid and the conformation and depth of ST based on high-resolution computed tomography (HRCT) scans.

Materials and methods

The medical records of 317 patients, who had undergone middle ear surgery at our center between 2014 and 2018, were retrospectively reviewed. Of these, 202 patients were affected by COM, 104 with chronic non-suppurative otitis media [CNSOM], 88 with chronic suppurative otitis media [CSOM], and 10 with adhesive otitis media (AOM) and had undergone HRCT scan of the temporal bone preoperatively. The patients with tympanic membrane perforation and dry ear for at least 3 months were accepted as having CNSOM, and those with perforated tympanic membrane and persistent ear discharge for more than 3 months were diagnosed with CSOM. Adhesive otitis media was considered if the tympanic membrane was attached to the incus, the stapes, or the promontorium. All operations were performed via an operating microscope (Möller-Wedel Optical®; Hamburg, Germany) under general anesthesia.

The data collected retrospectively included the patients' age and gender, type of disease, extent of mastoid pneumatization, and conformation and depth of ST. The exclusion criteria were being younger than 18 years of age, having a previous history of middle ear surgery, having middle ear pathologies except COM, complicated cases, having no preoperative HRCT scans, and the presence of congenital inner ear anomalies.

The research was approved by the local ethics committee (no: E-18-2076), and conducted as per the ethical principles of the Declaration of Helsinki. Informed consent was obtained from all the participants prior to surgery.

All the images had been obtained from the axial plane, in parallel projection to the orbitomeatal line, with a 1-mm slice thickness, using a tomography device with four detectors (Mx8000; Philips Medical Systems, Best, the Netherlands). Scanning from arcuate eminence to the jugular fossa was performed using HRCT. Two experienced radiologists evaluated the HRCT scans of the patients included in the study and their evaluations were accepted based on consensus.

The patients were separated into three groups with respect to the extent of mastoid pneumatization. The extent of pneumatization of the mastoid on HRCT scans was classified as pneumatized (group 1), diploic (group 2) or sclerotic (group 3).

The variation in the ST region was evaluated using a radiological classification of ST, as previously described by Marchioni et al. [10]. This classification is based on the morphological interrelationship between the medial boundary of ST and the third portion of FN. Based on radiological results, the authors classified the depth of ST into the following three types:

- Type A A relatively small ST that does not extend posteriorly and medially with respect to the third portion of FN (Fig. 1a).
- Type B A relatively large and deep ST and deep presenting with a medial extension with respect to the third portion of FN (Fig. 1b).
- Type C A relatively large ST presenting with a medial and posterior extension with respect to the third portion of FN (Fig. 1c).

The depth of ST was calculated by measuring the distance between the medial boundary of ST and the medial boundary of the third portion of FN on the HRCT scans in the axial view (Fig. 2). Since the third portion of the medial boundary of FN correlated with the depth of sinus in type A ST, the degree of the type A ST depth was considered to be 0 mm.

Statistical significance was analyzed using SPSS v. 20 (SPSS Inc, IBM company, Chicago). The data were expressed as means ± standard deviations and percentages (%). The Chi square test was used to compare the groups and recovery rates. We examined the data normality using the Kolmogorov–Smirnov test. The Wilcoxon and

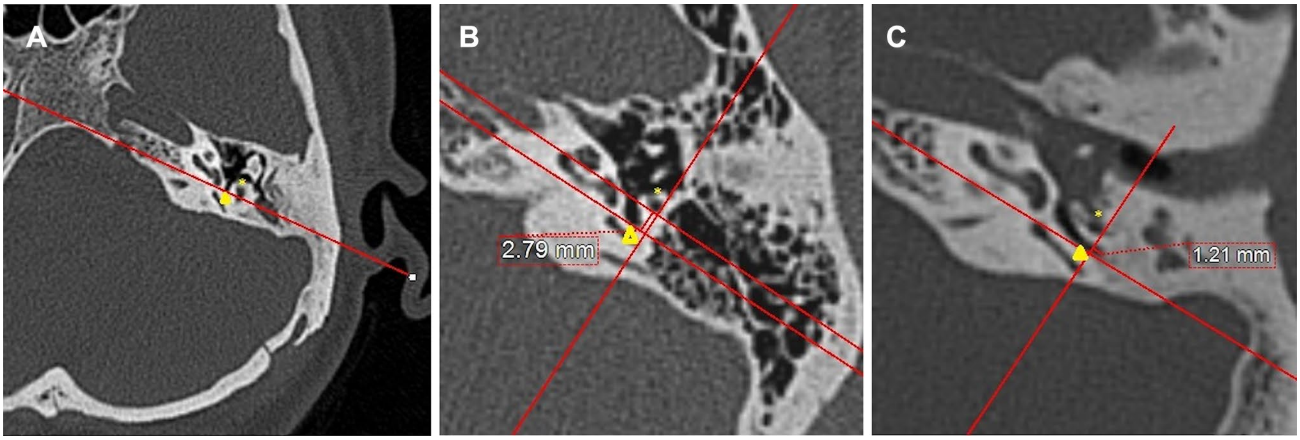

Fig. 1 Computed tomographic classification of ST. Type A, a relatively small ST without a medial and posterior extension with respect to the third portion of the facial nerve (**a**); type B, a relatively deep ST with a medial extension but without a posterior extension with respect to the third portion of the facial nerve (**b**); type C, a relatively deep ST with a posterior extension (1.21 mm) with respect to the third portion of the facial nerve (**c**). The asterisk indicates the facial nerve and the arrowhead indicates the medial wall of ST

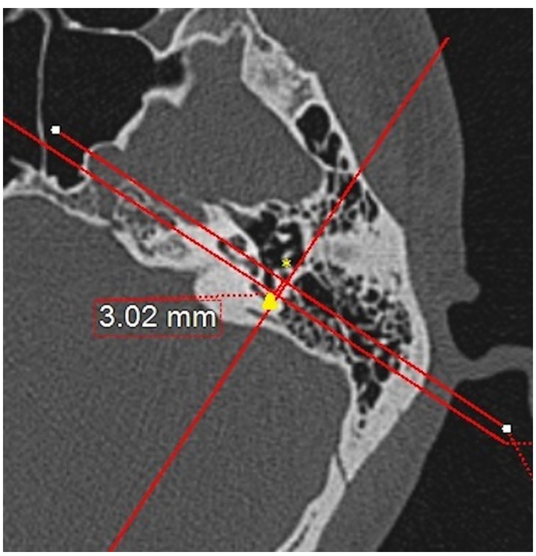

Fig. 2 Measurement of the ST depth on the HRCT scan in the axial view

Mann–Whitney *U* tests were utilized for non-parametric variables while the independent sample *t* test and one-way analysis of variance were employed for parametric variables. We considered $p < 0.05$ to be statistically significant.

Results

Of the 202 patients who met the criteria mentioned above (95 females, 107 males), 53 (27 females, 26 males) were in group 1, 86 (33 females, 53 males) were in group 2, and 63 (35 females, 28 males) were in group 3. There was no statistically significant difference between the groups in terms of gender ($p = 0.093$).

The mean age was 36.32 ± 14.59 years for the entire sample, ranging from 18 to 66 years. The mean ages were 34.52 ± 12.09 years in group 1, 36.31 ± 16.19 years in group 2, and 39.42 ± 13.93 years in group 3. There was no statistically significant difference between the groups concerning ages ($p = 0.180$).

In group 1, there were 42 patients (79.2%) with CNSOM, 11 patients (20.8%) with CSOM, and no patients with AOM. In group 2, there were 45 patients (52.3%) with CNSOM, 37 (43%) with CSOM, and 4 (4.7%) with AOM. Group 3 contained 17 patients (27%) with CNSOM, 40 (63.5%) with CSOM, and 6 (9.5%) with AOM. There was a statistically significant difference between the groups in terms of the type of COM ($p < 0.001$) (Table 1).

In group 1, there were four patients (7.5%) with a type A ST conformation, 41 (77.4%) with a type B ST conformation, and 8 (15.1%) with a type C ST conformation. In group 2, ST conformation was type A in 19 patients (22.1%), type B in 65 (75.6%), and type C in 2 (2.3%). Group 3 contained 28 patients (44.4%) with a type A ST conformation, 35 patients (55.6%) with a type B ST conformation, and no patients with a type C ST conformation. There was a statistically significant difference between the three groups in terms of the type of ST ($p < 0.001$).

The mean depth of ST was calculated as 1.34 ± 0.63 mm (0.20–3.02 mm) for type B, 2.49 ± 0.21 mm (2.15–2.80 mm) for type C, and 1.41 ± 0.68 mm for both. The mean depth of ST of groups 1–3 was 1.59 ± 0.82 mm (0.00–2.80 mm), 1.10 ± 0.79 mm (0.00–3.02 mm) and 0.53 ± 0.63 mm (0.00–2.60 mm), respectively, with a statistically significant difference ($p < 0.001$).

Table 1 The distributions of the type of disease, conformation and depth of ST in the study groups

	Group 1 (pneumatized)	Group 2 (diploic)	Group 3 (sclerotic)	*p* value
Type of disease, *N* (%)				
CNSOM	42 (79.2%)	45 (52.3%)	17 (27%)	< 0.001*
CSOM	11 (20.8%)	37 (43%)	40 (63.5%)	
AOM	0 (0%)	4 (4.7%)	6 (9.5%)	
ST, *N* (%)				
A	4 (7.5%)	19 (22.1%)	28 (44.4%)	< 0.001*
B	41 (77.4%)	65 (75.6%)	35 (55.6%)	
C	8 (15.1%)	2 (2.3%)	0 (0%)	
Depth of the ST (mm)	1.59 ± 0.82 mm	1.10 ± 0.79 mm	0.53 ± 0.63 mm	< 0.001*

CNSOM chronic nonsuppurative otitis media, *CSOM* chronic suppurative otitis media, *AOM* adhesive otitis media, *ST* sinus tympani, *N* number

*$p < 0.05$ was considered to be significant

Discussion

A wide variation of the degree of ST depth has been clinically widely acknowledged [3, 10, 13]. However, causes of such variation have not yet been fully elucidated. The present study confirmed the presence of a significant relationship between the extent of pneumatization of the mastoid and the depth of ST. Furthermore, mastoid pneumatization affects the posterior and medial outpouching of ST relative to the third part of FN.

Being the posterior extension of the mesotympanum, ST is a difficult area for otologic surgical procedures. It extends medially and posteriorly to FN and laterally to the vestibule and semicircular canals. It is one of the anatomical areas of the middle ear cavity that cannot be directly visualized using an operating microscope alone. Removal of middle ear diseases from ST is frequently performed by blind dissection using blunt instruments to eliminate the possibility of any residual disease. However, due to the invasion of ST by cholesteatoma and granular tissue, it is a common site of residual disease in cholesteatoma surgery, and it is difficult to successfully eliminate the disease in this area [10]. Sinus tympani presents with a posterior extension and high variability in depth. In some cases, ST is so deep that no instrument can sufficiently reach the affected area to completely remove the disease. Jansen [9] described the facial recess technique for providing access to the posterior tympanic area. However, a complete access to ST with medial and posterior extensions may not be possible using this technique. Radical procedures; for example, canal wall-down tympanomastoidectomy in which the posterior canal wall is removed may also not be efficient in allowing the exploration of ST. Ozturan et al. [13] suggested the retrofacial approach for accessing a large ST with a markedly posterior extension. The authors recommended HRCT of the temporal bone to assess the pneumatization and depth of ST and the surrounding bone prior to implementing this new approach. The limitations of this approach were reported to include the laterally positioned posterior semicircular canal (PSC), medially positioned FN, sigmoid sinus with a forward position, high position of the jugular bulb, and a poorly developed ST. However, these techniques have not yet been broadly adopted due to their particular disadvantages and requirement of an expert otologist.

Recently, endoscopic ear surgery has been presented to visualize blind pockets, such as ST. In their human cadaveric study on the temporal bone, Baki et al. [3] reported that the degree of the ST depth was highly variable (average: 2.6 mm, range: 0.9–6.1 mm), and in 20% of the specimens (six bones), ST was extremely deep, with a posterior extension to FN. In such cases, blind instrumentation would be required to eradicate cholesteatoma. In the current study, the mean ST depth was 1.41 ± 0.68 mm (0.20–3.00 mm), and posterior extension of FN was observed in 4.9% of the cases. In 2009, Marchioni et al. [10] classified ST into three types based on the results of temporal bone HRCT, as described above. In their study cohort consisting of 148 patients (296 ears), the authors found that 33.1% of the ears presented with type A, 62.5% with type B, and 4.4% with type C radiomorphology. Consistent with these results, in our study, a type A ST conformation was detected in 25.3% of the ears, type B in 69.8%, and type C in 4.9%. Marchioni et al. [11] also reported that in a total of 94 ears with an either type A or B conformation affected by cholesteatoma, a transcanal endoscopic surgical approach permitted visualization of the medial wall of ST. In the same study, in four ears with a type C conformation, visualization of the medial wall was not permitted, and a retrofacial approach, combining transmastoid and endoscopic approach, was adopted to eradicate cholesteatoma from ST. In this way, posterior wall of the external auditory canal was preserved. In the same study, of the 98 ears with cholesteatoma, four ears experienced recurrence in the middle ear cavity and there was ST involvement in a single patient with a type C ST conformation. The authors concluded that the different types of ST could be tested and classified by an HRCT scan preoperatively, conformation of ST could affect the surgical decisions during cholesteatoma surgery, and the presence of a deeper ST increased the possibility of having a residual disease [11]. Thus, the choice of surgical approach should be appropriate for the complete removal of the disease.

Numerous studies have investigated the relationship between mastoid pneumatization and the vital structures of the temporal bone, revealing that the varying degree of pneumatization of the mastoid bone has implications for the position and course of these structures. In an anatomical study by Singleton [20] in 1944, it was found that the tegmen tympani dipped downward posteriorly and laterally, overhanging the antrum. Graham [8] showed that the position of the sigmoid sinus and the height of the jugular bulb were influenced by mastoid pneumatization. Schatz and Sade [19] reported that the separation between the external auditory canal and the sigmoid sinus was considerably shorter in poorly pneumatized mastoids than in well-pneumatized mastoids. Dai et al. [4] found that FN tended to be situated more medially and backward in well-pneumatized mastoid bones, while the nerve had a more anterior and lateral course in poorly pneumatized mastoids. As mentioned in the introduction section, the factors that influence the extent of mastoid pneumatization have been a subject of debate for many years. The environmental theory suggests that early middle ear diseases (infection, inflammation) may be potent enough to inhibit mastoid bone development. The results of this study showed that pneumatization of the mastoid was influenced by the severity of middle ear disease. In our cohort, 40.4% of the patients with CNSOM had a well-pneumatized mastoid while this percentage was significantly reduced in patients with CSOM (12.5%) and those with AOM (0%) ($p < 0.001$).

Earlier studies failed to investigate the relationship between pneumatization of the mastoid and the ST area. Marchioni et al. [10] reported that the patients with a type C ST conformation had well-pneumatized mastoids, but they included no data concerning the association between the extent of mastoid pneumatization and ST conformation. We believe that our analysis of mastoid pneumatization led us to determine the relationship between the conformation and depth of the ST area and pneumatization of the mastoid bone. When pneumatization of the mastoid is normal (pneumatized), ST was larger and presented with a medial extension (type B) with respect to FN in 77.4% of ears. Furthermore, ST presented with a posterior extension (type C) in 15.1% of well-pneumatized mastoids. The mean depth of ST was significantly higher among pneumatized mastoids (1.59 ± 0.82 mm) than diploic (1.10 ± 0.79 mm) or sclerotic mastoids (0.53 ± 0.63 mm) ($p < 0.001$). Conversely, in poorly pneumatized mastoids, there was a tendency for ST to be shallow and to have no posterior and medial extension with respect to FN. The conformation of type A ST was detected in 44.4% of the ears with a sclerotic mastoid, 22.1% of those with a diploic mastoid, and 7.5% of those with a pneumatized mastoid ($p < 0.001$).

These results raise the question of why the medial wall of ST is deeper in cases with a well-pneumatized mastoid. We consider that pneumatization of the mastoid allows ST to extend posteriorly and medially with regard to FN, while a sclerotic mastoid blocks the development of a deep ST with a posterior extension. A pneumatized mastoid may increase extension of ST, or ST may tend to extend toward well-pneumatized and low resistant regions of the temporal bone. Conversely, our data support the hypothesis that chronic inner ear infection restrains the normal growth of the mastoid bone, which can alter the relative conformation and depth of ST.

Our study has certain limitations; e.g., it was a retrospective study, and the records of some of the patients (intraoperative findings, follow-up time, residual disease, or recurrence) obtained from the medical charts may have been inaccurate or incomplete. Thus, further prospective studies including preoperative clinical and HRCT findings, operative reports, and postoperative follow-up records can provide more reliable and accurate data to prove the role and importance of preoperative evaluation of mastoid pneumatization and ST conformation on HRCT in COM surgery.

Conclusion

The results of the current study suggest that preoperative assessment of the conformation and depth of ST is important for the success of COM surgery, particularly in patients with cholesteatoma. A well-pneumatized mastoid was found to be highly related with a deep and posteriorly positioned ST with respect to FN. Thus, we believe that the preoperative HRCT scans of patients with cholesteatoma with pneumatized mastoids should be carefully evaluated by the surgeon to determine the conformation and depth of ST since any residual disease in this area may contribute to treatment failure and disease recurrence.

Author contributions DB: project development and manuscript writing. IK: data management and analysis. IG: data collection and management. SA: Data collection. NYK: data collection. KGY: radiological evaluation. ISP: radiological evaluation. ROK: manuscript editing and data analysis. MO: supervision and critical review.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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