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Accuracy of High-Resolution Computed Tomography Compared to High-Definition Ear Endoscopy to Assess Cholesteatoma Extension

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Abstract

Objective. To correlate radiographic evidence of cholesteatoma in the retrotympanum with intraoperative endoscopic findings in cholesteatoma patients and to evaluate the clinical relevance of radiographic evidence of cholesteatoma in the retrotympanum.

Study Design. Case series with chart review.

Setting. Tertiary referral center.

Methods. Seventy-six consecutive cases undergoing surgical cholesteatoma removal with preoperative high-resolution computed tomography (HRCT) were enrolled in this study. A retrospective analysis of the medical records was conducted. The extension of cholesteatoma regarding different middle ear subspaces, into the antrum and mastoid were reviewed radiologically in preoperative HRCT and endoscopically from surgical videos. Additionally, facial nerve canal dehiscence, infiltration of the middle cranial fossa, and inner ear involvement were documented.

Results. Comparison of radiological and endoscopic cholesteatoma extension revealed statistically highly significant overestimation of radiological cholesteatoma extension for all retrotympanic regions (sinus tympani 61.8% vs 19.7%, facial recess 69.7% vs 43.4%, subtympanic sinus 59.2% vs 7.9%, and posterior sinus 72.4% vs 4.0%) and statistically significant overestimation for mesotympanum (82.9% vs 56.6%), hypotympanum (39.5% vs 9.2%), and protympanum (23.7% vs 6.6%). No statistically significant differences were found for epitympanum (98.7% vs 90.8%), antrum (64.5% vs 52.6%), and mastoid (26.3% vs 32.9%). Statistically significant radiological overestimation of facial nerve canal dehiscence (54.0% vs 25.0%) and invasion of tegmen tympani (39.5% vs 19.7%) is reported.

Conclusion. Radiologic cholesteatoma extension in different middle ear subspaces is overestimated compared to the intraoperative extension. The preoperative relevance of radiological retrotympanic extension might be limited in the choice of approach and transcanal endoscopic approach is always recommended first.

Keywords

cholesteatoma surgery, endoscopic ear surgery, radiomorphology, retrotympanum, temporal bone anatomy

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Endoscopic ear surgery has progressively evolved to almost all areas of otology during the last decade. Endoscopes combine the advantage of a wide field of view (FoV) together with the use of angled optics, allowing transcanal assessment of nearly all areas of the middle ear, especially those remaining invisible during the microscopic approach. In particular, the utilization of the endoscope in cholesteatoma surgery enabled the exploration of hidden recesses and consecutively reduced the rate of residual cholesteatoma compared to microscopic canal-wall-up mastoidectomy.[1-5] Furthermore, in revision canal-wall-down mastoidectomy, the endoscope is increasingly used as an exclusive or adjunct tool with favorable outcomes regarding complication rate, duration of surgery, and hospitalization days.[6]

With the introduction of the endoscope in middle ear surgery, different classifications for middle ear subspaces were developed. One of the key regions in this context is the retrotympanum, as it is one of the most common

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localizations of residual cholesteatoma.[7,8] The retrotympanum is located posterior to the mesotympanum and is divided by the subiculum into a superior and inferior part.[9] The sinus tympani is located superiorly and classified depending on the depth of the sinus in relation to the facial nerve as type A shallow sinus tympani, type B deep sinus tympani reaching the posterior border of the facial nerve, and type C as deep sinus tympani with extension posterior to the facial nerve.[10] Recently, similar classifications in type A-C related to the facial nerve have been proposed for the subtympanic sinus and facial recess.[11,12] According to these classifications it was demonstrated that the prediction of endoscopic exposure based on preoperative high-resolution computed tomography (HRCT) is feasible. Although complete endoscopic visualization might not always be possible in deep retrotympanic recesses,[13] no clinical studies have yet been published that have demonstrated limited endoscopic access to cholesteatoma in the retrotympanum. To evaluate the clinical relevance of this technical limitation of the endoscopic approach and the impact on the surgical approach, we studied the rate of radiological cholesteatoma extension in such recesses and compared them with intraoperative endoscopic findings. We hypothesize a radiological overestimation of retrotympanic cholesteatoma extension and no impact on the surgical approach.

Patients and Methods

Ethical Issues

The present study has been reviewed and approved by the local ethical review board (Kantonale Ethikkomission Bern, 2019-00555).

Image Acquisition

In-house computed tomography (CT) scans were acquired using the 128-slice CT scanner (SOMATOM1 Definition Edge; Siemens Healthcare). The following CT scan parameters were used: slice thickness (SL) of 0.6 mm, an FoV of 160 mm, a total acquisition time of 1 second by tube current-time product of 230 mA, and tube voltage 120 kV. The average CT dose index was 35 mGy with a dose-length product of 330 mGy cm. Image reconstruction was performed according to the standard in-house temporal bone protocol with a soft tissue window (kernel J45s) and a bone window (kernel J70h) of the acquired CT scans, each in the axial, coronal, and an oblique (Stenvers) plane. Two-dimensional and additionally reconstructed CT scans in multiplanar reconstruction mode were used for data analysis. External CTs of the temporal bone were scanned with a maximum of an SL 1 mm and a minimum of an SL 0.4 mm, the FoV differed between 150 and 250 mm with the resulting range of exposure parameters.

Radiological and Endoscopic Evaluation

A total of 76 consecutive cases undergoing surgical cholesteatoma removal were enrolled in this study. All patients underwent preoperative HRCT of the temporal bone within 3 months before surgery. Patients who underwent previous canal-wall-down surgery were excluded since the anatomy is usually too much affected.

All surgeries started with a transcanal endoscopic approach to the middle ear including inspection and removal of cholesteatoma under appropriate angled endoscopic view using 0° and 45° rod lens endoscopes (3 mm, 14 cm length) and coupled to a high-resolution monitor and camera (Karl Storz).

In the case of cholesteatoma extension to the mastoid, an additional retroauricular microscopic mastoidectomy was performed to completely eradicate the cholesteatoma. Patient's characteristics (age, date of surgery, side of surgery, surgical approach, previous ear surgery) were extracted from the electronic files. The extension of cholesteatoma regarding the different middle ear subspaces and its extension into the antrum and mastoid were reviewed from surgical videos and independently rated by 2 blinded experienced ear, nose, and throat surgeons. Additionally, facial nerve canal dehiscence, extension in the middle cranial fossa, and inner ear involvement were documented.

Radiological findings of cholesteatoma extension in preoperative HRCT were obtained by 2 board-certified neuroradiologists with more than 10 years of experience. The classification of the different regions was performed independently and blinded to the diagnosis and intraoperative findings. In case of different findings, a consensus was reached between the 2 surgeons or neuroradiologists during a second session. All investigators were blinded to each other for the initial staging.

Statistical Analysis

Statistical analysis was performed and the radiological findings were compared with the intraoperative endoscopic findings using the McNemar test between both groups. Statistically, significance was set at 2-tailed $\alpha < .05$.

Results

The findings of cholesteatoma extension in preoperative HRCT were compared with intraoperative endoscopic findings in 76 cases (**Figure 1**). The mean overall age was 42 years, with 40 left-sided surgical interventions and 24 cases of revision surgery. The surgical approach was feasible in 45 cases as an exclusive endoscopic approach, in 21 cases combined with a canal-wall-up mastoidectomy, and in 10 cases as a combined canal-wall-down procedure. The cholesteatoma was successfully removed from the middle ear and its subspaces using angled optics without the requirement of any retrofacial approach in all cases. Detailed demographic data for each surgical approach are summarized in **Table 1**.

Radiological cholesteatoma extension was most frequently predicted in the epitympanum (98.7%, n = 75), mesotympanum (82.9%, n = 63), posterior sinus (72.4%, n = 55), and facial recess (69.7%, n = 53). Endoscopic

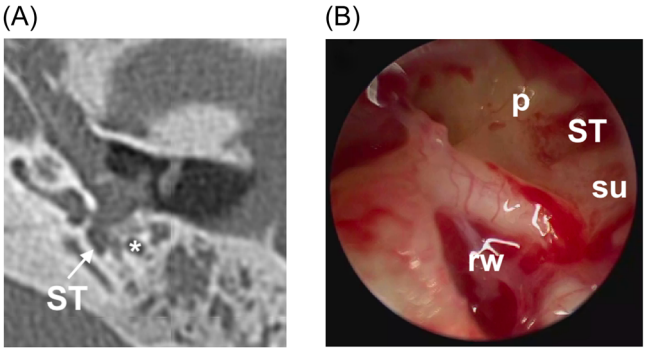

Figure 1. Comparison of discrepant preoperative radiologic (axial temporal bone CT scan) (A) and endoscopic (45°) cholesteatoma extension into the sinus tympani (B). p, ponticulus; rw, round window; ST, sinus tympani; su, subiculum; *, facial nerve.

Table 1. Detailed Demographic Data According to the Surgical Approach

	EES (59.2%)	CCWU (27.6%)	CCWD (13.2%)
Mean age (minimum-maximum years)	39 (8-84)	43 (21-81)	53 (31-94)
Right side	42.2%	57.1%	50.0%
Left side	57.8%	42.9%	50.0%
Last ear surgery	TPL 4.4% TCR 2.2% CWU 20%	TPL 4.8% CWU 19%	TPL 0% CWU 70%
No revision surgery	73.3%	76.2%	30%

Abbreviations: CCWD, combined canal-wall-down procedure; CCWU, combined canal-wall-up procedure; CWU, canal-wall-up procedure; EES, exclusive endoscopic surgery; TCR, transcanal cholesteatoma removal; TPL, tympanoplasty.

cholesteatoma extension usually involved the epitympanum (90.8%, n = 69), mesotympanum (56.6%, n = 43), as well as antrum (52.6%, n = 40). A detailed comparison of radiological and endoscopic cholesteatoma extension for each subsite is shown in **Table 2**. Comparison of radiological and endoscopic cholesteatoma extension revealed a statistically highly significant overestimation for all retrotympanic regions as sinus tympani ($p < .001$), facial recess ($p = .002$), subtympanic sinus ($p < .001$), and posterior sinus ($p < .001$) (**Figure 2**). There was also a statistically significant overestimation for mesotympanum ($p < .001$), hypotympanum ($p < .001$), and protympanum ($p < .001$). Comparing the radiological and endoscopic findings for the epitympanum, antrum, and mastoid, there were no statistically significant differences between radiological and endoscopic cholesteatoma extension. However, there was a statistically significant overestimation between radiological and endoscopic cholesteatoma extension for potential complications like facial nerve canal dehiscence and invasion of tegmen tympani, but no statistically significant difference for inner ear involvement (**Figure 3**).

Of the total 76 cases, 37 cases (48.7%) revealed epitympanic and mesotympanic extension, 32 cases (42.1%) showed primary epitympanic extension and 6 cases (7.9%) showed primary mesotympanic extension. One case (1.3%) demonstrated neither epitympanic nor mesotympanic extension with primary cholesteatoma in the facial recess.

Discussion

In this study, the prediction of cholesteatoma extension based on radiological findings was compared with intraoperative endoscopic findings in 76 cases during exclusive endoscopic or combined cholesteatoma removal. A comparison of these findings revealed a statistically highly significant difference between radiologically predicted and intraoperatively visible cholesteatoma extension in all retrotympanic subspaces. Also for other middle ear subspaces such as meso-, hypo-, and protympanum, statistically significant differences between radiologically predicted and endoscopically visible cholesteatoma extension were observed. However, no statistically significant difference was found between radiologically predicted and endoscopically visible cholesteatoma extension in the epitympanum, antrum, and mastoid.

In general, cholesteatoma appears as soft tissue-dense lesions on HRCT in the tympanic cavity or mastoid. Based on the density of the lesions, no differentiation between cholesteatoma, granulation tissue, mucosal swelling or cholesterol granuloma can be made on CT.[14] Previously reported significant differences of density measurement to discriminate cholesteatoma from inflammatory granulation tissue[15] failed to be reproduced.[16] However, the typical localization in the tympanic or mastoid cavity, associated bony erosions, and possible complications such as labyrinthine fistula, facial nerve canal dehiscence, or tegmen erosion indicate a cholesteatoma in native HRCT.[14,17] Several studies have correlated radiologic findings with intraoperative findings, resulting in good positive predictive values for the prediction of cholesteatoma and its complications in preoperative CT imaging.[18] Nevertheless, the correlation of radiological findings with intraoperative findings on the extension of the cholesteatoma into various retrotympanic subspaces has been investigated only sparsely in the literature. Walshe et al found the accurate radiologic prediction of disease extension with a sensitivity and specificity of 100% each into the sinus tympani in 75% and facial recess in 65% of the total of 20 patients.[19] Comparable results were reported by Karki et al with a sensitivity of 83.3% and specificity of 100% in comparing radiological and clinical disease extension to the sinus tympani and facial recess in 65 patients with only 6 patients showing intraoperative retrotympanic involvement.[20] Only Plodpai et al has previously reported a poor correlation of radiologic with intraoperative endoscopic findings for the sinus tympani and a fair correlation for the facial recess in 41 patients.[21] However, further details on the exact distribution and other retrotympanic subsites were not provided.

Table 2. Detailed Comparison of Radiological and Endoscopic Cholesteatoma Extension for Each Subsite

	Epitympanum	Mesotympanum	Hypotympanum	Protympanum	Antrum	Mastoid
Radiologic extension	98.7%	82.9%	39.5%	23.7%	64.5%	26.3%
Endoscopic extension	90.8%	56.6%	9.2%	6.6%	52.6%	32.9%
Sensitivity	0.99	0.88	0.71	0.40	0.75	0.32
Specificity	0.00[a]	0.24	0.64	0.77	0.47	0.78
PPV	0.91	0.60	0.17	0.11	0.61	0.40
NPV	0.00	0.62	0.96	0.95	0.63	0.70
p Value	.08	<.001	<.001	.006	.14	.46

	Sinus tympani	Facial recess	Subtympanic sinus	Posterior sinus
Radiologic extension	61.8%	69.7%	59.2%	72.4%
Endoscopic extension	19.7%	43.4%	7.9%	4.0%
Sensitivity	0.73	0.73	0.83	1.00
Specificity	0.41	0.33	0.43	0.29
PPV	0.23	0.45	0.11	0.05
NPV	0.86	0.61	0.97	1.00
p Value	<.001	.002	<.001	<.001

Abbreviations: NPV, negative predictive value; PPV, positive predictive value.
[a]Due to the high prevalence of epitympanic extension, sample size, and inclusion criteria.

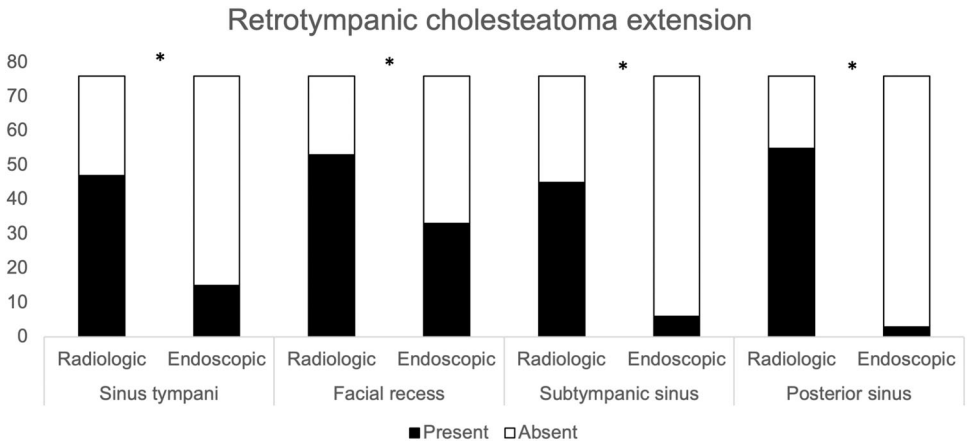

Figure 2. Comparison of radiologic and endoscopic retrotympanic extension.

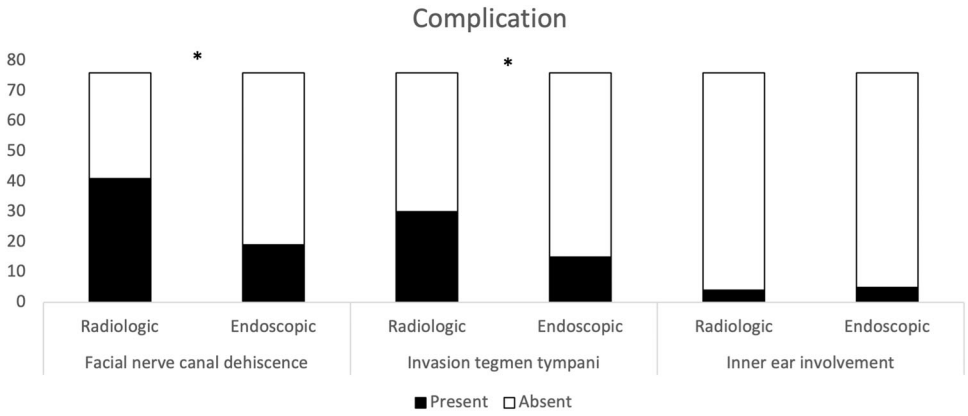

Figure 3. Comparison of radiologic and endoscopic complications of cholesteatoma extension.

In comparison to the study by Walshe et al, we evaluated a considerably larger number of patients and observed comparable radiologic cholesteatoma extension into the sinus tympani in 61.8% and facial recess in 69.7%. However, endoscopic correlation in our study revealed cholesteatoma extension in only 19.7% of the sinus tympani and 43.4% of the facial recess. Therefore, our study showed a statistically highly significant overestimation of radiologic retrotympanic cholesteatoma extension for various retrotympanic subspaces. One reason for the radiological overestimation might be that bony erosions are difficult to visualize in retrotympanic subspaces, thus usually only a soft tissue-dense opacity, in general, is seen.

Another way to improve the radiologic detection of cholesteatoma emerged with non-echoplanar diffusion-weighted magnetic resonance imaging (Non-EPI DW MRI). Non-EPI DW MRI has become the gold standard for radiological diagnosis of cholesteatoma with an overall sensitivity and specificity of 0.91 and 0.92, although small cholesteatoma of less than 3 mm might be missed.[22] However, crucial information like the exact spatial resolution as well as the bony erosions still remains hidden, as only HRCT can provide this information. This is of particular importance, as exact localization, as well as bony erosions, may predict the feasibility of an exclusive transcanal endoscopic approach. For more accurate preoperative localization of cholesteatoma, fusion images of HRCT and Non-EPI DW MRI might be generated.[23] Superior localization of cholesteatoma was demonstrated for various anatomical subsites in fusion HRCT-Non-EPI-DW-MRI compared to HRCT or Non-EPI DW MRI.[24] However, reduced sensitivity for cholesteatoma localization in the sinus tympani was observed in this study and confirmed in another study.[25] This might be explained by the small size of retrotympanic subspaces as the sinus tympani, which has a mean width of approximately 2 mm,[26] so that cholesteatoma may not be reliably detected. Furthermore, also slight misregistration in fusion images may result in failure of correct cholesteatoma localization.[24]

Nevertheless, rare but deep anatomical variants of retrotympanic subspaces might impede the surgical approach and require an additional transmastoid, retrofacial approach in case of cholesteatoma extension into these subspaces, in addition to the transcanal endoscopic approach.[13,27,28] Despite this potential limitation for transcanal endoscopic approach to the retrotympanum, no conversion to a retrofacial approach for complete cholesteatoma removal was necessary for our cohort. This might be explained due to the fact that retrotympanic pneumatization in cholesteatoma patients is most often a type A configuration and therefore amenable to an endoscopic approach.[29] Thus, in consideration of the overestimated radiologic retrotympanic extension, only meticulous intraoperative evaluation of cholesteatoma extension into retrotympanic subspaces can lead to the decision for a retrofacial approach. In particular, preoperative radiologic disease extension into retrotympanic subsites does not provide reliable information about intraoperative cholesteatoma extension in the retrotympanum. Despite the reliable exclusion of retrotympanic cholesteatoma extension due to its negative predictive value in the absence of radiological involvement, we recommend thorough endoscopic retrotympanic evaluation even in this case due to the potential extension of disease between the imaging date and the time of surgery. Therefore, we recommend the transcanal endoscopic approach as the first step in cholesteatoma removal.

Nevertheless, some limitations have to be mentioned. First, the study was conducted in a retrospective way and external CT scans with different SL were included in the study. The inclusion of different CT examinations with different SL might result in potential bias due to the small size of middle ear subspaces. Furthermore, the interpretation of complex middle ear anatomy is influenced by the experience of radiologists as well as surgeons, and consensus had to be reached to some extent in the absence of agreement.

Conclusion

Radiologic cholesteatoma extension in different middle ear subspaces and especially retrotympanic subspaces is overestimated compared to the intraoperative extension. The preoperative relevance of radiological retrotympanic extension might be limited for the choice of approach and transcanal endoscopic approach is always recommended as the first step in cholesteatoma removal.

Author Contributions

Sven Beckmann, data collection/management, data analysis, manuscript writing/editing, final approval of the manuscript; **Sara-Lynn Hool**, data collection/management, manuscript writing/editing, final approval; **Abraam Yacoub**, protocol/project development, data collection, final approval of the manuscript; **Arsany Hakim**, data collection/management, data analysis, final approval of the manuscript; **Marco Caversaccio**, protocol/project development, critical review and final approval of the manuscript; **Franca Wagner**, data collection/management, data analysis, critical review and final approval of the manuscript; **Lukas Anschuetz**, protocol/project development, data collection/management, data analysis, manuscript writing/editing, final approval of the manuscript.

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Disclosures

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