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Correlation of pre-operative computed tomography, intra-operative findings and surgical outcomes in revision tympanomastoidectomy

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Main Article

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Abstract

Objective. To correlate pre-operative computed tomography findings, intra-operative details and surgical outcomes with cholesteatoma recurrence in revision tympanomastoidectomy.

Methods. This retrospective, non-randomised, single-institution cohort study included 42 patients who underwent pre-operative computed tomography imaging and revision surgery for recurrent chronic otitis media. Twelve disease localisations noted during revision surgery were correlated with pre-operative temporal bone computed tomography scans. A matched pair analysis was performed on patients with similar intra-operative findings, but without pre-operative computed tomography scans.

Results. Pre-operative computed tomography identified 25 out of 31 cholesteatoma recurrences. Computed tomography findings correlated with: recurrent cholesteatoma when attic opacification and ossicular chain involvement were present; and revision surgery type. Sinodural angle disease, posterior canal wall erosion and dehiscent dura were identified as predictors of canal wall down tympanomastoidectomy. Patients with pre-operative computed tomography scans had a higher rate of cholesteatoma recurrence, younger age at diagnosis of recurrent disease, more revision surgical procedures and less time between previous and revision surgical procedures (all $p < 0.05$).

Conclusion. Pre-operative imaging and intra-operative findings have important clinical implications in revision surgery for chronic otitis media. Performing pre-operative computed tomography increases diagnosis accuracy and reduces the time required to diagnose recurrent disease.

Introduction

Chronic otitis media with recurrent cholesteatoma is common in otological surgery. Recurrence after initial surgery may be localised in the tympanic cavity only, but can also spread to the mastoid, or involve other highly sensitive structures in the temporal bone.[1,2] Otoscopy in the setting of recurrent disease may yield useful information regarding recurrence extent and localisation, but cannot accurately address deeper areas of retraction pockets or perifacial or mastoid disease.[3] High-resolution computed tomography (CT) of the temporal bone could be vital in assessing disease and key anatomical characteristics pre-operatively.[4,5]

Revision surgery is concerned with removing recurrent disease while dealing with other non-affected structures as sparingly as possible.[6] Published literature has focused on the outcomes of two types of surgical procedures most commonly used in revision surgery: canal wall down and canal wall up tympanomastoidectomy. Factors leading to post-operative failure after initial surgery are: inadequate meatoplasty, leaving a high facial ridge in canal wall down procedures; failure to address the mastoid apex cells; post-operative granulation; and mismanagement of high-risk areas, such as the facial recess, posterior wall of the ear canal and sinus tympani.[6,7]

Identifying and removing recurrent disease is central in achieving long-term disease control. To date, very few papers have analysed possible correlations between intra-operative findings in revision surgery and pre-operative imaging as predictors of cholesteatoma recurrence or poor surgical outcome, with most of the literature focusing on post-operative imaging.[5,8–10] In planning for revision surgery, the decision-making process is often based on prior surgical experience, and often depends entirely on the findings encountered upon executing the revision procedure.[7,11–13] There is clear clinical value in improving pre-operative planning to address possible disease recurrence patterns, especially to gain information about bone erosion, the integrity of the lateral semi-circular canal and tegmen, and sigmoid plate if the mastoid was drilled previously.

This study analysed the correlations between pre-operative CT imaging, intra-operative details of revision tympanomastoidectomy procedures and surgical outcomes. Describing disease recurrence patterns and determining the reliability of such findings on pre-operative scans could be of great assistance when making decisions regarding the timing, type and extent of revision surgery.

Materials and methods

A retrospective comparative cohort study was conducted comprising 42 patients surgically treated for recurrent chronic otitis media. The study was approved by the University Hospital Center Bioethical Board, adhering to the Helsinki Declaration Revision of 1989.

Inclusion criteria were met if: the patients underwent revision tympanomastoidectomy (either canal wall up or canal wall down), from 1 January 2010 to 1 May 2019, in our tertiary referral centre; the procedure was performed by the same otological team of three surgeons; and complete intra-operative data and pre-operative CT scans were available for analysis. The radiologist was blinded to the data regarding previous surgery. The CT scans were performed in all patients within the two weeks before surgery, and were performed as a routine surgical investigation in patients with active chronic otitis media, even if cholesteatoma recurrence was not immediately suspected. Recurrent cholesteatoma was diagnosed if the pre-operative CT scan showed the presence of a soft tissue mass with bony erosion in the middle-ear space, especially if auditory ossicle erosion was observed. The indication for surgery was continuing otorrhoea and/or evident disease recurrence after previous surgery. The patients' demographic data, type and instances of previous surgery, intra-operative findings, and CT findings were entered into a comprehensive database. Informed consent was obtained from all patients.

Exclusion criteria were: insufficient intra-operative details, where the analysis of localisations could not be assessed; and patients without pre-operative CT scans available for analysis.

In the 42 patients included in the study, 12 disease recurrence localisations were identified in the revision surgery notes, and these were then correlated with the corresponding CT sites (Table 1).

The CT scans were multi-slice, with collimation and 0.5 mm thickness. The scans were analysed by the same neuroradiologist, a member of the otology multidisciplinary team, who was tasked with commenting on the same 12 intra-operative sites noted during surgery.

Two binary outcomes relating to revision surgery were identified: the presence or absence of cholesteatoma, and whether a canal wall up or canal wall down procedure had been performed.

In order to extrapolate the impact of performing CT prior to revision surgery on secondary post-operative outcomes (cholesteatoma recurrence, type of surgery, number of previous surgical procedures and time elapsed from previous surgery), a matched pair analysis was performed. Each patient in the revision surgery group who had pre-operative CT was matched with a patient who had revision surgery performed by the same otologist but without a pre-operative CT examination. The patients were paired to have identical or similar intra-operative findings. This created a subset of 84 participants (42 matched pairs), who were included in the secondary analysis. The presence of pre-operative CT findings was designated as the dependent variable.

Statistical analysis was performed using SPSS Statistics for Windows software, version 22.0 (IBM, Armonk, New York, USA), using standard descriptive statistics and frequency tabulation as indicated. Associations between variables were assessed using a binary logistic regression model with odds ratios, the Kruskal–Wallis test for non-parametric independent samples, Spearman's correlation co-efficient ρ, and principal component analysis using direct oblimin rotation. All tests were performed using a two-sided 5 per cent type I error rate.

Table 1. Localisations of disease recurrence*

Localisation
Tympanic perforation
Sinodural angle
Facial ridge cells
Attic
Erosion of posterior canal wall
Ossicular chain disruption
Mastoid apex cells
Antrum
Mastoid erosion
Dehiscence of facial nerve canal
Hypotympanum
Exposed dura

*Identified on pre-operative computed tomography scans and during revision surgery

Results

The average age of patients was 34.1 years, ranging from 7 to 80 years. There were 21 males and 21 females. Of the total 42 patients, 8 had undergone only one previous surgery for chronic otitis media. Thirty-three patients had undergone multiple surgical procedures, with an average number of 2.9 surgical procedures per patient, with an average time since the previous surgery of nine years. All patients were initially treated for cholesteatoma. Of the 42 patients, 10 had been previously surgically treated in our institution.

Revision procedures encompassed 28 canal wall up and 14 canal wall down tympanomastoidectomy procedures. In the canal wall down revision procedure group, seven patients had previously undergone a canal wall up procedure. Seven patients had extensive disease and had already been treated with a canal wall down procedure prior to revision surgery.

Pre-operative CT identified 25 cholesteatoma recurrences out of 31 cases observed during revision surgery. Thus, the sensitivity rate was 80.65 per cent, with a specificity rate of 81.82 per cent, a positive predictive value of 92.59 per cent and a negative predictive value of 60 per cent (Table 2).

The binary logistic regression model identified a high level of correlation between pre-operative CT diagnosis of likely cholesteatoma and intra-operative findings ($p = 0.001$, odds ratio = 13.25). Among 12 localisations analysed on pre-operative CT scans, disease presence in the attic ($p = 0.018$, odds ratio = 5.634) and in the ossicular chain ($p = 0.040$, odds ratio = 4.209) were identified as significant positive predictors of cholesteatoma. Male patients also had a significantly higher risk for cholesteatoma recurrence ($p = 0.018$, odds ratio 5.634) (Table 3).

Cholesteatoma identified on CT scans was associated with a significantly higher likelihood of performing canal wall down tympanomastoidectomy ($p = 0.033$, odds ratio =

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Table 2. Distribution of revision tympanomastoidectomy patients with cholesteatoma recurrence

Revision procedure	Patients (*n*)	Cholesteatoma recurrence noted during revision surgery (*n*)	Cholesteatoma recurrence noted on pre-operative CT (*n*)
CWU tympanomastoidectomy	28	17	13
CWD tympanomastoidectomy	14	14	12
Total	42	31	25

CT = computed tomography; CWU = canal wall up; CWD = canal wall down

Table 3. Association between pre-operative CT findings and intra-operative recurrent cholesteatoma findings*

Localisation	CT finding (*n*)	Intra-operative finding (*n*)	*p*
Tympanic perforation	17	28	0.350
Residual perifacial cells	5	23	0.931
Ossicular chain erosion	23	23	0.040† (OR = 4.209)
Posterior EAC wall erosion	21	30	0.335
Residual mastoid apex cells	17	16	0.350
Antrum	19	20	0.556
Attic	21	26	0.018† (OR = 5.634)
Dehiscent facial nerve canal	3	16	0.106
Mastoid erosion & residual cells	12	18	0.449
Residual sinodural angle cells	11	16	0.969
Hypotympanum	8	6	0.909
Dura exposure	2	10	0.380

*Analysis includes 12 intra-operatively noted localisations identified as significant in the binary logistic regression model ($p = 0.001$, odds ratio = 13.25). †Statistically significant association. CT = computed tomography; OR = odds ratio; EAC = external auditory canal

Table 4. Association between pre-operative CT findings and extent of revision surgery*

CT localisation	CWD surgery (*n*)	CWU surgery (*n*)	*p*
Tympanic perforation	6	11	0.717
Residual perifacial cells	3	2	0.070
Ossicular chain erosion	7	16	0.735
Posterior EAC wall erosion	11	10	0.006† (OR = 7.552)
Residual mastoid apex cells	6	11	0.717
Antrum	6	13	0.585
Attic	9	12	0.153
Dehiscent facial nerve canal	2	1	0.217
Mastoid erosion & residual cells	3	9	0.574
Residual sinodural angle cells	9	2	0.001† (OR = 15.193)
Hypotympanum	2	6	0.733
Dura exposure	2	0	0.044† (OR = 4.055)

*Analysis includes 12 intra-operatively noted localisations identified as significant in the binary logistic regression model ($p = 0.033$, odds ratio = 4.557). †Statistically significant association. CT = computed tomography; CWD = canal wall down; CWU = canal wall up; EAC = external auditory canal; OR = odds ratio

4.557). Positive predictors for performing canal wall down surgery were: disease in the sinodural angle ($p = 0.001$, odds ratio = 15.193), erosion of the posterior canal wall ($p = 0.006$, odds ratio 7.552) and exposed dura ($p = 0.044$, odds ratio = 4.055) (Table 4). The likelihood of performing canal wall down surgery was also higher in male patients ($p = 0.037$, odds ratio = 4.364).

Spearman's correlation identified a significant positive correlation between CT scans and intra-operative findings of cholesteatoma recurrence ($\rho = 0.573$, $p = 0.001$). A likely cholesteatoma on pre-operative CT scans correlated well with disease located in the attic ($\rho = 0.379$, $p = 0.013$), in the antrum ($\rho = 0.336$, $p = 0.032$) and affecting the ossicular chain ($\rho = 0.329$, $p = 0.033$). In addition, pre-operative CT scans

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Table 5. Spearman's correlation co-efficient values*

CT localisation	CWD procedure (p (ρ))	Intra-operative cholesteatoma recurrence (p (ρ))
Tympanic perforation	0.829 (0.034)	0.311 (0.160)
Residual perifacial cells	0.186 (0.208)	0.745 (0.052)
Ossicular chain involvement	0.670 (−0.068)	0.033 (0.329)†
Posterior EAC wall erosion	0.008 (0.404)†	0.304 (0.162)
Residual mastoid apex cells	0.829 (0.034)	0.311 (0.160)
Antrum	0.832 (−0.034)	0.032 (0.336)†
Attic	0.199 (0.202)	0.013 (0.379)†
Dehiscent facial nerve canal	0.213 (0.196)	0.103 (−0.255)
Mastoid erosion & residual cells	0.4481 (−0.112)	0.387 (0.137)
Residual sinodural angle cells	0.001 (0.613)†	0.927 (−0.015)
Hypotympanum	0.589 (−0.086)	0.934 (0.013)
Dura exposure	0.041 (0.316)†	0.400 (0.133)

*Demonstrates positive correlations between computed tomography scans and: the likelihood of performing a canal wall down tympanomastoidectomy procedure (ρ = 0.316, p = 0.041) and cholesteatoma recurrence (ρ = 0.573, p = 0.001). †Statistically significant correlation. CT = computed tomography; CWD = canal wall down; EAC = external auditory canal

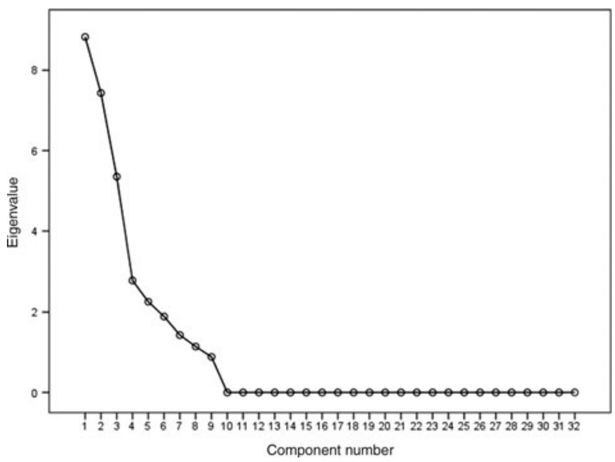

Fig. 1. Principal component analysis identified three primary components in our data set, represented on the scree plot with eigenvalue greater than 5, with the first three components encompassing 67.6 per cent of total variance.

correlated well with the likelihood of performing canal wall down surgery (ρ = 0.316, p = 0.041) when there was: disease found in the sinodural angle (ρ = 0.613, p = 0.001), posterior canal wall erosion (ρ = 0.404, p = 0.008) and exposed dura (ρ = 0.316, p = 0.041) (Table 5).

Principal component analysis was used to confirm the results of the binary logistic regression model and address possible confounds associated with the large number of variables. The results identified three primary components in our data set, with eigenvalue greater than 5 (Figure 1). Covariance co-efficient values in the first component encompassed most of the total variance, and showed significant correlation co-efficients for disease located in the attic (principal component 1 value = 0.958), mastoid apex (0.958) and hypotympanum (0.958), and mastoid erosion (0.900) on the pre-operative CT scan. The second principal component showed significant correlation co-efficients for performing canal wall down surgery, and posterior canal wall erosion (principal component 2 value = 0.643) and exposed dura (0.576) observed on the pre-operative CT scan (Table 6).

The matched pair analysis using the Kruskal–Wallis test showed that patients with pre-operative CT scans had a statistically: higher rate of cholesteatoma recurrence diagnosed pre-operatively (p = 0.043; Figure 2), younger age at diagnosis of recurrent disease (p = 0.044; Figure 3), higher number of revision surgical procedures (p = 0.0001; Figure 4), and shorter period of time between previous and revision surgical procedures (p = 0.043; Figure 5). There was no significant difference between type of surgery (canal wall up or canal wall down) and presence or absence of pre-operative CT scanning (p = 0.267).

Table 6. Principal component analysis*

Variable	Principal component 1	Principal component 2
Canal wall down surgery	−0.013	0.879
Intra-operative cholesteatoma	0.542	0.238
Cholesteatoma on pre-operative CT	0.826	0.200
Tympanic perforation	0.503	−0.304
Sinodural angle	0.621	0.380
Perifacial ridge cells	0.376	−0.437
Attic	0.958	0.026
Posterior canal wall erosion	0.236	0.643
Ossicular chain involvement	0.555	−0.090
Mastoid apex cells	0.958	0.026
Antrum	0.534	−0.064
Mastoid erosion	0.900	−0.205
Dehiscent facial nerve canal	0.445	−0.069
Hypotympanum	0.958	0.026
Exposed dura	0.383	0.576

*Describes a correlation matrix for the first two components, which encompassed 50.8 per cent of the total variance. Variables include disease localisation noted on pre-operative computed tomography scans, extent of surgery and intra-operative presence of cholesteatoma. CT = computed tomography

Discussion

Revision surgery for chronic otitis media ideally results in a manageable and dry middle-ear cavity, but it is often plagued

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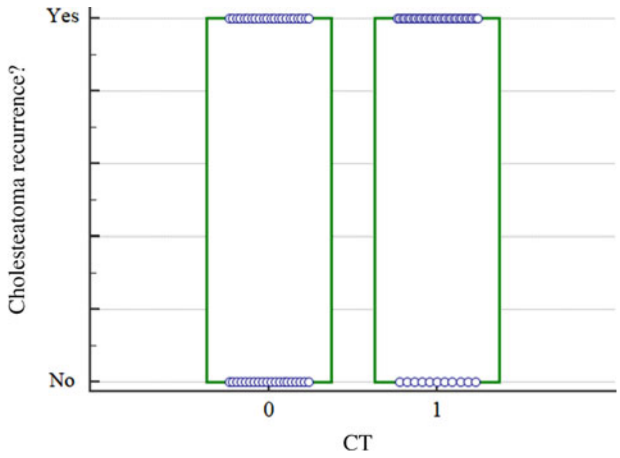

Fig. 2. Matched pair analysis showed that patients with pre-operative computed tomography (CT) scans had a statistically higher rate of cholesteatoma recurrence diagnosed pre-operatively ($p = 0.043$, Kruskal–Wallis test). 0 = no pre-operative CT scan; 1 = pre-operative CT scan available

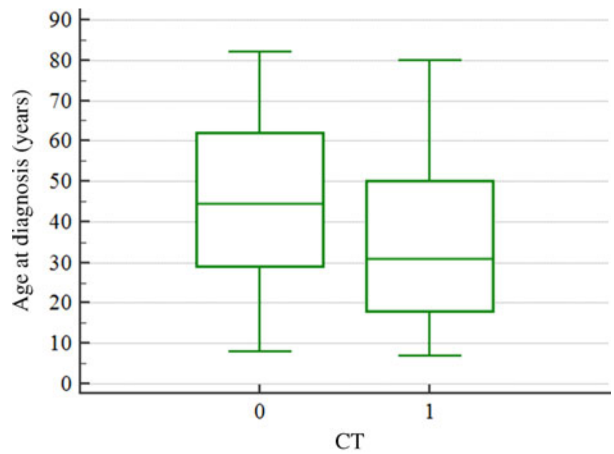

Fig. 3. Matched pair analysis showed that patients with pre-operative computed tomography (CT) scans had a statistically younger age at diagnosis of recurrent disease ($p = 0.044$, Kruskal–Wallis test). 0 = no pre-operative CT scan; 1 = pre-operative CT scan available

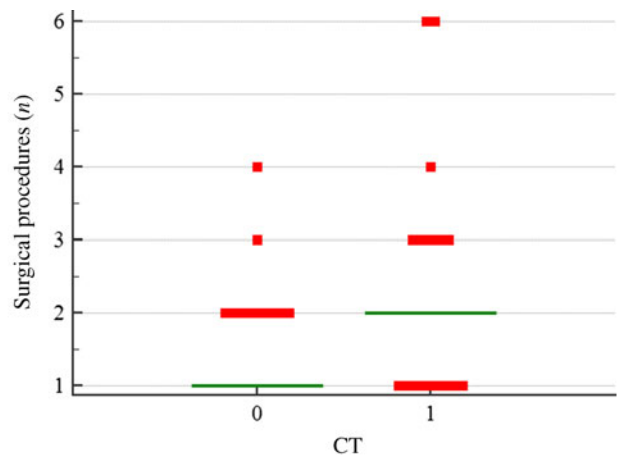

Fig. 4. Matched pair analysis showed that patients with pre-operative computed tomography (CT) scans had a statistically higher number of revision surgical procedures ($p = 0.0001$, Kruskal–Wallis test). 0 = no pre-operative CT scan; 1 = pre-operative CT scan available

with high failure rates, with cholesteatoma recurrences found in up to 49 per cent of patients after previous cholesteatoma surgery.[6,7] Recurrent disease is commonly identified when

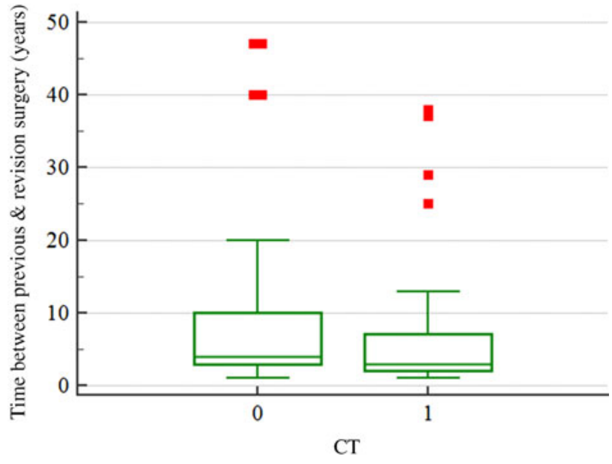

Fig. 5. Matched pair analysis showed that patients with pre-operative computed tomography (CT) scans had a statistically shorter period of time between previous and revision surgical procedures ($p = 0.043$, Kruskal–Wallis test). 0 = no pre-operative CT scan; 1 = pre-operative CT scan available

initial surgery fails to address tegmental, perifacial, mastoid apex and sinodural mastoid cells.[11,12] However, clinical follow up using otoendoscopy and presenting symptoms may not identify a significant portion of patients with occult disease recurrence, especially after previous canal wall up surgery.[8,9]

Pre-operative CT imaging is a first-line option in middle-ear imaging because of its excellent spatial resolution and delineation of vital landmarks.[9,10,14] It is especially useful in cases where the initial surgery was performed elsewhere, if complications are present, or when recurring disease cannot be properly assessed using otoendoscopy alone.[10] It is used to predict the extension of the disease into the sinus tympani and the attic, with antral and peri-antral involvement.[9] However, when interpreting CT scans, the inability to discriminate between cholesteatoma, granulation, fibrosis and thick mucus secretion in the middle ear must be taken into account; one should consider performing magnetic resonance imaging (MRI) as well, especially in the paediatric population.[9,15] Recurrent middle-ear cholesteatoma evaluated by MRI also represents a diagnostic challenge because of the small size of these tissues, the different kinds of surgical procedures, and the non-specific signal intensity characteristics on imaging. The presence of erosion caused by soft tissue on nearby bone structures is generally interpreted as indicating the presence of cholesteatoma.[14,15]

Previously published studies have been concerned with comparing pre- and post-operative CT and MRI scans in relation to initial surgery for chronic otitis media. However, very few studies have addressed the much more complicated issue of whether pre-operative imaging is useful in revision surgery. While MRI is still widely regarded as the most accurate imaging method for assessing cholesteatoma, high-resolution CT may represent an alternative imaging tool in patients with contraindications for MRI or in practices where pre-operative MRI is not routinely performed. At the cost of a low radiation burden, CT represents a cheaper and faster examination, with the additional advantage of providing high-resolution anatomical details.[16,17] Advancing imaging protocols may further minimise radiation, and, in some instances, cone beam CT may be useful. However, cone beam CT may not capture areas of interest outside the field of view (beyond 4 × 4 cm classically).[18] Cone beam CT may aid the surgeon's pre-operative plan and discussion of treatment options,

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which may be different from decisions made based on intra-operative findings or pre-operative imaging. In revision cases, the possibility of intra-operative complications and plan changes is higher, and the surgeon may be required to widen the extent of surgery beyond the original plan.

Several studies have assessed the value of diffusion-weighted MRI and concluded that a high signal on diffusion-weighted images does not always indicate the presence of cholesteatoma, with false-positive cases found in the post-operative period due to artefacts, bone dust, cartilage, tympanosclerosis, granulation tissue, proteinaceous fluid, purulent content, cholesterol granuloma or wax in the adjacent external auditory canal.[15] A recent meta-analysis of 1152 patients (both pre- and post-surgical cases) showed that the use of diffusion-weighted images alone led to 3.4 per cent of false-positive cases, with a lower specificity for post-operative controls.[16]

The principal question analysed in this study was whether pre-operative CT scans may present a useful tool in identifying localisations with high risk for recurrent disease, and in planning for revision surgery. The results confirm our hypothesis that CT can reliably identify recurrent disease. In the current study, CT identified 25 out of 31 cholesteatoma recurrences, with high sensitivity (80.65 per cent) and a high positive predictive value (92.59 per cent). This value is much higher than some of the results in the literature, which cite sensitivity and specificity as low as 42 per cent and 48 per cent, respectively.[17,19,20] Pre-operative CT scans revealed correlations between the presence of cholesteatoma and attic disease, ossicular chain involvement, sinodural angle cells, opacified facial ridge cells and an obstructed antrum. In addition, the likelihood of performing canal wall down tympanomastoidectomy was higher in patients presenting with disease in the sinodural angle, erosion of the posterior canal wall and exposed dura on the pre-operative CT scan, which was further confirmed by principal component analysis results.

- Recurrence after initial surgery for chronic otitis media may be difficult to identify in the tympanic cavity and mastoid prior to revision surgery
- High-resolution computed tomography (CT) of the temporal bone may be vital in assessing disease and key anatomical characteristics pre-operatively
- This study analysed correlations between pre-operative CT imaging and intra-operative revision tympanomastoidectomy details
- Describing disease recurrence patterns and determining the reliability of such findings on pre-operative scans may aid decisions regarding type and extent of revision surgery
- Pre-operative CT identified cholesteatoma recurrences with 80.65 per cent sensitivity and 81.82 per cent specificity
- Pre-operative CT increased accuracy of diagnosing recurrent cholesteatoma, reduced time required to diagnose, and lowered age at diagnosis and revision surgery

Male sex was linked to a higher risk of cholesteatoma recurrence, which has been described earlier, and indicates that our sample is representative of the larger patient population.[21]

The most common localisations of recurrent disease visible on pre-operative CT were tympanic perforation, ossicular chain involvement, posterior canal wall destruction, attic disease and antrum involvement. This correlated well with intra-operative findings (Table 3). These findings correspond to well-known disease recurrence patterns in published literature, confirming that failure to address these areas during initial or previous surgery may be a principal factor in disease recurrence.[21]

The results of the matched pair analysis also indicate that performing pre-operative CT scans increases the rate of accurate diagnosis of recurrent cholesteatoma, reduces the time required to diagnose recurrent disease, and lowers the average age at diagnosis and corresponding revision surgery, without influencing the type of surgery. Analysis of correlations between pre-operative CT scans and intra-operative findings in revision surgery is clearly of value when planning the extent and type of surgery, and when determining which areas are high risk for subsequent close scrutiny, without introducing bias when choosing the type and extent of surgery required to eliminate recurrent disease.[20]

The habit of analysing pre-operative imaging must be a valuable tool in any surgeon's armamentarium, and should not be relegated exclusively to the radiologist. However, a capable surgeon should be able to navigate a temporal bone to ensure that the bone bed is clear and comprehensively drilled as part of any approach when removing cholesteatoma disease, irrespective of pre-operative scanning. The point of obtaining the CT scan prior to surgery is not to aid the surgeon in identifying areas in the ear where there is concern for recurrence. It might seem obvious that CT may help with surgical planning, but data supporting objective analysis of the CT scan in revision surgery are surprisingly scarce, and supporting its consistent use would help clinicians show value to third parties who may question the need for CT in revision cases. Knowledge of fine anatomical detail provides additional refinement in surgical technique, which is a decisive factor influencing post-operative outcomes.[12,13] Recurrent cholesteatoma is associated with inaccurate pre- and intra-operative evaluation findings of the surgical field and a failure to address high-risk areas, putting patients at a higher risk of canal wall down procedures in revision surgery.[12] The correlations between CT scans and intra-operative findings identified in this study may be useful in follow up as well, as indicators of early recurrence, and for prompt timely surgical intervention in patients with otherwise occult disease.[21]

When planning for surgery, it may be especially valuable to have in mind the significant correlations between disease involving the sinodural angle and posterior canal wall and the presence of exposed dura, as early indicators that a canal wall down procedure might be required (Table 5). Similar findings have been reported previously, with intra-operative findings identifying posterior external auditory canal wall erosion, mastoid erosion and residual cells along the facial ridge as reliable predictors of cholesteatoma recurrence, and associated with canal wall down procedures, but they have not been linked with pre-operative CT findings.[11–13,22]

Conclusion

Utilising readily available pre-operative CT imaging alongside a detailed assessment of possible cholesteatoma recurrence patterns by a radiologist may improve outcomes of revision surgery. Performing pre-operative CT scans increases the rate of accurate diagnosis of recurrent cholesteatoma, reduces the time required to diagnose recurrent disease, and lowers the average age at diagnosis and corresponding revision surgery. The CT will mostly accurately predict where to look for cholesteatoma recurrence, but will not accurately predict that there is no recurrence and therefore that the surgery is not indicated.

Competing interests. None declared

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