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OTOLOGY

Correlation between pre-operative CT findings and intra-operative features in pediatric cholesteatoma: a retrospective study on 26 patients

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Abstract

Objective To assess the predictive value of pre-operative CT imaging in pediatric patients affected by cholesteatoma of the middle ear, comparing pre-operative CT findings to intra-operative features.

Methods A retrospective study was performed on a population of 26 pediatric patients who underwent tympanoplasty for middle ear cholesteatoma at the Otorhinolaryngology Departments of Verona and Modena University Hospitals between December 2011 and June 2018. Comparison between pre-operative CT images and intra-operative findings (assessed from video recording) was made focusing on the involvement of specific structures: ossicular chain, tegmen tympani, labyrinthine fistula, facial nerve, and temporal bone involvement. CT sensitivity, specificity, positive and negative predictive values were calculated.

Results Overall, 28 surgical procedures were evaluated. No statistically significant differences were encountered between CT images and intra-operatory findings regarding the selected parameters.

Conclusions Based on our study, pre-operative temporal bone CT scan is a valuable tool for the assessment of pediatric patient candidates for cholesteatoma surgery given the absence of statistically significant differences between radiologic and intra-operative findings. The present findings might support the indication to routinely perform temporal bone CT scan in children with cholesteatoma as part of pre-surgical plan.

Level of evidence III.

Keywords Pediatric cholesteatoma · CT imaging · Intra-operative findings · Endoscopy · Tympanoplasty

Introduction

Cholesteatoma is a chronic inflammatory process caused by the ectopic growth of epithelial tissue, replacing the mucosa in the middle ear and/or the mastoid. It has an erosive potential over the bony structures of the middle ear and the temporal bone, which makes its behavior critical, despite its benign nature. If left untreated, cholesteatoma could lead to relevant complications, such as hearing loss, facial palsy, vertigo and in few cases, intracranial involvement [1]. Despite cholesteatoma occurs rarely in children (3–15 cases per 100,000), pediatric cholesteatoma (PedC) is a highly relevant condition for the otologists, as it is known to be more extensive and destructive at time of diagnosis than its adult counterpart [1–3]. From a histological point of view, cholesteatoma in children consists of squamous epithelium and keratin, mixed with cholesterol crystals, as in the adults [2]. However, PedC tends to grow faster and expand into the middle ear cleft and the temporal bone at an early stage. This could be partially explained by the better pneumatization of the temporal bone in children, where large air cells constitute a direct way for the expansion of cholesteatoma. On the other hand, research at a histological and biomolecular

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level is showing different expressions of inflammatory and immune markers, in an attempt to better explain the behavior of cholesteatoma in the two populations [1].

Overall, in pediatric population multiple surgeries are usually required to achieve complete removal of the disease and avoid recurrences.

Middle ear cholesteatoma could be categorized into three classes: primary acquired (further subdivided in attic and mesotympanic); secondary acquired and congenital [4]. The vast majority of PedCs are acquired [2, 3].

As in the adult setting, the diagnosis of PedC is made by otoscopy/otoendoscopy and usually complemented by imaging, more commonly computed tomography (CT). Temporal bone CT without contrast helps in corroborating the suspect of cholesteatoma, but also gives a detailed overview of anatomical structures, either involved by the pathology or at risk of injury during the surgical procedure.

Since the extension of cholesteatoma surgery is ultimately decided on the basis of the intra-operative evaluation, having an imaging tool that reliably depicts the pre-operative extension and erosive features of the cholesteatoma may support the surgeon in planning the surgery (i.e. endoscopic vs combined or microscopic approach), preventing harm to the patient and predicting surgical outcomes.

Despite the amount of data regarding imaging in cholesteatoma and the progress of technology (in terms of imaging acquisition and reconstruction algorithms), concern is still present about how accurate is the pre-operative assessment of cholesteatoma by CT scan and the actual need to perform it routinely before surgery. Furthermore, literature exploring the role of CT imaging in PedC is extremely limited [2, 5, 6].

The aim of this retrospective study would be to compare pre-operative CT findings and intra-operative features of pediatric patients surgically treated for cholesteatoma, to assess the predictive value of pre-operatory CT imaging in this specific group of patients.

Materials and methods

A population of pediatric patients who underwent tympanoplasty for middle ear cholesteatoma at the Otorhinolaryngology Departments of Verona and Modena University Hospitals between December 2011 and June 2018 was selected for this research.

Inclusion criteria were age less or equal to 14 years, patients affected by either congenital, primary or secondary acquired cholesteatoma, and patients who underwent primary surgery for cholesteatoma removal. Patients who underwent previous middle ear surgery for cholesteatoma were excluded.

A pre-operative non-contrast temporal bone CT scan was performed for each patient with 1 mm slice thickness to assess the extension of the cholesteatoma and plan the subsequent surgical procedure.

All surgical interventions were performed by the senior authors (D.M. and L.P.). Both patients' parents had signed an informed consent before their children were operated on. The adopted surgical procedures were the transcanal endoscopic technique [7], the microscopic technique, or a combination of both, according to extension of pathology and mastoid involvement. During the operation, a video was recorded for further review and comparison with CT images.

To gain objective results, comparison was made focusing on the erosion of specific structures: ossicular chain (malleus erosion, incus erosion, stapes erosion, or not), tegmen tympani (erosion, or not), labyrinthine fistula (lateral semicircular canal erosion, or not), facial nerve (fallopian canal erosion, or not). Regarding temporal bone involvement (antrum involvement, mastoid involvement, or not), CT finding was considered positive (i.e. presence of cholesteatoma) if any isodense tissue was detectable in the antrum and/or mastoid area and either the antrum seemed enlarged or the mastoid cells were eroded or abnormally confluent.

Regarding mastoid involvement, the choice of the sole endoscopic procedure was dictated by the pre-operative CT images and the intra-operative findings: if both the CT scan and the endoscopic intra-operative view showed neither mastoid nor antrum involvement, the surgical procedure was limited to the endoscopic approach; on the other hand, if the CT images and/or the intra-operative findings showed the suspect of antrum or mastoid involvement, the surgical procedure was supported by the microscopic retroauricular transmastoid approach. In the first case, antrum and/or mastoid involvement was considered absent; on the contrary, in the second case, antrum and/or mastoid involvement was considered to be present.

To avoid data bias, CT images were viewed by neuroradiologists who were unaware of the intra-operative findings, and surgical findings were collected by examiners who were unaware of CT findings. All results were collected in a database for elaboration and further statistical analysis (Microsoft Excel® and Matlab®). Pearson's chi-square test and Fisher's exact test (whenever possible) were calculated by comparing CT imaging and intra-operative findings for every parameter mentioned above. Linear regression was calculated to assess possible differences between intra-operative findings and CT imaging according to period of time between CT acquisition and surgical operation. At last, CT sensitivity, specificity, positive and negative predictive values were calculated.

Results

A total of 26 children (20 males and 6 females; age 2–14 years, mean 8.05 years) were eventually included in the study. CT scans were performed 1–15 months before surgical operation (mean 4 months), between October 2011 and January 2018. In most cases, CT images had already been accomplished in other hospitals: in these children, even if there was a long amount of time (e.g., 15 months), no other CT imaging was collected, not to further irradiate them. Two patients underwent tympanoplasty twice due to bilateral cholesteatoma. Overall, 28 surgical procedures were performed. The affected side was right in 12 cases and left in 16. An exclusive endoscopic approach with a canal-wall-up tympanoplasty was performed in 18 ears, while a microscopic retroauricular approach was used in 2. A combination of the two previous procedures was performed in eight cases. Microscopic canal-wall-up technique was used in eight patients, while canal-wall-down and subtotal petrosectomy was accomplished in one case. The latter case was an 8-year-old girl affected by CHARGE syndrome, who had been operated on for right cochlear implantation 5 years before. Due to right otorrhea not responding to medical therapy, she underwent CT imaging, showing cholesteatoma. Thus, she was surgically treated for cholesteatoma removal and CI substitution.

Chain erosion has been divided into three categories (malleus, incus, stapes) and temporal bone involvement has been divided into two categories (antrum and mastoid). Statistical analysis for ossicular chain was calculated by considering erosion of malleus, incus or stapes. Statistical analysis for mastoid involvement was calculated by considering only microscopic procedures, so for this parameter a total of 21 cases were considered. No statistically significant differences was encountered between the analyzed parameters, since no p value resulted to be < 0.05.

The sum of the results for each parameter was correlated with the number of months elapsed between CT acquisition and operation accomplishment. No linear spots were obtained, and no statistical correlation was found. Overall R^2 value, obtained as an overall evaluation for all parameters, resulted to be 0.00000077474.

Comparison with intra-operative findings allowed evaluating reliability of CT, expressed as specificity, sensibility, positive and negative predictive value. All results are schematized in Table 1. Examples of CT and intra-operative findings are shown in Figs. 1, 2, 3, 4, 5, 6.

Discussion

The present study analyses the correlation between pre-operative CT scans and intra-operative findings (the radio-surgical agreement) in a group of pediatric patients affected by cholesteatoma.

The role of CT of the temporal bone in chronic ear disease, and specifically in cholesteatoma, is multi-faceted: first, it is a diagnostic tool; as reported by Chee and Mafee, cholesteatoma can be accurately diagnosed by high-resolution CT scan in the vast majority of cases [8, 9]. CT findings consistent with cholesteatoma are a homogeneous soft tissue mass, scutum erosion, aditus ad antrum widening, dislocation and/or erosion of the ossicular chain, labyrinthine fistula, fallopian canal dehiscence, tegmen erosion, mastoid enlargement, sigmoid plate dehiscence and external auditory canal roof erosion [8, 10–12].

However, others have underlined how CT cannot always differentiate cholesteatoma from other soft-tissue densities

Table 1 CT and intra-operative results among all 28 operated ears

Analyzed structures	CT scan	Operation	p value	Fisher	R^2	SNS (%)	SPC (%)	PPV (%)	NPV (%)
Malleus	9	11	0.7825	–	0.0047	82	94	90	89
Incus	12	19	0.0573	–	0.1809	55	75	85	40
Stapes	8	10	0.5770	0.7878	0.0065	64	88	78	79
Tegmen	2	3	0.6393	1	0.000002814	0	92	0	88
LSC	1	1	1	1	0.0013	0	96	0	96
Fallopian canal	5	6	1	1	0.0534	33	82	33	82
Scutum	9	8	0.7713	–	0.0281	50	75	44	79
Antrum	14	14	0.4200	–	0.1688	71	69	71	69
Mastoid[a]	19	8	0.1228	–	0.0859	100	62	62	100

CT-scan cholesteatoma involvement as found in pre-operative CT-scan, *Operation* cholesteatoma involvement as found intra-operatively, *Fisher p* value according to Fisher's exact test, R^2 square R value in calculated linear regression, *LSC* lateral semicircular canal, *SNS* sensitivity, *SPC* specificity, *PPV* positive predictive value, *NPV* negative predictive value

[a]Mastoid involvement was analyzed among 21 ears

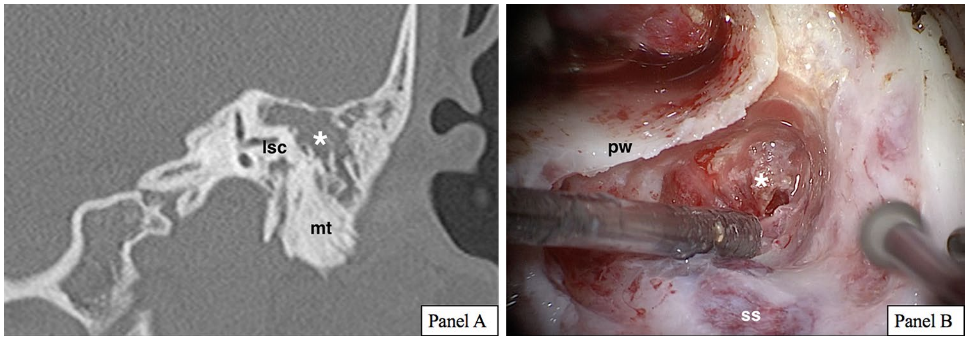

Fig. 1 Mastoid involvement was present in pre-operative CT images (**a**). The same result was confirmed by the intra-operative finding (**b**). The star indicates the cholesteatoma. *mt* mastoid tip, *lsc* lateral semicircular canal, *pw* posterior wall of the external auditory canal, *ss* sigmoid sinus

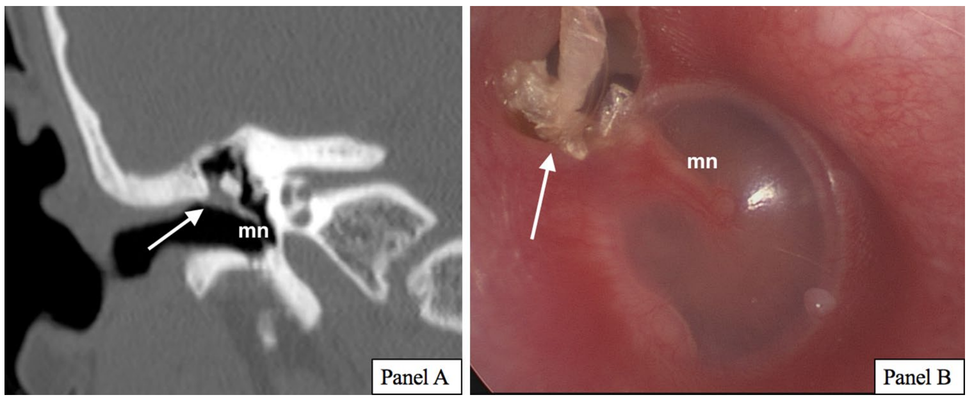

Fig. 2 An example of scutum erosion that was pre-operatively shown by CT images (**a**) and then confirmed by the intra-operative endoscopy (**b**). The arrow shows the scutum erosion. *mn* manubrium of the malleus

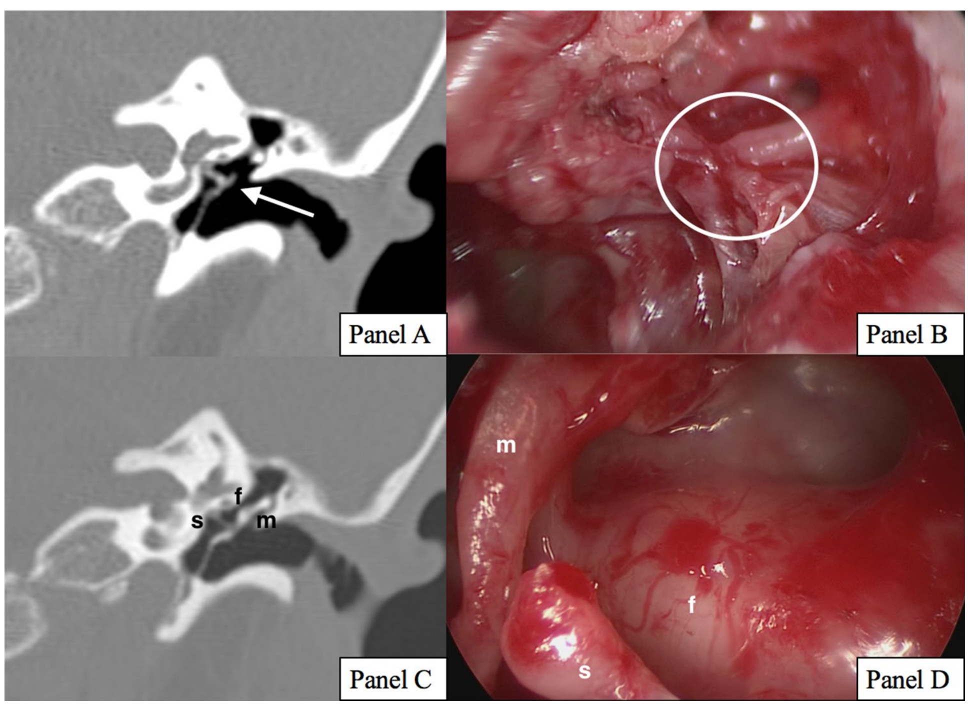

Fig. 3 The pre-operative imaging (**a**, **c**) showed integrity of the malleus, the stapes and the facial nerve. The incus was enveloped but not eroded by cholesteatoma and the incudo-stapedial joint was preserved (arrow in **a**). Intra-operatively, erosion of the long process of the incus was found with no contact between incus and stapes (circle in **b**), whereas, after cholesteatoma removal, the other structures resulted to be intact (**d**). *s* stapes, *m* malleus, *f* facial nerve

within the middle ear and mastoid, such as granulation tissue, mucosal edema, effusion or cholesterol granuloma, since the attenuation value of CT is similar for all these conditions [2, 11]. This could lead to misdiagnosis or overestimation of the extent of an actual cholesteatoma. Limitations of CT scan in detecting very early or limited diseases should also be pointed out.

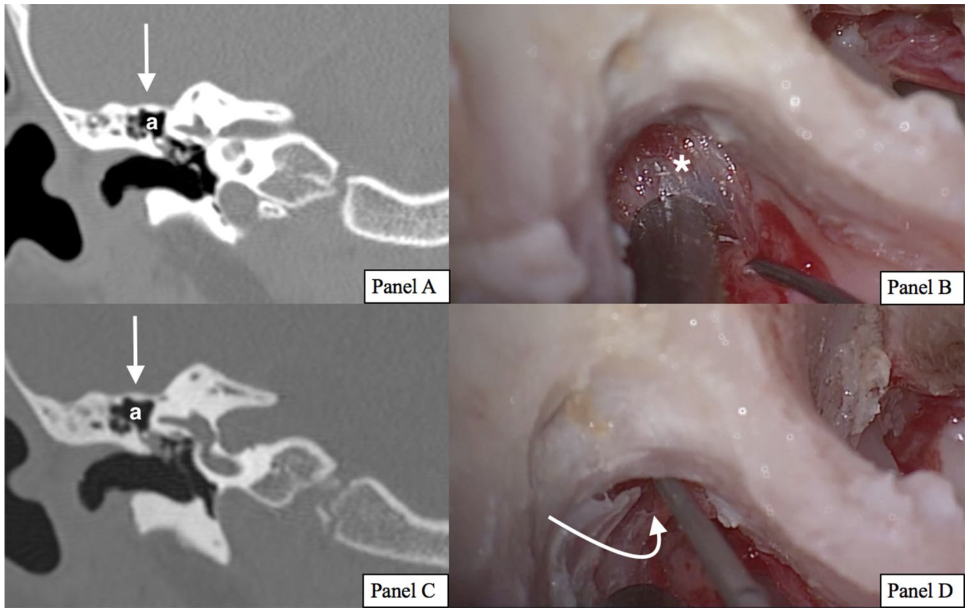

Fig. 4 CT images show involvement of the epitympanum, with preservation of antrum and tegmen ("a" and straight arrows in **a** and **c**). During surgery, epidermization of the antrum was found (star in **b**), as well as tegmen erosion (curved arrow in **d**). *a* antrum

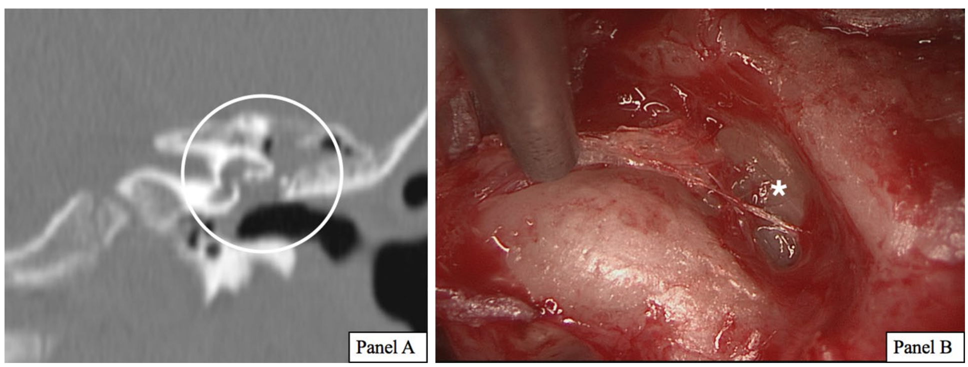

Fig. 5 **a** Shows a cholesteatoma involving the antrum and the middle ear, with erosion of the ossicular chain (circle). **b** Shows the result after cholesteatoma removal: the stapes was almost completely eroded and the base only (white star) was present

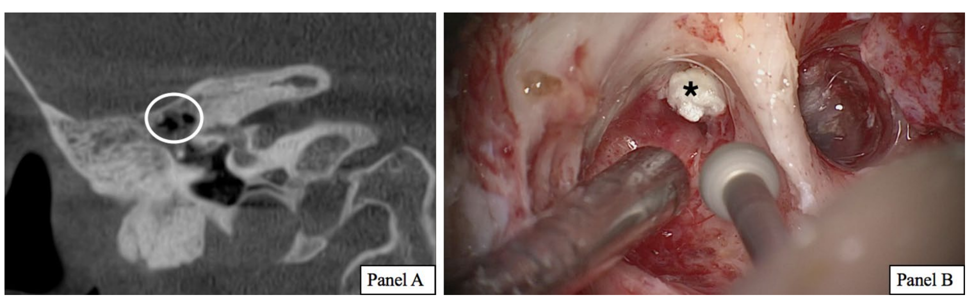

Fig. 6 Pre-operative imaging showed partial antrum involvement by a cholesteatoma, leaving some free space (circle in **a**). On the other hand, a complete obstruction of the antrum was determined by cholesteatoma as shown by intra-operative images (star in **b**)

The authors ultimately believe that CT imaging has always to be correlated with otoscopic/otoendoscopic findings and clinical history, bearing in mind that a definitive diagnosis of cholesteatoma could be confirmed only after surgical exploration [2, 8].

Second, pre-operative CT scan gives an overview of the anatomy of the middle ear and temporal bone, distinguishing involved and intact structures, and also guiding the best and safer surgical access. For example, CT scan may show a high or dehiscent jugular bulb or a highly pneumatized mastoid, which the surgeon must consider when performing a retroauricular approach. For the tendency of cholesteatoma to invade hidden recesses (such as the sinus tympani or the epitympanum), it is of help to assess these areas pre-operatively through the CT scan.

In children especially, it also demonstrates anatomic abnormalities of the skull base, responsible for a dysfunctional nose–rhinopharynx–Eustachian tube system that may play a role in the pathophysiology of PedC [2].

At last, CT images pre-operatively show the extension and erosive effects of cholesteatoma on the surrounding structures. Latter are the most crucial aspects for the surgeon in choosing the timing of surgery, the surgical technique and possibly predicting the surgical outcomes. If the CT scan shows an extensive complicated cholesteatoma, the decision could be to operate the patient promptly, whereas in cases where the CT is suggestive for a small epitympanic congenital cholesteatoma, the exploratory tympanotomy could be delayed. This is also important in patients' counselling.

Interestingly, controversy still exists about the predictive value of pre-operative CT imaging for cholesteatoma and the need for routinely perform it in uncomplicated cases [8].

In the present paper, the authors focused on a pediatric population because PedC is a highly relevant condition for the otologists: it is known to be more extensive and destructive than in adults and its treatment strategy, as well as follow-up, is challenging. Surprisingly, data about the role of CT in the assessment of PedC are lacking.

Results from our pediatric cohort have shown no statistically significant differences between CT findings and intra-operative features. Our investigation suggests that preoperative CT has a high predictive value over localization, extent and erosive effects of cholesteatoma, compared to intra-operative findings. Similar results have been reported from studies on adult or mixed (adults and children) cholesteatoma populations [8, 10, 12–18].

Ossicular chain (OC) and scutum

Some degree of OC and scutum erosion might be seen in several forms of chronic otitis media, not only in cholesteatoma. In the latter, OC erosion is very common and the long process of the incus and of the suprastructure of the stapes is the post common ossicular structures involved, followed by the body of the incus and the malleus. These findings have been seen also in children [2].

The erosion of the scutum is demonstrated at an early stage in primary acquired cholesteatoma of the pars flaccida, as a consequence of the close anatomical relationships between these structures. NG and colleagues suggested that the malleus head and incus body are best assessed on axial images, while the handle of the malleus and long process of the incus are better seen in coronal sections [18].

Our results showed a correlation between CT scan imaging and intra-operative status of the malleus, the incus and the stapes, as already reported by similar studies on adults [8, 9, 18]. Even if in some cases sensitivity and negative predictive values were not high (e.g., 55% and 64% sensitivity for incus and stapes, and 40% negative predictive value for incus), overall CT imaging showed to be reliable.

Pre-operative knowledge of the OC status may provide useful information about the need of ossiculoplasty and may be predictive of hearing outcomes, even if strong evidence about the influence the OC damage on hearing after surgery is lacking [19].

Tegmen tympani

The tegmen tympani is better assessed in coronal slices. Tegmen dehiscence would represent a contraindication to endoscopic procedures since a two-handed technique would be necessary during surgical maneuvering to repair the defect [4]. In our cohort, in only two cases, radiology was suspect for tegmen erosion and intra-operatively no erosion was noted, leading to a 0% sensitivity and positive predictive value. In all other cases, no erosion was seen during surgery nor detected in the CT images pre-operatively, giving a high specificity and negative predictive value (92% and 88%, respectively).

Labyrinthine fistula (LabF)

If labyrinthine fistula is present as a result of erosion of the labyrinth bone from cholesteatoma, the surgeon should be cautious not to aggressively remove the matrix from that region. Some authors suggest leaving a residual disease over the fistula. One stage or planned second-stage procedures have been applied [20]. For anatomical reasons, LabF most commonly occurs as erosion of the wall of the lateral semicircular canal. In our series, one patient showed suspect LabF at CT images but without intra-operative findings (giving null positive predictive value but 96% specificity), and another showed no erosion at CT, whereas it was found during operation (leading to a null sensitivity but a 96% negative predictive value).

Facial nerve (FN)

Facial nerve dehiscence or pathology-related absence of the fallopian canal is common in the middle two-thirds of the tympanic portion of the nerve [15]. This defect must raise awareness in the surgeon for the susceptibility of the nerve to injury during the procedure. High-resolution CT scan provides important information about FN anatomy, and its validity in assessing the intratympanic segment has been proved in our study as well as in similar ones [15, 17].

Magliulo et al. found that in patients younger than 16, as well as in previously un-operated patients, FN dehiscence is less commonly found [16]. They also reported that, compared to the past, the usefulness of CT in predicting FN intra-operative findings have improved, mostly thanks to better imaging techniques; however, their results remain fair, underlining the need of larger series of patients to better assess the sensitivity and specificity of high-resolution CT in this very topic.

Our results show no statistical significant difference in CT and intra-operative findings in assessing FN canal erosion. Specificity and negative predictive values, indeed, resulted to be 82%. A possible reason for this result can be that in our case series, only five patients showed FN canal erosion in CT-scan and six during operation. This fact is in agreement with the above-mentioned article [16], and so further studies are needed.

Antrum and mastoid involvement

Extension of the cholesteatoma into the mastoid process via the aditus ad antrum determines a widening of the aditus and, invading the air cells, it leads to the formation of a sharply marginated cavity within the mastoid itself, which is highly suggestive for cholesteatoma on CT images [2]. CT is fundamental in determining the extent of mastoid cells to be removed to avoid disease recurrence [11], but more importantly, to plan the surgical approach and the type of surgery (canal wall up vs canal wall down).

The microscopic/endoscopic approach is first dependent on the status of the mastoid. In selected cases, where the mastoid is sclerotic and/or only the antrum is involved by cholesteatoma, removal of the disease could be achieved with exclusively endoscopic technique. On the other hand, cases where mastoid involvement is present in pre-operative CT scans, microscopic technique should be selected from the beginning of surgery [4].

Even regarding these aspects, CT resulted to be reliable overall, with no statistically significant differences with videos (p value equal to 0.4 for antrum and to 0.1 for mastoid involvement). Regarding antrum involvement, sensibility, specificity, positive and negative predictive values resulted to be about 70% (69–71%). As mentioned in the "methods" paragraph, mastoid involvement was analyzed in 21 cases, and analysis showed 62% specificity and positive predictive value, and 100% sensibility and negative predictive values.

Further data collection would be needed to confirm the pre-operative value of CT scan in PedC, ideally involving larger cohorts of patients from different otologic centers. Result enlargement would be needed especially for rarely found aspects in our series (e.g. tegmen erosion, lateral semicircular canal and facial nerve involvement).

Our findings are based mainly on early stage or uncomplicated cases of cholesteatoma; further research should examine how temporal bone CT imaging is accurate in assessing the extension and the severity of advanced or complicated cholesteatoma.

Conclusion

Based on our study, pre-operative temporal bone CT scan is a valuable tool for the assessment of pediatric patient candidates for cholesteatoma surgery given the absence of statistically significant differences between radiologic and intra-operative findings. Thus, as in adult population, the present findings might support the indication to routinely perform temporal bone CT scan in children with cholesteatoma as part of pre-surgical plan.

Compliance with ethical standards

Conflict of interest The authors have no conflicts of interest, funding or financial relationships. The manuscript has not been submitted to more than one journal for simultaneous consideration. The manuscript has not been published previously (partly or in full). All of the authors have participated in the planning, writing or revising the manuscript.

Informed consent An informed consent has been obtained for any procedure involving the patients described in this article.

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