

Original Research Article

HIGH-RESOLUTION COMPUTED TOMOGRAPHY EVALUATION OF TEMPORAL BONE INVOLVEMENT AND COMPLICATIONS IN PATIENTS WITH CHOLESTEATOMA

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ABSTRACT

Background: Cholesteatoma is a locally destructive lesion of the middle ear and mastoid that may erode the ossicular chain and extend into adjacent temporal-bone structures. Accurate preoperative assessment of its anatomical extent and associated complications is essential for surgical planning. HRCT provides detailed visualization of the complex bony anatomy of the temporal bone. The aim is to evaluate temporal-bone involvement and associated complications using high-resolution computed tomography in patients with cholesteatoma.

Materials and Methods: This hospital-based observational cross-sectional study included 51 patients with clinically suspected or confirmed cholesteatoma. Thin-section HRCT images of the temporal bones were obtained and evaluated for soft-tissue characteristics, involvement of the middle-ear and mastoid compartments, ossicular erosion, scutum and Koerner's septum erosion, facial nerve canal involvement, labyrinthine fistula, tegmen erosion and sigmoid sinus plate erosion. HRCT findings were compared with intraoperative findings. Categorical data were presented as frequencies and percentages with 95% confidence intervals. Radiological-surgical agreement was assessed using Cohen's kappa coefficient. A p value below 0.05 was considered statistically significant.

Results: Mastoid sclerosis was present in all 51 patients (100.0%), while non-dependent soft-tissue lesions were detected in 50 (98.0%) and homogeneous soft-tissue attenuation in 49 (96.1%). Ossicular chain erosion was present in 47 patients (92.2%), Koerner's septum erosion in 45 (88.2%), aditus widening in 44 (86.3%) and scutum erosion in 40 (78.4%). Mastoid antrum involvement was detected in 44 patients (86.3%), facial recess extension in 39 (76.5%), sinus tympani extension in 36 (70.6%) and protympanic extension in 33 (64.7%). The incus was the most frequently eroded ossicle (74.5%), followed by the stapes (64.7%) and malleus (41.2%). Facial nerve canal and lateral semicircular canal involvement occurred in 19.6% and 13.7%, respectively. Labyrinthine fistula was present in 5.9%, tegmen erosion in 3.9% and sigmoid plate erosion in 2.0%. Overall HRCT-surgical agreement was 96.1%. Agreement was excellent for the labyrinth ($\kappa=0.922$), incus ($\kappa=0.891$), malleus ($\kappa=0.881$) and stapes ($\kappa=0.819$), and substantial for the facial nerve canal ($\kappa=0.648$); all $p<0.001$.

Conclusion: HRCT accurately demonstrated the extent of cholesteatoma and its associated bony complications. It showed excellent agreement with operative findings for ossicular and labyrinthine involvement and provided a valuable anatomical roadmap for surgical planning. Subtle facial canal and stapes

abnormalities remained relatively difficult to assess, and surgical findings continued to represent the definitive standard.

Keywords: Cholesteatoma; High-resolution computed tomography; Temporal bone.

INTRODUCTION

Cholesteatoma is a non-neoplastic, locally destructive lesion characterized by the presence of keratinizing stratified squamous epithelium within the middle ear cleft or other pneumatized portions of the temporal bone. It may be congenital or acquired, with acquired cholesteatoma commonly developing through tympanic membrane retraction, epithelial migration or implantation. Although histologically benign, cholesteatoma can progressively expand and cause erosion of adjacent bony structures through pressure effects, chronic inflammation and enzymatic osteolysis. Patients frequently present with persistent or recurrent foul-smelling otorrhoea, hearing impairment, earache, tinnitus or vertigo. Otoscopic examination remains essential for clinical diagnosis; however, it may not adequately demonstrate the complete extent of disease, particularly when the external auditory canal is narrowed or obstructed by discharge, granulation tissue or keratinous debris.^[1,2] High-resolution computed tomography (HRCT) of the temporal bone is an important imaging modality for the preoperative evaluation of cholesteatoma. Its excellent spatial resolution and ability to distinguish bone, air and soft tissue allow accurate assessment of the complex anatomy of the middle and inner ear. On HRCT, cholesteatoma usually appears as a non-enhancing soft-tissue-density lesion associated with characteristic bony erosion. Depending on its site of origin and direction of spread, the lesion may involve the Prussak space, epitympanum, mesotympanum, hypotympanum, aditus ad antrum, mastoid antrum and mastoid air cells. Widening of the aditus, erosion of the scutum and ossicular destruction are common imaging findings.^[2,3]

The primary clinical importance of HRCT lies in defining disease extent and identifying complications before surgery. Cholesteatoma can erode the ossicular chain, facial nerve canal, tegmen tympani, sigmoid sinus plate and semicircular canals. Potential complications include conductive or sensorineural hearing loss, facial nerve palsy, labyrinthine fistula, mastoiditis, intracranial abscess, meningitis and lateral sinus thrombosis. HRCT can also demonstrate surgically relevant anatomical variations, such as a low-lying tegmen, high-riding jugular bulb, anteriorly positioned sigmoid sinus or aberrant facial nerve canal, thereby reducing the risk of inadvertent intraoperative injury.^[3-5]

Aim

To evaluate temporal bone involvement and associated complications using high-resolution computed tomography in patients with cholesteatoma.

Objectives

1. To determine the location and extent of middle-ear and mastoid involvement in patients with cholesteatoma using HRCT.
2. To identify bony erosions and complications involving the ossicular chain, facial nerve canal, labyrinth, tegmen tympani and sigmoid sinus plate.
3. To assess the usefulness of HRCT in the preoperative evaluation and surgical planning of patients with cholesteatoma.

MATERIALS AND METHODS

Source of Data: The study participants were recruited from patients attending the Department of Otorhinolaryngology with clinical symptoms and otoscopic findings suggestive of cholesteatoma. Patients with persistent or recurrent otorrhoea, hearing impairment, retraction of the posterosuperior tympanic membrane, attic perforation, keratinous debris or an otoscopically visible cholesteatoma were referred to the Department of Radiodiagnosis for HRCT examination of the temporal bones.

Study Design: This was a hospital-based observational cross-sectional study.

Study Location: The study was conducted in the Department of Radiodiagnosis in collaboration with the Department of Otorhinolaryngology at Great Eastern Medical School and Hospital, Ragolu, Srikakulam, Andhra Pradesh.

Study Duration: The study was conducted over a period of 18 months.

Sample Size: A total of 51 patients who fulfilled the eligibility criteria were included. The sample size was estimated using a 95% confidence level, a 5% absolute margin of error and an anticipated population proportion of 3.4%. Consecutive eligible patients presenting during the study period were enrolled until the required sample size was achieved.

Inclusion Criteria

The study included:

1. Patients clinically suspected or diagnosed with congenital or acquired cholesteatoma.
2. Patients of either sex and all eligible age groups.
3. Patients referred for HRCT of the temporal bone for suspected or confirmed cholesteatoma.
4. Patients who had not undergone previous surgical treatment for cholesteatoma.
5. Patients with adequate clinical history and medical records.
6. Patients who provided written informed consent.
7. For participants below the legally permissible age, patients whose parents or legally authorised representatives provided consent and who provided assent wherever applicable.

Exclusion Criteria

The following patients were excluded:

1. Patients with a history of previous ear or mastoid surgery that could alter normal temporal bone anatomy.
2. Patients with middle-ear tumours, severe otosclerosis or other pathological conditions that could interfere with HRCT interpretation.
3. Patients whose HRCT images showed severe motion or metallic artefacts that prevented adequate assessment.
4. Pregnant women because of the potential risk associated with ionising radiation.
5. Patients with cochlear implants or other metallic implants in the temporal region producing substantial imaging artefacts.
6. Patients who were unwilling or unable to provide informed consent.
7. Patients whose clinical or imaging information was incomplete.

Data Collection: Data were collected using a predesigned and pretested case-record form. Information regarding age, sex, presenting symptoms, duration of illness, affected ear, previous treatment, otoscopic findings and provisional clinical diagnosis was recorded. Relevant symptoms, including otorrhoea, hearing impairment, otalgia, tinnitus, vertigo, headache and facial weakness, were documented.

HRCT findings were recorded systematically for the side, location and extent of the lesion; involvement of the epitympanum, mesotympanum, hypotympanum, aditus, antrum and mastoid air cells; mastoid pneumatization; and erosion of adjacent bony structures. Each patient was assigned a unique study identification number, and confidentiality was maintained throughout the study.

Procedure and Methodology: After obtaining informed consent, patients underwent a detailed clinical assessment and otoscopic examination in the Department of Otorhinolaryngology. The indication for HRCT was verified, and relevant clinical information was recorded.

All examinations were performed using a Siemens helical CT scanner. Before scanning, patients were instructed to remove metallic objects, including earrings, jewellery, hearing aids and hair accessories, which could produce artefacts. Patients were adequately counselled to remain still during image acquisition. Mild sedation was considered in paediatric or uncooperative patients according to institutional protocol and under appropriate clinical supervision.

For axial acquisition, the patient was positioned supine with the head immobilized and the neck flexed. The scan plane was aligned approximately 30° to pass parallel to the external auditory canal and supraorbital margin. When direct coronal imaging was performed, the patient was positioned prone with maximum safe neck extension, and the scanning plane was oriented through the external auditory meatus parallel to the posterior margin of the maxillary sinus. When direct coronal acquisition was

not feasible, coronal and sagittal images were reconstructed from thin-section axial data.

The CT acquisition parameters included a 512 × 512 matrix, field of view of approximately 15-20 cm, 1-mm slice thickness, tube voltage of 120 kV, tube current of approximately 100 mA and pitch of 1. Images were reconstructed using a high-resolution bone algorithm. Magnification factors of approximately 1.7-2.0 were used for bilateral evaluation, while higher magnification was employed when detailed examination of an individual temporal bone was required. Both temporal bones were evaluated to allow comparison with the contralateral side. Intravenous contrast was not routinely administered but was reserved for patients in whom an intracranial, vascular or suppurative complication was suspected.

Image Evaluation: The HRCT images were reviewed in axial and coronal planes using appropriate bone and soft-tissue windows. The site and extent of the soft-tissue-density lesion were assessed in the following anatomical regions:

- External auditory canal
- Prussak space and epitympanum
- Mesotympanum and hypotympanum
- Sinus tympani and facial recess
- Aditus ad antrum
- Mastoid antrum and mastoid air cells

The following HRCT features were specifically evaluated:

1. Soft-tissue opacity in the middle ear or mastoid cavity.
2. Erosion or blunting of the scutum.
3. Widening of the aditus ad antrum.
4. Displacement, erosion or destruction of the malleus, incus and stapes.
5. Erosion or dehiscence of the facial nerve canal.
6. Erosion of the tegmen tympani or tegmen mastoideum.
7. Labyrinthine fistula involving the lateral, superior or posterior semicircular canal.
8. Involvement of the vestibule or cochlea.
9. Mastoid sclerosis, coalescence or automastoidectomy.
10. Erosion or dehiscence of the sigmoid sinus plate.
11. Extension into the external auditory canal or petrous apex.
12. Evidence of extracranial or intracranial complications.

An HRCT diagnosis of cholesteatoma was considered when a non-dependent soft-tissue-density lesion was accompanied by characteristic bony erosion, expansion or displacement of adjacent structures. Relevant anatomical variations that could influence the surgical approach were also documented.

Sample Processing: As this was a radiological imaging study, no blood, tissue or other biological specimen was routinely collected or processed. The “sample” consisted of HRCT image datasets and corresponding clinical information. The acquired

images were reconstructed using a bone-specific algorithm and reviewed on the CT workstation. Multiplanar reconstructions were generated whenever required. Images were anonymized, labelled with study identification numbers and stored digitally in the institutional imaging archive. In cases undergoing surgery, HRCT findings could be documented alongside available intraoperative observations for clinicoradiological assessment.

Statistical Methods: The collected data were entered into Microsoft Excel and analysed using an appropriate statistical software package. Continuous variables such as age and duration of symptoms were summarized using mean and standard deviation or median and interquartile range, depending on data distribution. Categorical variables, including sex, presenting symptoms, site of involvement, bony erosion and complications, were expressed as frequencies and percentages.

Where surgical findings were available, the diagnostic performance of HRCT was assessed using sensitivity, specificity, positive predictive value, negative predictive value and overall accuracy, along with 95% confidence intervals. Agreement between HRCT and intraoperative findings was evaluated using Cohen's kappa coefficient. Associations between categorical variables were examined using the chi-square test or Fisher's exact test, as appropriate. A p value of <0.05 was considered statistically significant.

Ethical Considerations: The study was conducted after obtaining approval from the Institutional Ethics Committee. Written informed consent was obtained from every adult participant or from the parent or

legally authorised representative of a minor. Assent was obtained from eligible children wherever applicable. Patient confidentiality was maintained, and HRCT examinations were performed using dose-optimization principles.

RESULTS

[Table 1] presents the overall HRCT findings among 51 patients with cholesteatoma. Mastoid sclerosis was identified in all 51 patients (100.0%; 95% CI: 93.0-100.0), while a non-dependent or fixed soft-tissue lesion was found in 50 (98.0%; 95% CI: 89.6-100.0). Homogeneous soft-tissue attenuation was observed in 49 patients (96.1%), and 47 (92.2%) had an expansile lesion with smooth bony expansion. Ossicular chain erosion was also detected in 47 patients (92.2%; 95% CI: 81.1-97.8). Other frequent destructive findings included Koerner's septum erosion in 45 (88.2%), widening of the aditus ad antrum in 44 (86.3%) and scutum erosion in 40 patients (78.4%). Facial nerve canal involvement was present in 10 (19.6%), semicircular canal involvement in seven (13.7%) and tegmen tympani erosion in two patients (3.9%). Sigmoid sinus plate erosion and automastoidectomy were each detected in one patient (2.0%). All findings showed a statistically significant difference from the reference prevalence of 50% ($p<0.001$), demonstrating that mastoid sclerosis, ossicular erosion, Koerner's septum erosion and aditus widening were particularly characteristic HRCT findings in this study.

Table 1: Overall HRCT profile of temporal bone involvement and associated complications in patients with cholesteatoma (N=51)

HRCT finding	Present, n (%)	Absent, n (%)	Prevalence, 95% CI	z value	p value
Homogeneous soft-tissue attenuation	49 (96.1)	2 (3.9)	86.5-99.5	6.58	<0.001
Non-dependent/fixed soft-tissue lesion	50 (98.0)	1 (2.0)	89.6-100.0	6.86	<0.001
Expansile lesion with smooth bony expansion	47 (92.2)	4 (7.8)	81.1-97.8	6.02	<0.001
Mastoid sclerosis	51 (100.0)	0 (0.0)	93.0-100.0	7.14	<0.001
Ossicular chain erosion	47 (92.2)	4 (7.8)	81.1-97.8	6.02	<0.001
Aditus ad antrum widening	44 (86.3)	7 (13.7)	73.7-94.3	5.18	<0.001
Scutum erosion	40 (78.4)	11 (21.6)	64.7-88.7	4.06	<0.001
Koerner's septum erosion	45 (88.2)	6 (11.8)	76.1-95.6	5.46	<0.001
Facial nerve canal involvement	10 (19.6)	41 (80.4)	9.8-33.1	-4.34	<0.001
Semicircular canal involvement	7 (13.7)	44 (86.3)	5.7-26.3	-5.18	<0.001
Tegmen tympani erosion	2 (3.9)	49 (96.1)	0.5-13.5	-6.58	<0.001
Sigmoid sinus plate erosion	1 (2.0)	50 (98.0)	0.0-10.4	-6.86	<0.001
Automastoidectomy	1 (2.0)	50 (98.0)	0.0-10.4	-6.86	<0.001

Table 2: Location and extent of middle-ear and mastoid involvement detected using HRCT (N=51)

Anatomical location or extent	Involved, n (%)	Not involved, n (%)	Prevalence, 95% CI	z value	p value
Partial occupation of middle-ear cavity and antrum	41 (80.4)	10 (19.6)	66.9-90.2	4.34	<0.001
Complete occupation of middle-ear cavity	6 (11.8)	45 (88.2)	4.4-23.9	-5.46	<0.001
Disease restricted to attic and mastoid antrum	4 (7.8)	47 (92.2)	2.2-18.9	-6.02	<0.001
Mastoid antrum involvement	44 (86.3)	7 (13.7)	73.7-94.3	5.18	<0.001
Expansion of mastoid antrum	38 (74.5)	13 (25.5)	60.4-85.7	3.50	<0.001
Smooth partial bony erosion of mastoid antrum	12 (23.5)	39 (76.5)	12.8-37.5	-3.78	<0.001
Obstruction of protympanic/Eustachian tube pathway	38 (74.5)	13 (25.5)	60.4-85.7	3.50	<0.001
Facial recess extension	39 (76.5)	12 (23.5)	62.5-87.2	3.78	<0.001
Sinus tympani extension	36 (70.6)	15 (29.4)	56.2-82.5	2.94	0.005
Protympanic extension	33 (64.7)	18 (35.3)	50.1-77.6	2.10	0.049
External auditory canal extension	11 (21.6)	40 (78.4)	11.3-35.3	-4.06	<0.001
Acellular/sclerotic mastoid	34 (66.7)	17 (33.3)	52.1-79.2	2.38	0.024

[Table 2] demonstrates the location and extent of cholesteatoma within the middle ear and mastoid. Mastoid antrum involvement was observed in 44 patients (86.3%; 95% CI: 73.7-94.3; $z=5.18$, $p<0.001$), while partial occupation of the middle-ear cavity and antrum was present in 41 (80.4%; 95% CI: 66.9-90.2; $z=4.34$, $p<0.001$). Facial recess extension occurred in 39 patients (76.5%), and both mastoid antrum expansion and obstruction of the protympanic/Eustachian tube pathway were observed in 38 patients each (74.5%). Extension into the sinus

tympani was found in 36 patients (70.6%; $p=0.005$), whereas protympanic extension was detected in 33 (64.7%; $p=0.049$). An acellular or sclerotic mastoid was present in 34 patients (66.7%; 95% CI: 52.1-79.2; $p=0.024$). Less frequent findings included smooth partial erosion of the mastoid antrum in 12 (23.5%), external auditory canal extension in 11 (21.6%), complete occupation of the middle-ear cavity in six (11.8%) and disease restricted to the attic and mastoid antrum in four patients (7.8%).

Table 3: Bony erosions and complications involving important temporal bone structures on HRCT (N=51)

Bony erosion/complication	Present, n (%)	Absent, n (%)	Prevalence, 95% CI	z value	p value
Any ossicular chain erosion	47 (92.2)	4 (7.8)	81.1-97.8	6.02	<0.001
Incus erosion	38 (74.5)	13 (25.5)	60.4-85.7	3.50	<0.001
Stapes erosion	33 (64.7)	18 (35.3)	50.1-77.6	2.10	0.049
Malleus erosion	21 (41.2)	30 (58.8)	27.6-55.8	-1.26	0.262
Medial displacement of ossicular chain	11 (21.6)	40 (78.4)	11.3-35.3	-4.06	<0.001
Lateral displacement of ossicular chain	2 (3.9)	49 (96.1)	0.5-13.5	-6.58	<0.001
Any facial nerve canal involvement	10 (19.6)	41 (80.4)	9.8-33.1	-4.34	<0.001
Partial facial nerve canal erosion	7 (13.7)	44 (86.3)	5.7-26.3	-5.18	<0.001
Complete facial nerve canal destruction	3 (5.9)	48 (94.1)	1.2-16.2	-6.30	<0.001
Any lateral semicircular canal involvement	7 (13.7)	44 (86.3)	5.7-26.3	-5.18	<0.001
Partial lateral semicircular canal erosion	4 (7.8)	47 (92.2)	2.2-18.9	-6.02	<0.001
Labyrinthine fistula	3 (5.9)	48 (94.1)	1.2-16.2	-6.30	<0.001
Tegmen tympani erosion/dehiscence	2 (3.9)	49 (96.1)	0.5-13.5	-6.58	<0.001
Sigmoid sinus plate erosion	1 (2.0)	50 (98.0)	0.0-10.4	-6.86	<0.001
Scutum erosion	40 (78.4)	11 (21.6)	64.7-88.7	4.06	<0.001
Scutum blunting/partial erosion	32 (62.7)	19 (37.3)	48.1-75.9	1.82	0.092
Complete scutum destruction	8 (15.7)	43 (84.3)	7.0-28.6	-4.90	<0.001
Koerner's septum erosion	45 (88.2)	6 (11.8)	76.1-95.6	5.46	<0.001
Partial Koerner's septum erosion	30 (58.8)	21 (41.2)	44.2-72.4	1.26	0.262
Complete Koerner's septum erosion	15 (29.4)	36 (70.6)	17.5-43.8	-2.94	0.005

[Table 3] summarizes the bony erosions and complications detected using HRCT. Ossicular chain erosion was the predominant complication, affecting 47 patients (92.2%; 95% CI: 81.1-97.8; $z=6.02$, $p<0.001$). Among the individual ossicles, the incus was most frequently eroded in 38 patients (74.5%; $p<0.001$), followed by the stapes in 33 (64.7%; $p=0.049$) and the malleus in 21 patients (41.2%; $p=0.262$). Thus, malleus erosion did not differ significantly from the reference prevalence. Medial ossicular displacement was identified in 11 patients (21.6%), whereas lateral displacement was uncommon, occurring in only two (3.9%). Facial nerve canal involvement was observed in 10 patients (19.6%), comprising seven cases of partial erosion and three cases of complete destruction. Lateral

semicircular canal involvement occurred in seven patients (13.7%), including four with partial erosion and three with a labyrinthine fistula. Tegmen tympani erosion was identified in two patients (3.9%), and sigmoid sinus plate erosion was detected in one (2.0%). Scutum erosion occurred in 40 patients (78.4%), including 32 with partial erosion or blunting and eight with complete destruction. Koerner's septum erosion was detected in 45 patients (88.2%), comprising 30 with partial erosion and 15 with complete erosion. Overall, HRCT demonstrated extensive ossicular, scutal and Koerner's septum destruction, while potentially serious facial nerve, labyrinthine, tegmental and sigmoid plate complications were less common.

Table 4: Agreement between preoperative HRCT and intraoperative findings in cholesteatoma (N=51)

Structure assessed	HRCT-surgical agreement, n (%)	Agreement, 95% CI	Cohen's κ (95% CI)	z value for κ	p value
Malleus	48 (94.1)	83.8-98.8	0.881 (0.730-1.000)	13.18	<0.001
Incus	49 (96.1)	86.5-99.5	0.891 (0.707-1.000)	11.46	<0.001
Stapes	47 (92.2)	81.1-97.8	0.819 (0.631-0.958)	9.37	<0.001
Facial nerve canal	44 (86.3)	73.7-94.3	0.648 (0.380-0.862)	5.18	<0.001
Labyrinth/lateral semicircular canal	50 (98.0)	89.6-100.0	0.922 (0.697-1.000)	10.35	<0.001
Overall diagnostic agreement	49 (96.1)	86.5-99.5		6.58†	<0.001

†One-sample proportion z value for overall agreement compared with 50% agreement.

[Table 4] shows the agreement between preoperative HRCT and intraoperative findings. The highest

agreement was obtained for labyrinthine or lateral semicircular canal involvement, for which HRCT agreed with surgery in 50 of 51 patients (98.0%; 95% CI: 89.6-100.0). The corresponding kappa coefficient

was 0.922 (95% CI: 0.697-1.000; $z=10.35$, $p<0.001$), indicating excellent agreement. Agreement was also excellent for the incus at 96.1% ($\kappa=0.891$; 95% CI: 0.707-1.000), malleus at 94.1% ($\kappa=0.881$; 95% CI: 0.730-1.000) and stapes at 92.2% ($\kappa=0.819$; 95% CI: 0.631-0.958); all comparisons were statistically significant at $p<0.001$. Facial nerve canal assessment showed comparatively lower agreement of 86.3%, with a kappa coefficient of 0.648 (95% CI: 0.380-0.862; $p<0.001$), indicating substantial agreement but some difficulty in detecting subtle dehiscence. The overall diagnostic agreement between HRCT and surgical findings was 96.1% (95% CI: 86.5-99.5; $z=6.58$, $p<0.001$).

DISCUSSION

The present study evaluated HRCT findings and their operative correlation in 51 patients with cholesteatoma. HRCT demonstrated a characteristic pattern comprising non-dependent soft-tissue attenuation, smooth expansion of the middle-ear spaces and erosion of adjacent bony structures. These findings support the established role of HRCT as the principal imaging modality for mapping the anatomical extent and bony complications of cholesteatoma before surgery. Kuo et al. (2015),^[1] described cholesteatoma as a locally destructive condition capable of producing extensive intratemporal complications when diagnosis and treatment are delayed. Similarly, Thukral et al. (2015),^[2] emphasized that thin-section HRCT provides excellent delineation of temporal-bone anatomy and enables the detection of subtle bony erosion.

In the present study, homogeneous soft-tissue attenuation was observed in 96.1% of patients, a non-dependent or fixed lesion in 98.0%, and smooth bony expansion in 92.2%. Gulati et al. (2019),^[9] described a non-dependent soft-tissue mass in the middle ear, together with scutum and ossicular erosion, as a typical HRCT appearance of acquired cholesteatoma. However, they also emphasized that HRCT cannot reliably differentiate cholesteatoma from granulation tissue, mucosal oedema or effusion when characteristic bony destruction is absent. Therefore, the high prevalence of bone erosion in the present study strengthened the radiological diagnosis.

Mastoid sclerosis was observed in all patients, while an acellular or markedly sclerotic mastoid was identified in 66.7%. This likely reflected chronic Eustachian tube dysfunction and longstanding otomastoid inflammation. Chatterjee et al. (2015),^[4] reported that HRCT assessment of mastoid pneumatization, sclerosis, antral disease and anatomical variations provided important information for choosing the surgical approach. Bathla et al. (2018),^[6] similarly observed that temporal-bone HRCT was particularly useful in detecting disease extension and bony complications in atticointral chronic suppurative otitis media.

Mastoid antrum involvement was found in 86.3% of patients, with antral expansion in 74.5%. Partial occupation of the middle-ear cavity and antrum occurred in 80.4%, whereas complete middle-ear occupation occurred in only 11.8%. Facial recess, sinus tympani and protympanic extension were detected in 76.5%, 70.6% and 64.7%, respectively. These observations demonstrate the ability of cholesteatoma to spread into hidden recesses that may not be completely evaluated by routine otoscopy. Gulati et al. (2019),^[9] highlighted the value of HRCT in identifying disease within the anterior epitympanic recess, facial recess and sinus tympani. Poswal et al. (2018),^[7] also reported a useful correlation between preoperative HRCT and operative assessment of disease extension in squamous chronic otitis media.

Obstruction of the protympanic or Eustachian tube pathway was found in 74.5% of patients. Persistent Eustachian tube dysfunction can promote tympanic membrane retraction and contribute to the development and progression of acquired cholesteatoma. The external auditory canal was involved in 21.6%, suggesting more extensive disease in approximately one-fifth of the cases. Mandal et al. (2019),^[10] observed that HRCT had considerable predictive value in assessing attic, aditus, antral and mastoid involvement in atticointral disease.

Ossicular chain erosion was the most frequent destructive complication, affecting 92.2% of the study population. The incus was the most commonly eroded ossicle at 74.5%, followed by the stapes at 64.7% and malleus at 41.2%. The greater vulnerability of the incus can be explained by its exposed position, delicate long process and relatively poor blood supply. Kanotra et al. (2015),^[3] reported that HRCT correlated well with intraoperative findings for ossicular erosion and helped anticipate the requirement for ossicular reconstruction. Karki et al. (2017),^[5] and Dashottar et al. (2019),^[8] likewise documented good agreement between HRCT and surgical findings for ossicular involvement, although evaluation of the stapes was comparatively difficult because of its small size and surrounding soft-tissue opacity.

Scutum erosion was detected in 78.4% of patients, including complete destruction in 15.7%. Koerner's septum erosion was present in 88.2%, with complete erosion in 29.4%. Scutum erosion represents an important feature of pars flaccida cholesteatoma, whereas destruction of Koerner's septum and widening of the aditus suggest extension into the mastoid antrum. Mandal et al. (2019),^[10] reported that scutum erosion, aditus widening and ossicular destruction were among the most reliable HRCT indicators of atticointral disease. Singh et al. (2020),^[11] also found that HRCT effectively depicted the extent of unsafe chronic suppurative otitis media and showed good correlation with operative findings. Facial nerve canal involvement was identified in 19.6% of patients, comprising partial erosion in

13.7% and complete destruction in 5.9%. Preoperative recognition of facial canal involvement is important because an exposed or dehiscence facial nerve is vulnerable to injury during cholesteatoma removal. Nevertheless, HRCT evaluation can be difficult because of the canal's small size, oblique tympanic course, surrounding soft tissue and possible developmental dehiscence. This limitation was reflected by the relatively lower HRCT-operative agreement for the facial canal in the present study (86.3%; $\kappa=0.648$). Kataria et al. (2022),^[12] reported 85.71% sensitivity and 96.83% specificity for HRCT detection of facial canal dehiscence, supporting its usefulness while acknowledging that subtle defects may be missed or overestimated.

Lateral semicircular canal involvement was detected in 13.7%, including partial erosion in 7.8% and labyrinthine fistula in 5.9%. Cholesteatoma most commonly affects the lateral semicircular canal because of its anatomical proximity to the epitympanum and mastoid antrum. Preoperative detection is essential to minimize the risk of perilymphatic leakage, sensorineural hearing loss and postoperative vertigo. Kataria et al. (2022),^[12] reported 100% sensitivity and 98.51% specificity for detecting lateral semicircular canal erosion. The excellent HRCT-surgical agreement for labyrinthine involvement in the present study (98.0%; $\kappa=0.922$) further confirmed the value of HRCT for identifying this complication.

Tegmen tympani erosion and sigmoid sinus plate erosion were relatively uncommon, occurring in 3.9% and 2.0%, respectively. Although infrequent, these findings have major clinical relevance because they may indicate an increased risk of dural exposure, cerebrospinal fluid leakage, intracranial infection or vascular injury. Gulati et al. (2019),^[9] recommended systematic evaluation of the tegmen, sigmoid plate, facial nerve canal and bony labyrinth in every patient with cholesteatoma. Automastoidectomy was identified in one patient, reflecting advanced spontaneous bony destruction.

The overall agreement between HRCT and surgical findings was 96.1%. Excellent agreement was obtained for the malleus ($\kappa=0.881$), incus ($\kappa=0.891$), stapes ($\kappa=0.819$) and labyrinth ($\kappa=0.922$), while substantial agreement was obtained for the facial nerve canal ($\kappa=0.648$); all agreements were statistically significant at $p<0.001$. Singh et al. (2020),^[11] demonstrated close radiological-operative correlation in both paediatric and adult patients with unsafe chronic suppurative otitis media. Kataria et al. (2022),^[12] reported 92.31% sensitivity and 100% specificity for ossicular erosion and concluded that HRCT was useful for diagnosis, assessment of disease extent and surgical planning. Kapoor et al. (2023),^[13] also confirmed that HRCT findings correlated well with intraoperative observations and reduced unexpected findings during surgery.

Collectively, the study findings indicated that HRCT accurately mapped the location and extent of cholesteatoma, demonstrated ossicular and temporal-

bone destruction and detected surgically important complications. Its limitation in differentiating various soft-tissue lesions and detecting subtle facial canal or stapes abnormalities should, however, be recognized. Findings should therefore be interpreted with otoscopic, audiological and operative information, while diffusion-weighted MRI may be considered when differentiation of cholesteatoma from granulation tissue or postoperative recurrence is required.

CONCLUSION

High-resolution computed tomography was highly useful for evaluating the location, extent and complications of temporal-bone cholesteatoma. Mastoid sclerosis, ossicular erosion, Koerner's septum erosion, aditus widening and scutum erosion were the predominant findings. The incus was the most frequently eroded ossicle, followed by the stapes and malleus. HRCT also detected clinically important complications involving the facial nerve canal, lateral semicircular canal, tegmen tympani and sigmoid sinus plate.

HRCT demonstrated an overall agreement of 96.1% with intraoperative findings. Agreement was excellent for ossicular and labyrinthine involvement and substantial for facial nerve canal involvement. Thus, HRCT provided an accurate preoperative anatomical roadmap, facilitated selection of the surgical approach and helped surgeons anticipate potential complications. However, surgical exploration remained the definitive standard, especially for subtle facial canal and stapes abnormalities.

Limitations of Study:

1. The study was conducted at a single tertiary-care hospital, limiting the generalizability of the findings.
2. The sample size of 51 patients was relatively small, particularly for estimating uncommon complications such as tegmen and sigmoid plate erosion.
3. The cross-sectional design did not permit evaluation of disease progression, postoperative outcomes, residual disease or recurrence.
4. Patients referred to a tertiary centre may have had more advanced cholesteatoma, producing referral and spectrum bias and explaining the high prevalence of bony erosion.
5. HRCT had limited ability to differentiate cholesteatoma from granulation tissue, mucosal oedema, fibrosis and middle-ear effusion when characteristic bone erosion was absent.
6. Small structures such as the stapes and facial nerve canal were susceptible to partial-volume effects, which could result in underestimation or overestimation of erosion.
7. Developmental facial nerve canal dehiscence could not always be reliably differentiated from pathological erosion.

8. Interobserver and intraobserver reliability between radiologists was not evaluated.
9. The interval between HRCT examination and surgery was not incorporated into the analysis; disease progression during this interval could have produced radiological-operative discrepancies.
10. Diffusion-weighted MRI was not routinely used to confirm equivocal soft-tissue findings.
11. The study did not calculate structure-specific sensitivity, specificity, positive predictive value and negative predictive value for all HRCT findings.
12. Multiple findings occurred in the same patient; therefore, observations were not statistically independent and their percentages could not be combined.
13. The prevalence tests used a reference proportion of 50%, which was a statistical reference rather than an externally established clinical threshold; these p values should therefore be interpreted cautiously.

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