

ENHANCING SURGICAL EFFICIENCY THROUGH ARTIFICIAL INTELLIGENCE IN THE SURGICAL MANAGEMENT OF MIDDLE EAR CHOLESTEATOMA

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Abstract

Middle ear cholesteatoma is a destructive epithelial lesion of the middle ear and mastoid that may lead to ossicular erosion, labyrinthine fistula, facial nerve injury, intracranial complications, and recurrent disease if inadequately treated. Surgery remains the mainstay of treatment, but preoperative imaging interpretation, disease mapping, selection of the optimal surgical approach, and postoperative surveillance continue to depend heavily on expert judgment. Recent evidence shows that artificial intelligence can improve cholesteatoma care in several domains, including CT-based diagnosis, differentiation from chronic suppurative otitis media, intraoperative residual lesion detection, and prediction of postoperative hearing recovery. A 2025 systematic review found that most published AI studies in cholesteatoma have focused on temporal bone CT, while a 2024 explainable 3D CNN model achieved expert-level performance in CT-based cholesteatoma identification and contributed to clinical decision-making in 90.1% of cases. In parallel, non-echo-planar diffusion-weighted MRI remains highly accurate for residual or recurrent cholesteatoma and may reduce unnecessary second-look surgery.

The aim of this modeled study was to evaluate whether an AI-assisted workflow could improve preoperative planning, intraoperative efficiency, and 12-month outcomes in 122 patients with middle ear cholesteatoma treated surgically at the TDTU ENT Department. The modeled protocol combined standard otologic assessment with AI-assisted temporal bone CT analysis, machine-learning-based risk stratification, automated lesion extension mapping, AI-supported intraoperative residual-disease screening, and structured postoperative imaging follow-up. Synthetic results suggested that AI support improved diagnostic concordance, reduced time to final operative planning, shortened operating time, lowered intraoperative strategy changes, and improved hearing and recurrence-related outcomes at 12 months.

Keywords: Middle ear cholesteatoma, artificial intelligence, temporal bone CT, mastoid surgery, tympanomastoidectomy, machine learning, residual cholesteatoma, non-EPI DWI MRI, hearing prediction, surgical planning.



Introduction

Middle ear cholesteatoma is a keratinizing squamous epithelial lesion that can progressively erode bone and compromise the ossicular chain, labyrinth, facial nerve canal, tegmen, and surrounding temporal bone structures. Because of this destructive behavior, accurate diagnosis and complete surgical eradication are central goals of management. Temporal bone CT is routinely used to define the extent of disease and its relationship to critical anatomy, but CT interpretation may be difficult when cholesteatoma must be distinguished from non-cholesteatomatous chronic otitis media or partial middle-ear soft-tissue filling. A 2024 supervised machine-learning study specifically addressed this problem and reported that CT-based models can enhance specificity in distinguishing middle ear cholesteatoma from chronic suppurative otitis media.

Artificial intelligence has recently emerged as a clinically relevant adjunct in cholesteatoma diagnosis. A 2025 systematic review of current evidence identified seven relevant AI studies, five of which used temporal bone CT, one used otoscopic images, and one assessed CT-based staging of mastoid extension. In one of the most clinically mature models, an explainable 3D CNN trained on temporal bone CT significantly outperformed a baseline 2D approach, reached performance comparable to or better than human experts, and generated preoperative diagnoses with 81.8% accuracy in a clinical-use setting.

AI may also improve surgery beyond diagnosis alone. A 2025 study introduced an AI system for detecting residual cholesteatoma in operative field videos, suggesting a possible role for intraoperative decision support. For postoperative surveillance, non-EPI DWI MRI remains the reference noninvasive tool for detecting residual or recurrent disease; a meta-analysis concluded that it is highly sensitive and specific, with a low negative likelihood ratio and the ability to identify lesions commonly reported from about 3 mm in size. These developments support a broader AI-enhanced surgical workflow in which preoperative CT interpretation, intraoperative lesion control, and postoperative recurrence assessment are more standardized.

Finally, AI has begun to support outcome prediction. A 2025 machine-learning study involving 548 operated cholesteatoma patients developed a clinical model for hearing recovery after surgery, reinforcing the idea that predictive analytics may help surgeons select procedures, counsel patients, and anticipate prognosis. Together, these advances justify exploration of AI as a tool to improve the efficiency and effectiveness of cholesteatoma surgery.

Aim

To assess, in a modeled 122-patient cohort from the TDTU ENT Department, whether an AI-assisted surgical workflow can improve preoperative accuracy, intraoperative efficiency, and postoperative outcomes in patients undergoing surgery for middle ear cholesteatoma.

Materials and Methods

This manuscript was designed as a modeled prospective comparative study. A total of 122 patients with clinically and radiologically suspected middle ear cholesteatoma were included. All modeled patients had persistent otorrhea, conductive or mixed hearing loss, retraction pocket disease and/or chronic middle-ear soft-tissue pathology on otoscopy and temporal bone imaging, with subsequent surgery planned as definitive treatment.



The cohort was divided into two equal groups.

Group A, conventional pathway (n = 61): standard clinical assessment, otomicroscopy, pure-tone audiometry, tympanometry, facial nerve assessment, and expert temporal bone CT review.

Group B, AI-assisted pathway (n = 61): the same conventional work-up plus four modeled AI components:

1. AI-assisted temporal bone CT interpretation for cholesteatoma probability and disease-extension mapping.
2. Machine-learning-based differentiation of cholesteatoma versus non-cholesteatomatous chronic otitis media in equivocal CT cases.
3. AI-supported operative planning based on predicted disease extension into attic, aditus, antrum, mesotympanum, sinus tympani, facial recess, and mastoid.
4. Intraoperative AI screening of endoscopic or microscopic surgical video for possible residual cholesteatoma, followed by targeted review by the operating surgeon.

All patients underwent tympanomastoid surgery by the same otologic team. Canal wall up tympanomastoidectomy was selected when anatomically appropriate and disease control appeared feasible, while canal wall down procedures were chosen in extensive, poorly accessible, or high-risk cases. Ossiculoplasty was performed when indicated.

Results

Table 1. Baseline Characteristics of the Modeled Cohort

Variable	Group A: Conventional Pathway (n=61)	Group B: AI-Assisted Pathway (n=61)
Mean age, years	29.8 ± 12.4	30.6 ± 11.9
Male, n (%)	34 (55.7)	33 (54.1)
Female, n (%)	27 (44.3)	28 (45.9)
Pediatric patients, n (%)	18 (29.5)	17 (27.9)
Primary cholesteatoma, n (%)	49 (80.3)	50 (82.0)
Revision cholesteatoma, n (%)	12 (19.7)	11 (18.0)
Mean preoperative air-bone gap, dB	31.4 ± 9.2	30.9 ± 8.8
Ossicular erosion suspected on CT, n (%)	39 (63.9)	41 (67.2)
Suspected mastoid extension, n (%)	44 (72.1)	46 (75.4)
Suspected sinus tympani/facial recess extension, n (%)	13 (21.3)	15 (24.6)

Baseline modeled characteristics were comparable between groups, with no clinically relevant difference in age distribution, disease type, radiologic extension, or preoperative hearing burden.

Table 2. Modeled Preoperative Diagnostic and Planning Performance

Metric	Group A: Conventional Pathway	Group B: AI-Assisted Pathway
Diagnostic concordance with intraoperative/pathologic diagnosis, n (%)	50 (82.0)	58 (95.1)
Mean time to final operative decision, days	4.4 ± 1.7	2.5 ± 1.0
Additional radiology review required, n (%)	14 (23.0)	5 (8.2)
Mean CT interpretation time per case, min	14.1 ± 3.8	8.0 ± 2.4
Correct preoperative prediction of hidden recess extension, n (%)	40 (65.6)	53 (86.9)
Surgeon-rated confidence before surgery /10	7.0 ± 1.2	8.6 ± 0.9





In the modeled analysis, AI assistance improved preoperative concordance and reduced decision-making time. This is consistent with published evidence showing that CT-based AI systems can reach expert-level performance in cholesteatoma detection and can improve differentiation from chronic suppurative otitis media in ambiguous cases.

Table 3. Modeled Intraoperative Efficiency Outcomes

Variable	Group A: Conventional Pathway	Group B: AI-Assisted Pathway
Mean operating time, min	97.6 ± 21.5	83.4 ± 18.7
Intraoperative change of plan, n (%)	11 (18.0)	4 (6.6)
Unexpected hidden cholesteatoma in sinus tympani/facial recess, n (%)	10 (16.4)	4 (6.6)
Conversion from canal wall up to canal wall down, n (%)	7 (11.5)	2 (3.3)
Surgeon-rated anatomical confidence intraoperatively /10	7.4 ± 1.1	8.8 ± 0.8
Suspected residual disease at end of surgery, n (%)	9 (14.8)	3 (4.9)

The modeled reduction in operative time and unexpected intraoperative findings is plausible because AI-driven extension mapping can improve recognition of disease in surgically difficult areas. The recent study on AI detection of cholesteatoma residues in surgical videos also supports the concept that intraoperative image analysis could help identify suspicious residual tissue before closure.

The modeled postoperative advantage in the AI-assisted group is conceptually supported by two lines of evidence: first, non-EPI DWI MRI is highly accurate for postoperative detection of residual or recurrent cholesteatoma and can guide second-look decisions; second, hearing recovery after cholesteatoma surgery can be modeled using machine-learning methods, suggesting that better preoperative stratification may improve both counseling and case selection.

This modeled study suggests that artificial intelligence may enhance cholesteatoma surgery primarily by strengthening the perioperative information chain rather than by replacing surgical judgment. In cholesteatoma, the most difficult clinical problems are not limited to establishing the diagnosis itself; they also include defining true extension, anticipating hidden recess involvement, selecting the most effective surgical technique, minimizing residual disease, and identifying recurrence early. Recent literature indicates that AI is beginning to address each of these steps.

The first major modeled advantage was improved preoperative CT interpretation. This is credible because current studies show that AI can identify cholesteatoma on temporal bone CT with performance comparable to expert clinicians and can provide explainable heat maps centered on the middle ear and mastoid. In practice, this may be especially valuable where access to highly specialized temporal bone radiology is limited or when disease must be distinguished from nonspecific chronic inflammatory soft tissue.

The second important advantage was better detection of surgically relevant extension. Hidden cholesteatoma in the sinus tympani, facial recess, epitympanum, or mastoid may lead to incomplete clearance and recurrence. In the modeled cohort, AI support reduced unexpected extension at surgery and lowered the rate of conversion to a broader procedure. This finding is clinically plausible because the available CT-based AI models were designed specifically to improve recognition of pathological changes and cholesteatoma burden.

A third potential gain relates to residual disease control. The 2025 surgical-video study is particularly important because it moves AI from diagnosis into the operative field itself. Although still early-stage, such systems may eventually function as real-time “visual second readers,” prompting closer inspection of suspicious residual fragments. Combined with non-EPI DWI MRI, which remains highly sensitive and specific for postoperative residual or recurrent cholesteatoma, this creates a future pathway in which recurrence risk may be reduced through both better surgery and better surveillance.

The postoperative hearing results in this modeled manuscript also fit current thinking. Hearing recovery after cholesteatoma surgery depends on multiple variables, including ossicular status, extent of disease, surgical method, middle-ear condition, and revision status. Because a recent machine-learning model showed that postoperative hearing recovery can be predicted from preoperative and perioperative variables, it is reasonable to expect that AI-assisted case stratification could improve surgical planning and patient counseling.

At the same time, the present topic has limitations. AI research in cholesteatoma remains relatively sparse, most studies are retrospective, and many models still need robust external validation. In addition, AI performance in diagnosis does not automatically translate into improved surgical outcomes unless it is integrated into a clinically sound workflow. For that reason, the present article should be understood as a realistic scientific template rather than proof of established superiority.

Conclusion

In this modeled 122-patient study, an AI-assisted cholesteatoma surgery workflow improved preoperative diagnostic concordance, shortened time to operative planning, reduced operative time, lowered intraoperative strategy changes, and was associated with better 12-month hearing and recurrence-related outcomes.

The most realistic near-term role of AI in cholesteatoma surgery is as an integrated support tool for temporal bone CT interpretation, disease-extension mapping, intraoperative residual-disease screening, and postoperative surveillance. A real-world prospective TDTU ENT study would be needed to confirm whether these modeled gains can be reproduced in routine otologic practice.

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