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ENHANCING SURGICAL EFFICIENCY THROUGH ARTIFICIAL INTELLIGENCE IN THE SURGICAL TREATMENT OF OTOSCLEROSIS

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Abstract

Otosclerosis is a localized disorder of otic capsule bone remodeling that commonly causes progressive conductive or mixed hearing loss through stapes footplate fixation. High-resolution temporal bone CT is the principal imaging study used to support diagnosis and surgical planning, but its diagnostic yield is variable, with umbrella-review data showing CT sensitivity of 60% to 95% and specificity of 75% to 100%. Deep-learning tools for temporal bone CT now show promising diagnostic performance, and recent studies suggest that AI can support otosclerosis detection, improve image quality, assist middle-ear diagnostic interpretation, and predict postoperative hearing after stapedotomy.

The aim of this modeled study was to evaluate whether an AI-assisted workflow could improve preoperative decision-making, intraoperative efficiency, and 12-month hearing outcomes in 122 patients with otosclerosis treated surgically at the TDTU ENT Department. The modeled protocol combined standard otologic assessment with deep-learning-enhanced CT review, AI-based otosclerosis focus detection, machine-learning interpretation of wideband immittance data, and a preoperative hearing-outcome prediction model. Synthetic results suggested that AI support improved diagnostic concordance, shortened time to final operative planning, reduced operative time and intraoperative plan changes, and improved the proportion of patients achieving favorable air-bone gap closure at follow-up.

Keywords: Otosclerosis, artificial intelligence, stapedotomy, temporal bone CT, machine learning, wideband immittance, hearing prediction, surgical planning, temporal bone imaging.

Introduction

Otosclerosis is a common cause of stapes fixation and conductive hearing loss in adults. In clinical practice, otoscopy is usually normal, audiometry typically shows conductive or mixed hearing loss, and the stapedial reflex is often absent. High-resolution temporal bone CT is the key imaging test used to identify antefenestral or retrofenestral foci, although the lesions may be very small and subtle, and some patients with clinical otosclerosis may still have CT scans that are initially interpreted as normal.

Surgery remains a major treatment option for appropriately selected patients. In the recent umbrella review of otosclerosis diagnosis and management, endoscopic and microscopic stapedotomy showed similar air-bone gap closure rates, while endoscopic surgery was associated with reduced dysgeusia risk and less chorda tympani manipulation. The same review also emphasized that CT is useful but imperfect, reinforcing the need for better preoperative support tools.

Artificial intelligence has become increasingly relevant in temporal bone imaging because the region contains numerous small, densely packed anatomical structures that are difficult to interpret consistently. A 2025 systematic review highlighted the growing role of AI in temporal bone imaging, while a 2024 otology review noted that AI improves temporal bone CT interpretation and can support diagnosis in diseases such as otosclerosis.

For otosclerosis specifically, AI has already shown promise in several domains. A 2024 pilot study reported that an AI algorithm achieved 79% sensitivity and 98% specificity in detecting surgically confirmed otosclerosis on temporal bone CT, with performance comparable to a trained radiologist. Another 2024 deep-learning study developed an interpretable automated detection system using CT scans from 182 participants with otosclerosis and 157 controls. Earlier work also demonstrated that deep-learning analysis of temporal bone CT could be non-inferior to a subspecialty-trained radiologist, with model accuracies up to 0.86 and radiologist accuracy of 0.89.

AI may also improve operative efficiency indirectly by refining case selection and setting realistic hearing expectations. A 2024 machine-learning study on stapedotomy showed that postoperative hearing quality could be predicted from preoperative features, with mean absolute errors of about 6 dB at air-conduction frequencies between 1000 and 3000 Hz. In parallel, machine-learning approaches using wideband immittance or wideband tympanometry have shown useful diagnostic performance in differentiating otosclerosis from normal ears and other middle-ear disorders, including reported accuracy around 89.7% and sensitivity around 89.2% in one CNN-based setting.

Finally, AI can contribute at the image-acquisition and computer-assisted surgery levels. Deep-learning reconstruction has been shown to reduce image noise and improve depiction of the otic capsule, auditory ossicles, and tympanic membrane on high-resolution temporal bone CT. A 2025 review of robotic and computer-assisted ear surgery further noted that computer-assisted platforms are being explored for tasks such as stapes footplate fenestration, with AI-driven monitoring and tracking expected to improve precision and safety.

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 hearing outcomes in patients undergoing surgery for otosclerosis.

Materials and Methods

This manuscript was designed as a modeled prospective comparative study. A total of 122 patients with clinically and audiometrically suspected otosclerosis were included. All modeled patients had progressive conductive or mixed hearing loss, absent or markedly reduced acoustic reflexes, and temporal bone imaging suitable for surgical planning. Surgery was considered in accordance with the principle described in recent ML literature, namely in patients with clinically meaningful conductive hearing loss and appropriate operative candidacy.

The modeled cohort was divided into two equal groups. Group A, the conventional pathway, included 61 patients assessed by the standard preoperative workflow consisting of otomicroscopy, pure-tone audiometry, impedance testing, and expert temporal bone CT review. Group B, the AI-assisted pathway, included 61 patients assessed by the same standard work-up plus four modeled AI components:

1. deep-learning-reconstructed high-resolution temporal bone CT;
2. AI-based automated otosclerosis focus detection on CT;
3. machine-learning-supported interpretation of wideband immittance data;
4. a machine-learning postoperative hearing prediction module for preoperative counseling and operative planning.

These components were selected because each has a precedent in the contemporary literature, even though the present integrated workflow is modeled rather than previously validated as a single package.

All patients in the modeled study underwent stapes surgery performed by the same otologic team. Small-fenestra stapedotomy was the planned primary procedure, while limited stapedectomy or modified footplate management was reserved for anatomically difficult cases. The primary endpoints were preoperative diagnostic concordance, time to final operative decision, operative time, intraoperative change of plan, and hearing success at 12 months. Secondary endpoints included postoperative residual air-bone gap, bone-conduction stability, transient dysgeusia, vertigo, and revision-free status.

The reference diagnosis was based on intraoperative confirmation of stapes fixation. Postoperative hearing success in the modeled analysis was defined primarily as residual air-bone gap of 10 dB or less at the main speech frequencies, with secondary analyses based on conductive gain and symptom improvement. This choice is consistent with commonly used otosclerosis outcome frameworks in the recent literature.

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	37.8 ± 9.6	38.5 ± 10.1
Female, n (%)	39 (63.9)	41 (67.2)
Male, n (%)	22 (36.1)	20 (32.8)
Bilateral otosclerosis, n (%)	36 (59.0)	38 (62.3)
Mixed hearing loss, n (%)	15 (24.6)	17 (27.9)
Mean preoperative air-bone gap, dB	29.7 ± 8.3	30.2 ± 8.1
Mean preoperative bone-conduction PTA, dB	19.4 ± 7.0	18.9 ± 7.3
HRCT suggestive of otosclerosis, n (%)	47 (77.0)	49 (80.3)
Wideband immittance performed, n (%)	18 (29.5)	61 (100)
Planned small-fenestra stapedotomy, n (%)	58 (95.1)	59 (96.7)

Baseline characteristics were modeled to be similar between groups, with no clinically meaningful difference in age, sex distribution, bilateral disease frequency, or preoperative air-bone gap.

Table 2. Modeled Preoperative Diagnostic and Planning Performance

Metric	Group A: Conventional Pathway	Group B: AI-Assisted Pathway
Diagnostic concordance with intraoperative confirmation, n (%)	51 (83.6)	58 (95.1)
Mean time to final operative decision, days	4.0 ± 1.4	2.2 ± 0.9
Additional imaging or repeat review required, n (%)	13 (21.3)	5 (8.2)
Mean imaging interpretation time per case, min	12.6 ± 3.2	7.1 ± 2.0
Correct prediction of difficult footplate/oval window anatomy, n (%)	44 (72.1)	55 (90.2)
Preoperative hearing-outcome counseling rated “high confidence,” n (%)	37 (60.7)	54 (88.5)

In the modeled analysis, the AI-assisted group showed higher diagnostic concordance and faster operative planning. This is plausible in light of the published data showing that AI can detect otosclerosis on CT with performance comparable to expert radiologists, that deep-learning reconstruction improves temporal bone image quality, and that ML models can estimate postoperative hearing from preoperative variables.

Table 3. Modeled Intraoperative Efficiency Outcomes

Variable	Group A: Conventional Pathway	Group B: AI-Assisted Pathway
Mean operative time, min	52.8 ± 11.7	43.9 ± 9.8
Intraoperative change of plan, n (%)	9 (14.8)	3 (4.9)
Difficult exposure of oval window niche, n (%)	11 (18.0)	5 (8.2)
Need for conversion from planned stapedotomy strategy, n (%)	7 (11.5)	2 (3.3)
Surgeon-rated anatomical confidence /10	7.3 ± 1.1	8.7 ± 0.8
Transient dysgeusia, n (%)	7 (11.5)	4 (6.6)
Immediate postoperative vertigo >24 h, n (%)	5 (8.2)	3 (4.9)

The modeled reduction in operative time and intraoperative change of plan reflects the intended benefit of more precise preoperative mapping. Contemporary evidence supports the idea that computer-assisted ear surgery is being developed to improve precision in narrow middle-ear spaces, and recent otosclerosis-management reviews show that less invasive stapes techniques can reduce tissue manipulation-related morbidity.

The modeled hearing outcomes in both groups are compatible with the modern otosclerosis literature, where surgery is generally effective but not uniformly successful, and where outcome reporting varies depending on the metric used. Recent reviews and predictive-modeling studies suggest that better preoperative characterization may help optimize candidate selection and expectations.

The present modeled study suggests that artificial intelligence may improve otosclerosis surgery mainly by strengthening the preoperative phase. In otosclerosis, the key bottlenecks are subtle radiologic findings, difficult differentiation from other causes of conductive hearing loss, uncertainty about surgical difficulty, and imperfect prediction of hearing gain. These are exactly the areas in which recent AI studies have shown the most promise.

First, AI-assisted CT analysis may improve diagnostic confidence. Published pilot data showed that AI detection reached 79% sensitivity and 98% specificity in a surgically confirmed cohort, while earlier deep-learning work found that some neural-network models were non-inferior to a subspecialty radiologist. Because antefenestral and footplate lesions can be submillimetric and occasionally overlooked, even modest improvements in false-negative reduction may have meaningful clinical value.

Second, AI may improve operative efficiency by enhancing the quality and interpretability of preoperative imaging. Deep-learning reconstruction has been shown to reduce image noise and improve depiction of the otic capsule and ossicles, which are central structures in stapes surgery planning. In the modeled cohort, this translated into shorter operative time and fewer intraoperative plan changes, which is a plausible consequence of better visualization before surgery.

Third, AI may strengthen patient selection and counseling. The 2024 machine-learning stapedotomy study demonstrated that postoperative hearing can be predicted from preoperative features with mean absolute errors around 6 dB at key speech frequencies. In practical terms, this kind of tool could help identify borderline candidates, improve shared decision-making, and support individualized expectations regarding air-bone gap closure and residual hearing.

Fourth, adjunctive AI analysis of wideband immittance may support preoperative differentiation of stapes fixation from other middle-ear disorders. Although not yet standard in all centers, machine-learning approaches applied to WAI and WBT data have shown promising performance, including reported accuracy near 89.7% in one CNN-based study separating normal ears from otosclerotic ears. In a surgical pathway, such support may reduce diagnostic uncertainty and improve the efficiency of the preoperative work-up.

The broader future role of AI in otologic surgery may extend beyond diagnosis and prognosis into real-time computer assistance. A 2025 review of robotic and computer-assisted ear surgery described emerging systems for tasks including stapes footplate fenestration, as well as AI-driven instrument tracking and monitoring aimed at greater safety and precision. However, these applications remain early-stage, and larger clinical trials are still needed before routine adoption.

Several limitations must be acknowledged. The present article is modeled and does not report real TDTU patient data. In addition, the current literature on AI in otosclerosis is still relatively sparse compared with other imaging domains, and most studies remain single-center, retrospective, or limited to diagnostic rather than fully integrated perioperative workflows. Therefore, the present manuscript should be read as a realistic scientific template rather than as evidence of proven clinical superiority.

Conclusion

In this modeled 122-patient study, an AI-assisted otosclerosis surgery workflow improved preoperative diagnostic concordance, shortened time to operative planning, reduced operative time, lowered the rate of intraoperative strategy changes, and improved 12-month hearing outcomes compared with a conventional pathway.

The most realistic near-term role of AI in otosclerosis surgery is not autonomous surgical execution, but integrated support for temporal bone CT interpretation, middle-ear diagnostic clarification, preoperative hearing-outcome prediction, and anatomy-aware surgical planning. A real-world prospective TDTU ENT study would be required to confirm whether these modeled gains can be reproduced in routine otologic practice.

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