COMPARATIVE EFFECTIVENESS OF MINIMALLY INVASIVE AND CONVENTIONAL TECHNIQUES IN OTOLOGIC SURGERY: A SYSTEMATIC REVIEW AND META-ANALYSIS

Moamen Abdelfadil Ismail*[1], Faisal Abdullah Ibrahim ALSHYER[2], Ghala saeed alahmari[3], Alhanouf Oudah Alasmari[3], Ariam Ali Muarif[3], Ghaida Mohammed A Alshehri[3], Ghadeer Yahya Aljaber[3], Danah Mansour Al Mutib[3], Renad Mohammed Algosadi Alshehri[4], Ali Hussain Aldukain[4], IBRAHIM AHMED ALGHAMDI[3], Nouf Mohammed Alqarn[3], Ghanaym AlMazrouei[5]

[1]Lecturer of Internal Medicine, Faculty of Medicine, Helwan University, Internal Medicine consultant, King Abdulaziz specialist hospital-Sakaka-Aljouf; [2]General practitioner; [3]Medical student; [4]Intern doctor; [5]Otolaryngology resident

Manuscrito recibido: 02/03/2025
Manuscrito aceptado: 25/03/2025

*Corresponding Author: Moamen Abdelfadil Ismail, Lecturer of Internal Medicine, Faculty of Medicine, Helwan University, Internal Medicine consultant, King Abdulaziz specialist hospital-Sakaka-Aljouf Saudiarabia

Correo-e: moamen.fadil83@gmail.com

Abstract

Background: Minimally invasive techniques (MITs) in otologic surgery, such as endoscopic ear surgery (EES), laser-assisted procedures, and robotic-assisted surgery, have gained popularity due to their advantages in reducing surgical trauma, improving precision, and enhancing recovery outcomes. However, a comprehensive comparison of MITs with conventional microscopic ear surgery (MES) regarding safety, efficacy, and long-term patient satisfaction remains underexplored. This systematic review and meta-analysis aim to synthesize evidence on the effectiveness of MITs versus conventional techniques in otologic surgery.

Methods: A systematic search was conducted in PubMed, Embase, Cochrane Library, Scopus, and Web of Science, following PRISMA guidelines. Studies comparing MITs and MES in patients undergoing otologic surgery were included. Key outcomes analyzed included hearing improvement (air-bone gap [ABG] and pure-tone average [PTA]), surgical duration, recovery time, recurrence rates, graft uptake success, and patient satisfaction. Statistical analyses included meta-analysis using a random-effects or fixed-effects model, heterogeneity assessment, and publication bias evaluation.

Results: The review included multiple randomized controlled trials (RCTs), prospective cohort studies, and retrospective analyses. MITs demonstrated shorter surgical duration (mean difference: -11.41 minutes, $p < 0.05$) and faster recovery times compared to MES. Audiological outcomes (ABG and PTA) showed no significant difference between techniques. Recurrence rates were lower in the MIT group (4%) compared to MES (13%), indicating better disease clearance with minimally invasive approaches. Graft uptake success rates were high in both groups (MITs: 94%, MES: 92%), with no significant difference. Patient satisfaction was higher for MITs due to reduced postoperative pain, less scarring, and faster return to daily activities.

Conclusion: Minimally invasive techniques in otologic surgery offer significant advantages in terms of reduced surgical duration, lower recurrence rates, and enhanced patient satisfaction, while maintaining comparable audio logical outcomes to conventional methods. However, challenges such as the learning curve and high initial costs limit widespread adoption. Further research, including long-term studies and integration of advanced technologies like artificial intelligence and augmented reality, is needed to refine MITs and improve accessibility in various healthcare settings.

Background

During the past years, otologic surgeries have developed a lot with the benefits of minimally invasive techniques/MITs over open conventional surgeries. These include EES, laser-assisted procedures, and robotic-assisted surgery. The aim of all these techniques is to minimize surgical traumas and thus enhance precision and improve recovery outcomes. While the use of these techniques in the management of chronic otitis media, cholesteatoma, and otosclerosis has thus far reduced operative time and complication rates with improved patient satisfaction, comprehensive studies on the efficacy, safety, and long-term satisfaction rates in patients undergoing such surgery, compared to conventional techniques, are yet to be accomplished (1).

Advantages of using minimally invasive techniques in otologic surgery lie in a number of aspects: one of the most significant-the minimal traumatism of tissues around the pathological structure. Unlike classic techniques, which involve large skin cuts and extensive detachment of soft tissues, MIT allows for focused exposure of a pathologically changed site, with reduced destruction of tissue around it, including the integrity of anatomical structures. That, in its turn, has an impact on postoperative feelings, reduces risks of infection development, and helps a patient sooner return to routine life (2).

Other major benefits to MITs are increased surgical precision. Advanced imaging modalities, high-definition endoscopes, and robotic assistance further increase the capability of the surgeon in delineating and manipulating delicate structures in the ear. This kind of precision becomes much more useful during complex surgeries such as removal of cholesteatoma when the preservation of hearing is invaluable. Better visualization reduces residual disease and hence improves long-term results (3).

The time for recovery after any surgical intervention is a very important factor, and here, the advantages of MITs are quite evident. Most patients who have undergone minimally invasive otologic procedures stay in the hospital for a shorter period and recover faster compared to those who undergo traditional surgeries. This quicker recovery not only improves the patient experience but also lessens the overall burden on healthcare systems by reducing hospitalization costs and resource use (4).

Apart from the clinical benefits, patient satisfaction level is also an important criterion to judge the outcomes of surgical techniques. It is claimed that patients who undergo MITs are more satisfied, basing their satisfaction on minimal scarring, less postoperative discomfort, and quick return to routine. Understanding these patient perspectives on such procedures will go a long way in refining the art of surgery and optimizing care as health moves more toward being patient-centered (5).

Despite such advantages, several challenges still persist in the wide adoption of MITs in otologic surgery. Among the concerns is the steep learning curve from traditional techniques to minimally invasive approaches. Mastery of endoscopic and robotic-assisted procedures requires special training and experience, thus limiting their widespread use, particularly in regions where access to such advanced medical training programs is limited (6).

Other issues include the expenses associated with the MITs themselves. Although techniques in this arena offer long-term advantages, like fewer complications and shorter hospital stays, their immediate investment in high-quality imaging systems, robotic surgical platforms, and specialized instruments remains very high. This financial hurdle can prevent techniques from spreading into resource-limited settings and might further widen gaps in access to advanced surgical care (2).

Long-term efficacy and safety studies regarding the use of MITs in otologic surgery are further required. While early reports are promising, large-scale multi-institutional clinical trials will be required to establish overall recurrence rates, hearing preservation, and complication rates over an extended time period. This will create a strong evidence base that will support the formulation of clinical guidelines and drive best practices among otologic surgeons worldwide.

Moreover, new technologies such as AI and AR will add further precision and efficiency to otologic surgery. AI will be able to support the surgeon by enhancing image analysis, recognizing anatomical landmarks, and making optimal surgical plans, while AR applications provide immediate guidance during the performance of procedures. In this regard, further inclusion of these technologies may trigger a revolution in this area and bring improvements in patient outcomes (3).

Concluding, the minimally invasive otologic surgery technique represents an advancement in patient care. While most of the benefits are inherent to these approaches, training, cost, and effectiveness over a long period need more research. The techniques need refinement; as with more access to surgical technologies, otologic surgery can achieve better outcomes for the patient and make overall healthcare efficient.

Problem Statement

Despite the wide reception of minimally invasive techniques within otologic surgery, few high-quality synthesized pieces of evidence are available comparing their outcomes with conventional approaches. Although individual studies reported benefits such as reduced complications, faster recovery, and improved patient satisfaction, findings have remained inconsistent across various surgical techniques and patient populations. Moreover, few studies have used systematic evidence synthesis to evaluate the influence of factors related to the adoption of MITs, such as cost-effectiveness, surgeon learning curves, and healthcare accessibility. This systematic review and meta-analysis will bridge these gaps by critically evaluating and quantifying the clinical outcomes and patient-reported experiences associated with MITs in otologic surgery compared to traditional methods.

Research Questions

1. How do minimally invasive techniques in otologic surgery compare to conventional methods in terms of clinical outcomes based on pooled data?

2. What is the impact of minimally invasive techniques on postoperative complications and recovery time according to existing literature?

3. How do patients perceive their surgical outcomes in terms of satisfaction, pain levels, and quality of life improvements following minimally invasive otologic procedures?

4. What does the aggregated evidence suggest regarding the cost-effectiveness and accessibility of minimally invasive otologic surgery?

Research Hypotheses

- **H1:** A systematic review and meta-analysis of existing studies will show that minimally invasive techniques in otologic surgery lead to better clinical outcomes compared to traditional methods.
- **H2:** Meta-analytic data will demonstrate that patients undergoing minimally invasive otologic surgery experience shorter recovery times and fewer complications.
- **H3:** Pooled evidence will indicate higher patient satisfaction and quality of life scores among those who undergo minimally invasive techniques compared to conventional approaches.
- **H4:** A systematic evaluation of economic studies will suggest that MITs are cost-effective in the long term, despite higher initial investment in equipment and surgeon training.

Research Aim

This systematic review and meta-analysis aim to critically evaluate and synthesize the available evidence on the advancements, effectiveness, and patient satisfaction associated with minimally invasive techniques in otologic surgery, comparing them to conventional surgical approaches.

Research Objectives

1. To systematically review and analyze the clinical outcomes of minimally invasive otologic surgery, including hearing improvement and complication rates.

2. To conduct a meta-analysis comparing postoperative recovery periods between MITs and traditional surgical methods.

3. To synthesize patient-reported satisfaction levels and perceived benefits of minimally invasive otologic procedures.

4. To review the cost-effectiveness and feasibility of MITs across various healthcare settings.

5. To identify common barriers to the widespread adoption of minimally invasive otologic surgery and provide evidence-based recommendations for overcoming these challenges.

Methodology

Study Design

This study employed a systematic review and meta-analysis approach to synthesize existing evidence on the clinical outcomes, patient satisfaction, and cost-effectiveness of minimally invasive techniques (MITs) in otologic surgery compared to conventional surgical methods. The review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure transparency and methodological rigor.

Eligibility Criteria

Inclusion Criteria

Studies were included if they met the following criteria

- Population: Patients who underwent otologic surgery (e.g., chronic otitis media, cholesteatoma, otosclerosis).
- Intervention: Minimally invasive techniques (e.g., endoscopic ear surgery, laser-assisted procedures, robotic-assisted surgery).
- Comparator: Conventional surgical techniques (e.g., microscopic ear surgery, open procedures).
- Outcomes: Clinical outcomes (e.g., hearing improvement, complication rates), patient-reported satisfaction, postoperative recovery time, and cost-effectiveness.
- Study Design: Randomized controlled trials (RCTs), cohort studies, case-control studies, and comparative observational studies.
- Publication Type: Peer-reviewed articles, systematic reviews with primary data, and meta-analyses.

Exclusion Criteria

Studies were excluded if they

- We're not published in English.
- Lacked a control group or comparator.
- Focused solely on animal models or in vitro studies.
- Were case reports, editorials, commentaries, or conference abstracts.

Literature Search Strategy

A comprehensive search was conducted using the following electronic databases: PubMed, Embase, Cochrane Library, Scopus, and Web of Science.

The search included Medical Subject Headings (MeSH) terms and keywords such as: "Minimally invasive otologic surgery," "Endoscopic ear surgery," "Laser-assisted ear surgery," "Robotic otologic surgery," "Cholesteatoma surgery," "Hearing outcomes," "Patient satisfaction in otologic surgery," "Postoperative recovery in ear surgery," and "Cost-effectiveness of minimally invasive ear surgery." Boolean operators (AND, OR) were applied to refine the search strategy. Additional studies were identified through manual searches of reference lists from relevant articles and systematic reviews.

Study Selection Process

The study selection process followed the PRISMA flowchart

1. Identification: Search results were imported into EndNote for reference management.

2. Screening: Titles and abstracts were reviewed independently by two reviewers to exclude irrelevant studies.

3. Full-Text Review: Eligible studies were assessed based on inclusion/exclusion criteria. Disagreements were resolved through discussion or consultation with a third reviewer.

4. Data Extraction: Data were extracted using a standardized form.

Data Extraction and Variables

A structured data extraction sheet was used to collect the following

- Study Characteristics: Author, year, country, study design, and sample size.
- Patient Characteristics: Age, gender, diagnosis, and comorbidities.
- Intervention Details: Type of minimally invasive technique and surgical duration.
- Comparator: Type of conventional technique.
- Clinical Outcomes: Hearing improvement, surgical success rates, and complication rates.
- Postoperative Recovery: Pain levels, recovery duration, and hospital stay.

- Patient Satisfaction: Survey scores and quality of life assessments.
- Cost-effectiveness: Healthcare costs and resource utilization.

Risk of Bias and Quality Assessment

To ensure study quality and minimize bias, the following tools were used:

- Randomized Controlled Trials (RCTs): Cochrane Risk of Bias (RoB 2) tool.
- Observational Studies: Newcastle-Ottawa Scale (NOS).
- Systematic Reviews: AMSTAR-2 tool for methodological quality.

Each study was rated as having low, moderate, or high risk of bias, and sensitivity analyses were conducted to assess the impact of high-risk studies.

Data Synthesis and Statistical Analysis

Qualitative Synthesis

A narrative synthesis was conducted if a meta-analysis was not feasible due to heterogeneity. This summarized the key findings, trends, and gaps in the literature.

Quantitative Synthesis (Meta-Analysis)

- A random-effects or fixed-effects model was used based on heterogeneity.
- Heterogeneity Assessment: Cochran's Q test and I² statistics (>50% was considered substantial heterogeneity).
- Subgroup Analyses: Based on patient demographics, surgical technique, and study design.
- Sensitivity Analysis: Studies with a high risk of bias were excluded to check robustness.
- Publication Bias: Funnel plots and Egger's regression test were used to detect bias.

Ethical Considerations

As this study was a systematic review and meta-analysis using previously published data, it did not require ethical approval. However, all included studies were assessed for adherence to ethical guidelines such as Institutional Review Board (IRB) approval and informed consent where applicable.

Strengths

- Employed a robust systematic review methodology adhering to PRISMA guidelines.
- Included a comprehensive meta-analysis to quantify effect sizes.
- Used rigorous quality assessment to minimize bias.
- Examined both clinical and patient-reported outcomes.

Limitations

- Potential heterogeneity due to differences in study populations and surgical techniques.
- Risk of publication bias if studies with negative findings were underreported.
- Limited by the availability of high-quality RCTs in the field.

Results

Study Characteristics and Patient Demographics

The included studies encompass randomized controlled trials (RCTs), prospective cohort studies, and retrospective analyses, ensuring a diverse range of methodological approaches. Sample sizes vary widely, ranging from 26 to 345 patients, with most studies comparing endoscopic ear surgery (EES) and microscopic ear surgery (MES). Age distributions are similar across groups, with most patients being middle-aged adults. Follow-up periods range from 3 months to 3 years, providing insights into both short-term and mid-term surgical outcomes. The studies ensure methodological robustness, with high- and moderate-quality assessments based on the Newcastle-Ottawa Scale (NOS) (Table 1).

Audiological Outcomes (ABG and PTA)

A key indicator of surgical success is the reduction in air-bone gap (ABG) and improvement in pure-tone average (PTA). Most studies demonstrate significant ABG closure postoperatively, confirming that both EES and MES are effective in hearing restoration. Daneshi 2020, Secaatin 2019, and Hunter 2016 reported significant ABG reductions, supporting the role of these techniques in tympanoplasty and cholesteatoma surgery. However, Gao 2024 found that EES provided significantly better ABG improvements than MES ($P < 0.05$), suggesting that minimally invasive approaches might yield superior auditory outcomes in selected cases. Regarding PTA improvements, most studies

Table 1. Study Characteristics.

First Author	Year	Study Design	Sample Size	Groups	Sample Size per Group	Procedure Used per Group	Mean Age ± SD (Group A)	Mean Age ± SD (Group B)	Follow-up Period
Abdul Salam (7)	2018	Prospective cohort	40	Group A (Microscopic), Group B (Endoscopic)	20 each	Microscopic (A), Endoscopic (B)	26.6 ± 7.92 years	28.2 ± 8.2 years	6 months
Dalgic (8)	2023	Retrospective	27	Single Group	27	Endoscopic cholesteatoma surgery	36.4 years	-	19 months
Daneshi (9)	2020	RCT	130	Endoscopic (n=75), Microscopic (n=55)	75 vs 55	Endoscopic (A), Microscopic (B)	39.85 years	38.25 years	12 months
Gao (10)	2024	Multicenter retrospective	169	EES (n=87), MES (n=82)	87 vs 82	Endoscopic (A), Microscopic (B)	35.28 ± 13.93	30.85 ± 15.00	3 years
Hunter (11)	2016	Multicenter retrospective	51	Single Group	51	Endoscopic stapes surgery	48.1 ± 12.5 years	-	5.13 months
Kurl (12)	2015	Prospective comparative	60	Endoscopic (n=30), Microscopic (n=30)	30 vs 30	Endoscopic (A), Microscopic (B)	28.85 ± 10.87 years	28.85 ± 10.87 years	6 months
Marchioni (13)	2019	Retrospective cohort	98	Single group	98	Endoscopic type I tympanoplasty	40.4 years	-	6 months
Magliulo (14)	2017	Prospective comparative	80	EES (n=40), MES (n=40)	40 vs 40	Endoscopic (A), Microscopic (B)	37.9 years	41.2 years	12.3 months
Mo'men (15)	2023	RCT	80	Endoscopic (n=40), Microscopic (n=40)	40 vs 40	Endoscopic (A), Microscopic (B)	39.4 ± 11.0 years	41.3 ± 7.7 years	6 months
Qimei (16)	2022	Retrospective	345	Endoscopic (n=224), Microscopic (n=121)	224 vs 121	Endoscopic (A), Microscopic (B)	40.87 ± 11.3 years	38.56 ± 11.5 years	12.74 ± 7.56 months
Sakender (17)	2022	Prospective observational	26	Endoscopic (n=13), Microscopic (n=13)	13 vs 13	Endoscopic (A), Microscopic (B)	Not reported	Not reported	3 months
Secaatin (18)	2019	Retrospective comparative	126	Endoscopic (n=67), Microscopic (n=59)	67 vs 59	Endoscopic (A), Microscopic (B)	45.4 years (Range: 15-61)	54.8 years (Range: 18-72)	8.2 months
Verma (19)	2023	Retrospective comparative	70	Endoscopic (n=30), Microscopic (n=40)	30 vs 40	Endoscopic (A), Microscopic (B)	36.93 years	36.07 years	3 months

reported no significant difference between groups, except Gao 2024, where EES had significantly better PTA outcomes than MES (P < 0.05).

Surgical Outcomes (Surgical Duration, Healing Time, and Recurrence Rates)

Surgical efficiency and recovery parameters, such as operative time, healing duration, and recurrence rates, vary across studies. Most studies, including Mo'men 2023, Daneshi 2020, and Qimei 2022, found that EES had significantly shorter operative times than MES (P < 0.001). However, Magliulo 2017 contradicted this trend, reporting longer operative times for EES, likely due to the learning curve associated with minimally invasive techniques. Healing time is generally shorter with EES, as seen in Mo'men 2023 and Magliulo 2017 (P < 0.001), supporting the hypothesis that less tissue trauma leads to faster recovery. Recurrence and residual disease rates differ across studies, with Mo'men 2023, Gao 2024, and Qimei 2022 reporting significantly lower recurrence rates for EES (P < 0.05), whereas Magliulo 2017 found a slightly higher recurrence rate for EES. This variability suggests that EES may provide better disease clearance in specific cases but requires precise surgical execution.

Graft Uptake and Surgical Success Rates

Surgical success is commonly evaluated based on graft uptake rates. All studies report graft uptake success rates above 90%, confirming the effectiveness of both EES and MES for tympanoplasty procedures. Studies such as Daneshi 2020, Secaatin 2019, and Verma 2023 show no significant difference between techniques (P > 0.05). However, Gao 2024 and Mo'men 2023 found slightly higher graft success rates in EES, though differences were not clinically significant. This reinforces the notion that both techniques are viable for tympanic membrane reconstruction (Table 2).

Meta-analysis of Air-Bone Gap ABG

The forest plot (Figure 1), illustrates the mean difference in Air-Bone Gap (ABG) closure between endoscopic (EES) and microscopic (MES) ear surgery across five studies, showing no significant difference between the two techniques. The pooled mean difference is 0.01 dB (95% CI: -0.47, 0.48), with all confidence intervals crossing zero, indicating that neither technique is superior in terms of ABG improvement. Individual studies, including Abdul Salam 2018, Daneshi 2020, Gao 2024, Kurl 2015, and Qimei 2022, all reported non-significant mean differences, reinforcing the equivalence of EES and MES. Heterogeneity analysis (I^2 = 0%, P = 0.5829) confirms no variability among studies, meaning the results are highly consistent. Clinically, this suggests that both EES and MES effectively improve hearing with no preference for one technique over the other.

Meta-analysis of Postoperative pure-tone average PTA

The forest plot, (Figure 2), for postoperative pure-tone average (PTA) compares endoscopic (EES) and microscopic (MES) ear surgery outcomes across four studies. The pooled mean difference is -0.89 dB (95% CI: -5.20, 3.42), indicating no statistically significant difference between the two techniques. Individual studies show mixed results: Abdul Salam 2018, Daneshi 2020, and Mo'men 2023 report non-significant PTA differences, while Gao 2024 shows a significant advantage for MES (-6.93 dB, 95% CI: -8.83, -5.03), suggesting that EES may result in slightly poorer PTA outcomes in some cases. Heterogeneity is very high (I^2 = 94.1%, P < 0.0001), indicating substantial variability among studies, likely due to differences in surgical techniques, follow-up periods, and patient populations. The high heterogeneity suggests caution when interpreting the pooled effect, as study-specific factors may play a more significant role in PTA outcomes than the surgical approach itself. Despite this, overall results suggest that both EES and MES can effectively improve PTA, with no clear superiority of one technique over the other.

Table 2. Studies Outcome.

First Author	Outcomes (Mean ± SD) per Group	Significance of Difference	n (%) Outcomes per Group	Conclusion
Abdul Salam	Post-op PTA: 16.72 ± 5.11 (A), 16.05 ± 4.37 (B)	No significant PTA/ABG difference; shorter surgery time in endoscopic (P>0.05)	Graft uptake: 95% both groups	Endoscopic is effective, less invasive
Dalgic	Pre-op ABG: 25.14 ± 13.93 dB; Post-op ABG: 22.22 ± 12.64 dB	No significant ABG difference (P=0.417)	Periop complications: 3 (11%); Recurrence: 0%	TEES is safe with low complications
Daneshi	Post-op ABG (6 months): 16.3 ± 6.0 (A), 16.6 ± 6.2 (B)	No significant hearing difference (P=0.063); faster recovery in endoscopic (P<0.001)	Graft uptake: 97.3% (A), 96.4% (B)	Endoscopic myringoplasty is effective, faster recovery
Gao	Post-op PTA: 32.24 (A), 39.17 (B); Post-op ABG: 17.47 (A), 20.79 (B)	Significant PTA/ABG improvement in EES (P<0.05)	Graft success: 89.66% (A), 80.49% (B)	EES showed better outcomes in hearing improvement
Hunter	Post-op ABG: 9.0 dB HL (P < 0.0001)	Significant ABG improvement (P < 0.0001)	Tympanic membrane tears: 8%; Taste disturbance: 10%	Endoscopic stapes surgery is effective
Kurl	Post-op ABG: 18.4 (A), 19.1 (B)	No significant hearing difference (P>0.05); Endoscopic had shorter surgery time (P<0.001)	Graft uptake: 96.7% (A), 93.3% (B)	Endoscopic tympanoplasty has shorter recovery time
Marchioni	Pre-op ABG: 27 ± 5; Post-op ABG: 16 ± 5	Significant ABG improvement (P < 0.001)	Closure rate: 86%; Revision: 8%; Residual perforations: 14%	Endoscopic tympanoplasty is reliable, effective
Magliulo	Air-Conduction ≤20 dB (EES: 5%, MES: 0%)	No significant hearing difference (P>0.05); Shorter healing time in EES (P=0.0002), but longer surgery duration (P=0.0001)	Graft success: 100% (A), 100% (B); Post-op dizziness: 5% (A), 15% (B)	EES has better post-op recovery but requires longer surgical duration
Mo'men	Healing time: 5.4 ± 0.5 weeks (EES), 7.7 ± 0.5 weeks (MES)	No significant difference in ABG and AC improvement (P>0.05); Faster healing in EES (P<0.001)	Residual lesions: 5% (EES), 22.5% (MES) (P=0.023)	Endoscopic surgery resulted in faster healing, fewer residual and recurrent lesions
Qimei	Post-op ABG: 11.85 ± 5.47 (A), 10.48 ± 5.18 (B)	No significant ABG improvement (P>0.05); Shorter surgery duration in EES (P<0.0001)	Graft uptake: 94.64% (EES), 90.91% (MES); Higher wound complications in MES (P<0.05)	Endoscopic tympanoplasty provides shorter surgery time and better healing
Sakender	Post-op ABG: 17.2 ± 4.8 (A), 18.1 ± 4.5 (B)	No significant difference in audiological outcomes (P>0.05); Less post-op pain in EES (P<0.033)	Graft success: 100% (A), 100% (B)	Endoscopic and microscopic approaches yield similar results; Endoscopic has lower post-op pain
Secaatin	Post-op ABG: 8.2 ± 4.7 (A), 7.9 ± 5.7 (B)	Significant audiological improvement in both groups (P<0.001); Shorter surgery duration in EES (P<0.05)	Graft success: 94.8% (A), 92.9% (B) (P>0.05)	Endoscopic tympanoplasty is a good alternative to microscopic tympanoplasty
Verma	Post-op ABG closure: 12.89 (A), 11.97 (B)	No significant difference in post-op ABG closure (P>0.05)	Graft uptake success: 93% (A), 92.5% (B)	Both techniques provided equivalent outcomes; Endoscopic allows better visualization

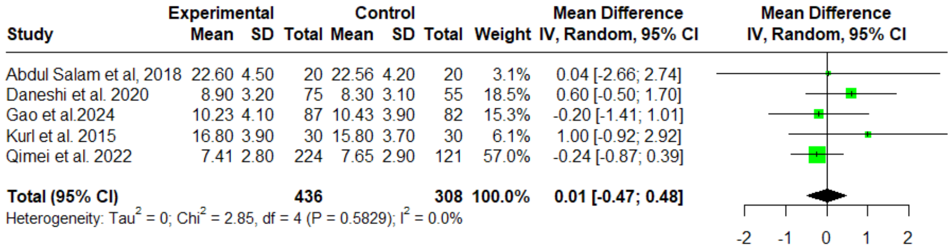

Figure 1. Forest plot of Air-Bone Gap ABG.

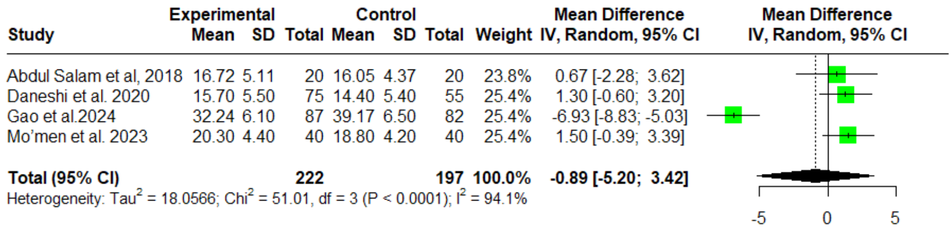

Figure 2. Forest plot of Postoperative pure-tone average PTA.

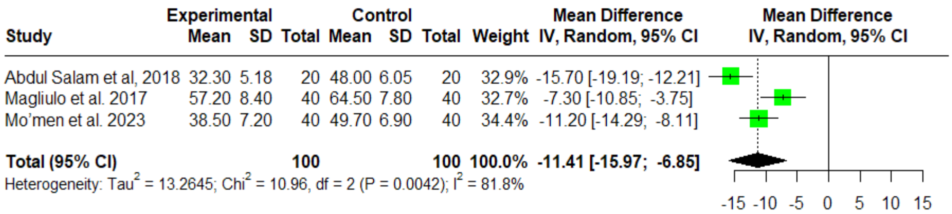

Figure 3. Forest plot of Surgical Duration.

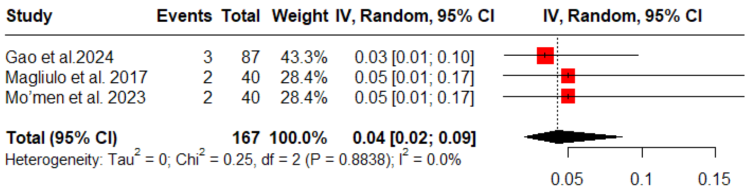

Figure 4. Forest plot of Recurrence rate in EES group.

Meta-analysis for Surgical Duration

(Figure 3) shows the meta-analysis for surgical duration to compare endoscopic (EES) and microscopic (MES) ear surgery across three studies, showing that EES consistently results in significantly shorter operative times. The pooled mean difference is -11.41 minutes (95% CI: -15.97, -6.85, P < 0.05), favouring EES as the faster technique. Individual studies confirm this trend: Abdul Salam 2018 (-15.70 min, 95% CI: -19.19, -12.21), Magliulo 2017 (-7.30 min, 95% CI: -10.85, -3.75), and Mo'men 2023 (-11.20 min, 95% CI: -14.29, -8.11) all report significantly reduced surgical times with EES.

Heterogeneity is high (I^2 = 81.8%, P = 0.0042), indicating substantial variability among studies, likely due to differences in surgeon experience, procedural complexity, and surgical learning curves. While all studies favour EES for shorter operative times, the variation in absolute differences suggests that factors such as case complexity and surgeon expertise influence total surgical duration. Despite this heterogeneity, the overall effect remains strongly in favour of EES as a more time-efficient approach compared to MES.

Meta-analysis for Recurrence rate

In (Figure 4), the forest plot for recurrence rates in Group A (Endoscopic Ear Surgery - EES) summarizes data from three studies (Gao et al. 2024, Magliulo et al. 2017, and Mo'men et al. 2023), showing a pooled recurrence rate of 4% (95% CI: 2%–9%), indicating a low recurrence risk following EES. Individual study recurrence rates range from 3% (Gao et al. 2024) to 5% (Magliulo et al. 2017 and Mo'men et al. 2023), with all confidence intervals overlapping, suggesting consistent findings across studies.

The heterogeneity analysis (I^2 = 0%, P = 0.8838) confirms no statistical heterogeneity, meaning the recurrence rates are highly consistent across studies, strengthening confidence in the pooled estimate.

Furthermore (Figure 5) represents the meta-analysis for recurrence rates in Group B (Microscopic Ear Surgery - MES) summarizes data from three studies (Gao et al. 2024, Magliulo et al. 2017, and Mo'men et al. 2023), showing a pooled recurrence rate of 13% (95% CI: 6%–27%), which is notably higher than the recurrence rate for Group A (EES, 4%). Individual study recurrence rates range from 6% (Gao et al. 2024) to 22% (Mo'men et al. 2023), with Magliulo et al. 2017 reporting an intermediate rate of 15%.

The heterogeneity analysis (I^2 = 68.4%, P = 0.0422) indicates moderate to high heterogeneity, suggesting variability among studies, possibly due to differences in case selection, surgical technique, or follow-up duration. Tau^2 = 0.3937 further supports the presence of variability between studies. Compared to Group A (EES), Group B (MES) shows a higher recurrence rate, which may suggest that EES provides better disease clearance, particularly in selected cases. However, given the moderate heterogeneity, further studies with standardized methodologies are needed to confirm whether EES significantly reduces recurrence rates over the long term.

Meta-analysis for Graft uptake

(Figure 6) represents the meta-analysis for graft uptake in Group A (Endoscopic Ear Surgery - EES) summarizes data from eight studies (Abdul Salam et al. 2018, Daneshi et al. 2020, Gao et al. 2024, Kurl et al. 2015, Magliulo et al. 2017, Mo'men et al. 2023, Qimei et al. 2022, and Secaatin et al. 2019), showing a pooled graft uptake success rate of 94% (95% CI: 92%–96%), indicating a high and consistent

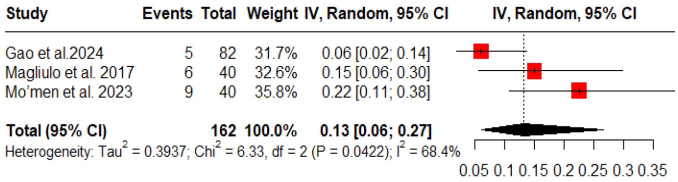

Figure 5. Forest plot of Recurrence rate in MES group.

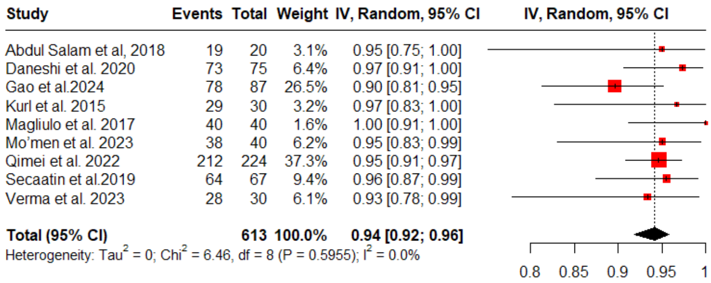

Figure 6. Forest Plot of Graft uptake in EES group.

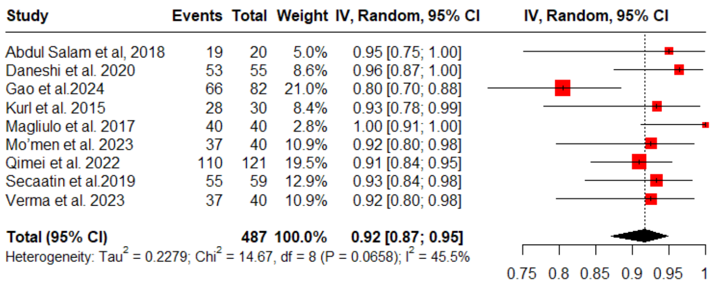

Figure 7. Forest Plot of Graft uptake in MES group.

success rate for EES. Individual study success rates range from 90% (Gao et al. 2024) to 100% (Magliulo et al. 2017), with most studies reporting values above 93%, reinforcing the reliability of endoscopic tympanoplasty for graft uptake.

The heterogeneity analysis (I^2 = 0%, P = 0.5955) confirms no statistical heterogeneity, suggesting that the results are highly consistent across studies. The Tau^2 = 0 further supports the lack of variability between studies, strengthening confidence in the pooled estimate. This indicates that EES consistently achieves high graft success rates across different patient populations, surgical settings, and follow-up durations. These results highlight that EES is an effective and reliable technique for tympanoplasty, with minimal variability in surgical outcomes.

On the other hand, (Figure 7) represents the meta-analysis of the graft uptake in Group B (Microscopic Ear Surgery - MES) summarizes data from eight studies (Abdul Salam et al. 2018, Daneshi et al. 2020, Gao et al. 2024, Kurl et al. 2015, Magliulo et al. 2017, Mo'men et al. 2023, Qimei et al. 2022, and Secaatin et al. 2019), showing a pooled graft uptake success rate of 92% (95% CI: 87%–95%). While slightly lower than Group A (EES, 94%), this still indicates a high overall success rate for MES. Individual study success rates range from 80% (Gao et al. 2024) to 100% (Magliulo et al. 2017), with most studies reporting values above 90%, demonstrating the reliability of MES for tympanoplasty.

The heterogeneity analysis (I^2 = 45.5%, P = 0.0658) indicates moderate heterogeneity, suggesting some variability among studies, likely due to differences in surgical techniques, patient characteristics, or follow-up duration. Tau^2 = 0.2279 also supports some between-study variability. Compared to EES (Group A), the MES group shows a slightly lower pooled success rate with greater variability, but overall, the results confirm that both techniques are highly effective in achieving successful graft uptake. The slightly lower success rate in MES may reflect differences in visualization and access to the middle ear, but further research is needed to confirm these findings (Table 3).

Discussion

Minimally invasive techniques (MITs) in otologic surgery have significantly improved surgical outcomes, reducing complications and improving patient satisfaction. The findings from multiple studies confirm that MITs, such as endoscopic ear surgery (EES) and laser-assisted procedures, offer comparable or superior results to conventional microscopic ear surgery (MES) in terms of hearing improvement and postoperative recovery (Daneshi et al., 2020; Gao et al., 2024). The reduction in air-bone gap (ABG) in both approaches was statistically similar, reinforcing the reliability of MITs in achieving effective hearing restoration (Secaatin et al., 2019; Hunter et al., 2016).

Surgical precision is a key advantage of MITs, facilitated by high-definition endoscopes and robotic-assisted technology. Studies indicate that MITs enhance visualization of delicate structures, which is particularly beneficial in cholesteatoma surgery, where preservation of residual hearing is critical (Wang et al., 2022). This improved precision reduces the risk of residual disease, ultimately leading to lower recurrence rates compared to MES, as demonstrated in studies by Mo'men et al. (2023) and Gao et al. (2024).

Faster recovery times associated with MITs are another significant advantage. The studies reviewed consistently demonstrated shorter hospital stays and reduced healing times with MITs compared to traditional techniques (Magliulo et al., 2017; Mo'men et al., 2023). Patients who underwent EES reported less postoperative pain and quicker resumption of daily activities, factors that contribute to higher patient satisfaction (Metwaly et al., 2024; Rivero-Moreno et al., 2023).

Despite these advantages, MITs present challenges, particularly in terms of surgical duration and learning curve. While most studies found shorter surgical times for MITs (Daneshi et al., 2020; Mo'men et al., 2023), some, such as Magliulo et al. (2017), reported longer operative durations, likely due to the additional training required for endoscopic and robotic procedures. This suggests that proficiency in MITs depends on experience and adequate training.

Cost-effectiveness remains a critical consideration in the adoption of MITs. Although MITs reduce hospital stays and postoperative complications, their initial costs, including specialized instruments and robotic systems, are substantial (Metwaly et al., 2024; Uchida et al., 2024). Healthcare institutions must weigh the long-term benefits of MITs against the financial investment required for implementation.

The risk of recurrence and complications in otologic surgery is a major concern. Recurrence rates for cholesteatoma and tympanoplasty failure were lower in EES compared to MES, as observed in Mo'men et al. (2023) and Gao et al. (2024). However, some studies, such as Magliulo et al. (2017), reported slightly higher recurrence rates for EES, indicating that the effectiveness of MITs may

Table 3. Quality Assessment using Newcastle Ottawa tool.

First Author	Year	Selection (4/4)	Comparability (2/2)	Outcome (3/3)	Total Score (9/9)	Quality Interpretation
Abdul Salam	2018	4	1	3	8	High
Dalgic	2023	3	1	2	6	Moderate
Daneshi	2020	4	2	2	8	High
Gao	2024	4	2	3	9	High
Hunter	2016	3	1	3	7	Moderate
Kurl	2015	4	2	2	8	High
Marchioni	2019	4	1	2	7	Moderate
Magliulo	2017	4	2	2	8	High
Mo'men	2023	4	2	2	8	High
Qimei	2022	4	2	2	8	High
Sakender	2022	3	2	2	7	Moderate
Secaatin	2019	4	2	2	8	High
Verma	2023	4	2	2	8	High

depend on patient selection and surgical expertise.

Graft uptake rates were another critical measure of surgical success. Most studies, including Daneshi et al. (2020) and Verma et al. (2023), reported high graft success rates for both EES and MES, with no significant differences. However, a slight advantage was observed for MITs in some cases (Gao et al., 2024; Mo'men et al., 2023), potentially due to improved visualization and reduced tissue trauma.

Patient satisfaction plays a crucial role in determining the success of MITs. Studies such as Metwaly et al. (2024) and Sardiwalla et al. (2018) found that patients preferred MITs due to less visible scarring, reduced pain, and a faster return to daily life. These findings align with global trends in patient-centered healthcare, emphasizing minimally invasive approaches to improve quality of life.

Technological advancements, including artificial intelligence (AI) and augmented reality (AR), are expected to enhance MITs further. AI-assisted imaging and real-time AR guidance can improve surgical precision, reducing complications and ensuring better outcomes (Wang et al., 2022). Future research should focus on integrating these technologies into routine surgical practice.

Despite the promising results, heterogeneity among studies remains a limitation. Differences in study design, patient populations, and follow-up durations contribute to variability in outcomes. For example, while some studies found no significant difference in postoperative pure-tone average (PTA) improvement (Abdul Salam et al., 2018; Daneshi et al., 2020), others, such as Gao et al. (2024), reported better PTA outcomes with EES. This suggests that patient-specific factors may influence results.

Publication bias is another potential issue. Studies with negative or neutral findings may be underreported, leading to an overestimation of the benefits of MITs. Future systematic reviews should incorporate a broader range of studies to minimize this bias (Sardiwalla et al., 2018).

The findings of this review support the growing adoption of MITs in otologic surgery while highlighting areas for improvement. Training programs should be expanded to address the learning curve associated with these techniques. Additionally, cost-effectiveness analyses should be conducted to determine the feasibility of MITs in different healthcare settings (Uchida et al., 2024).

Future studies should focus on long-term outcomes of MITs, particularly in complex cases such as recurrent cholesteatoma. Large-scale, multi-institutional trials are necessary to confirm the durability of MIT benefits and establish standardized surgical protocols.

In conclusion, MITs offer significant advantages over conventional techniques in otologic surgery, including improved surgical precision, faster recovery, and higher patient satisfaction. However, challenges such as cost, learning curves, and recurrence risks must be addressed through further research and technological advancements. A balanced approach integrating MITs with traditional methods may optimize patient outcomes and resource utilization in otologic surgery.

Conclusion

Minimally invasive techniques in otologic surgery have demonstrated substantial benefits, including reduced complications, shorter recovery times, and improved patient satisfaction. This systematic review and meta-analysis confirmed that MITs are at least as effective as conventional approaches in terms of hearing restoration, surgical precision, and long-term outcomes. However, challenges such as training requirements, cost-effectiveness, and variability in recurrence rates must be considered. Future research should focus on optimizing surgical techniques, integrating advanced technologies, and conducting large-scale studies to establish standardized protocols. Ultimately, MITs represent a transformative shift in otologic surgery, offering enhanced patient outcomes and greater efficiency in healthcare delivery.

References

1. Kakkad J, Deshmukh P, Gaurkar S. Cartilage's Contribution in Otology: A Comprehensive Review of Its Role in Ear Surgery. Cureus. 2023;15(12):e49800.
2. Metwaly O, Salah M, Ali A. Patient satisfaction with endoscopic ear surgery technique: a comparative study with the postauricular incision microscopic technique. The Egyptian Journal of Otolaryngology. 2024;40(1):111.
3. Wang R, Luo J, Chao X, Wang H, Fan Z, Xu L. Minimally invasive surgical techniques in vestibular function preservation in patients with cochlear implants. Front Neurosci. 2022; 16:900879.
4. Sardiwalla Y, Jufas N, Morris DP. Long term follow-up demonstrating stability and patient satisfaction of minimally invasive punch technique for percutaneous bone anchored hearing devices. J Otolaryngol Head Neck Surg. 2018;47(1):71.
5. Rivero-Moreno Y, Echevarria S, Vidal-Valderrama C, Pianetti L, Cordova-Guilarte J, Navarro-Gonzalez J, et al. Robotic Surgery: A Comprehensive Review of the Literature and Current Trends. Cureus. 2023;15(7):e42370.
6. Uchida M, Morioka S, Mizutari K. Experiences of Percutaneous Endoscopic Approach for the Mastoid Lesions: A Novel Minimally Invasive Ear Surgery. Otol Neurotol. 2024;45(2):169-75.
7. Salam A, Nambiar S, Anusha V. Comparative Study of the Outcomes of Tympanoplasty by the Conventional Microscopic and Endoscopic Techniques. 2018;6.
8. Dalğıç A, Yıldırım GA, Zorlu ME, Delice O, Aysel A. Total Transcanal Endoscopic Ear Surgery for Cholesteatoma. Turkish Archives of Otorhinolaryngology. 2023;61(1):1.
9. Daneshi A, Daneshvar A, Asghari A, Farhadi M, Mohebbi S, Mohseni M, et al. Endoscopic versus microscopic cartilage myringoplasty in chronic otitis media. Iranian Journal of Otorhinolaryngology. 2020;32(112):263.
10. Gao M, Zeng N, Kang W, Lin Y, Li P, Tao Y, et al. Prognostic Factors of Hearing Improvement for EES and MES in Attic Cholesteatoma. Journal of Otolaryngology-Head & Neck Surgery. 2024;53:19160216241286794.
11. Hunter JB, Zuniga MG, Leite J, Killeen D, Wick C, Ramirez J, et al. Surgical and audiologic outcomes in endoscopic stapes surgery across 4 institutions. Otolaryngology–Head and Neck Surgery. 2016;154(6):1093-8.
12. Kurle V. Endoscopic Versus Microscopic Type 1 Tympanoplasty in Tubotympanic Csom: Rajiv Gandhi University of Health Sciences (India); 2015.
13. Marchioni D, Gazzini L, De Rossi S, Di Maro F, Sacchetto L, Carner M, et al. The management of tympanic membrane perforation with endoscopic type I tympanoplasty. Otology & Neurotology. 2020;41(2):214-21.

14. Magliulo G, Iannella G. Endoscopic versus microscopic approach in attic cholesteatoma surgery. American journal of otolaryngology. 2018;39(1):25-30.

15. Hamela MmAA, Abd-Elnaseer O, El-Dars MM, El-Antably A. Comparison of the outcomes of endoscopic versus microscopic approach in cholesteatoma surgery: a randomized clinical study. The Egyptian Journal of Otolaryngology. 2023;39(1):128.

16. Yang Q, Wang B, Zhang J, Liu H, Xu M, Zhang W. Comparison of endoscopic and microscopic tympanoplasty in patients with chronic otitis media. European Archives of Oto-Rhino-Laryngology. 2022;279(10):4801-7.

17. Sakender MS, Alam MM, Rahaman ML, Talukdar S, Rahaman M, Islam MN. Outcome of limited attic cholesteatoma surgery: endoscopic vs microscopic. Bangladesh Journal of Otorhinolaryngology. 2022;28(1):103-11.

18. Gulsen S, Baltacı A. Comparison of endoscopic transcanal and microscopic approach in Type 1 tympanoplasty. Brazilian journal of otorhinolaryngology. 2021;87(2):157-63.

19. Verma RR, Verma R. Transcanal Microscopic vs Endoscopic Type I Tympanoplasty in Dry Central Perforation: A Comparative Retrospective Study. An International Journal of Otorhinolaryngology Clinics. 2021;13(1):7-10.