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Systematic Review

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Comparing CO_2 Laser and Microdrill in Primary Stapedotomy: A Systematic Review and Meta-Analysis of Post-Operative Hearing Outcomes and Complications

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Keywords
Otosclerosis · Ear surgery · Otological surgery · Deafness

Abstract
Introduction: The gold-standard treatment of otosclerosis is stapedectomy. Recent surgical advancements have led to the use of two approaches for stapedectomy: CO_2 laser and microdrill-assisted stapedotomy. There is limited data on the comparison of both interventions. This study aims to provide an update on evidence-based medicine on the use of CO_2 laser and microdrill in stapedotomy. ***Methods:*** A systematic review and meta-analysis were conducted using the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) Guidelines and an electronic search was conducted to identify studies comparing CO_2 laser versus microdrill for stapedectomy. Post-operative hearing outcomes and the rates of sensorineural hearing loss (SNHL) were identified as primary outcomes. Secondary outcomes included post-operative complications such as vertigo and abnormal taste sensation. The analysis was based on fixed or random-effects modelling. ***Results:*** Four studies enrolling 1,540 patients were identified. Post-operative hearing outcomes (odds ratio [OR] = 1.23, p = 0.1), SNHL (OR = 0.8, p = 0.74), and abnormal taste sensation post-operatively (OR = 0.84, p = 0.58) were not significantly different between both interventions. However, a significant difference was found between both groups for post-operative vertigo, showing a higher rate for the microdrill group (OR = 2.54, p = 0.02). ***Conclusion:*** In conclusion, CO_2 laser and microdrill are both effective procedures for stapedectomy, as they both produced comparable outcomes in post-operative hearing outcomes and SNHL. However, microdrill had higher rates of post-operative vertigo, possibly indicating that the CO_2 laser is a slightly more preferable option.

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Introduction

Otosclerosis is a progressive middle ear condition characterised by abnormal bone remodelling of the otic capsule, leading to conductive hearing loss [1]. The

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disease affects the fixation of the stapes, preventing efficient sound transmission from the environment through to the cochlea. Surgical intervention, first pioneered by Rosen in 1953, has revolutionised the management of otosclerosis, offering significant hearing restoration [2].

Since the development of stapedectomy and stapedotomy, various surgical modifications have been proposed to optimise hearing outcomes and minimise complications [3]. Traditional techniques involve mechanical fenestration of the stapes footplate using a microdrill; however, laser-assisted techniques have been introduced recently to reduce mechanical trauma and surgical complications [4]. The CO_2 laser, in particular, has gained popularity due to its precise energy delivery, limited footplate mobilisation, and reduced risk of acoustic trauma [5]. Despite these advantages, concerns remain regarding thermal damage to the perilymph and its potential impact on inner ear function, which is still under current research [6].

The comparative efficacy of CO_2 laser and microdrill-assisted stapedotomy remains an ongoing debate. While some studies suggest better air-bone gap closure rates with laser-assisted techniques, others report comparable audiometric outcomes between the two methods [7]. Additionally, post-operative complications, such as sensorineural hearing loss (SNHL), vertigo, and taste disturbances, require further investigation [8].

Beyond clinical outcomes, the practical considerations of laser-assisted stapedotomy have also been discussed. CO_2 laser use requires specialized training, intraoperative setup, and additional equipment, which may influence surgical efficiency and case selection. On the other hand, the microdrill, a widely available and well-established technique, remains a preferred method in many institutions and centres [9]. The implications of these differences in operative time and technical complexity warrant further exploration.

This systematic review aims to synthesise and critically appraise the latest evidence comparing CO_2 laser and microdrill-assisted stapedotomy, focusing on post-operative hearing outcomes, surgical complications, and procedural efficiency. By incorporating data from multiple studies across diverse settings, this review seeks to provide a comprehensive update on the efficacy and safety of these two surgical techniques. It also aims to fill a gap in the literature, being the first meta-analysis to compare the microdrill and CO_2 laser. Furthermore, it aims to address key limitations identified in prior systematic reviews on laser and microdrill stapedectomy overall.

Methods

This systematic review and meta-analysis were conducted per the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. A completed PRISMA checklist is included in the supplementary material (for all online suppl. material, see https://doi.org/10.1159/000546504).

Eligibility Criteria

This study aimed to evaluate the comparative outcomes of CO_2 laser-assisted stapedotomy and microdrill-assisted stapedotomy by synthesising available evidence from randomised controlled trials (RCTs) and observational studies. Studies were included if they directly compared CO_2 laser and microdrill-assisted stapedotomy to treat otosclerosis. Eligible studies had to report at least one of the primary or secondary outcomes relevant to the review. The intervention group consisted of patients undergoing CO_2 laser-assisted stapedotomy, while the comparator group included those undergoing microdrill-assisted stapedotomy. No restrictions were placed on participant demographics such as age, sex, or comorbidities. Only studies published in English were considered for inclusion.

Studies were excluded if they were case reports, single-arm observational studies without a comparator, narrative reviews, or conference abstracts. Additionally, studies that did not report specific hearing outcomes or post-operative complications relevant to the review were excluded.

Primary Outcomes

The primary outcomes are post-operative hearing outcomes, measured by the air-bone gap closure, and the SNHL rates, defined as a threshold shift of more than 10 decibels (dB) at any tested frequency following surgery.

Secondary Outcomes

The secondary outcomes included post-operative vertigo, abnormal taste sensation, and ear infection presence, as well as operative time.

Literature Search Strategy

A comprehensive search of relevant literature was conducted by two authors independently across multiple electronic databases, including MEDLINE (via PubMed), EMBASE, CINAHL, Web of Science, and the Cochrane Central Register of Controlled Trials (CENTRAL). The final search was completed on 1st March 2025.

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The search strategy incorporated Medical Subject Headings (MeSH) terms and free-text keywords such as "CO_2 laser," "carbon dioxide laser," "microdrill," "stapedotomy," "otosclerosis surgery," "hearing outcomes in stapes surgery," and "stapedotomy complications." Boolean operators ("AND" and "OR") were utilized to refine search results.

In addition to database searches, grey literature, and ongoing or unpublished trials were identified through searches of the World Health Organization International Clinical Trials Registry, ClinicalTrials.gov, and the ISRCTN Register. To ensure thorough coverage, reference lists of all included studies and relevant systematic reviews were manually screened for additional eligible articles.

Study Selection

Two independent reviewers, blinded to each other's assessments, screened all retrieved studies for eligibility based on titles and abstracts. Full-text articles were obtained for studies that appeared to meet the inclusion criteria. If discrepancies in the selection process were identified, they were resolved through discussion or consultation with a third reviewer, N.G.

Data Extraction and Management

A standardised data extraction spreadsheet was created in Microsoft Excel, based on the Cochrane data collection form for intervention reviews. The spreadsheet underwent pilot testing to ensure consistency and reliability. Two independent reviewers extracted data from the included studies, and any disagreements were resolved through discussion. The extracted data included: study characteristics (author, year, country, study design, and sample size), patient demographics (mean age and sex distribution), surgical intervention details (CO_2 laser vs. microdrill technique), and primary and secondary outcomes, including hearing improvement, post-operative complications, and operative time.

Data Synthesis

A meta-analysis was conducted for outcomes reported by at least four studies. Mean differences were used to assess continuous variables while odds ratios (ORs) were used for dichotomous outcomes. A fixed-effect model was applied for statistical analysis.

Review Manager 5.3 (RevMan) software was used for data analysis and results were presented as forest plots with 95% confidence intervals (CIs). The degree of heterogeneity among studies was evaluated using Cochrane's Q test (χ^2) and the I^2 statistic. The I^2 statistic was interpreted as follows: 0–25%: low heterogeneity, 25–75%: moderate heterogeneity, and 75–100%: high heterogeneity.

Risk of Bias and Quality Assessment

The methodological quality of the included studies was assessed independently by two reviewers. For randomised controlled trials (RCTs), the Cochrane Risk of Bias Tool was applied, evaluating the following domains: selection bias, performance bias, detection bias, attrition bias, and reporting bias. Each RCT was categorised as having a low, unclear, or high risk of bias based on these criteria. For non-randomised studies, the Newcastle-Ottawa Scale was used [10]. It uses a star grading system to assess study selection criteria, comparability of groups, and the outcome assessment and follow-up. Each study was assigned a score out of 9 stars, with higher scores indicating higher methodological quality. In addition, the Agency for Healthcare Research and Quality (AHRQ) criteria were used to classify studies as good, fair, or poor quality [10].

Results

Literature Search Results

Our search strategy retrieved 46 studies. After thoroughly screening the retrieved articles, the authors identified four studies that met the eligibility criteria (Fig. 1).

Description of Studies

Four studies were appraised, with a total of 1,540 patients. A total of 582 patients were included in the carbon dioxide laser group and 958 in the microdrill group. Table 1 summarises the baseline characteristics of the included studies. The studies were standardised in the population and design, comparing carbon dioxide laser versus microdrill for patients undergoing stapedotomy [11–14].

Primary Outcomes

Post-Operative Hearing Outcome

No statistically significant difference was seen in the OR analysis in the post-operative hearing outcome between CO_2 laser and microdrill, showing a higher rate for the carbon dioxide laser group (OR = 1.23, CI, 0.96–1.58 $p = 0.1$). A moderate level of heterogeneity was found among these studies ($I^2 = 61\%$, $p = 0.05$). This is shown in Figure 2.

Sensorineural Hearing Loss

No statistically significant difference was seen in the OR analysis in the rate of SNHL between CO_2 laser and microdrill, showing a higher rate for the carbon dioxide

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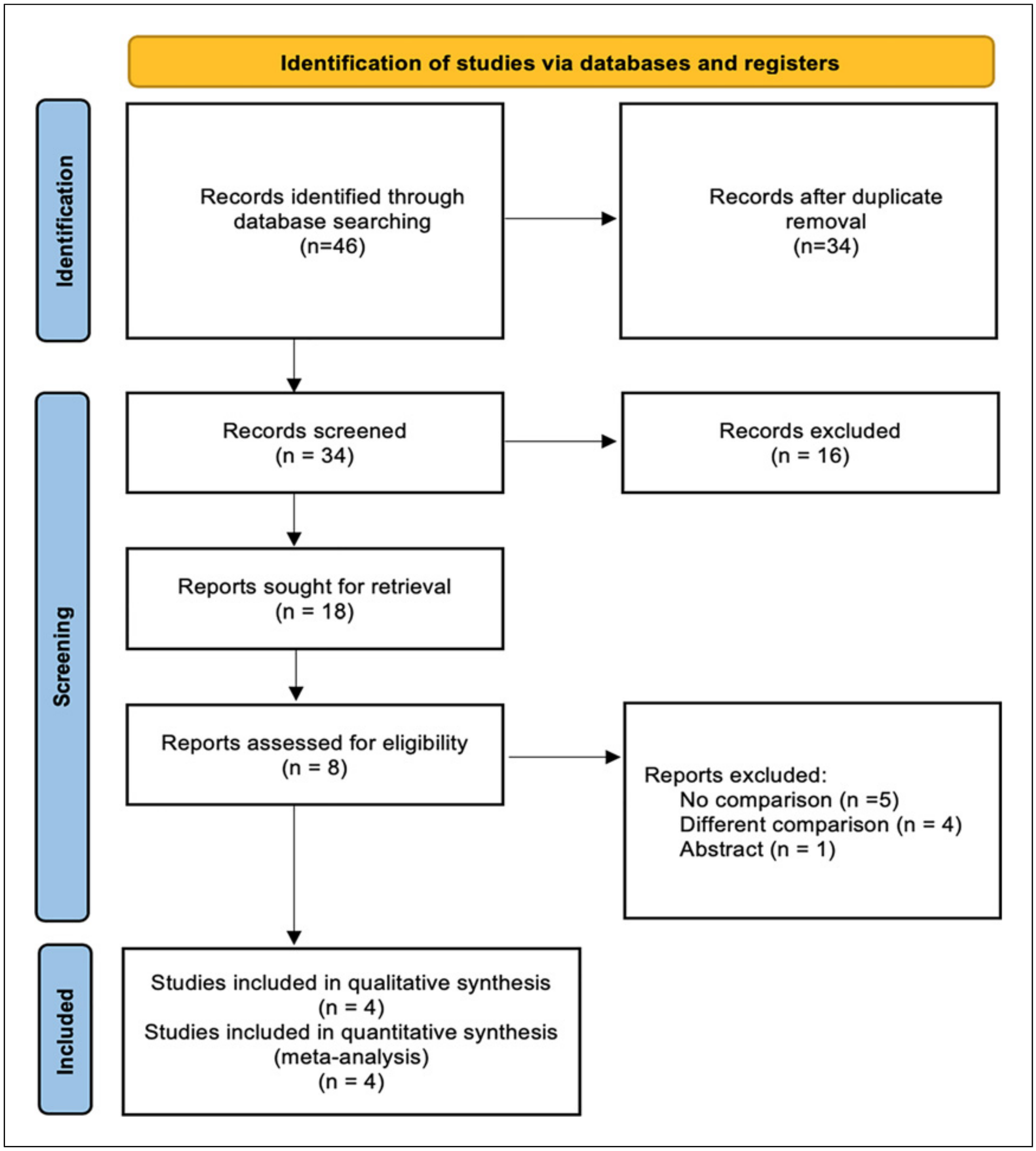

Fig. 1. PRISMA flowchart.

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laser group (OR = 0.8, CI, 0.21–3.07 p = 0.74). A low level of heterogeneity was found among these studies ($I2$ = 0%, p = 0.72). This is shown in Figure 3.

Secondary Outcomes

Vertigo

There was a statistically significant difference seen in the OR analysis in the rate of post-operative vertigo presence between carbon dioxide laser and microdrill, showing a higher rate for the microdrill group (OR = 2.54, CI, 1.17–5.52, p = 0.02). A low level of heterogeneity was found among these studies ($I2$ = 0%, p = 0.84). This is shown in Figure 4.

Abnormal Taste Sensation

No statistically significant difference was seen in the OR analysis in the presence of post-operative abnormal taste sensation between carbon dioxide laser and microdrill, showing a higher rate for the microdrill group (OR = 0.84, CI, 0.44–1.59, p = 0.58).

Table 1. Baseline characteristics of the included studies

Author (Year)	Journal, Country	Study design	Age (mean±SD), years	Sex (M: F)	Total sample, *n*	Prosthesis type
Molinari et al. [11] (2023)	Eur Arch Otorhinolaryngol, Italy	RCT	49.7±10.7	12: 34	46	Platinum/polytetrafluoroethylene or platinum/fluoroplastic
De Vito et al. [12] (2021)	Eur Arch Otorhinolaryngol, Italy	Retrospective	49.13	103: 231	333	Titanium/polytetrafluoroethylene
Altamami et al. [13] (2019)	Eur Arch Otorhinolaryngol, France	Retrospective	CO_2: 45.9±12.1, Microdrill: 51.3±12.4	270: 472	742	NR
Pauli et al. [14] (2019)	Laryngoscope, Sweden	Retrospective	CO_2: 50±12.8, Microdrill: 50±13.4	182: 302	419	Platinum/polytetrafluoroethylene (84% of cases reported only)

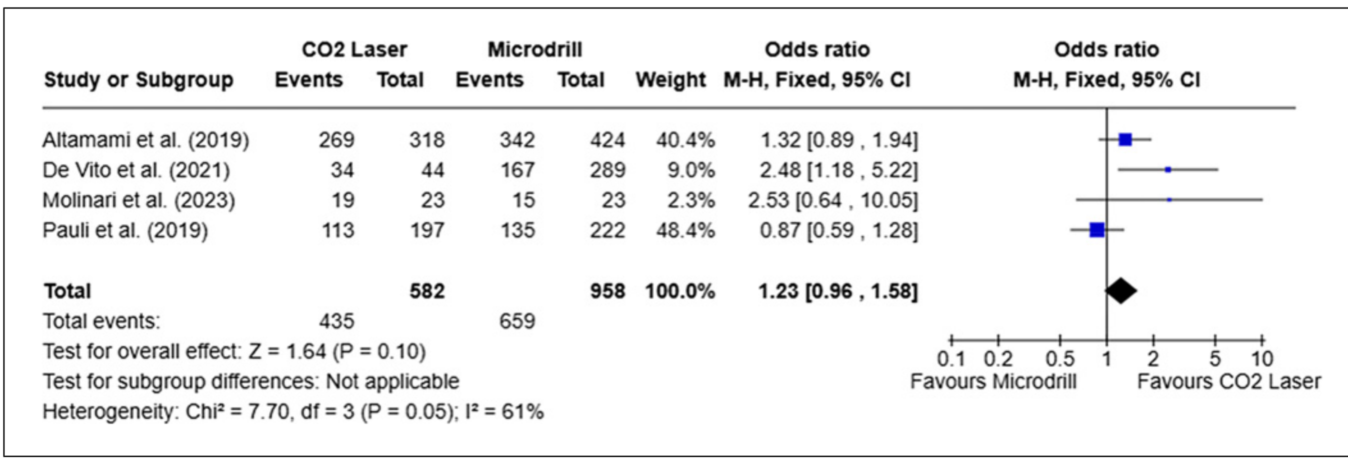

Fig. 2. Forest plot of CO_2 laser versus microdrill for stapedectomy – post-operative hearing outcome.

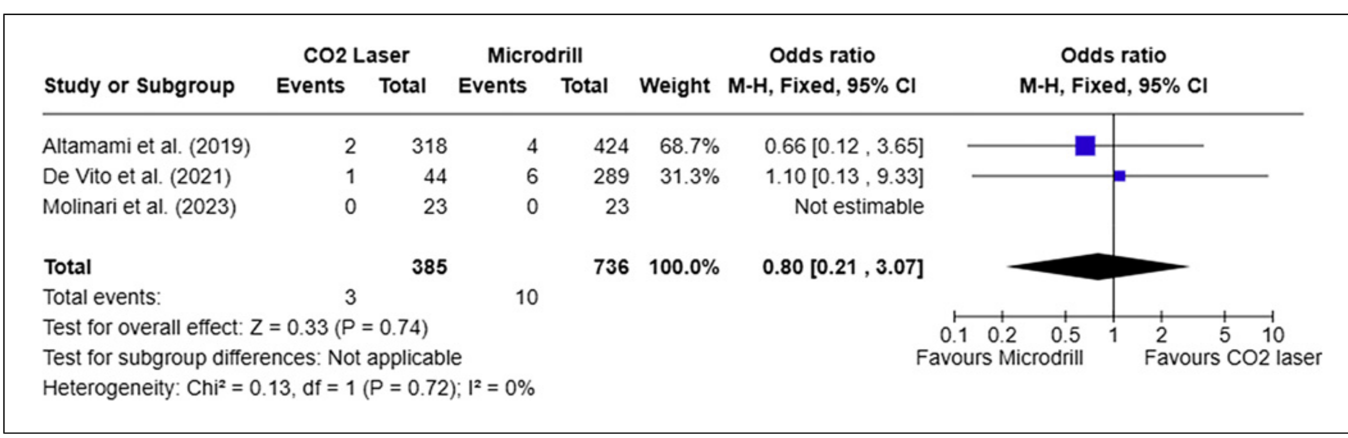

Fig. 3. Forest plot of CO_2 laser versus microdrill for stapedectomy – post-operative SNHL.

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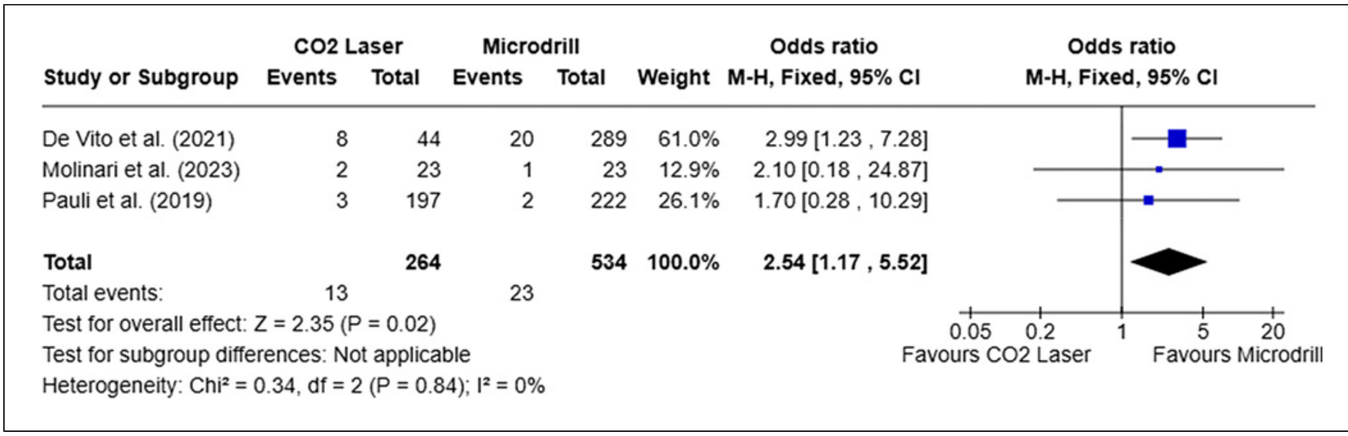

Fig. 4. Forest plot of CO_2 laser versus microdrill for stapedectomy – post-operative vertigo.

A low level of heterogeneity was found among these studies ($I2$ = 17%, p = 0.30). This is shown in Figure 5.

Tinnitus

Molinari et al. [11] and Pauli et al. [14] investigated the post-operative presence of tinnitus. Molinari et al. [11] reported that 3 patients from those who underwent microdrill for stapedectomy had the presence of tinnitus and none who underwent carbon dioxide stapedectomy reported tinnitus presence [11]. Pauli et al. [14] reported that 16 out of the 197 patients who underwent carbon dioxide stapedectomy had the post-operative presence of tinnitus, whilst 11 out of the 222 patients who underwent microdrill stapedectomy had post-operative tinnitus.

Ear Infection

Molinari et al. [11] and Pauli et al. [14] investigated the post-operative presence of ear infections. Molinari et al. [11] reported that no patients from those who underwent microdrill or carbon dioxide laser for stapedectomy had the presence of an ear infection post-operatively. Pauli et al. [14] reported that 2 out of the 197 patients who underwent carbon dioxide stapedectomy had a post-operative ear infection, whilst 5 out of the 222 patients who underwent microdrill stapedectomy had a post-operative ear infection.

Operative Time

Molinari et al. [11] reported that the mean operative time for carbon dioxide laser stapedectomy (65 min) was longer than in the microdrill stapedectomy (45 min), p = 0.003. De Vito et al. [12] reported that the average surgical procedure duration was 46.2, 35.5, and 55.3 min in manual microdrill, electric microdrill, and carbon dioxide laser respectively. The average surgical time of laser carbon dioxide surgery was longer than other surgical procedures (manual microdrill vs. carbon dioxide laser p = 0.04; electrical microdrill vs. carbon dioxide laser p = 0.03). From both papers, we can deduce that there is a statistically significant difference in time between the carbon dioxide laser and the microdrill for stapedectomy.

Methodological Quality and Risk of Bias Assessment

The quality of the randomised studies was assessed using the Cochrane Collaboration tool. This is summarised in Table 2. The retrospective studies were evaluated using the Newcastle-Ottawa scale, summarised in Table 3. According to the Agency for Healthcare Research and Quality standards, all the studies were rated to be good quality.

Discussion

Stapedotomy remains the gold-standard surgical intervention for otosclerosis, aiming to restore hearing while minimising procedure-related auditory damage [15]. Among the various techniques employed for stapedotomy, the microdrill and CO_2 laser are the two most commonly used methods for stapes footplate fenestration [16]. Despite their widespread adoption, no clear consensus remains on which technique offers superior hearing outcomes and fewer post-operative complications. Consequently, the choice of surgical approach is often based on individual surgeon preference rather than high-quality comparative evidence [17].

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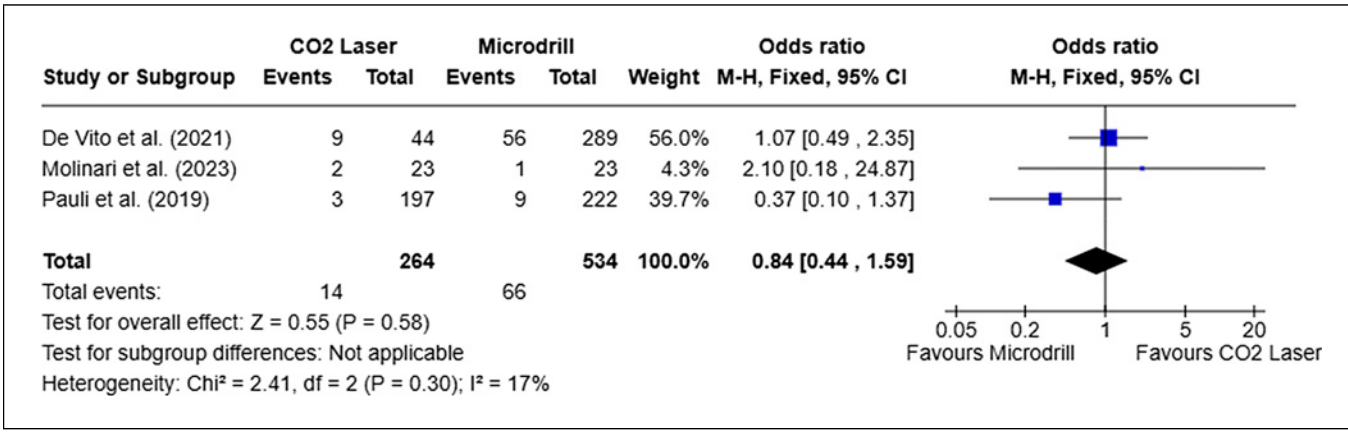

Fig. 5. Forest plot of CO_2 laser versus microdrill for stapedectomy – post-operative abnormal taste sensation.

Table 2. Bias analysis of the randomised control trials using the Cochrane collaboration tool

Author (Year)	Bias	Authors judgement	Support for judgement
Molinari et al. [11] (2023)	Random sequence generation (selection bias)	Low	The study matched cases and controls based on specific criteria, reducing selection bias
	Allocation concealment (selection bias)	Low	Matching was performed by an independent investigator blinded to intraoperative findings and post-operative outcomes
	Blinding of outcome assessment (detection bias)	Low	Post-operative audiometric assessments were performed by the same team of audiologists, ensuring consistency
	Incomplete outcome data (attrition bias)	Low	All consecutive cases were included with clear exclusion criteria, and there were no patients lost to follow-up
	Selective reporting (reporting bias)	Low	The study reported all planned outcomes, including audiometric and complication data, without evidence of selective omission
	Other bias	Low	There is no indication of significant other biases; data collection and statistical methods appear robust

Table 3. Newcastle-Ottawa scale to assess the quality of non-randomised studies

Author (Year)	Selection (out of 4 stars)	Comparability (out of 2 stars)	Outcome/exposure (out of 3 stars)	Quality assessment based on the Agency for Healthcare Research and Quality (AHRQ)
De Vito et al. [12] (2021)	****	*	***	Good
Altamami et al. [13] (2019)	****	*	***	Good
Pauli et al. [14] (2019)	****	**	***	Good

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While previous systematic reviews have broadly assessed laser versus non-laser techniques in stapedotomy, they have grouped all laser modalities without distinguishing between specific laser types or directly comparing them to microdrill techniques [18, 19]. Notably, the most recent meta-analysis by Bartel et al. (2020) evaluated post-operative hearing outcomes between laser-assisted and conventional stapedotomy; however, it did not account for post-operative side effects. This is a key limitation in assessing overall surgical success. Furthermore, no previous reviews have specifically compared CO_2 laser to microdrill, despite these being the two most frequently employed techniques. Therefore, this review directly addresses this gap by providing a focused comparison between microdrill-assisted and CO_2 laser-assisted stapedotomy, with a particular emphasis on both hearing outcomes and post-operative complications. By focusing on these two techniques, this study aims to provide a clearer, more clinically relevant assessment that can inform surgical decision-making and optimise patient outcomes.

This meta-analysis demonstrates that CO_2 laser and microdrill techniques are effective in stapedotomy, with no significant differences observed in the primary outcomes of post-operative hearing improvement and SNHL. These findings suggest that both techniques are viable surgical options for the management of otosclerosis, yielding comparable audiological outcomes. However, a statistically significant higher incidence of post-operative vertigo (p = 0.02) was noted in the microdrill group compared to the CO_2 laser group, indicating a potential difference in the impact of these techniques on vestibular function. Given that the heterogeneity among the included studies was low to moderate, a fixed-effect model was employed for analysis, thereby enhancing the reliability of these findings. On the other hand, post-operative tinnitus and vertigo may be influenced by multiple factors, including preoperative vestibulocochlear function, individual patient susceptibility, and the gentleness of surgical handling. While surgical instrumentation may play a minor role, attributing causality to technique alone would oversimplify these complex outcomes [20].

The findings of this meta-analysis align with existing literature, which suggests that both CO_2 laser and microdrill techniques achieve comparable hearing restoration [21]. However, discrepancies exist regarding the extent of inner ear trauma and long-term vestibular outcomes [19]. Some studies, including those by Forton et al. [22] and Cuda et al. [16] propose that CO_2 laser may induce less perilymphatic disturbance, whereas others report no clear advantage over mechanical microdrill techniques. Additionally, concerns persist regarding the thermal effects of laser application, as excessive energy absorption could theoretically lead to inner ear damage or delayed SNHL [23].

Beyond the primary outcomes, this review also examined several secondary outcomes, including operative time, post-operative vertigo, and abnormal taste sensation. Both Molinari et al. and De Vito et al. reported that CO_2 laser stapedotomy was associated with a longer operative time compared to the microdrill technique. While increased operative duration may present logistical challenges in surgical settings, the CO_2 laser technique's non-contact nature may reduce mechanical trauma to the footplate, potentially contributing to the lower rates of post-operative vertigo observed in this study.

Additionally, no significant differences were identified in the incidence of post-operative abnormal taste sensation, a recognised complication of stapedotomy attributed to chorda tympani nerve manipulation. This suggests that while the choice of technique may influence vestibular function, there is minimal impact on chorda tympani nerve.

A systematic approach was employed to ensure that conclusions were drawn based on high-quality evidence. This meta-analysis incorporated one RCT and three non-randomised studies, encompassing a total sample size of 1,540 patients across a broad age range. The inclusion of a large and diverse patient cohort enhances the generalisability of the findings, providing a comprehensive overview of the comparative effectiveness of CO_2 laser and microdrill stapedotomy. Overall, this systematic review evaluates the utility and the clinical effectiveness of microdrill and CO_2 laser techniques by providing evidence that both approaches yield comparable hearing outcomes.

Despite these strengths, several limitations should be acknowledged. The search strategy identified only four relevant studies, limiting the statistical power necessary to establish definitive conclusions regarding the superiority of one technique over the other. Additionally, double-blind randomisation was not feasible due to the nature of surgical interventions, as both the surgeon and patient are inherently aware of the procedure performed. The included studies also exhibited heterogeneity in patient demographics, surgical indications, and procedural techniques, which may introduce potential confounding variables, therefore affecting the overall results. Furthermore, surgeon experience and technical proficiency were not consistently accounted for across the studies, which could have influenced post-operative results. Moreover, only two of the four included studies reported the type of prosthesis used in full. One study provided partial data, and one did not report it at all. This limited

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our ability to analyse outcomes by prosthesis type, which may be a confounding factor affecting post-operative hearing outcomes.

Conclusion

Given these findings, CO_2 laser stapedotomy does not necessarily offer superior hearing outcomes compared to microdrill techniques. However, the observed increased incidence of post-operative vertigo in the microdrill group suggests that patient selection and preoperative counselling may be critical in determining the most appropriate surgical approach. Patients with pre-existing vestibular dysfunction may benefit from CO_2 laser-assisted stapedotomy, given its association with a lower incidence of post-operative vertigo. In conclusion, these findings offer a clinically relevant message that both techniques are valid options for otosclerosis management and may be selected based on surgeon expertise and equipment availability rather than perceived superiority.

Future well-designed, multicentre RCTs with larger sample sizes and long-term follow-up are warranted to further assess the safety, efficacy, and durability of these techniques. Additionally, further research should evaluate cost-effectiveness, learning curve implications, and patient-reported functional outcomes to facilitate evidence-based decision-making in clinical practice.

Registration and Protocol

This systematic review was registered in the PROSPERO International Register of Systematic reviews, registration number: CRD420251007980. The protocol is available from https://www.crd.york.ac.uk/PROSPERO/view/CRD420251007980. No amendments were made to the protocol.

Statement of Ethics

A Statement of Ethics is not applicable because this study is based exclusively on published literature.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

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Author Contributions

Eyad Jamileh collected and analysed data, contributed to drafting, and revised the article. Zuha Akhtar, Nadeem Gire, and Abdulmalik Alsaif collected and analysed data and contributed to drafting; Abdullah Ahmed revised the article and contributed to final approval; Mohannad Jamileh, Munir Ahmed, and Mohamed Xamza contributed to the design of the study and final approval and is accountable for all aspects.

Data Availability Statement

All data generated or analysed during this study are included in this article. Further enquiries can be directed to the corresponding author.

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