REVIEW ARTICLE

Comparing Ultrasonically Activated Irrigation and Laser-Activated Irrigation for Postoperative Pain Reduction in Endodontics: A Systematic Review and Meta-Analysis of Randomized Controlled Trials

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ABSTRACT

Introduction: This systematic review and meta-analysis evaluate the effects of ultrasonically activated irrigation (UAI) and laser-activated irrigation (LAI) on postoperative pain following root canal treatment (RCT). **Methods:** An extensive search of the literature was performed using MEDLINE, Web of Science, Embase, and the Cochrane Library from January 2000 to March 2025. Eligible randomized controlled trials (RCTs) comparing UAI with LAI and reporting postoperative pain outcomes at multiple postoperative time on the visual analog scale were included. The included RCTs were thoroughly evaluated for potential risk of bias and overall quality of evidence, and their data were pooled and analyzed using a random-effects model. **Results:** Seven RCTs (n = 490 teeth, 30 comparisons) were meta-analyzed, showing that LAI significantly reduced postoperative pain compared to UAI (standard mean difference [SMD] = −0.58; 95% CI: −0.94 to −0.22; P = .0016). Subgroup analysis highlighted the greatest pain reduction at 24–48 hours (SMD = −1.00), especially with pulsed Er: YAG lasers (PIPS: SMD = −1.10; SWEEPS: SMD = −1.57), while diode lasers showed no significant effect (SMD = 0.03). Sensitivity analyses supported the reliability of these findings. **Conclusions:** LAI provides a statistically and clinically meaningful reduction in postoperative endodontic pain compared to ultrasonic activation, with the most pronounced effects observed between 24- and 48-hours post-treatment. Among laser types, pulsed Er: YAG modalities—especially SWEEPS—demonstrated the strongest analgesic benefit. *(J Endod 2026;52:37–46.)*

SIGNIFICANCE

This review suggests LAI may offer a short-term advantage over UAI for pain management in the first day after treatment, although both effectively reduce postoperative discomfort.

KEY WORDS

Endodontics; laser-activated irrigation; postoperative pain; root canal treatment; ultrasonically activated irrigation

Root canal treatment (RCT) aims to eradicate root canal infections and prevent reinfection. Despite advancements in instrumentation and irrigation protocols, postoperative pain remains a prevalent complication, with up to 58% of patients affected[1]. Postoperative pain following root canal treatment is not only prevalent but variable in intensity. Randomized clinical trials have reported mean visual analog scale (VAS) scores ranging from 2 to 4 out of 10 at 24 hours post-treatment, with pain gradually declining over time[1-7]. Various factors contribute to pain, including the type of instrumentation, administration of analgesics, extrusion of debris or irrigants, the preoperative condition (symptomatic or asymptomatic), and host factors[2].

To address these challenges and improve disinfection efficacy, advanced irrigation techniques such as ultrasonically activated irrigation (UAI) and laser activated irrigation (LAI) have been explored. UAI utilizes acoustic streaming and cavitation, whereas LAI capitalizes on photomechanical and

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photoacoustic effects to augment irrigant penetration. Several laser types (Er: YAG, Er, Cr: YSGG, diode) have been studied for their ability to enhance cleanliness and disinfection of complex canal anatomies[3,4].

UAI is widely adopted in clinical practice due to its cost-effectiveness and ease of integration into daily workflows. However, it may be limited in its ability to clean anatomically complex areas such as lateral canals and isthmuses due to restricted fluid penetration[6]. LAI, particularly with pulsed Er: YAG systems, improves fluid dynamics and enhances irrigant penetration through photoacoustic streaming, resulting in superior debridement of complex canal morphologies[7]. Nevertheless, LAI's adoption is hindered by higher equipment costs, training demands, and infrastructure requirements, which may restrict its accessibility in general practice.

While the European Society of Endodontology does not currently recommend the routine use of irrigant activation methods due to limited evidence on long-term outcomes, some studies suggest that laser-assisted endodontic procedures may lead to more effective debris removal and less irrigant extrusion, which could result in lower postoperative pain[1,4-6,8]. However, results vary among published randomized controlled trials[3,7]. Despite a growing body of evidence demonstrating the efficacy of LAI in reducing postoperative pain, a comprehensive systematic review and meta-analysis consolidating these findings and comparing its effectiveness to UAI has not yet been conducted. Thus, the primary aim of this systematic review and meta-analysis is to evaluate and compare the postoperative pain outcomes of UAI versus LAI following root canal treatment. We hypothesize that LAI may result in a lower incidence or intensity of early postoperative pain compared to UAI, thereby providing clinicians with evidence-based insights into its potential advantages for improving clinical outcomes.

MATERIALS AND METHODS

This review was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and has been prospectively registered in the PROSPERO database (CRD420251054544). Studies were deemed eligible for inclusion based on the following criteria.

Eligibility Criteria

1. Population: Patients undergoing primary nonsurgical root canal treatment (NSRCT) on permanent teeth with irreversible pulpitis, necrotic pulp and symptomatic/asymptomatic apical periodontitis.
2. Intervention: LAI.
3. Comparison: UAI.
4. Outcome: Postoperative pain following NSRCT measured by the VAS.
5. Study Design: Randomized controlled trials (RCTs).

The inclusion criteria focused on studies involving human participants undergoing NSRCT with LAI, comparing LAI with UAI, and the outcome measure was reporting postoperative pain. Eligible studies included randomized controlled trials published as full-text articles in peer-reviewed journals. Studies were excluded if they lacked a clearly defined comparison group, or if they were *in vitro* or animal studies, narrative reviews, case reports or case series, or articles that did not report postoperative pain outcomes using the VAS.

Search Methods for Identifying Studies

A comprehensive search strategy was developed collaboratively by 3 reviewers in consultation with a medical librarian. A structured search of the literature was carried out using tailored keywords and Medical Subject Headings (MeSH) across multiple databases, including PubMed (MEDLINE), Web of Science, Embase, and the Cochrane Library. The literature search included studies released from January 2000 through March 2025 (see Supplemental Fig. 1).

Beyond the electronic database search, gray literature was examined using sources such as Google Scholar and ProQuest Dissertations and Theses. Additional manual searches were performed by reviewing the reference lists of pertinent articles and book chapters. The reference lists of all included studies were also screened to ensure comprehensive coverage of the available literature.

Given the limited number of comprehensive comparisons between LAI and PUI, a systematic review and meta-analysis were conducted to evaluate their effects on postoperative pain following root canal treatment (RCT). The review included studies published from 2000 onward. All retrieved records were imported into Covidence[9] (Melbourne, Australia) for screening, with duplicate entries removed automatically.

Screening and Data Extraction

Two independent reviewers (A.H. and J.G.) screened all retrieved records using Covidence systematic review software (Veritas Health Innovation, Melbourne, Australia), which also facilitated duplicate removal and title and abstract management. The screening process was conducted in 2 phases: an initial title and abstract review, followed by full-text evaluation of potentially eligible studies. To ensure consistency, the reviewers jointly screened the first 20 articles. Disagreements were resolved by a third reviewer (M.S.). Reasons for exclusion at the full-text stage are provided in Supplemental Table 1.

Data extracted from each included study were compiled in an Excel spreadsheet (Microsoft Corp, Redmond, WA) and included the following variables.

1. Publication details (year, author, and journal)
2. Characteristics of participants (demographic characteristics, sample size, pre-operative diagnosis, and file system used)
3. The number of subjects and the randomization methodology for each treatment group
4. Irrigation protocol: type of ultrasonic device or laser system
5. Pain assessment: VAS measurement time points, mean scores, and standard deviation (SD)
6. Duration of postoperative follow-up

Two reviewers (A.H. and J.G.) independently cross-checked all extracted information for accuracy.

Risk of Bias Assessment

Risk of bias for each included study was independently assessed by 2 reviewers (A.H. and J.G.) using the Cochrane Risk of Bias tool[10], which evaluates 7 domains: random sequence generation, allocation concealment, blinding, incomplete outcome data, selective reporting, and other potential sources of bias. A third reviewer (M.S.) resolved any disagreements. Studies were classified as "low risk" if all domains were judged to have low risk, "some concerns" if at least one domain raised concerns or was unclear, and "high risk" if there were concerns in 3 or more domains or a high risk judgment in any single domain.

Quality of Evidence

The certainty of the evidence was evaluated using the Grading of Recommendations, Assessment, Development, and Evaluation (GRADE) approach (GRADEpro GDT: GRADEpro Guideline Development Tool; McMaster University, Hamilton, ON,

Canada)[11]. Two reviewers (H.H. and J.G.) independently assessed the quality of evidence across 5 domains: risk of bias, inconsistency, indirectness, imprecision, and potential publication bias. Discrepancies were resolved through consensus with a third reviewer (M.S.).

QUANTITATIVE ANALYSIS

Data Extraction and Effect-Size Computation

We extracted group means, standard deviations, and sample sizes for postoperative pain (visual analogue scale, VAS) from each included trial arm. Standardized mean differences (SMDs) with Hedges' g correction were computed using the inverse-variance method via the escalc () function in the metafor package[12]. When trials reported multiple postoperative time points or laser modalities, each comparison was treated as a separate data point. A random-effects model was fitted using restricted maximum-likelihood estimation in metafor. The primary analysis pooled all SMDs for LAI versus UAI regardless of time point or laser type. Between-study heterogeneity was quantified with the I^2 statistic, τ^2 (tau-squared), and Cochran's Q-test. All analyses were performed in R (version 4.4.0; R Foundation for Statistical Computing, Vienna, Austria) using the metafor and readxl packages. Forest and funnel plots were generated with built-in plotting functions.

Sensitivity and Subgroup Analyses

We stratified the data into subgroups based on 2 criteria: (1) postoperative time intervals (early: 6–12 hours; intermediate: 24–48 hours; late: 72 hours–7 days) and (2) laser technology (diode, Er,Cr: YSGG, Er: YAG-PIPS, Er: YAG-SWEEPS, and Er: YAG Lightwalker). Between-subgroup differences were assessed using χ^2 statistics for subgroup effects. Robustness was examined via 2 internal sensitivity checks:[1] exclusion of Erkan et al[2] trials with imputed data and[2] sequential removal of high-influence comparisons (Mittal et al[6] SWEEPS-48 hours, Elmallawany et al 7 days, and remaining extreme effect estimates).

Publication Bias Assessment

A funnel plot of standard error versus SMD was inspected visually for asymmetry. Formal statistical tests (eg, Egger's regression, trim-and-fill) were not performed due to the limited number of comparisons and high heterogeneity.

RESULTS

Study Selection and Characteristics

Figure 1 (PRISMA Flow Diagram) summarizes the study selection process. A total of 645 articles were initially retrieved; after removing 253 duplicates, 100 references were marked as ineligible by automation tools in the Covidence software, and screening abstracts, 12 full texts[1-7,13-16] were evaluated, resulting in 7 RCTs[1-7] that met the inclusion criteria.

Study Characteristics and Data Overview

Population

The 7 prospective clinical trials (2021–2023) contributed 490 teeth treated with endodontic irrigation, yielding 30 LAI ($n = 214$) versus UAI ($n = 159$) comparisons across multiple time points[1-7]. Sample sizes per trial ranged from 20 to 200 teeth. Diagnoses included symptomatic irreversible pulpitis[2,6,7], necrotic pulp with symptomatic apical periodontitis[3,4], necrotic pulp with or without apical periodontitis[1], and Asymptomatic tooth with vital or necrotic pulp[5]. The number of teeth, diagnoses, and time points are included in Table 1.

Interventions

The LAI techniques employed in the studies were diode lasers[1,3,6], Er: YAG lasers in PIPS and SWEEPS modes[2,5,7], and Er,Cr: YSGG lasers[4]. UAI arms used passive ultrasonic irrigation with IrriSafe or similar ultrasonic tips[1-3,5-7]. The type of laser interventions is included in Table 1.

Outcome Assessment

Postoperative pain was measured at 6, 8, 12, 24, 36, and 48 hours, and up to 7 days. Postoperative pain was the primary outcome in all included studies, assessed using a VAS at multiple time points ranging from 6 hours to 7 days post-treatment as shown in Table 1. Erkan et al[2] reported median pain scores with ranges rather than means and SDs. We applied the formulas of Wan et al[17] and Luo et al[18] to convert medians and ranges into estimated means and standard deviations. To evaluate the influence of these imputed values, we performed sensitivity analyses excluding all Erkan et al[2] comparisons.

Risk of Bias

Risk of bias for the 6 included randomized controlled trials was assessed using the Cochrane Risk of Bias 2.0 (RoB 2) tool[18], as illustrated in Figure 2. Overall, 2 trials[5,7] had a low risk of bias. However, 5 trials[1-4,6] raised some concerns, mainly due to limited details regarding allocation concealment or a lack of operator blinding.

While all studies mentioned a randomization process, only 4[2-4,6] provided a clear description of the method and measures for concealing allocation. The remaining 3 studies[1,5,7] did not fully report their randomization procedure, leading to concerns in this domain. Most studies[4-6] reported double blinding, while others[1-3,7] lacked operator blinding due to the nature of the intervention, which could introduce performance bias.

Crucially, none of the trials showed evidence of deviations from the intended interventions or protocol violations. All studies provided complete or clearly reported outcome data, and no study was found to have a high risk due to attrition. Furthermore, postoperative pain measurement was consistent across trials, typically using the VAS. All studies demonstrated a low risk in the measurement and selective reporting domains.

The overall risk of bias assessment suggests that all included trials demonstrate high methodologic and reporting quality, as illustrated in the summary plots[19] (see Fig. 2).

Data Synthesis

Primary Meta-Analysis

A random-effects model demonstrated a significant overall benefit of LAI over UAI (SMD = −0.58; 95% CI: −0.94 to −0.22; $P = .0016$) with low to moderate certainty; Table 2). Heterogeneity was high ($I^2 = 88.4\%$, $\tau^2 = 0.8539$, $Q_6 = 258.90$, $P < .0001$), reflecting variation in time points, laser technologies, and protocols. The analysis presented a low to moderate certainty of evidence (Table 2). Although visual inspection of the forest plot showed no single extreme outlier, wide confidence intervals and elevated heterogeneity warranted further sensitivity and subgroup analyses (Fig. 3A). Sensitivity analysis, excluding the Erkan et al's[2] trial (imputed data), showed an attenuated pooled effect of SMD = −0.34 (95% CI: −0.63 to −0.06; $P = .012$). Heterogeneity also reduced to $I^2 = 71.5\%$ ($\tau^2 = 0.3250$, $Q_5 = 17.35$, $P < .0001$). Further removal of high-influence comparisons (Mittal SWEEPS-48 hours, Elmallawany 7 days, Erkan PIPS-8 hours) decreased the SMD to −0.20 (95% CI: −0.42 to 0.02) and I^2 to 54.4% ($\tau^2 = 0.1252$, $Q_3 = 6.56$, $P = .0024$). These internal checks confirm that, while effect magnitude is modestly sensitive to extreme data, the directional advantage of LAI persists across analyses.

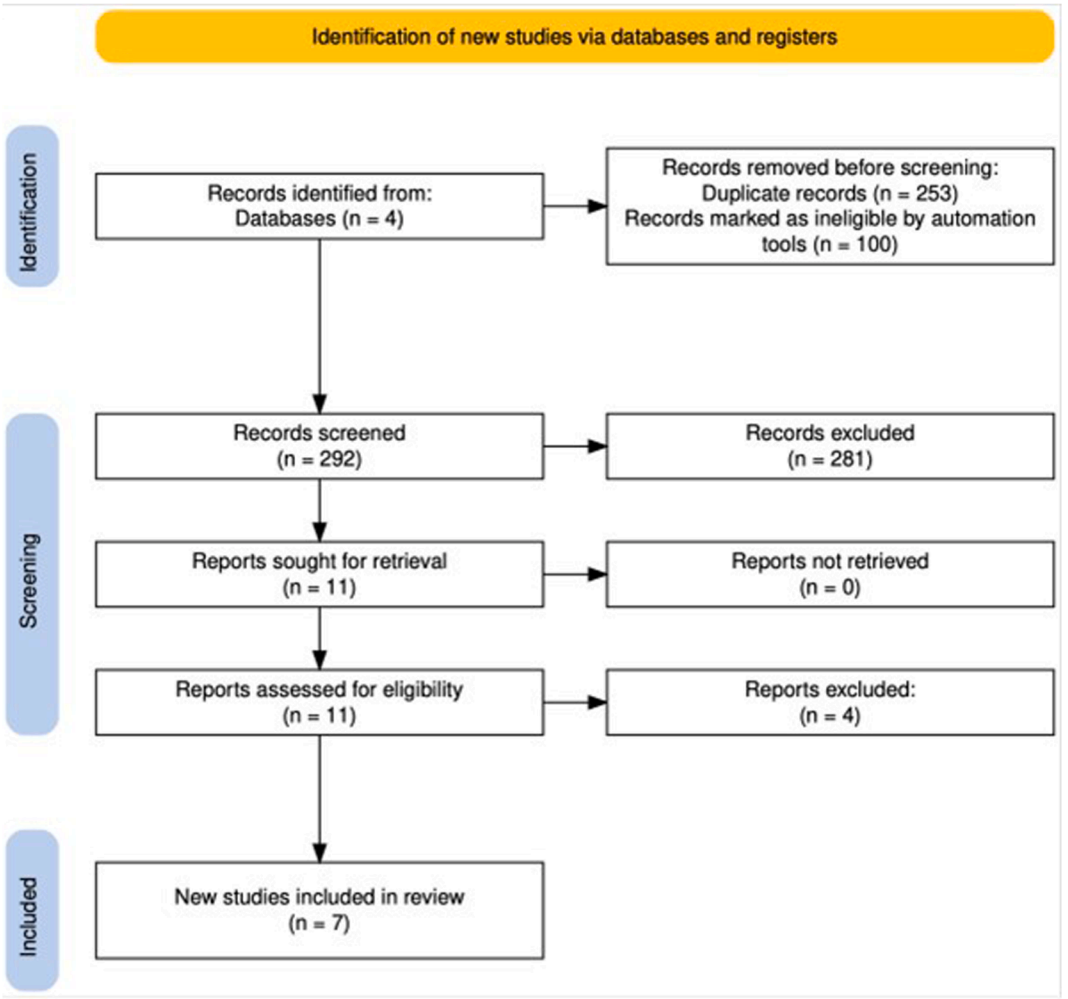

FIGURE 1 – PRISMA flow diagram.

Subgroup Analysis by Postoperative Time Intervals

Subgroup analysis was performed by stratifying data based on both time intervals and discrete time points. When grouped into early (6–12 hours), intermediate (24–48 hours), and late (72 hours–7 days) windows, the analysis revealed significant differences. The early window showed an SMD of −0.20 (95% CI: −0.45 to 0.06; I^2 = 34.0%), while the intermediate window had an SMD of −1.00 (95% CI: −1.51 to −0.48; I^2 = 90.7%), and the late window exhibited an SMD of 0.10 (95% CI: −0.15 to 0.35; I^2 = 42.2%). These subgroup differences across the 3 intervals were highly significant (χ^2 = 14.56; P = .0007), suggesting that the timing of postoperative intervention critically influences the analgesic effect of LAI.

In sensitivity analyses excluding Erkan et al[2], the grouped-window pooled SMD attenuated from −0.57 (95% CI: −0.92 to −0.22) to −0.35 (95% CI: −0.66 to −0.05), and I^2 improved from 88.4% to 74.8%. Notably, the intermediate window sustained a large, significant effect (SMD ≈ −0.90; 95% CI: −1.38 to −0.42), while early and late windows remained nonsignificant, demonstrating that the temporal peak in analgesic benefit is resilient to imputation biases (Fig. 3B).

Subgroup Meta-Analysis by Postoperative Timepoints

A subgroup meta-analysis was conducted to compare postoperative pain between LAI and UAI at specific timepoints following endodontic treatment (Fig. 3C). SMDs were pooled using a random-effects model for each subgroup.

At 6 hours h (n = 128 teeth), LAI showed a small, non-significant reduction in pain (SMD = −0.35; 95% CI: −0.84 to 0.14; I^2 = 61%)

At **8 hours** (n = 80 teeth), LAI showed a statistically significant reduction in pain compared to UAI (SMD = −0.33; 95% CI: −0.54 to −0.12; P < .01), with moderate heterogeneity observed (I^2 = 55.2%).

At **12 hours** (n = 128), the pooled effect again favored LAI (SMD = −0.48; 95% CI: −0.84 to −0.11; P = .01), although heterogeneity remained moderate (I^2 = 52.4%).

At **24 hours** (n = 259), the effect size remained significant (SMD = −0.48; 95% CI: −0.70 to −0.25; P < .001), with low heterogeneity (I^2 = 27.8%), indicating consistent effects across studies.

By **48 hours** (n = 259), the benefit of LAI persisted and even increased (SMD = −0.62; 95% CI: −0.84 to −0.40; P < .001), with low heterogeneity (I^2 = 11.2%).

At **7 days** (n = 194), pain levels had decreased in both groups, but LAI still provided a significant advantage over UAI (SMD = −0.51;

TABLE 1 - Characteristics of the Included Studies

Study	Type of study	Diagnosis/ Tooth type	File system used	Sample size	Control group (ultrasonic)	Experimental group (laser)	Follow-up duration
Mathevanan et al[7]	Randomized controlled trial	symptomatic irreversible pulpitis, mandibular first molars	ProTaper Gold (Dentsply)	*n* = 50	*n* = 25 PUI (IrriSafeTM)	*n* = 25 LAI (Er: YSGG 2940 nm, Waterlase iPlus, BIOLASE)	6h, 24h, 48h
Liapis et al[5]	Randomized controlled trial	Asymptomatic tooth with vital or necrotic pulp	ProTaper Universal (Dentsply)	*n* = 56	*n* = 28 UAI (IrriSafe)	*n* = 28 LAI (Er: YAG (Lightwalker ATS, 2940 nm	6h, 24h, 48h, 72h
Krishnakumar et al[4]	Randomized controlled trial	Symptomatic necrotic teeth, single rooted teeth	Not reported	*n* = 61	*n* = 21 CUI (Satelec P5 piezo electronic ultrasonic unit	*n* = 21 LAI (980 nm diode laser, Epic X BIOLASE), *n* = 19 laser irradiation 980 nm diode	24h, 48h, 7d
Kaplan et al[3]	Randomized controlled trial	Symptomatic apical periodontitis	VDW.ROTATE Ni-Ti file system	*n* = 40	*n* = 20 EDDY (sonic irrigation activation system)	*n* = 20 CNI + laser irradiation 980 nm diode	8h, 24h, 48h, 7d
Mittal et al[6]	Randomized controlled trial	Symptomatic irreversible pulpitis molars	Hyflex EDM (Coltene)	*n* = 45	*n* = 15 ultrasonic activation (Ultra X)	*n* = 15 PIPS (Er: YAG Lightwalker 2940 nm) *n* = 15 SWEEPS (Er: YAG 2940 nm	24h, 48h
Elmallawany et al[1]	Randomized controlled trial	Necrotic mandibular molars	Revo-S rotary file system	*n* = 20	*n* = 10 continuous ultrasonic irrigation (CUI)	*n* = 10 conventional syringe irrigation with diode laser 810 nm	6, 12, 24, 36, 48 h and 7 d
Erkan et al[2]	Randomized controlled trial	Symptomatic irreversible pulpitis, mandibular premolar teeth	ProTaper Next; Dentsply-Sirona	*n* = 120	*n* = 40 passive ultrasonic irrigation (PUI)	*n* = 40 PIPS, *n* = 40 SWEEPS (er-YAG laser system)	8h, 24h, 48 h, 7d

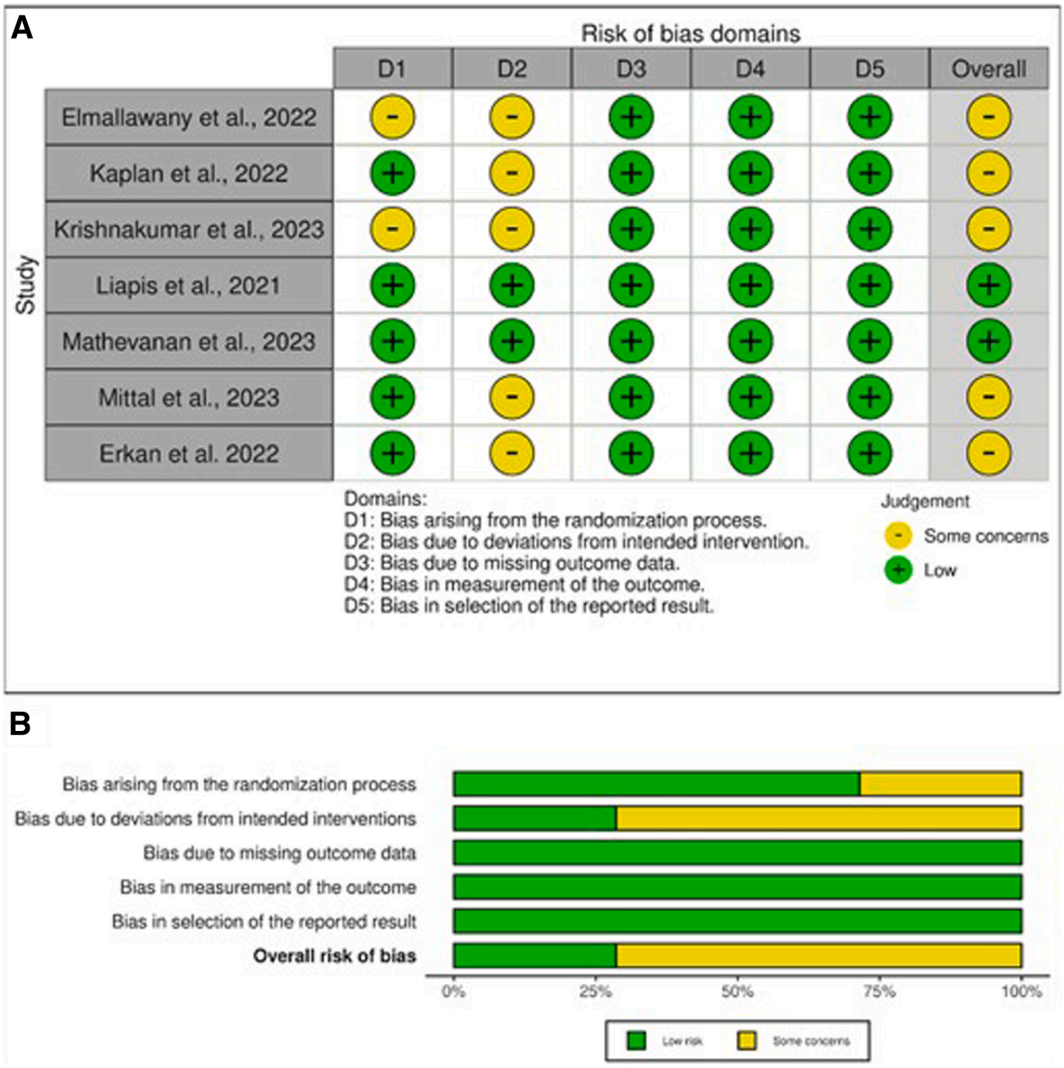

FIGURE 2 – (*A*) A summary of the risk of bias in the included studies. (*B*) A review of the authors' judgments about each risk of bias domain presented as percentages across the included studies.

95% CI: −0.84 to −0.18; $P = .003$), with moderate heterogeneity ($I^2 = 37.2\%$).

The overall pooled effect across all-time points favored LAI with a significant reduction in postoperative pain (SMD = −0.48; 95% CI: −0.62 to −0.32; $P < .001$), and heterogeneity across all subgroups was moderate ($I^2 = 42.5\%$). No subgroup significantly deviated from the overall effect, suggesting a consistent analgesic benefit of laser activation across all evaluated time intervals. These findings indicate that LAI consistently results in lower patient-reported postoperative pain levels compared to UAI, with the most pronounced effects observed between 24 and 48 hours post-treatment.

Subgroup Analysis by Laser Technology

Laser type significantly moderated the analgesic effect ($\chi^2_4 = 13.01$; $P = .0112$). Diode lasers ($n = 51$ teeth) showed no significant effect (SMD = 0.03; 95% CI: −0.22 to 0.27; $I^2 = 11.8\%$), and Er,Cr: YSGG devices ($n = 25$ teeth) a modest, non-significant reduction (SMD = −0.35; 95% CI: −0.89 to 0.19; $I^2 = 81.2\%$). Er: YAG-PIPS ($n = 55$ teeth) demonstrated a large benefit (SMD = −1.10; 95% CI: −1.97 to −0.24; $I^2 = 93.0\%$), and Er: YAG-SWEEPS ($n = 55$ teeth) an even greater effect (SMD = −1.57; 95% CI: −2.76 to −0.38; $I^2 = 95.5\%$), both highly significant. The Er: YAG Lightwalker ($n = 28$ teeth) system yielded a small, non-significant effect (SMD = −0.25; 95% CI: −0.54 to 0.04; $I^2 = 19.6\%$). These results indicate that pulsed Er: YAG technologies (PIPS and SWEEPS) confer the strongest postoperative analgesia.

Sensitivity analyses excluding Erkan et al[2] confirmed these rankings. The overall pooled SMD became −0.35 (95% CI: −0.66 to −0.05; $I^2 = 74.8\%$), with subgroup estimates unchanged for diode and Er,Cr: YSGG lasers. Er: YAG-PIPS (represented by Mittal-PIPS 24 hours) deepened to SMD = −1.71 (95% CI: −2.57 to −0.86), and Er: YAG-SWEEPS (2 trials) remained strongest (SMD = −2.04; 95% CI: −2.74 to −1.33). These findings demonstrate that pulsed Er: YAG technologies—especially SWEEPS—offer the most pronounced and consistent postoperative analgesia (Fig. 3D).

Publication Bias Assessment

Visual inspection of the funnel plot (Fig. 4) revealed no obvious asymmetry: study scatter was roughly symmetrical around the pooled SMD, and most points lay within the pseudo-95% confidence contours. Given the high heterogeneity ($I^2 \approx 88\%$) and modest number of comparisons, formal statistical tests were

TABLE 2 - Grading of Recommendations, Assessment, Development, and Evaluation Approach

Outcome (time-point)	Participants/ Studies	Risk of bias	Inconsistency	Indirectness	Imprecision	Publication bias	Overall certainty
Pain 6–12 h (pooled SMD = −0.33, 95% CI –0.54 to −0.12; I^2 = 55%)	≈490 teeth (7 RCTs)	Some concerns in 5/7 RCTs → −1	Moderate (I^2 55%) → −0	Direct PICO, clinical setting → −0	CI borders the minimal important difference and includes trivial benefit → −1	Funnel plot symmetrical → −0	⨁⨁◯◯ Low
Pain 24 h (SMD = −0.48, −0.70 to −0.25; I^2 = 27%)	≈480 teeth	Same RoB pattern → −1	Low heterogeneity → −0	Direct → −0	CI clear of no-effect, width acceptable → −0	None → −0	⨁⨁⨁◯ Moderate
Pain 48 h (SMD = −0.62, −0.84 to −0.40; I^2 = 11%)	≈470 teeth	−1	Very low heterogeneity → −0	Direct → −0	Precise effect → −0	None → −0	⨁⨁⨁◯ Moderate
Pain 7 d (SMD = −0.51, −0.84 to −0.18; I^2 = 37%)	≈450 teeth	−1	Moderate (I^2 37%) → −0	Direct → −0	CI does not cross no-effect but is relatively wide → −0	None → −0	⨁⨁⨁◯ Moderate

not performed; consequently, mild small-study effects cannot be entirely excluded.

DISCUSSION

This meta-analysis of 7 randomized trials (30 comparisons; n = 490) demonstrates that LAI significantly reduces postoperative endodontic pain compared with UAI, with a pooled SMD of −0.58 (95% CI −0.94 to −0.22; P = .0016). Subgroup analyses showed that the greatest pain relief occurred in the intermediate postoperative window (24–48 hours; SMD = −1.00; 95% CI −1.51 to −0.48) and with pulsed Er: YAG modalities—SWEEPS (SMD = −1.57) and PIPS (SMD = −1.10).

These quantitative findings are reinforced by the results of Krishnakumar et al[4], who reported lower median pain scores with LAI than UAI at both 24 hours and 48 hours, mirroring the magnitude and temporal pattern of our pooled estimates. Their reported median pain reductions align closely with the moderate-to-large effects observed in our analysis, underscoring the consistency of LAI's analgesic benefit across diverse measures and study designs.

Our results align with, and extend, the limited existing literature. McGillivray and Dutta[20] concluded that diode-based LAI reduces pain at 6–48 hours post-treatment, though they did not perform a meta-analysis due to study heterogeneity. Liapis et al[5] showed pulsed Er: YAG LAI significantly reduced early (6 hours) pain compared to UAI ($P < .05$), with no later difference. Our meta-analysis of 7 trials, including Krishnakumar et al's data, corroborates these early benefits, extending them to 48 hours with a sustained moderate-to-large effect size.

The pronounced efficacy of pulsed Er: YAG systems likely reflects their superior fluid-dynamic performance. Rapid vapor bubble expansion and collapse generate intense acoustic streaming that clears debris and disrupts biofilm more effectively than ultrasonic irrigation[5]. This enhanced irrigant penetration into dentinal tubules may reduce periapical inflammation and nociceptive signaling, translating into lower patient-reported pain in the 24–48 hours window. It is also important to distinguish between short-term pain reduction and long-term periapical healing. Although pulsed Er:YAG systems demonstrate enhanced irrigant penetration and reduced postoperative discomfort, these effects have not consistently translated into superior healing of periapical lesions[16]. This may reflect the multifactorial nature of periapical healing, which involves host

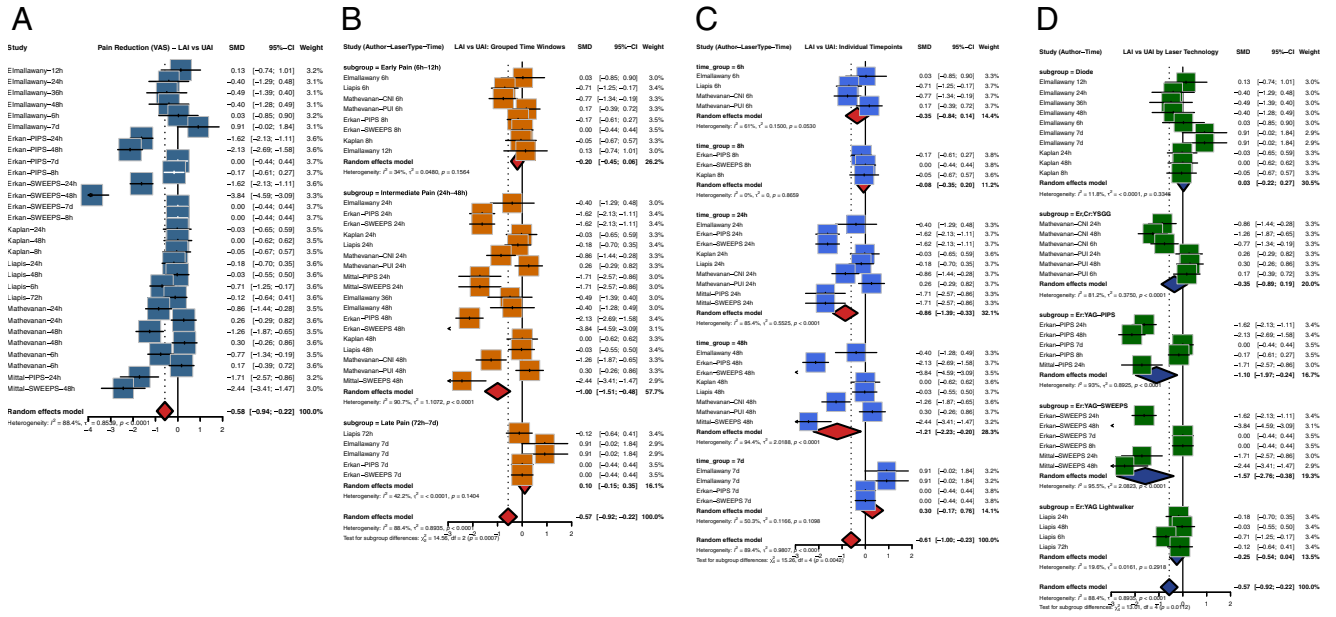

FIGURE 3 – (*A*) Forest plot of the primary random-effects meta-analysis comparing LAI versus UAI across all time points and laser types. (*B*) Forest plot of subgroup meta-analysis by postoperative time intervals (early: 6–12 h; intermediate: 24–48 h; late: 72 h–7 d). (*C*) Forest plot of subgroup meta-analysis by laser technology. (*D*) Forest plot of subgroup meta-analysis by individual postoperative timepoints. LAI, laser-activated irrigation; UAI, ultrasonically activated irrigation.

immune response, microbial load, and long-term canal sealing.

This review's strengths include the application of validated imputation methods[17,18] for studies reporting medians and ranges, rigorous sensitivity analyses to test the impact of imputed and high-influence data, and detailed subgroup analyses by postoperative interval and laser technology. The inclusion of Krishnakumar et al's trial further corroborates our findings without biasing quantitative estimates.

Nonetheless, substantial residual heterogeneity ($I^2 \approx 88\%$) remained, reflecting variability in laser settings, patient populations, and pain-assessment protocols. One trial could only be summarized qualitatively, and the absence of individual-patient data precluded formal exploration of effect modifiers such as age or baseline pain. Finally, formal tests for publication bias were not feasible given the modest number of comparisons.

Clinically, these results suggest that practitioners seeking to optimize postoperative comfort should consider pulsed Er: YAG LAI—particularly SWEEPS or PIPS—when targeting maximal pain control in the 24–48 hours postoperative period. Although postoperative analgesics such as NSAIDs are well established in reducing pain after root canal treatment, their use does not preclude the benefit of adjunctive strategies[21]. Techniques like laser or ultrasonically activated irrigation may enhance debridement, less extrusion of debris and reduce periapical inflammation, thereby contributing to pain reduction through nonpharmacologic means[5,7]. While adoption of these modalities may enhance patient satisfaction, barriers such as device cost, limited availability, and operational complexity in clinical settings must be considered in real-world implementation.

Future research should include head-to-head RCTs comparing diode, Er,Cr:

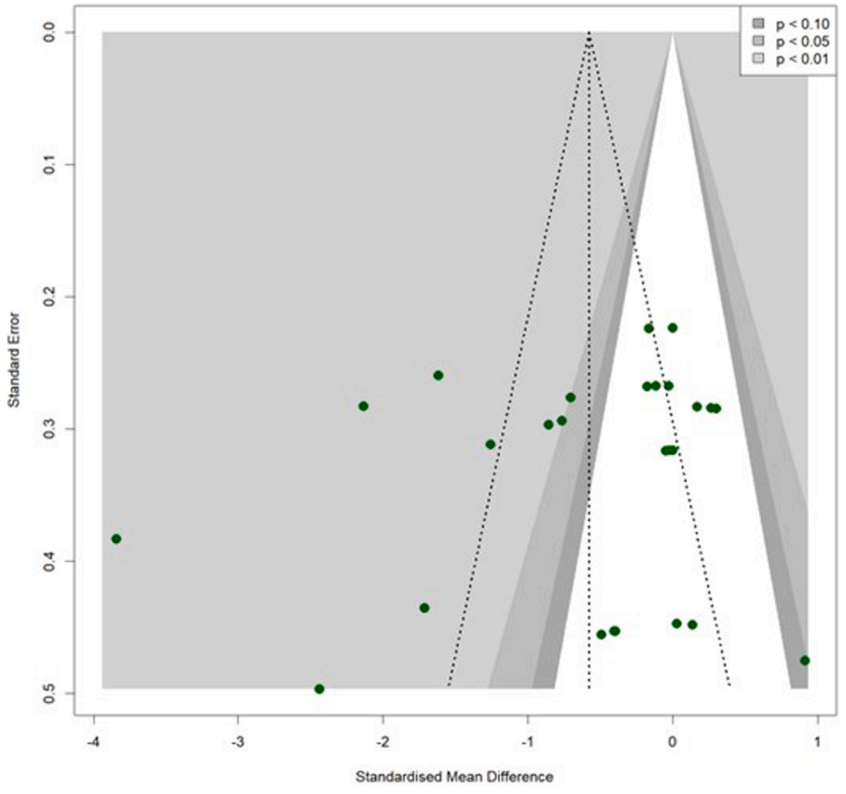

FIGURE 4 – Funnel plot of standard error versus standardized mean difference for all LAI versus UAI comparisons. LAI, laser-activated irrigation; UAI, ultrasonically activated irrigation.

YSGG, and pulsed Er: YAG technologies with standardized VAS pain assessments at uniform intervals. Full reporting of means and standard deviations will facilitate future meta-analyses, and sharing individual-patient data would allow meta-regression to identify moderators of LAI efficacy. As more trials accrue, formal publication-bias assessments and quantitative exploration of heterogeneity will further refine our understanding.

CONCLUSION

In conclusion, LAI produces a statistically significant and clinically meaningful reduction in postoperative endodontic pain compared with ultrasonic irrigation, with the most pronounced benefits observed using pulsed Er: YAG modalities in the 24–48 hours postoperative period.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Each author included in this paper made significant contributions to the design, analysis of data, and writing the manuscript. Each author approved the final version of the paper. Each author can verify the accuracy of the work and can resolve any questions or issues related to this.

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The authors deny any conflicts of interest related to this study.

SUPPLEMENTARY MATERIAL

Supplementary material associated with this article can be found in the online version at www.jendodon.com (https://doi.org/10.1016/j.joen.2025.08.002).

REFERENCES

1. Elmallawany A, Hussein YF, Ali MM, et al. Effect of ultrasonic and diode laser irrigation activation on post-operative pain and microbial reduction in single-visit endodontic treatment of necrotic mandibular molars. Open Access Maced J Med Sci 2022;10:210–20.
2. Erkan E, Gündoğar M, Uslu G, et al. Postoperative pain after SWEEPS, PIPS, sonic and ultrasonic-assisted irrigation activation techniques: a randomized clinical trial. Odontology 2022;110:786–94.
3. Kaplan T, Kaplan SS, Sezgin GP. The effect of different irrigation and disinfection methods on post-operative pain in mandibular molars: a randomised clinical trial. BMC Oral Health 2022;22:601.
4. Krishnakumar K, Tandale AS, Talreja T, et al. Comparative evaluation of postoperative pain with continuous ultrasonic irrigation, laser-activated irrigation, and laser irradiation: a randomized clinical trial. Endod 2023;35:267–72.
5. Liapis D, De Bruyne MAA, De Moor RJG, et al. Postoperative pain after ultrasonically and laser-activated irrigation during root canal treatment: a randomized clinical trial. Int Endod J 2021;54:1037–50.
6. Mittal N, Baranwal HC, Gupta S, et al. Comparative analysis of reduction in pain scores after single-visit root canal treatment using endodontic irrigation protocols: conventional needle irrigation, PUI, PIPS and SWEEPS: a randomized control trial. J Conserv Dent 2023;26:143–9.
7. Mathevanan S, Sureshbabu NM, Solete P, et al. Comparison of postoperative pain reduction following laser, ultrasonic activation and conventional needle irrigation after root canal treatment – a randomized clinical trial. J Clin Exp Dent 2023;15:e1045–53.
8. Duncan HF, El-Karim IA. Endodontic S3-level clinical practice guidelines: the European Society of Endodontology process and recommendations. Br Dent J 2025;238:580–6.
9. Covidence Systematic Review software. Melbourne, Australia: Veritas Health Innovation. Available at: https://www.covidence.org; 2025. Accessed March 2025.
10. Higgins JP, Altman DG. Assessing risk of bias in included studies. In: Higgins JPT, Green S, editors. Cochrane handbook for systematic reviews of interventions. Chichester, UK: Wiley-Blackwell; 2008. p. 187–241.
11. Puhan MA, Schünemann HJ, Murad MH, et al. A GRADE working group approach for rating the quality of treatment effect estimates from network meta-analysis. BMJ 2014;349:g5630.
12. Viechtbauer W. Conducting meta-analyses in R with the metafor package. J Stat Softw 2010;36:1–48.
13. Dedania MS, Shah NC, Shah R, et al. Effect of passive ultrasonic irrigation and laser disinfection in single visit root canal therapy on postoperative pain. J Clin Diagn Res 2021;15:ZC33–6.

14. Ibrahim EA, Hessein WA, Roshdy NN, et al. Evaluation of postoperative pain following sonic and ultrasonic root canal irrigation activation protocols in patients with non-vital teeth associated with apical periodontitis: a randomized clinical trial. Future Dent J 2022;8:69–74.

15. Ismail HH, Obeid M, Hassanien E. Efficiency of diode laser in control of post-endodontic pain: a randomized controlled trial. Clin Oral Investig 2023;27:2797–804.

16. Verma A, Yadav RK, Tikku AP, et al. A randomized controlled trial of endodontic treatment using ultrasonic irrigation and laser activated irrigation to evaluate healing in chronic apical periodontitis. J Clin Exp Dent 2020;12:e821–9.

17. Wan X, Wang W, Liu J, et al. Estimating the sample mean and standard deviation from the sample size, median, range and/or interquartile range. BMC Med Res Methodol 2014;14:1–3.

18. Luo D, Wan X, Liu J, et al. Optimally estimating the sample mean from the sample size, median, mid-range, and/or mid-quartile range. Stat Methods Med Res 2018;27:1785–805.

19. McGuinness LA, Higgins JPT. Risk-of-bias VISualization (robvis): an R package and Shiny web app for visualizing risk-of-bias assessments. Res Synth Methods 2021;12:55–61.

20. McGillivray A, Dutta A. The influence of laser-activated irrigation on postoperative pain following root canal treatment: a systematic review. J Dent 2024;144:104928.

21. Di Spirito F, Scelza G, Fornara, et al. Post-operative endodontic pain management: an overview of systematic reviews on post-operatively administered oral medications and integrated evidence-based clinical recommendations. Healthcare 2022;10:760.