

ACTIVATION OF IRRIGATING SOLUTIONS IN ENDODONTICS: ULTRASONIC AND LASER TECHNOLOGIES. A NARRATIVE REVIEW

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Abstract

Background. Effective irrigation is a key component of chemomechanical root canal preparation. Conventional needle irrigation (CNI) delivers the solution, but its effectiveness is limited by complex canal anatomy, especially in the apical third, lateral canals and isthmuses.

Irrigant activation aims to enhance fluid movement and contact with canal walls. The most studied methods are passive ultrasonic irrigation (PUI) and laser-activated irrigation (LAI), including photon-induced photoacoustic streaming (PIPS) and shock wave-enhanced emission photoacoustic streaming (SWEEPS).

Objective. To evaluate current evidence on ultrasonic and laser activation of irrigants and to compare their effects on irrigant penetration, debris and smear layer removal, microbial load, postoperative pain, periapical healing and apical extrusion.

Methods. A narrative review of systematic reviews, meta-analyses, clinical and laboratory studies published in international peer-reviewed journals, predominantly in 2018–2026, was performed. Quantitative estimates are reported as published and were not re-pooled.

Results. Activation improved irrigant delivery to working length in straight canals by 51.94% versus CNI, and increased sodium hypochlorite (NaOCl) penetration into lateral canals by 34.3% overall and by 60.9% with PUI. In clinical trials, PUI reduced the risk of pain at 24 h (RR 0.50) and microbial load (SMD –0.40), with low to very low certainty, and increased periapical healing (RR 1.10; moderate certainty). Compared with ultrasonic activation, LAI reduced postoperative pain (SMD –0.58; 95% CI –0.94 to –0.22), most markedly at 24–48 h and with PIPS and SWEEPS. No technique eliminated apical extrusion.

Conclusion. Neither technique is universally superior across all outcomes. PUI has the longer clinical evidence base, including periapical healing; pulsed Er:YAG LAI shows promising results for early postoperative pain and laboratory cleaning. Protocol selection should consider canal anatomy, irrigant, activation parameters, extrusion risk and equipment availability.

Keywords: endodontics; root canal irrigation; passive ultrasonic irrigation; laser-activated irrigation; PIPS; SWEEPS; sodium hypochlorite; smear layer

1. Introduction

The main goal of endodontic treatment is to reduce the microbial load and remove infected tissue from the complex root canal system, followed by hermetic obturation. Mechanical preparation creates space for irrigant delivery but does not by itself clean all anatomical areas.

Chemical irrigation and methods that enhance fluid movement are therefore of fundamental importance [1, 2].

Conventional needle irrigation (CNI) remains the basic delivery method, but fluid movement is limited in narrow, curved and anatomically complex areas. Irrigant activation increases the hydrodynamic effect and solution exchange within the canal. Ultrasonic activation generates acoustic streaming and cavitation, whereas pulsed laser activation causes rapid bubble formation and collapse, producing photoacoustic fluid motion [3, 4].

Sodium hypochlorite (NaOCl) is of particular importance owing to its strong antimicrobial activity and ability to dissolve organic tissue. However, irrigation safety depends on control of needle depth, pressure, apical anatomy and delivery method. Apical extrusion of NaOCl is a rare but potentially serious complication, so the efficacy of activation must be assessed together with its safety [5, 6].

Laboratory superiority of one method does not always translate directly into clinical outcomes. PUI improves several laboratory parameters, but studies of clinical healing remain few.

Likewise, LAI shows promising results, yet laser parameters, tip type, pulse energy, frequency and operating mode vary considerably between studies [3, 4, 7]. Techniques should therefore be compared outcome by outcome.

The **aim** of this review was to evaluate current evidence on the effectiveness of ultrasonic and laser activation of irrigants in endodontic treatment and to compare their effects on irrigant penetration, debris and smear layer removal, microbial load, postoperative pain, periapical healing and apical extrusion.

2. Materials and Methods

Study design. This work is a narrative review of the scientific literature. It is not a systematic review or meta-analysis and does not attempt a new statistical synthesis of primary data.

Sources. Publications indexed in PubMed/MEDLINE and articles from international peer-reviewed journals and full-text databases were used, with emphasis on 2018–2026. Earlier studies were included when they provided key evidence for a specific outcome. Systematic reviews, meta-analyses and randomised controlled trials (RCTs) were treated as priority sources.

Eligibility criteria. Studies were considered relevant if they (i) investigated irrigant activation during endodontic treatment; (ii) compared PUI or LAI with CNI or with each other; and (iii) assessed irrigant penetration, debris or smear layer removal, antimicrobial effect, postoperative pain, periapical healing or apical extrusion. Laboratory studies were used to assess mechanisms and canal cleaning; clinical studies were used to assess symptoms and treatment outcomes.

Data handling. Quantitative data were not re-pooled. Where an outcome came from a meta-analysis, the published effect estimate is reported with its confidence interval (CI) and, where available, statistical significance and certainty of evidence. Differences between in vitro, ex vivo and clinical study designs were taken into account in interpretation.

3. Results

3.1. Passive ultrasonic irrigation

PUI uses an ultrasonic tip that activates the irrigant in the canal without requiring constant contact with the canal walls. Its main physical effects are acoustic streaming and, under appropriate conditions, cavitation. These phenomena enhance fluid movement and exchange in areas inaccessible to direct instrument contact [3, 8].

Clinical evidence on PUI is heterogeneous. A systematic review including 45 in vitro and 3 clinical studies found no benefit of ultrasonic activation over syringe irrigation for healing of apical periodontitis, but greater effectiveness in removing pulp tissue remnants and hard tissue debris [8].

A more recent systematic review and meta-analysis of three RCTs with 474 patients and 501 teeth showed a higher periapical healing rate with PUI than with conventional syringe irrigation: RR 1.10 (95% CI 1.01–1.21), $I^2 = 0\%$; certainty of evidence was rated moderate [9].

The difference from earlier reviews reflects the growing clinical evidence base, but the number of trials remains limited.

For microbiological and pain outcomes, a meta-analysis of ten RCTs found a reduced risk of postoperative pain at 24 h with ultrasonic activation: RR 0.50 (95% CI 0.35–0.71; 308 teeth).

The pooled effect on microbial load was SMD -0.40 (95% CI -0.78 to -0.02 ; $I^2 = 0\%$; 126 teeth). The authors rated the certainty of evidence as low or very low [10].

3.2. Irrigant penetration

The ability to deliver fresh irrigant to inaccessible areas is one of the most direct criteria of activation efficacy. A 2023 systematic review and meta-analysis included 20 studies, 17 of which entered the meta-analysis.

In straight canals, activation techniques improved irrigant delivery to working length by 51.94% (95% CI 39.20–64.67%) compared with CNI. In curved canals, the standardised mean difference was SMD 1.08 (95% CI 0.64–1.52). Apical negative pressure irrigation was the most effective technique, followed by PUI [2].

Another systematic review and meta-analysis of NaOCl penetration into lateral canals included 12 studies, 10 of which were analysed quantitatively. In straight canals, activation increased penetration by 34.3% overall compared with CNI.

In the PUI subgroup, the increase was 60.9%, the largest among the techniques studied [1].

Both analyses are based mainly on laboratory models, so greater penetration should not be interpreted automatically as evidence of better long-term clinical outcomes.

Table 1. Quantitative meta-analytic results on irrigant delivery and penetration

Outcome	Result	Interpretation	Ref.
Delivery to working length, straight canals	51.94% higher than CNI (95% CI 39.20–64.67%)	Activation improves delivery	[2]
Delivery to working length, curved canals	SMD 1.08 (95% CI 0.64–1.52)	Positive effect of activation	[2]
NaOCl penetration into lateral canals	34.3% higher than CNI	Overall effect of activation techniques	[1]
PUI, straight canals	60.9% higher than CNI	Largest effect among activation techniques in this analysis	[1]

3.3. Smear layer and dentine debris removal

The smear layer forms during mechanical preparation of the canal walls and contains organic and inorganic components. It may prevent contact of irrigants and sealers with dentinal tubules, so its removal is an important part of final canal cleaning [4, 11].

The systematic review and meta-analysis by Virdee et al. included scanning electron microscopy studies assessing the coronal, middle and apical thirds of the canal, and evaluated PUI, sonic irrigation, manual dynamic activation and apical negative pressure. The results generally supported activated irrigation over CNI, but the magnitude of effect depended on the canal third and the specific technique [11].

In a direct comparison of LAI and ultrasonically activated irrigation (UAI), the systematic review by Badami et al. included 23 studies, all in vitro. Most reported advantages of LAI in removing microorganisms, dentine debris and smear layer. However, the authors stressed substantial variability in laser and ultrasonic parameters, irrigant concentrations and activation times, and judged quantitative pooling inappropriate [4]. LAI therefore appears promising for wall cleaning, but claims of universal superiority over PUI require caution, as most direct comparisons are laboratory-based.

1. 3.4. Antimicrobial efficacy

Microbial elimination is a clinically significant goal of irrigation, as mechanical preparation cannot fully eliminate microorganisms from accessory anatomy. Ultrasonic activation enhances fluid movement and surface contact, whereas LAI produces a pronounced photoacoustic effect [3, 10].

The review of LAI versus UAI evaluated antimicrobial efficacy among other outcomes; most of the 23 in vitro studies favoured LAI, but methodological heterogeneity precluded meta-analysis [4]. In an ex vivo study on *Enterococcus faecalis*-infected canals, PIPS, diode laser and PUI all significantly reduced intracanal bacteria, but none eliminated them completely and all were associated with apical bacterial extrusion; the diode laser performed best [12]. Such findings remain experimental, as an infected extracted-tooth model does not fully reproduce the clinical situation.

Higher-level clinical evidence is available for PUI: the meta-analysis of RCTs reported a pooled reduction in microbial load of SMD -0.40 (95% CI -0.78 to -0.02), with low or very low certainty [10]. Current data therefore do not support a claim that LAI is clinically superior to PUI for microbial elimination.

2. 3.5. Laser-activated irrigation: PIPS and SWEEPS

LAI uses laser energy to activate the irrigant in the canal. Pulsed Er:YAG lasers with a wavelength of 2940 nm are the most studied. In PIPS, the tip is positioned mainly in the coronal pulp chamber, and the effect results from bubble formation and collapse followed by photoacoustic streaming. SWEEPS uses a sequence of pulses designed to enhance cavitation [3].

The efficacy of LAI depends on wavelength, pulse energy, pulse duration, frequency, tip type, distance to the target area and irrigant properties; two studies with substantially different protocols cannot be considered fully comparable [3].

An RCT of 200 patients with symptomatic irreversible pulpitis compared SWEEPS, PIPS, sonic activation, PUI and manual dynamic activation. The PIPS and SWEEPS groups had the lowest pain levels and prevalence ($p < 0.001$) [13]. A 2024 systematic review of RCTs on LAI and pain during the first postoperative week suggested a potential reduction with LAI but called for higher-quality trials [14]. A 2025 meta-analysis focused on Er:YAG LAI in primary root canal treatment [15], and further evidence, including a direct meta-analysis of LAI versus UAI, accumulated in 2025–2026.

3.6. LAI versus UAI: postoperative pain

The most current quantitative evidence is a 2026 systematic review and meta-analysis of seven RCTs (490 teeth, 30 comparisons). LAI was associated with lower postoperative pain than UAI: SMD -0.58 (95% CI -0.94 to -0.22 ; $p = 0.0016$). The largest reduction was at 24–48 h (SMD -1.00). The effect was SMD -1.10 for PIPS and -1.57 for SWEEPS, whereas diode lasers showed no significant effect (SMD 0.03) [16].

These data do not prove that any laser protocol is better than any ultrasonic protocol. Laser type, pulse mode, pulp status, baseline symptoms, preparation technique and other clinical factors influence the result. A 2026 Bayesian network meta-regression (57 trials qualitatively, 31 quantitatively) also ranked LAI first for day-1 pain, but certainty was low or very low for most comparisons [7].

Table 2. Laser versus ultrasonic activation: postoperative pain

Outcome	Effect vs UAI	Evidence / limitations	Ref.
Overall postoperative pain (LAI)	SMD -0.58 (95% CI -0.94 to -0.22)	7 RCTs; 490 teeth; largest effect at 24–48 h	[16]
Pain at 24–48 h (LAI)	SMD -1.00	Subgroup analysis	[16]
PIPS	SMD -1.10	Subgroup analysis	[16]
SWEEPS	SMD -1.57	Strongest subgroup effect	[16]
Diode laser	SMD 0.03	No significant effect	[16]

3.7. Periapical healing and clinical outcomes

Long-term periapical healing is the most important measure of a method's clinical value. Here PUI has a more developed evidence base than LAI: the 2024 meta-analysis of three RCTs (474 patients, 501 teeth) showed RR 1.10 (95% CI 1.01–1.21; I² = 0%) in favour of PUI over conventional syringe irrigation, with moderate certainty [9].

Clinical studies of LAI exist, but systematic reviews note heterogeneous protocols and limited high-quality long-term data [3, 7]. An RCT of 56 patients with large periapical lesions compared manual dynamic activation, PUI, SWEEPS and non-activated irrigation over 12 months.

CBCT lesion volume decreased by 86.9% with SWEEPS, 85.4% with PUI, 80.4% with manual dynamic activation and 74.5% in controls, with no statistically significant differences [17].

It is therefore more accurate to describe LAI as promising than as proven superior to PUI for periapical healing.

3.8. Safety and apical extrusion

Greater hydrodynamic activity may improve cleaning but requires safety control. Apical extrusion of NaOCl can cause chemical tissue injury. The risk depends on apical foramen anatomy, preparation size, needle position, pressure and activation parameters [5, 6].

In an ex vivo study by Vidas et al., all tested LAI modes produced less irrigant extrusion than most needle irrigation modes, with the least extrusion for PIPS; this does not, however, demonstrate absolute clinical safety [5]. In severely curved canals, PIPS showed the lowest mean extrusion among the tested groups, but differences were not statistically significant [6]. A 2026 systematic review of apical debris extrusion concluded that no technique eliminates extrusion; some studies reported greater debris extrusion with PIPS and high-power lasers than with CNI, while data on PUI were inconsistent [18]. Safety therefore cannot be judged by technology name alone: activation parameters, working-length control, apical anatomy and delivery technique all matter.

Table 3. Comparative characteristics of the main irrigant activation methods

Method	Main mechanism	Advantages	Key limitations	Ref.
CNI	Hydrodynamic delivery	Accessible, simple, widely used	Limited penetration into complex areas	[1, 2]
PUI	Acoustic streaming and cavitation	Well studied clinically; improves delivery and cleaning	Effect depends on anatomy and settings; part of the evidence is of low certainty	[8–10]
LAI / PIPS	Photoacoustic streaming and cavitation	Promising cleaning; reduced early postoperative pain	High cost; heterogeneous protocols; limited long-term clinical data	[3, 16]
LAI / SWEEPS	Enhanced pulsed cavitation	Marked effect on early postoperative pain	Results depend on mode and settings; further clinical validation needed	[13, 16]

4. Discussion

Interpretation of the literature requires a clear separation of laboratory and clinical outcomes. Evidence on irrigant penetration and debris removal is predominantly ex vivo or in vitro. For postoperative pain, RCTs and meta-analyses are available. For periapical healing, PUI has the strongest clinical evidence base among the techniques reviewed [1, 2, 4, 9, 16] (Table 4).

Protocol heterogeneity is an important limitation. Studies differ in NaOCl concentration, activation time, ultrasonic power, tip diameter and type, laser pulse energy and frequency, tooth type and degree of infection. Results obtained with one device cannot be assumed to apply fully to another.

A statistically significant difference does not always mean clinically meaningful superiority. This applies particularly to postoperative pain, which is influenced by baseline symptoms, pulp status, number of visits, preparation technique and other factors. Network meta-analyses provide useful rankings, but with low or very low certainty such rankings must be interpreted cautiously [7, 16].

Table 4. Summary of evidence for the main clinically relevant outcomes

Outcome	Most robust finding	Certainty / limitations	Ref.
Irrigant delivery	Activation improves delivery to working length vs CNI	Moderate/limited; laboratory models	[2]
NaOCl penetration into lateral canals	PUI showed a marked advantage in straight canals	Limited to laboratory studies	[1]
Smear layer / debris	Activated methods outperform CNI; LAI often better in laboratory studies	Limited by methodological heterogeneity	[4, 11]
Microbial load	PUI reduces microbial load; LAI promising	Low/very low for PUI; mostly in vitro for LAI	[4, 10, 12]
Postoperative pain	LAI, especially PIPS/SWEEPS, outperforms UAI at 24–48 h	RCTs and meta-analyses available; heterogeneity persists	[7, 16]
Periapical healing	PUI: RR 1.10 vs CNI; no significant difference between SWEEPS and PUI in large lesions	Moderate, based on few RCTs	[9, 17]
Apical extrusion	No technique eliminates it; results are protocol-dependent	Highly heterogeneous data	[5, 6, 18]

4.1. Limitations

First, this is a narrative review: literature search and selection were not performed as a registered systematic review with a formal PRISMA protocol, so the results should not be regarded as a new meta-analysis. Second, laboratory studies predominate for canal cleaning, irrigant penetration and antimicrobial effect; such models control experimental conditions but do

not fully reproduce clinical anatomy, the microbiome or the host response. Third, technical heterogeneity of LAI and UAI (power, frequency, activation time, tip type, irrigant concentration, canal design) hampers direct comparison. Finally, the small number of clinical RCTs limits definitive conclusions on long-term superiority of any method.

5. Conclusion

Irrigant activation is an important direction in modern endodontics, as it enhances fluid movement and contact with areas of the root canal system that are poorly reached by conventional needle irrigation. Systematic reviews and meta-analyses confirm improved irrigant delivery and several cleaning parameters with activated methods [1, 2, 11].

PUI has the most established clinical evidence base among the methods reviewed. It is associated with improved irrigant delivery, reduced microbial load and, according to a recent meta-analysis, a higher periapical healing rate than conventional syringe irrigation [9, 10]. The effect is not universal, however, and the certainty of some evidence is limited.

LAI, particularly pulsed Er:YAG PIPS and SWEEPS, shows marked potential. Laboratory studies often report effective removal of smear layer, debris and microorganisms, and clinical trials and meta-analyses indicate reduced early postoperative pain compared with UAI [4, 16]. Data on long-term clinical outcomes remain insufficient to claim unconditional superiority of LAI.

At present, the most justified approach is individualised selection of the activation protocol based on canal anatomy, clinical situation, irrigant and device parameters. Multicentre RCTs with uniform protocols, standardised outcomes and long-term follow-up are needed, with attention not only to cleaning efficacy but also to safety, including control of apical extrusion [3, 7, 16, 18].

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