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A Literature Review on the Effectiveness of Manual and Mechanically Enhanced Irrigation Techniques in Root Canal Disinfection

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Authors' contributions

This work was carried out in collaboration among all authors. Author JOJ designed the study, managed the literature searches, performed the data analysis and interpretation, and wrote the first draft of the manuscript. Author RRDL also designed the study, managed the literature searches, performed the data analysis and interpretation, and contributed to writing the manuscript. Author KOJ designed the study and oversaw the critical review and final revisions of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Aims: To compare the effectiveness of manual irrigation techniques with enhanced irrigation methods in the disinfection and cleaning of the root canal system in Endodontics.
Study Design: Descriptive literature review.

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Place and Duration of Study: The review was conducted using scientific articles retrieved from the SciELO, PubMed, and LILACS databases, covering the period from February to August 2019.
Methodology: A total of 45 scientific articles published between 1970 and 2019 were selected based on predefined eligibility criteria. The search included descriptors in Portuguese and English related to irrigation techniques in Endodontics. The selected studies focused on the performance of various irrigation methods, including manual irrigation with syringe and needle, Passive Ultrasonic Irrigation (PUI), the Easy Clean system, and the XP-Endo Finisher file.
Results: Manual irrigation was found to be the least effective method for canal disinfection and debris removal. In contrast, activation techniques such as PUI, Easy Clean, and XP-Endo Finisher showed significantly better cleaning outcomes, especially in anatomically complex areas. Among them, the XP-Endo Finisher provided the most effective results in cleaning after instrumentation and final irrigation.
Conclusion: Enhanced irrigation techniques, particularly those involving mechanical activation, significantly improve root canal cleaning compared to conventional methods. Nevertheless, manual irrigation remains a valuable tool when applied with appropriate solutions and clinical protocols. The choice of irrigation strategy should be guided by anatomical considerations and clinical objectives to ensure the success of endodontic treatment.

Keywords: Irrigation; endodontics; ultrasonic systems; smear layer; chemo-mechanical preparation.

1. INTRODUCTION

The success of endodontic treatment is one of the central goals of contemporary clinical dental practice. In this context, technological advances and the consolidation of scientific knowledge have driven the development of techniques and materials aimed at improving the predictability and therapeutic efficacy of endodontic procedures (Arias & Peters, 2022).

The literature reports success rates exceeding 78% in endodontic treatments, a result attributed to the evolution of clinical protocols, the improvement of materials used, and the increasing training of specialized professionals in the field. However, the high success rate does not eliminate the need for clinical and radiographic follow-up of treated cases, since failures may still occur even after the completion of treatment (NG *et al*., 2011).

Effective decontamination of the root canal system (RCS) depends on the proper execution of biomechanical preparation, whose goal is the removal of necrotic tissues and present microorganisms. In this process, irrigation plays a key role, as studies have shown that considerable portions of root canal walls are not touched by endodontic instruments, highlighting the need for the use of chemical adjuncts (Haapasalo *et al*., 2010; Vera *et al*., 2012).

Despite significant advances in endodontic materials and instrumentation, treatment failures still occur, often due to the persistence of resistant microorganisms within the root canal system. Among these, *Enterococcus faecalis* is frequently associated with refractory endodontic infections and retreatment cases (Stuart *et al*., 2006). Its ability to penetrate dentinal tubules, survive in nutrient-deprived environments, and resist conventional disinfection protocols highlights the limitations of mechanical instrumentation alone (Stuart *et al*., 2006; Zhou *et al*., 2024). Therefore, the effectiveness of irrigation strategies should also be evaluated based on their capacity to eliminate such resistant species, underscoring the critical role of irrigants not merely as mechanical adjuncts, but as essential agents in overcoming microbial challenges in complex endodontic cases (Zhou *et al*., 2024).

The use of irrigation in Endodontics dates back to the 19th century, when Taft, in 1859, recommended the use of irrigating solutions such as sodium chloride. Since then, a wide variety of substances have been investigated regarding their effectiveness in cleaning and disinfecting the root canal. The ideal properties of an irrigating solution include tissue dissolution capacity, dentin debris removal, biocompatibility, low toxicity, broad-spectrum antimicrobial activity, canal lubrication, low surface tension, and efficacy in smear layer removal (Abraham *et al*., 2015).

The conventional irrigation technique involves the introduction of irrigating solutions using syringes and blunt needles, preferably positioned up to the apical third of the canal. However, recognizing the limitations of this method, several strategies have been developed to optimize the action of irrigating solutions. Among these are ultrasonic irrigation, sonic irrigation, negative pressure irrigation, continuous irrigation coupled with rotary instrumentation, endocanal brushes, and laser-activated methods (Barbosa et al., 2021).

Passive Ultrasonic Irrigation (PUI) is one such strategy and consists of activating the irrigating solution within the RCS through ultrasonic tips, generating an acoustic streaming effect with energy capable of disrupting bacterial biofilms and efficiently removing debris. This technique allows access to anatomically challenging areas without direct contact with the canal walls, thereby reducing the risk of canal transportation or perforation (Queiroz *et al*., 2016; Rödig *et al*., 2019).

Given the variety of available options, comparative studies are essential to support the dental surgeon in selecting the most effective irrigation technique, contributing to the predictability of clinical outcomes and the reduction of therapeutic failures (Queiroz *et al*., 2016; Rödig *et al*., 2019).

Thus, the present study aimed to compare, through a literature review, the different endodontic irrigation methods in terms of their effectiveness in cleaning the root canals.

2. MATERIALS AND METHODS

The study selection process followed PRISMA guidelines and is illustrated in

Fig. 1. A total of 120 articles were initially identified across PubMed, SciELO, and LILACS databases. After removing 15 duplicates**,** 105 records were screened based on title and abstract. Of these, 65 full-text articles were assessed for eligibility, and 45 studiesmet the inclusion criteria and were included in the final review.

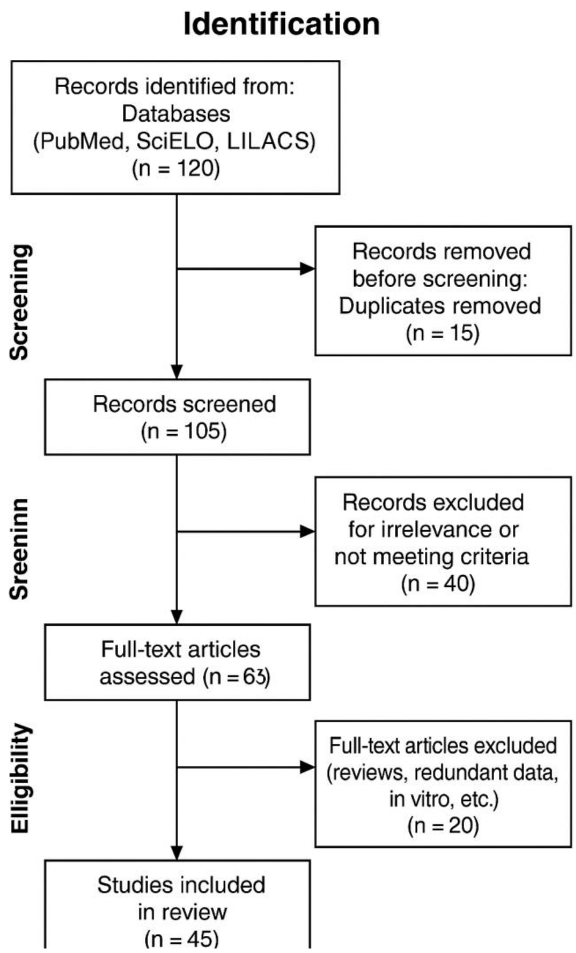

Fig. 1. Articles selection process for this study

Table 1. Eligibility criteria"):

Inclusion Criteria	Exclusion Criteria
Studies published between 1970 and 2019	Duplicates or redundant data
Articles in English or Portuguese	Studies not focused on irrigation techniques in Endodontics
Original research related to root canal irrigation	In vitro studies not involving irrigation techniques
Evaluation of manual or activated irrigation methods	Reviews, editorials, conference abstracts
Available in full-text	Studies unrelated to cleaning/disinfection of the root canal system

The inclusion criteria comprised studies published in English or Portuguese between 1970 and 2019, addressing irrigation techniques in Endodontics, with a focus on cleaning, disinfection, or removal of smear layer and debris. Exclusion criteria included review articles, conference abstracts, editorials, studies with redundant data, and those not directly related to irrigation protocols. Only full-text original studies evaluating manual or enhanced irrigation techniques were considered. A detailed summary of the eligibility criteria is presented in Table 1.

3 THEORETICAL FRAMEWORK

3.1 Endodontic Treatment

Endodontic infections are generally associated with the colonization of the pulp tissue by microorganisms that invade the root canal system (RCS) due to pulp necrosis, dental trauma, extensive carious lesions, defective restorations, or failures in previous endodontic treatments (Kirkevang *et al*., 2007).

The primary objective of endodontic treatment is the complete decontamination of the RCS, which includes the removal of necrotic tissues, microbial biofilm, and their byproducts. This cleaning is achieved through chemomechanical preparation (CMP), which combines endodontic instruments with irrigating solutions possessing antimicrobial, solvent, and chelating properties (Plotino *et al*., 2016).

3.2 Main Irrigating Solutions

The success of endodontic therapy depends not only on effective mechanical instrumentation but also on the chemical action of irrigants. These solutions must reach areas that instruments cannot, such as lateral canals, isthmuses, and dentinal tubules. To meet these goals, irrigants must possess specific properties, including broad-spectrum antimicrobial activity, the ability to dissolve organic and inorganic tissues, biocompatibility, low toxicity, and effective smear layer removal.

3.2.1 Sodium hypochlorite (NaOCl)

Sodium hypochlorite (NaOCl) is considered the gold standard irrigant in Endodontics due to its ability to dissolve organic tissues and its broad-spectrum antimicrobial effect. Historically, hypochlorite-based solutions have been used as disinfectants since the 18th century. In the 19th century, Labarraque recommended their use as hospital antiseptics, and by 1920, NaOCl had been adopted as an endodontic irrigant (Zehnder, 2006).

Among its advantages are its action against anaerobic and facultative bacteria, its efficacy in dissolving pulp tissues and biofilms, and its low cost (Basrani and Haapasalo, 2012). However, disadvantages include high cytotoxicity when extruded, unpleasant odor, and chemical instability. Recent studies also highlight the use of heated NaOCl and its ultrasonic activation as strategies to enhance its antimicrobial and solvent action, contributing to improved canal cleanliness (Basrani and Haapasalo, 2012).

NaOCl must be in direct contact with the tissue to be disinfected to exert a satisfactory effect. Its mechanisms of action include oxidation, hydrolysis, and to some extent, osmotic removal of tissue fluids. Clinically, this means that the irrigant must reach the full extent of the root canal system, including dentinal tubules, accessory canals, apical deltas, and isthmuses. Literature indicates that short exposure times—especially with 1% or 2.5% concentrations for 15 minutes or less—may be insufficient for complete biofilm dissolution. In contrast, longer contact time (30 minutes), with frequent replenishment, even at lower concentrations, achieves similar effectiveness to 5.25% NaOCl for 5 minutes (Basrani and Haapasalo, 2012).

One clinical advantage of using lower concentrations is reduced cytotoxicity. However, shorter contact time may compromise the cleaning efficacy, particularly in the apical third (Basrani and Haapasalo, 2012). Therefore, NaOCl remains the main irrigating solution used in endodontic treatment, fulfilling the essential requirements of an ideal irrigant (Zehnder, 2006; Basrani and Haapasalo, 2012).

3.2.2 Chlorhexidine (CHX)

Chlorhexidine was developed in the late 1940s with the original aim of serving as an antiviral agent. Due to its limited efficacy against viruses, it was redirected as an antibacterial agent. Its initial forms—chlorhexidine acetate and hydrochloride—were replaced by chlorhexidinedigluconate due to solubility improvements (Zehnder, 2006).

It is widely used for plaque control at concentrations of 0.1–0.12%. In Endodontics, a 2.0% CHX solution is used for its antimicrobial efficacy and residual substantivity. It is particularly effective against *E. faecalis* and *C. albicans*, microorganisms often related to persistent infections (Basrani and Haapasalo, 2012). Nonetheless, CHX does not dissolve organic tissue and shows lower efficacy against Gram-negative species (Naenni *et al*. 2004; Clegg *et al*., 2006).

Although 2% CHX may eliminate cultivable microorganisms after 15 minutes, the smear layer remains unaffected under SEM analysis (Clegg *et al*., 2006). Therefore, its use should be combined with irrigants capable of removing biofilm and smear layer, since CHX's main function is antimicrobial (Clegg *et al*., 2006).

3.2.3 Ethylenediaminetetraacetic Acid (EDTA)

Ethylenediaminetetraacetic acid (EDTA) is a chelating agent first described by Ferdinand Münz in 1935 and introduced into endodontic practice by Nygaard-Östby in 1957. It is widely used to remove the inorganic component of the smear layer, softening the dentinal surface by chelating calcium ions (Calt and Serper, 2002).

The standard concentration used in Endodontics is 17%, typically applied for 1 to 3 minutes at the end of canal instrumentation. Its chelating action promotes superficial demineralization of the dentin (approximately 20 to 30 µm), exposing collagen fibrils and opening the dentinal tubules (Lopes & Siqueira, 2004). The sequential use of EDTA and sodium hypochlorite (NaOCl) is well-documented for its synergistic effect on smear layer removal. While EDTA removes the mineral component, NaOCl can then dissolve the organic matrix, enhancing overall cleanliness of the canal walls (Lopes and Siqueira, 2004). However, this sequence must be used cautiously, as prolonged exposure to EDTA or its use at higher concentrations may result in erosion of the peritubular and intertubular dentin, compromising the structural integrity of the root (Lopes & Siqueira, 2004).

Moreover, the modifications induced by EDTA on dentin surfaces affect the adaptation and penetration of sealers. Studies have shown that smear layer removal increases the penetration depth of resin-based sealers into dentinal tubules, potentially improving the seal and resistance to microleakage (Lopes & Siqueira, 2004). On the other hand, excessive erosion can lead to weakening of the sealer-dentin interface, especially if a highly demineralized collagen matrix remains unsupported and is subsequently degraded.

Therefore, the use of EDTA should be limited to short application times, followed by NaOCl irrigation to remove exposed collagen and enhance antimicrobial efficacy, while avoiding excessive dentin damage (Lopes & Siqueira, 2004).

3.2.4 Combined Irrigant solu tions (QMix, MTAD)

QMix is a commercially available irrigant that combines EDTA, chlorhexidine, and a surfactant in a single formulation. This composition allows it to simultaneously remove the smear layer and exhibit broad-spectrum antimicrobial activity with residual substantivity, which enhances its performance in complex canal anatomies. Its low surface tension improves penetration into dentinal tubules and anatomical irregularities (Javed and Ali, 2025). MTAD (a mixture of doxycycline, citric acid, and detergent) has also demonstrated effective smear layer removal and action against *Enterococcus faecalis*, with the added benefit of biocompatibility. However, both irrigants are relatively costly, and QMix in particular has the potential to stain dental tissues. These agents must be used according to manufacturer instructions and established clinical protocols to maximize efficacy and avoid adverse effects (Javed and Ali, 2025).

3.2.5 Experimental Irrigants (Nanoparticles, Calcium Hypochlorite)

The search for improved irrigants has led to the exploration of experimental solutions such as nanoparticles and calcium hypochlorite. Nanoparticle-based irrigants, especially those formulated with silver, chitosan, or zinc oxide, have demonstrated enhanced antimicrobial effects and deeper penetration into biofilms due to their small particle size and high surface area (Javed and Ali, 2025). These materials show promise when used as adjuncts to conventional irrigants, although their long-term safety and clinical efficacy remain under investigation.

Calcium hypochlorite ($Ca(OCl)_2$) has been proposed as an alternative to sodium hypochlorite due to its greater chemical stability and higher concentration of available chlorine. Preliminary studies suggest comparable tissue dissolution capacity and antimicrobial effects. However, clinical trials are still needed to determine its ideal concentration, cytotoxicity profile, and interaction with other irrigants (de Almeida *et al*., 2014).

3.2.6 Precipitate Formation and Clinical Implications

One of the most critical aspects in irrigant selection is the possibility of chemical interactions that lead to the formation of precipitates. The most studied and clinically relevant interaction occurs between NaOCl and CHX, which results in the formation of a brownish-orange precipitate containing para-chloroaniline (PCA) or similar by-products (Rasimick *et al*., 2008; Basrani and Haapasalo, 2012). PCA is potentially cytotoxic and may interfere with the sealing of the canal by blocking dentinal tubules or altering the interface with the root canal sealer.

To avoid these complications, it is strongly recommended to use an intermediate rinse (e.g., distilled water or saline) when switching between incompatible irrigants. In addition to biological risks, precipitate formation can affect long-term treatment outcomes due to its impact on adhesion and sealing (Basrani and Haapasalo, 2012).

3.2.7 Physical Properties, Application Variables, and Complications

The effectiveness of irrigating solutions is also influenced by their physical properties and clinical application parameters. Heating sodium hypochlorite significantly increases its reactivity and ability to dissolve organic tissue, especially when combined with ultrasonic or mechanical activation. Surfactants incorporated into solutions like QMix reduce surface tension and promote greater irrigant penetration (Basrani and Haapasalo, 2012).

Additionally, the volume of irrigant used and the contact time within the canal are directly related to cleaning efficacy. Larger volumes and prolonged contact time allow better interaction with debris and biofilms, particularly in the apical third. However, care must be taken to prevent extrusion, especially with NaOCl, as it may cause severe tissue irritation, necrosis, and postoperative complications (Zehnder, 2006).

3.3 Traditional Irrigation Method (Manual)

Manual irrigation is performed using a syringe coupled with a side-vented needle, allowing the irrigating solution to be delivered along the length of the root canal (GU, 2009).

3.3.1 Needle Gauge

The effectiveness of irrigating solutions may be compromised when needles with larger diameters are used, as they hinder access to the apical third of the canal (Filho *et al*., 2013). In a study by Filho *et al*. (2013), four needle gauges were tested at different stages of instrumentation: 23G (side-vented), 22G (end-vented), 30G (side-vented), and 30G (end-vented). Distilled water was used as the irrigant at a volume of 2 mL and a flow rate of 5 mL/minute. The results demonstrated that 30G needles, both side-vented and end-vented, were more effective in debris removal in the apical region.

3.3.2 Needle Bevel Design

The bevel design of irrigation needles aims primarily to optimize solution delivery and minimize apical extrusion. Recently, new designs have been proposed to improve irrigation control (Zhou *et al*., 2024). Zhou *et al*. (2024) compared three types of needles: open-ended, closed-ended with a single lateral port, and closed-ended with dual lateral ports. The results indicated that the closed-ended needle with dual lateral ports presented the lowest level of apical extrusion, making it clinically safer.

3.4 Methods for Enhancing Irrigation

The complex anatomy of the root canal system (RCS) has driven the development of techniques aimed at optimizing the action of irrigating solutions. Two critical factors influence this process: the type of irrigant and the delivery system. The latter can be divided into manual methods and those assisted by automated or energy-based devices. Assisted agitation techniques aim to increase disinfection effectiveness by enhancing irrigant penetration, especially in anatomically challenging areas (Zhou *et al*., 2024).

3.4.1 Passive Ultrasonic Irrigation (PUI)

Passive Ultrasonic Irrigation (PUI) consists of activating the irrigating solution using a non-cutting ultrasonic tip, which vibrates within the canal, generating acoustic streaming and cavitation. This technique has demonstrated high efficacy in removing debris and smear layer, especially in the apical third (Zhou *et al*., 2024). It is widely used as a final irrigation step in cases involving complex anatomies or persistent infection. However, its effectiveness can be limited in narrow canals, and it requires piezoelectric equipment.

3.4.2 Easy Clean System (Easy®)

The Easy Clean system is a plastic instrument with an "airplane wing"-shaped cross-section, operated in reciprocating or rotary motion. It promotes mechanical activation of the irrigant without significant abrasion of the dentinal walls (Zhou *et al*., 2024). It is a simple and inexpensive method, compatible with most endodontic motors, and is often used as a supplementary activation tool in curved or irregular canals. Nevertheless, its efficacy in smear layer removal may be inferior to that of ultrasonic methods.

3.4.3 XP-Endo Finisher (FKG®)

The XP-Endo Finisher is a NiTi file with shape-memory properties that allow it to expand and adapt to the internal morphology of the canal when exposed to intracanal temperature. This device reaches areas that conventional instruments cannot touch, promoting improved cleaning in flattened or oval (Zhou *et al*., 2024). Although it does not produce cavitation effects, it is particularly useful in retreatments and final irrigation steps following instrumentation. Its use requires operator training due to its technique-sensitive nature.

3.4.4 EDDY Device

EDDY is a flexible polyamide tip activated by an air scaler at approximately 6,000 Hz. It produces sonic energy and turbulent flow, promoting irrigant activation without generating heat or damaging dentinal walls (Eggmann *et al*., 2020). EDDY has shown good efficacy in smear layer and biofilm removal and is especially recommended for curved or narrow canals. It requires specific air-scaler equipment but is considered safe and easy to handle in routine practice.

3.4.5 EndoActivator System

The EndoActivator system is a cordless sonic device that uses non-cutting polymer tips operating at low frequencies (2,000–10,000 Hz). It enhances the dynamic movement of the irrigant and improves canal cleanliness. This system is commonly used in pediatric endodontics, immature teeth, or conservative preparations, given its gentle activation and low risk of extrusion (Susin *et al*., 2010). However, its lower power output may limit its effectiveness in cases requiring intense debridement.

3.4.6 Laser-Activated Irrigation (LAI – Er:YAG, PIPS, SWEEPS)

Laser-assisted irrigation has emerged as an advanced method to activate irrigants through light-based photoacoustic effects. The Er:YAG laser (2940 nm) is the most commonly used for this purpose, with two well-known techniques: Photon-Induced Photoacoustic Streaming (PIPS) and Shock Wave Enhanced Emission Photoacoustic Streaming (SWEEPS). These methods create vapor bubbles that implode within the canal space, improving irrigant penetration and disrupting biofilms (Liu *et al*., 2022; Fiegler-Rudol *et al*., 2025). Although laser-assisted irrigation demonstrates excellent cleaning in inaccessible areas, it requires expensive equipment and expertise, which may limit its use in routine clinical settings.

3.4.7 GentleWave® Multisonic System

The GentleWave® system is a recent innovation that uses multisonic sound waves combined with continuous irrigant flow under negative pressure. It promotes deep and uniform cleaning throughout the entire canal system without requiring mechanical contact with the dentinal walls (Molina *et al*., 2015). Studies have shown that GentleWave® preserves dentin structure, reduces apical extrusion, and improves cleaning in minimally instrumented canals. Despite its promising results, the system's high cost and need for specialized infrastructure limit its availability in general clinical practice.

4. RESULTS AND DISCUSSION

The primary objective of endodontic treatment is to promote effective decontamination of the root canal system (RCS), ensuring the elimination of organic tissue, microbial biofilms, and debris.

This process relies heavily on the synergistic interaction between mechanical instrumentation and chemical (Haapasalo, 2012).

Among the irrigants evaluated, sodium hypochlorite (NaOCl) remains the most clinically effective solution due to its strong tissue-dissolving capacity and broad antimicrobial spectrum (Zehnder, 2006; Basrani; Haapasalo, 2012). However, its efficacy is highly dependent on concentration, temperature, volume, and duration of contact within the canal. Studies have shown that heated NaOCl enhances chemical activity and tissue dissolution, especially when used with ultrasonic activation or in larger volumes (Basrani and Haapasalo, 2012).

Chlorhexidine (CHX), although lacking tissue-dissolving ability, provides strong antimicrobial action and substantivity, making it a useful adjunct, particularly in retreatment cases or when NaOCl is contraindicated (Basrani and Haapasalo, 2012). However, the combination of CHX with NaOCl results in the formation of a precipitate containing para-chloroaniline (PCA), which is cytotoxic and may impair sealer penetration by blocking dentinal tubules (Rasimick *et al*., 2008; Basrani and Haapasalo, 2012).

The sequential use of EDTA and NaOCl continues to be widely accepted for removing both organic and inorganic smear layer components. EDTA application time must be limited to avoid dentin erosion, especially in combination with NaOCl. Smear layer removal improves sealer adaptation and penetration, enhancing long-term sealing (Lopes & Siqueira, 2004).

Surfactant-containing irrigants such as QMix combine EDTA, CHX, and a detergent, enabling simultaneous smear layer removal and antimicrobial action with lower surface tension for better penetration (Javed and Ali, 2025). While effective, QMix should not be used immediately after NaOCl to avoid similar chemical interactions as CHX.

In terms of irrigant activation, Passive Ultrasonic Irrigation (PUI) remains highly effective due to the formation of acoustic streaming and cavitation, improving cleaning in the apical third. Easy Clean and XP-Endo Finisher offer mechanical agitation that adapts well to irregular anatomies, although they do not promote cavitation (Haapasalo, 2012).

Sonic systems like EDDY and EndoActivator have also demonstrated favorable results. EDDY, activated by an air scaler, provides effective activation in curved canals without heat generation (Eggmann *et al*., 2020). The EndoActivator operates at lower frequencies and is indicated in cases of immature apices or conservative shaping (Susin *et al*., 2010).

Laser-activated irrigation methods, such as PIPS and SWEEPS using Er:YAG lasers, have shown strong potential in biofilm disruption and debris removal through photoacoustic effects (Liu *et al*., 2022; Fiegler-Rudol *et al*., 2025). Despite their effectiveness, their high cost and operational complexity limit routine use.

The GentleWave® multisonic system represents one of the most recent innovations, using sound waves and negative pressure to promote deep canal cleaning with minimal instrumentation. Micro-CT and in vitro studies have confirmed its superiority in debridement and smear layer removal, particularly in minimally shaped canals (Molina *et al*., 2015).

In retreatment scenarios—where anatomical complexity, residual materials, and resistant microorganisms such as *Enterococcus faecalis* are prevalent—activated irrigation protocols are essential. Techniques like XP-Endo Finisher, PUI, and GentleWave® offer significant advantages over traditional syringe irrigation (Zhou *et al*., 2024).

However, potential complications such as apical extrusion of NaOCl must be considered, especially in immature or over-instrumented canals. This adverse event can lead to severe soft tissue reactions, reinforcing the importance of careful irrigation technique and the use of negative pressure systems where possible (Zehnder, 2006).

Recent systematic reviews and meta-analyses support the superiority of activated irrigation systems over conventional syringe irrigation in reducing microbial load, improving smear layer removal, and increasing treatment success (Javed and Ali, 2025).

5. CONCLUSION

Based on the literature reviewed, it is evident that no single irrigation method is universally superior in all clinical situations. Sodium hypochlorite (NaOCl) remains the most effective irrigant due to its tissue-dissolving capacity and broad-spectrum antimicrobial activity. Its effectiveness is significantly enhanced by heating, longer contact time, and mechanical activation.

For smear layer removal, the sequential use of ethylenediaminetetraacetic acid (EDTA) followed by NaOCl demonstrates excellent synergistic action, although caution is advised to avoid dentin erosion. In cases requiring antimicrobial substantivity, adjuncts such as chlorhexidine (CHX) or QMix may be beneficial, provided that potential chemical interactions—such as PCA precipitate formation—are avoided.

Activation techniques such as Passive Ultrasonic Irrigation (PUI) and XP-Endo Finisher improve irrigant penetration and effectiveness, especially in anatomically complex canals or retreatment cases. Sonic systems (EDDY, EndoActivator) and laser-assisted methods (PIPS, SWEEPS) offer additional benefits depending on the clinical context. The GentleWave® system stands out for its ability to clean minimally instrumented canals using multisonic energy and negative pressure, though accessibility and cost may limit its routine use.

Clinicians should select irrigation protocols based on anatomical challenges, case complexity, and the risk of complications such as apical extrusion. An evidence-based and case-specific approach is essential to optimize disinfection, improve sealer adaptation, and ensure long-term endodontic success.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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