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Root canal irrigation for optimal cleaning and disinfection treatment: a systematic review by clinical studies

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Abstract

Introduction: In endodontic treatment, debridement is crucial for removing microbiota, byproducts, pulp tissue, and organic/inorganic debris. Root canal irrigation complements mechanical instrumentation, ensuring that the root canal system is thoroughly disinfected and the smear layer is removed. This is crucial for eliminating microorganisms, dissolving organic debris, and improving disinfection. **Objective:** The aim was to conduct a systematic review to describe and compare the various methods of root canal irrigation through clinical studies, with the goal of establishing the optimal cleaning and disinfection treatment protocol. **Methods:** The PRISMA Platform systematic review rules were followed. The search was carried out from July to August 2025 in the Scopus, Embase, PubMed, Science Direct, Scielo, and Google Scholar databases. The quality of the studies was based on the GRADE instrument, and the risk of bias was analyzed according to the Cochrane instrument. **Results and Conclusion:** A total of 175 articles were found, and 40 articles were evaluated in full, and 30 were included and developed in the present systematic review study. Considering the Cochrane tool for risk of bias, the overall assessment resulted in 30 studies with a high risk of bias and 25 that did not meet the GRADE and AMSTAR-2 criteria. According to the GRADE instrument, most studies presented homogeneity in their results, with X^2=91.2%>50%. It was concluded that irrigation plays a fundamental role in the success of endodontic treatment. Although hypochlorite is the most important irrigating solution, no irrigator can perform all the tasks required by irrigation. A detailed understanding of the mode of action of various solutions is important for optimal irrigation. Within the limitations of this study, the use of the self-adjusting filing system with the combination of EDTA and NaOCl improved the removal of $Ca(OH)_2$. Passive ultrasonic irrigation and self-adjusting filing system were more effective in removing $Ca(OH)_2$ from the lateral grooves in the apical parts of the root canal than EndoVac and conventional syringe irrigation systems.

Keywords: Endodontic treatment. Root canal irrigation. Disinfection treatment. Clinical studies.

Introduction

In endodontic treatment, debridement is crucial for removing microbiota, byproducts, pulp tissue, and organic/inorganic debris. Root canal irrigation complements mechanical instrumentation, ensuring that the root canal system is thoroughly disinfected and the smear layer is removed. This is crucial for eliminating microorganisms, dissolving organic debris, and improving disinfection. Although all irrigation techniques lead to some degree of debris and irrigant extrusion, the extent varies [1-3].

Efforts have been ongoing to improve irrigation systems in endodontics, which are classified as systems with and without irrigator activation. Activation and administration of irrigation solutions are believed to improve their flow and distribution throughout the root canal system. Endodontic irrigator activation techniques include manual irrigation, heating (internal or external), negative apical pressure, sonic techniques, passive ultrasonic irrigation, and laser techniques. Each method offers distinct advantages for improving irrigation results. Despite the widespread use of conventional needle irrigation, it cannot safely and effectively deliver large volumes of irrigating solution throughout the root canal system, including difficult-to-reach areas [4-8].

The arsenal of irrigation solutions designed for endodontic treatment and commercially available is broad. The choice of the correct solution depends on the combination of the properties of the solution associated with the effects to be obtained with irrigation, according to the clinical condition [1,2]. In cases where the pulp is mortified and there is an infection, the irrigating solutions have the function of promoting asepsis, dissolving the necrotic tissue, and facilitating its removal, in addition to neutralizing the bacterial toxin [2-5].

In this context, ethylenediaminetetraacetic acid (EDTA) is generally used after endodontic instrumentation for its chelating action, by which it removes the layer from the smear layer [3]. EDTA in endodontics was introduced in 1957 by Ostby, in the form of a 15.5% aqueous solution and pH 7.3. This facilitates the atresia of irrigating instrumentation channels, can demineralize dentin using stable calcium ions [3]. EDTA is one of the most widely used endodontic irrigators, and the clinician must become aware of the irrigant's properties.

Also, the drug calcium hydroxide, $Ca(OH)_2$ and with good antimicrobial properties against most endodontic pathogens, is used in the treatment of endodontic infections as an intracanal pathogens relevant in tactical terms [4]. Research shows that the remaining $Ca(OH)_2$ in the dentin walls can affect the penetration of sealers in dentinal tubules and increase apical leakage. Therefore, it is recommended to completely remove the $Ca(OH)_2$ placed inside the root canal before filling the root system [4].

Thus, the most frequently described method for removing $Ca(OH)_2$ is the instrumentation of the root canal with a main apical file at the working length and the abundant irrigation of sodium hypochlorite (NaOCl) and EDTA. Previous studies have investigated the effectiveness of removing $Ca(OH)_2$ with different irrigation devices and systems [5]. Continuous passive ultrasonic irrigation (PUI) uses an ultrasound-activated file inside the root canal with a continuous irrigator provided by the handpiece. Studies have shown that PUI was more effective in removing $Ca(OH)_2$ from the walls of the root canal than the release of irrigant by positive pressure [5].

The EndoVac system (Discus Dental, Culver City, CA) is an apical negative pressure (ANP) irrigation device designed to provide irrigation solutions for the apical portion of the canal system and to suck up debris. The EndoVac system ANP effectively cleans dentinal surfaces. ANP irrigation with sufficient volume and flow removes the smear layers and displaces debris [5].

Also, the self-adjusting filing system (SAF) (Re-Dent-Nova, Raanana, Israel) adapts to the three-dimensional shape of the root canal to allow continuous irrigation during the preparation and activation of vibrating irrigators. The SAF system is operated by vibrating a slightly abrasive lattice in an in and out movement to remove dentin. SAF is more effective at removing dentine debris from the canal root than rotary instrumentation. However, whether the SAF can remove the drug $Ca(OH)_2$ from the root canal wall is not known [6].

Therefore, the present study aimed to carry out a systematic review to describe and compare the different methods of root canal irrigation through clinical studies, to establish the best cleaning and disinfection treatment protocol.

Methods

Eligibility and Study Design

This study followed the international systematic review model, following the PRISMA (preferred reporting items for systematic reviews and meta-analysis) rules. Available at: http://www.prisma-statement.org/?AspxAutoDetectCookieSupport=1. Accessed on: 08/11/2025. The AMSTAR 2 (Assessing the methodological quality of systematic reviews) methodological quality standards were also followed. Available at: https://amstar.ca/. Accessed on: 08/11/2025.

Search Strategy and Search Sources

The literature search process was carried out from July to August 2025 and developed based on Web of Science, Scopus, Embase, PubMed, Lilacs, Ebsco, Scielo, and Google Scholar, covering scientific articles from various periods to the present day. The following descriptors (DeCS /MeSH Terms) were used *Endodontic treatment. Root canal irrigation. Disinfection treatment. Clinical studies*, and using the Boolean "and" between MeSH terms and "or" between historical findings.

Study Quality and Risk of Bias

Quality was classified as high, moderate, low, or very low regarding the risk of bias, clarity of comparisons, precision, and consistency of analyses. The most evident emphasis was on systematic review articles or meta-analysis of randomized clinical trials, followed by randomized clinical trials. Low quality of evidence was attributed to case reports, editorials, and brief communications, according to the GRADE instrument. The risk of bias was analyzed according to the Cochrane instrument by analyzing the Funnel Plot graph (Sample size versus Effect size), using Cohen's d test.

Results and Discussion

Summary of Findings

As a corollary of the literature search system, a total of 175 articles were found that were submitted to eligibility analysis, 40 articles were evaluated in full and 30 final studies were selected to compose the results of this systematic review. The studies listed were of medium to high quality (Figure 1), considering the level of scientific evidence of studies such as meta-analysis, consensus, randomized clinical, prospective, and observational studies. Biases did not compromise the scientific basis of the studies. According to the GRADE instrument, most studies presented homogeneity in their results, with X^2=91.2%>50%. Considering the Cochrane tool for risk of bias, the overall assessment resulted in 30 studies with a high risk of bias and 25 studies that did not meet GRADE and AMSTAR-2.

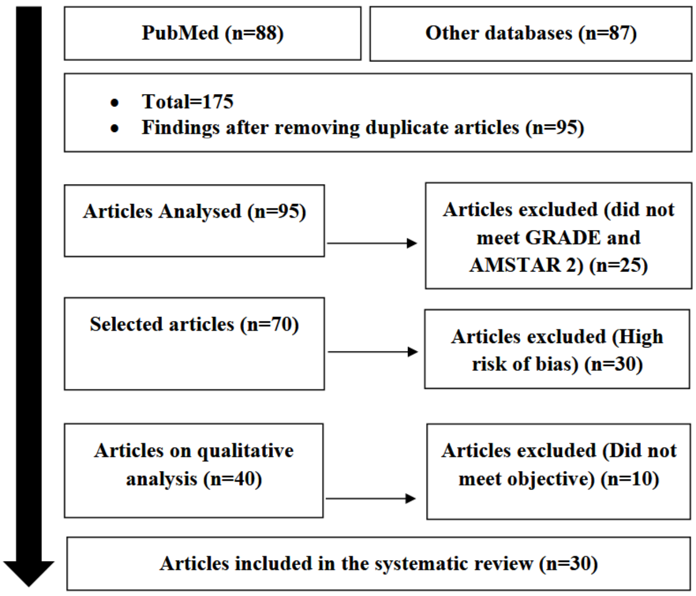

Figure 1. Flowchart showing the article selection process. Source: Own Authorship.

Figure 2 presents the results of the risk of bias of the studies using the Funnel Plot, showing the calculation of the Effect Size (Magnitude of the difference) using Cohen's Test (d). Precision (sample size) was determined indirectly by the inverse of the standard error (1/Standard Error). This graph had a symmetrical behavior, not suggesting a significant risk of bias, both among studies with small sample sizes (lower precision) that are shown at the base of the graph and in studies with large sample sizes that are shown at the top.

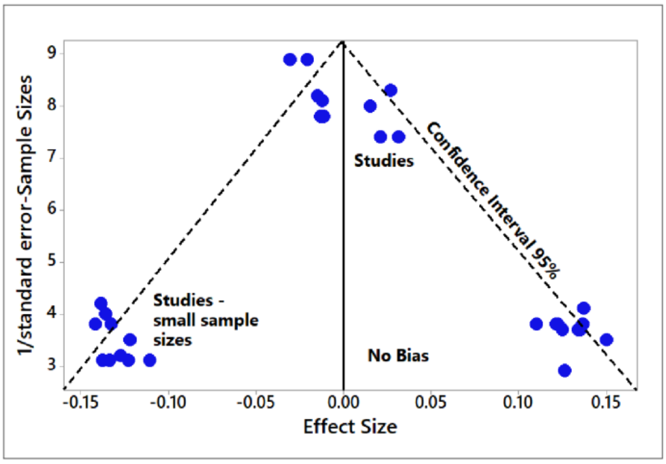

Figure 2. The symmetrical funnel plot does not suggest a risk of bias among the studies with small sample sizes that are shown at the bottom of the graph. Studies with high confidence and high recommendation are shown above the graph (n=30 studies). Source: Own Authorship

Major Clinical Findings

The success of endodontic treatment depends on the eradication of microbes (if present) from the root canal system and the prevention of reinfection [1]. The root canal is formed with manual and rotating instruments under constant irrigation to remove inflamed and necrotic tissue, microbes/biofilms, and other debris from the root space. The main purpose of instrumentation is to facilitate effective irrigation, disinfection, and filling. Several studies using advanced techniques, such as microcomputed tomography, have shown that proportionally large areas of the main root canal wall remain untouched by the instruments, emphasizing the importance of chemical means to clean and disinfect all areas of the root canal [2-4].

There is no single irrigation solution that, by itself, sufficiently covers all the functions required of an irrigator [3,4]. The ideal irrigation is based on the combined use of 2 different irrigation solutions, specific sequence, to obtain the objectives of safe and effective irrigation. Traditionally, irrigators are distributed in the space of the chest canal using syringes and metal needles of different sizes and designs. Clinical experience and research have shown, however, that this classic approach typically results in ineffective irrigation, especially in peripheral areas, such as canals, fins, and the most apical part of the main root canal [8,9-12].

Therefore, many of the compounds used for irrigation have been chemically modified, and several mechanical devices have been developed to improve irrigation penetration and efficiency [13-15]. In this sense, the removal of the smear layer generated during the instrumentation of the root canal walls is an essential condition for the best antimicrobial effectiveness of the irrigation solution in the dentinal tubules, in addition to improving the sealing ability of the obturator [6]. The smear layer removal power by the EDTA chelator makes it one of the most used in the irrigation of root canals. This is generally used as the gold standard for the removal of the smear layer in comparative studies conducted in research comparing the effectiveness of EDTA 17% maleic acid to 7% and noted greater effectiveness of maleic acid in removing the smear layer from the apical third of uniradicular human teeth. When compared to maleic acid, 5% EDTA 17% proved to be equally effective [7].

In a recent study that evaluated the removal of the smear layer in SEM for various irrigation agents (EDTA, apple cider vinegar, 5% maleic acid, acetic acid, and distilled water as a control), EDTA promoted the best results, proving to be the most effective solution [8]. Another work, noting the removal of the smear layer with an SEM evaluation, was carried out by Cehreli et al. (2013) [16]. This work, carried out in vivo, promoted the instrumentation and irrigation channels with 5.25% NaOCl or 17% EDTA, or MTAD Biopure, and were extracted immediately. And among these irrigation solutions, EDTA showed significantly better results at the expense of greater dentin erosion [16].

In a study by Zia et al. (2014) [17] performed on extracted teeth, EDTA equivalence to MTAD Biopure can be observed, being more efficient than brine. Another study compared three different formulations of QMix with EDTA and found better effectiveness of QMix in removing the smear layer in the apical third and equivalence between the results of the solutions in the middle and cervical thirds, showing a viable alternative to EDTA for the end of irrigation [9]. The alternative would be to use the EDTA gel, which proved to be as effective as the liquid in the same concentrations and conditions of use [9].

Antimicrobial action

As it is well used in the endodontic irrigator, EDTA has been studied for its antimicrobial properties, as it is usually the final irrigating treatment [9]. Bryce et al. (2009) [18] conducted a study to verify the antimicrobial action of irrigating agents on biofilms of microorganisms isolated from root canals. The authors observed low antimicrobial efficacy of EDTA in biofilm, especially when compared to sodium hypochlorite. Also, EDTA, which conditions dentin to allow an increase in the number of connected microorganisms, as well as resistance to adhesion, and compared to other types of irrigation, has low retention power in reinfection or activity residual is low, which can only be improved with the addition of auxiliaries in a composition [19-21].

In mixed biofilms developed in situ in the oral cavity, Ordinola-Zapata et al. (2012) [22] evaluated the efficacy of irrigation agents commonly used in endodontics and found that sodium hypochlorite was the most effective for dissolving and depleting biofilm. But EDTA was not effective for that purpose and had a stake compared to saline. Low efficacy of EDTA results was found in another study in which we compared EDTA to Qmix, 0.2% cetrimide, 2% chlorhexidine, and EDTA, antimicrobial activity, and also substantivity. However, some contradict these findings. There is a study that shows almost no potential for disruption of the biofilm structure; however, a high antimicrobial potential for EDTA, reaching levels similar to sodium hypochlorite when used at pH 12 and 50 mmol/L, affects the integrity of the biofilm membrane 24 hours after *E. faecalis, L. paracasei,* and *S. anginosus*.

EDTA also has antifungal activity against *Candida albicans*, which is a fungus commonly associated with endodontic failure. The evaluation of the antifungal effect of EDTA to tilenoglycol-tetraacetic acid, titanium tetrafluoride, sodium fluoride, nystatin, ketoconazole, and EDTA and titanium tetrafluoride showed better antifungal activity [22]. This study corroborates another previous study that compared the inhibition of the halo EDTA with several antifungals and sodium hypochlorite and EDTA with more satisfactory results [23].

One way to improve the antimicrobial action of EDTA would be the association with cetrimide. Ferrer-Luque et al. (2010) [20] found that EDTA associated with the same 15% cetrimide, compared to maleic acid, has a lower antimicrobial activity. Also, EDTA has a low potential to prevent the recolonization of the root canal and, therefore, can associate with another irrigating solution to improve the substantivity of the action of the final irrigant. One of the viable options studied is the addition of cetrimide EDTA, with promising results [21,24-29].

Biocompatibility

Chandrasekhar et al (2013) [26] injected 0.1 ml of various solutions into the mice's back and found that EDTA had toxicity similar to QMix and was less toxic when compared to 3% NaOCl, and more toxic than the physiological solution. Prado et al (2015) [30] compared the cytotoxicity of 17% EDTA compared to 37% phosphoric acid, 10% citric acid, 5.25% NaOCl, and 2% chlorhexidine. In this study, it is possible to observe a lower cytotoxicity of EDTA and citric acid, when compared with other tested substances, presenting a good biocompatibility of EDTA.

An alternative EDTA (EDTA-T) to the conventional one has been studied and has shown good results to remove the smear layer and a good antimicrobial action, but has demonstrated a greater potential to generate inflammation than conventional EDTA 17% and citric acid 10%. Even when compared to personnel sensitized by light, FotoSan EDTA showed a similar cytotoxic action, showing a biocompatible material and similar to other decontamination methods used [10].

Dentin changes

Studies have shown that, in addition to the removal of microorganisms, dissolved organic and inorganic matter, irrigators can damage the dentin microstructure, leading to changes in the organic material/inorganic surface [11]. The type and intensity of these changes in the proportion of dentinal components depend on the irrigation solution used and may influence the quality of adhesion of sealants and cements used for intraradicular cementation [12].

Another study evaluated the effects of QMix EDTA Chlorhexidine + EDTA + NaOCl and maleic acid on the root dentin microhardness. In this study, the authors found that maleic acid has a high capacity to reduce dentin hardness compared to the other groups. The lowest reduction in hardness was found in the association EDTA + NaOCl, which can be explained by the fact that one substance has the power to neutralize the other [24].

Still, another study examined the effect of the final irrigation protocols (17% EDTA, Biopure MTAD, and SmearClear QMiX) on dentine root canal hardness and erosion. All irrigating agents promoted a reduction in dentin hardness, and EDTA promoted erosion of dentinal tubules. When compared to alternative chelating agents, such as 2.25% peracetic acid, which demonstrated good antimicrobial power, EDTA 17 % shows a similar erosion of power in the dentinal walls [25].

Ballal et al (2013) [31] evaluated the influence of irrigants (EDTA, 2.5% NaOCl, maleic acid, and 7% QMix) on the wetting of two cements (AH Plus and ThermaSeal) on intra-root dentin. QMix proved to be the most favored irrigator over the wetting of cements in the root canal dentin, which promoted better adherence and sealing of the obturator. As Aranda-Garcia et al 2013 studied the influence of three different irrigating adhesives (QMix, EDTA, and Smear Clear) of a cement epoxy resin, not checking the interference of the adhesiveness of these materials on the root canal wall.

Elnaghy (2014) [32] conducted a study that evaluated the influence of various irrigations on the adhesion of sealants, biodentin, and MTA. The author found that QMix did not influence the adhesion of the materials and obtained results similar to those of EDTA and NaOCl. Another study by Elnaghy (2014) [33] to assess the influence of EDTA associated with chlorhexidine on the adhesion of fiberglass pins cemented with resin cement in the root canal and showed that QMix and EDTA associated with chlorhexidine provided the best adhesion results.

There are contradictory results in the literature on the need to remove $Ca(OH)_2$ [13-17]. However, it is well established that residual $Ca(OH)_2$ must be removed because it influences the bonding and sealing of endodontic materials [18]. The use of the SAF system with the combination of EDTA and NaOCl improved $Ca(OH)_2$ removal. Thus, the combination of EDTA and NaOCl as a final rinse had no important role in removing $Ca(OH)_2$ residues from the dentin walls. The differences between the studies may stem from the use of SAF to remove Ca(OH)2. Previous studies used a standardized artificial groove design in assessments of $Ca(OH)_2$ removal. Also, this model allows for standardizing the size and location of the grooves and the quantities of medication used before irrigation. A disadvantage of this standardized artificial groove design is that it does not represent the complexity of a natural root canal system [19].

A study showed that PUI with continuous irrigation and SAF were more effective than EndoVac and the conventional syringe in removing the $Ca(OH)_2$ drug from a standardized artificial groove in the apical part of the root canal. Similar to these findings, several previous studies have shown that removal of the drug $Ca(OH)_2$ was superior to PUI compared to irrigation with a conventional syringe and sonic irrigation [20-24]. The higher speed of the irrigating flow generated by the PUI may explain its efficiency in removing $Ca(OH)_2$ from the root canals. PUI's efficiency is also improved by replacing fresh irrigators [25-28].

It can be assumed that the removal of the drug $Ca(OH)_2$ can influence the suction effect of the microcannula and result in insufficient removal of Ca(OH)2. The SAF system improved the removal of gutta-percha from the root canal. However, there are no data available in the literature on the effect of APS on the removal of the drug $Ca(OH)_2$ [29-33]. The artificial furrow model was created in the apical part of the root canal to simulate uninstructed extensions of the canal [34]. Studies report that the removal of the drug $Ca(OH)_2$ from the apical part of the root canal wall is very difficult [35]. After the removal of the $Ca(OH)_2$ drug from the main canal, the remnants may remain in canal extensions or irregularities [36,37].

Conclusion

It was concluded that irrigation plays a fundamental role in the success of endodontic treatment. Although hypochlorite is the most important irrigating solution, no irrigator can perform all the tasks required by irrigation. A detailed understanding of the mode of action of various solutions is important for optimal irrigation. Within the limitations of this study, the use of the self-adjusting filing system with the combination of EDTA and NaOCl improved the removal of $Ca(OH)_2$. Passive ultrasonic irrigation and self-adjusting filing system were more effective in removing $Ca(OH)_2$ from the lateral grooves in the apical parts of the root canal than EndoVac and conventional syringe irrigation systems.

CRediT

Author contributions: **Conceptualization**; **Formal Analysis**; **Investigation**; **Methodology**; **Project administration**; **Supervision**; **Writing - original draft and Writing-review & editing-** Bianca Fávero da Silva, Janaina Cardoso Moreira.

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Informed Consent

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No additional data are available.

Conflict of Interest

The authors declare no conflict of interest.

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Application of Artificial Intelligence (AI)

Not applicable.

Peer Review Process

It was performed.

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