An Update on Ethylenediaminetetraacetic Acid for Optimal Endodontic Outcomes: A Narrative Review

Abstract

Aims
Ethylenediaminetetraacetic acid (EDTA) is a chelating agent primarily used in the final rinse to remove the smear layer formed during mechanical root canal preparation. This study aims to review the latest scientific insights on EDTA, evaluate its necessity in irrigation protocols, compare its effectiveness with alternative options, and eventually provide a concise, practical conclusion on the necessity of EDTA in a successful irrigation protocol.

Materials and Methods and Results
Reviewing numerous articles, this article suggests that EDTA can effectively remove the smear layer, enhancing canal cleanliness, it has notable antimicrobial properties, and also effectively increasing dentine permeability. While EDTA is a legitimate and accepted clinical practice as final rinsing in root canal therapy, current evidence suggests that it may not be the unique optimum choice in all cases. Alternatives such as citric acid, which is less aggressive to dentinal tubules, and carbohydrate-derived fulvic acid, which demonstrates superior smear layer removal, show promise as better options.

Conclusions
Further studies are needed to clarify the comparative efficacy and safety of these alternatives, as well as to determine whether EDTA remains the most appropriate choice in clinical practice.

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Keywords

EDTA, Endodontic, chelating agent, Ethylenediaminetetraacetic acid.

DOI

10.23805/JO.2025.703

INTRODUCTION

A successful endodontic treatment relies on effective mechanical instrumentation, appropriate irrigation protocols, and thorough three-dimensional obturation of the canal system(1). Ethylenediaminetetraacetic acid (EDTA) is a chelating agent introduced in endodontics in 1957 by Nygaard-Ostby, primarily used during the final rinse to remove the smear layer formed during mechanical root canal preparation. The chelating action of EDTA, which involves forming stable complexes with metallic ions in the hydroxyapatite matrix of root dentine, can reduce the mineral content and alter the dentine's mechanical properties. It binds with calcium and phosphate ions in the dentin, softening the smear layer and allowing it to be flushed out, exposing clean dentinal tubules. While EDTA has minimal antibacterial effects on its own, it complements sodium hypochlorite (NaOCl), which provides strong antimicrobial action. Together, it is believed that they improve disinfection by enabling NaOCl to penetrate deeper into dentinal tubules. However, direct contact between EDTA and NaOCl reduces NaOCl's effectiveness, making it crucial to flush the canal with a neutral solution before reintroducing NaOCl(2,3). Proper timing, concentration, and volume are essential for the optimal use of EDTA in endodontic therapy. Furthermore, this chelating agent has been shown to have benefits on regenerative endodontic procedures; releasing growth factors from dentine (TGF-β), cell migration, attachment, and differentiation (4,5). On the other hand, some misdesigned Irrigation protocols can lead to erosion, which impacts the ultrastructure of radicular dentin(1). Until today, numerous experimental studies (6) have been done on this important topic, but none can confirm that EDTA should eventually be necessary for an endodontist's irrigation protocol. This study aimed to review the latest scientific ideas on EDTA and explore its necessity of usage in the irrigation protocol, comparing it with other possible options, and its probable harms, and finally come to a brief practical conclusion so that a dentist can decide whether to use it or not.

The function of EDTA in the irrigation process

Influence of EDTA on smear layer

The smear layer is formed on any tooth's hard tissue surface during shaping with mechanical instruments. In the definition by Mader et al., published in 1984(7), it is a layer formed by inorganic particles from the root dentine, and organic particles derived from the pulp remnants, odontoblastic processes, and biofilm. In this scanning electron microscopy study was also underlined that in smear layer there are two different components, one that is on the root dentine surface and other that is packed into the dentinal tubules. The canal wall smear layer is typically 1 to 2 microns in thickness, whereas the depth of penetration to the tubules varies from a few microns to up to 40 microns(7). Another confirmatory scanning electron study was conducted in 1995 by Sen et al, where was stated that this smear layer is always formed during the mechanical instrumentation of the root canal. Under scanning electron microscope this layer has an irregular and granular appearance, derived from the dentinal debris, and an uneven distribution (8). The hypothesis for the necessity of full removal of smear layer for a success in endodontic therapy has been proven controversial in the in vitro studies conducted in last decades. Since smear layer may form a mechanical hindrance for the antibacterial endodontic irrigants to properly clean the canal, it has been advised to remove the smear layer in full, also removing smear plugs in dentinal tubules(9). However, this should be reached without excessive disruption to the calcified matrix of the root dentine, that would lead to the degradation of the dentinal tubule orifices and lower the mechanical properties of the root. In a study in 2020 scanning electron microscopic evaluation of root showed that EDTA when used as final rinse irrigation material (5ml, 17% for 1 minute), has an overall acceptable ability to remove smear layer even if this ability is less in apical root third of the canal(10).

Influence of EDTA on biofilm

The antimicrobial effect of EDTA has been tested in vitro with different biofilm models in the last decade. Since NaOCl has long been the default antimicrobial agent in root canal therapies, but its deleterious effects on the dentine mechanical properties have been recognized, the study foci have shifted. In 2019 Hartmann et al used an *Enterococcus faecalis* biofilm model to compare the antimicrobial efficacy of two chelators: 0.5% peracetic acid and 17% EDTA. The irrigants were either agitated manually or activated with PUI. The remaining bacterial growth was measured by calculating the CFU after a 24-hour blood agar incubation. No bacterial growth was detected in the group with peracetic acid activated with PUI, other groups did not have significant differences amongst themselves, yet all were effective(3). In another *Enterococcus faecalis* biofilm model, conducted by Oliveira et al in 2022, they measured the antimicrobial activity with a quantitative polymerase chain reaction before and after irrigation. In the protocol, groups of 1% peracetic acid, 0.1% cetrimide and 17% EDTA were compared, activated with PUI or Easy Clean, and all were finished with a 2.5% NaOCl flush. The E. faecalis reduction was significant in all test groups, except for saline rinse and Easy Clean activation that had no statistically significant reduction. The results suggest that an activated chelator is antimicrobial against *E. faecalis* biofilm(11). A novel 3D-printed resin root canal model with a mature E. faecalis biofilm also investigated the antimicrobial effect of EDTA, in a study published in 2023 by Virdee et al. The canals were prepared mechanochemically after the injection of the biofilm. Irrigants that were compared were 17% EDTA and 2% NaOCl. The results were measured with immunofluorescent staining under confocal laser scanning microscopy. In this study model, 17% EDTA was as effective as 2% NaOCl in eradicating the monobacterial *E. faecalis* biofilm(12). Overall it seems that EDTA has an acceptable antimicrobial function as a final irrigating agent.

Influence of EDTA on root dentine

Dentine permeability is a phenomenon of passage through the dentinal tubules. It increases in the apical direction, and is highest at the pulpal ends, where the diameter and density of dentinal tubules is higher and allowing a higher flow rate. Permeability characteristics are tooth and patient-specific, and they also go through variations in aging. This physiological mechanism allows passage also to bacteria and their toxins in an infected root canal. The action of irrigants should be effective enough to clear the dentinal tubules, allowing them to be sealed at the end of the endodontic therapy. Pashley has conducted extensive research on the topic of dentine permeability. In 1990 he with H. M. Fogel conducted a study on human radicular dentine slabs for hydraulic conductance before and after smear layer production with K-files. The presence of the smear layer reduced the permeability by up to 49%. A chelating rinse was able to increase the permeability significantly, whereas a NaOCl rinse had no effect. This early study model was able to prove that the smear layer is a hindrance to passage by blocking the dentinal tubules(13). In a comparative study of different chelating agents, published in 2015 by Jardine et al., the ability of EDTA in smear layer removal and sealer penetrability was compared to QMix, BioPure MTAD, and saline control. The basis of this study is to evaluate the sealer permeability to the dentinal tubules by a confocal laser scanning microscope, after the removal of the smear layer. The amount of smear layer removal was analyzed in SEM. The sealer used in this study was AH Plus. The QMix and EDTA groups presented similar values of sealer penetration and were the best performing in the smear layer removal in the apical root thirds. In the control and BioPure MTAD groups the amount of smear layer removal was lower, which also correlated to lower sealer penetration values(14). It can be concluded that EDTA is effective in the removal of the smear layer and that it directly correlates with an increase in dentine permeability. Its importance clinically cannot be directly extracted from in vitro studies; however, it has been hypothesized that sealer penetration is important in obturating the fine lateral structures that gutta percha is unable to fill.

There is a common consensus that the effect of irrigants in general weakens the root dentine. The chelating action of EDTA is based on the formation of stable complexes with the metallic ions of the hydroxyapatite matrix of root dentine. Therefore, EDTA lowers the mineral content of the dentine, which can change its mechanical properties. More specifically, it can alter the mineral content of root dentin like P, K, Mg, Na, and S. In a study with aim of assessing the effect of several chelating agents on the mineral content of root dentin, the effect of EDTA was assessed as well. EDTA did significantly decrease calcium levels but also other chelating agents under test did (Peracetic acid and citric acid) (15).

In the study by Marending et al. from 2007, the effects of irrigation were studied on three-point bending tests where the modulus of elasticity and flexure strength values were measured. The irrigation protocol was twenty-four minutes of 2.5% NaOCl, with or without 17% EDTA as final rinse for three minutes. The values of flexure strength were significantly lower in the group of NaOCl irrigation, whereas the elastic modulus was not affected. The EDTA rinse did not affect the mechanical characteristics of the dentine bar(16). In a study by Baldasso et al., from 2017, the microhardness reduction was compared between different chelators (17% EDTA, 10% citric acid, 1% peracetic acid) and a NaOCl solution control and negative control with distilled water. In the chelator groups, the rinsing was finished with a NaOCl final flush and distilled water to remove any chemical solution residues. The microhardness was measured with a Knoop indenter. Three measurements were recorded at 100 and 500 microns from the root canal lumen. All the irrigation protocols lowered the microhardness to a significant level at the 100 microns depth. EDTA and QMix were the only irrigants that lowered the microhardness also in the 500 microns measurement point. EDTA in final rinse lowers the microhardness of the root dentine(17). Later, to study the organic dentine composition after irrigation, a study by Retana- Lobo et al., in 2022 used a Raman and energy dispersive x-ray analysis, in addition to SEM studies, and microhardness tests. The irrigation protocols were combinations of NaOCl and EDTA, and EDTA and chlorhexidine, with or without passive ultrasonic irrigation. The irrigation protocols with NaOCl, especially if activated with PUI, had a significantly reduced organic content in the Raman spectra. In the group where no NaOCl was used after EDTA, the organic content did not show a significant reduction when compared to the control group. In the microhardness test the control group had the highest values, whereas the group with the following sequence; NaOCl-EDTA-NaOCl activated with PUI, showed the lowest. The test groups did not have statistical significance amongst themselves. This study suggests that the usage of PUI during the conventional irrigation protocol is detrimental to the microhardness and erosion of the root canal dentine(18). The deleterious effects of irrigation on the mechanical and structural characteristics of the root canal dentine have been proven to be dependent on the usage of NaOCl, and activation of it. EDTA itself has less potentiality to cause excessive degradation of the peritubular or intratubular dentine matrix.

Sealer penetration and adhesion

As mentioned earlier, Chelating solutions have been recommended to enhance chemo-mechanical debridement during root canal treatment by eliminating the smear layer, along with demineralized and softened dentin from the canal walls. This process exposes numerous dentinal tubules, increasing the contact area and improving the adaptation between the sealer and the root canal dentin. In theory, the removal of the smear layer can improve the sealer's adhesion to the dentin(19). This topic was investigated well by Carvalho et al., trying to evaluate the effect of 17% EDTA, 2.25% peracetic acid, or 10% citric acid on the push-out bond strength of calcium silicate-based endodontic sealers (MTA and Total Fill BC Sealer) to root dentine. The result of this research showed that the adherence of sealants to dentin was more related to the type of sealant rather than the type of irrigation used in rinsing, and there was no significant difference between tested irrigation materials(20). The study of Scelza et al., with the same design but with different sealants (AH Plus, Ad Seal, and Real Seal), concluded the same results(21). Another study on extracted human teeth investigating the same topic has indicated that doing the final irrigation with EDTA, MA, and CA after the use of NaOCl has no significant effect on sealer penetration(22).

Administration parameters

Timing

The time necessary for a complete smear layer removal by EDTA has been studied in various in vitro protocols. In the study by Calt and Serper published in 2002 they studied the effect of EDTA irrigation time in an in vitro study model. They used extracted human teeth divided into two equal segments that were then compared to one minute versus 10 minutes of EDTA irrigation. The volume used was 10mL. Before evaluating the dentine specimens, the final rinse was completed with a 5% NaOCl rinse. The data of smear layer removal was collected by scanning electron microscopy. In this study was found that one minute of 17% irrigation was sufficient for smear layer removal while keeping the dentinal tubules intact. Ten-minute irrigation protocol also successfully removed the smear layer but caused excessive peritubular and intertubular dentinal erosion. EDTA contact time of ten minutes was able to erode the openings of the tubules, causing a wormhole like appearance seen on SEM, almost doubling the tubule opening diameters when compared to the group with contact time of one minute. Conclusion from this study is that EDTA irrigation should not be prolonged for more than one minute to avoid the negative side effects on root dentine(23).

In a study by Saito et al, they aimed to determine what was the value below one minute that would be effective in smear layer removal. This study was similarly conducted using extracted human teeth, 17% EDTA, and scanning electron microscopy imaging. The volumes used in the protocol were the following: 1mL of EDTA and 3mL of NaOCl. It was found that a one-minute EDTA irrigation group had a significantly better smear layer removal capacity, when compared to study groups with irrigation times of 30-seconds and 15-seconds(24). In a more recent study model from Singh et al, they also compared EDTA to MTAD, in addition to shortened irrigation times. MTAD is an endodontic irrigant mixture of doxycycline, citric acid, and a detergent, that has been proven to have similar effectiveness in smear layer removal when compared to EDTA(25–27). In this study they confirmed what Calt and Serper had previously found; a one-minute-long irrigation with EDTA was sufficient in smear layer removal. Interestingly, there was no significant difference in the ability of smear layer removal in the 1 minute and 30 seconds irrigation groups in the apical section of the samples. In coronal and middle sections one-minute irrigation time was more effective. Despite the differences in the study protocols mentioned before, mainly regarding the volume of irrigant used, a conclusion can be drawn that prolonged EDTA irrigation is not desired. An excess degradation of the peritubular and intertubular dentine is an adverse outcome and should be avoided, therefore EDTA contact should not be extended over one minute during the final rinse.

Dosage and PH

The volume of EDTA used during irrigation is a key factor to ensure a sufficient contact between the irrigant and the intracanal matter. In 1983 a study was conducted regarding high-volume final rinse by Yamada et al, where they concluded that 10ml of 17% paired with sodium hypochlorite was the most effective in smear layer removal. Using 20ml of 17% EDTA did not improve the results in debris or smear layer removal. In this study, the contact times were also variable(28). On the other end of the spectrum of the volume of EDTA used in the final rinse, Crumpton et al conducted an in vitro study in 2005 where they compared low volumes. Single-rooted extracted human teeth were divided into three test groups, which were irrigated with 1ml, 3ml, or 10ml of 17% EDTA. In this test, the time was constant with one minute for every group. The rinse was concluded with 3ml of 5.25% NaOCl. Under SEM analysis, removal of smear layer and tubule opening did not improve in the volumes greater than 1ml. From the findings of this study, 1ml of 17% EDTA for one minute is sufficient in cleaning the root canal from the smear layer(29). In anothr study by Mello et al., published in 2008, a similar study protocol was used to study the effectiveness of EDTA in smear layer removal in different volumes. Extracted human teeth were divided into three test groups for 5ml, 10ml, or 15ml rinses, and the results were analyzed under SEM. In this study no statistically significant differences were found between the groups when coronal, middle, and apical thirds were compared(30). This supports the findings from Crumpton et al. A study focusing also on the irrigation delivery to the canal in addition to the volume used, was conducted by Mello et al in 2010. In this study 17% EDTA was either used as a continuous rinse for three minutes or by soaking the canal for two minutes and thirty seconds. The volume used in the continuous rinse group was 5ml, whereas the soaking group was 1ml. In SEM analysis was found that the continuous rinse was more effective in smear layer removal than rinse and soaking and the control group. Again, 5ml of 17% EDTA for three minutes was confirmed to be sufficient for an effective smear layer removal in all areas of the root canal walls. From all mentioned in vitro studies, it can be concluded that the volume necessary for an effective smear layer removal by 17% EDTA is 5ml(31).

When EDTA was first introduced into endodontics by Nygaard-Otsby in 1957(32), the recommended formulation was a 15% solution, with a pH of 7.3, formed from disodium salts of EDTA. In the evolution of endodontic chelation this formulation has been modified in concentration, pH, and in mixtures with other substances, such as a detergent. The pH and concentration of EDTA solution have been proven to affect the demineralization of root dentine by Serper and Calt in 2002. In this study, they compared 10% and 17% EDTA at pH 7.0 and 9.0. Another variable was time. In this in vitro model, it was proven that the higher concentration and time of irrigation caused an increase in the liberated phosphorus. On the contrary, a neutral pH solution was more effective than pH 9.0, but the effect of pH is smaller than that of the concentration and time. To avoid excessive erosion, the best solution of EDTA would have a lower concentration with a neutral pH (33). To further investigate the effect of EDTA concentration, an in vitro comparative study was conducted in 2005 by Perez and Rouqueyrol-Pourcel. In this study model(34) they irrigated instrumented root canals with 15% or 8% EDTA, for one or three minutes. The dentine samples were evaluated with scanning electron microscopy for the amount of debris and smear layer. They also individually studied three sections of the root to evaluate differences in chelation between cervical, middle, and apical sections. In general, as proven by previous studies as well, the ability of EDTA to remove debris and smear layer was the most effective in the coronal third. Both debris and smear scores increased in this study in the apical sections regardless of irrigation protocol. A suitable concentration for effective smear layer and debris removal was not concluded in this study, since both 15% and 8% EDTA were able to clean the dentinal tubules effectively. 15% solution reached this result in one minute, whereas the 8% solution reached the goal in three minutes of time. In conclusion, the chelation and cleaning ability of EDTA on dentine seems to be inversely related to the concentration of solution and time of irrigation(34).

Surface tension of EDTA

Surface tension is a key factor influencing the wetting of a solid surface by a liquid. Lowering the surface tension can enhance the contact between irrigants and the dentinal walls of the root canal system. While EDTA naturally has a relatively low surface tension(35), Yılmaz et al., studied the effect of pH and temperature changes on the surface tension of EDTA solutions. At room temperature, the surface tension remained similar at pH 5.5 and 10.5, but was significantly lower at pH 7.5. At 37°C, the surface tension decreased at pH 5.5 and increased notably at pH 7.5 and 10.5. The addition of a surfactant to the EDTA solution significantly reduced the surface tension under both pH and temperature variations(36). Cetrimide (as a bactericidal cationic surfactant used against Gram-positive bacteria) with or without 5% EDTA solution was tested in an in vitro study to investigate the microhardness of human root dentin (the result was not significantly different between test groups). Furthermore, The use of surfactants higher than 0.25% in concentration is questionable for clinical conditions, as shown in Akcay et al., study(37).

Which is better for the final rinse: EDTA or other canal irrigants?

While ago, Ballal et al. compared EDTA with other chelating solutions and found no significant differences between QMix (a mixture of EDTA, chlorhexidine, and a surfactant), 7% maleic acid, and 17% EDTA in removing the smear layer from the coronal and middle thirds, with all solutions revealing open dentinal tubules. However, in the apical third, only 7% maleic acid showed open dentinal tubules(38). These findings cast doubt on the suitability of EDTA for the final rinse. On the other hand, Wu et al. found that 17% EDTA is more effective at removing the smear layer compared to 20% citric acid. MTAD (a combination of 3% doxycycline, 4.25% citric acid, and 0.5% polysorbate 80) did not show any advantage over 20% citric acid. Still, both were more effective than SmearClear (which contains anionic surfactant, cetrimide, and 17% EDTA)(39). MTAD in another study (10) showed significant superior abilities in removing the smear layer, as well as QMix, in comparison to EDTA. Regarding microhardness of dentin, in a study there was a comparison between the ability of 5% carbohydrate derived-fulvic acid (CHD-FA) with 17% EDTA on smear layer removal when used as a final irrigant, and assessing their effect on root dentin microhardness. As a result, surprisingly 5% CHD-FA could be a promising final irrigant for smear

	Smear layer removal	Antimicrobial effect	Clearing dentinal tubules	Sealer penetration and adhesion	Erosion of the dentinal tubules	Cytotoxicity	Effect on decreasing dentin micro hardness
EDTA<18%	✓✓✓	✓✓✓	✓✓✓	✓✓✓	negligible	✓✓	✓✓✓(47)
NaOCl <5.25%	✓	✓✓✓	✓✓	✓✓✓	✓ (48)	✓✓	✓✓✓
Citric acid 10-42%	✓(49)	✓✓✓(50)	✓ (49)	✓✓✓✓	✓✓✓(50)	✓✓✓(50)	✓✓✓(47)
QMix	✓✓✓✓ (10)	✓✓✓(51)	NE	✓✓✓✓(52)	✓	✓(53)	✓✓✓✓(51,54)
maleic acid<8%	✓(55)	✓✓✓(56)	NE	✓✓✓✓	NE	✓(57)	✓✓✓(58)
Peracetic Acid 0.5-1%	✓✓ (59)	✓✓✓(60)	✓✓ (61)	✓✓✓ (62)	negligible(63)	✓✓✓ (64)	✓✓✓✓
Etidronic acid<10%	✓✓ (65,66)	✓✓✓(67,68)	✓✓✓✓ (69)	✓✓	✓(42)	✓✓	✓✓✓✓(42)
MTAD	✓✓✓✓ (10)	✓✓✓	✓✓✓✓	✓✓✓✓ (70,71)	negligible(72)	✓(70,73)	✓✓(74)
CHD-FA 5%	✓✓✓✓(40)	NE	NE	NE	NE	NE	✓✓(40)
H2O2 3%	✓(75)	✓(73)	NE	✓✓	NE	✓✓✓(73)	NE

**NE stands for not enough data available*

Table 1: Comparative Efficacy of Various Agents for Final Rinse.

layer removal with decreased microhardness reduction on root dentin compared to 17% EDTA (significant difference being present)(40). De Deus et al. also have tried to compare peracetic acid solutions and 17% EDTA in smear layer removal. After 1 minute of contact, 0.5% peracetic acid solution dissolved the smear layer without significant differences with 2.25% peracetic acid combined with 17% EDTA(41). Ulusoy investigated the impact of various solutions on nano hardness reduction in root dentin erosion by applying 17% EDTA, 9% etidronic acid (HEBP), and 2% peracetic acid (PAA), both individually and in combination with sodium hypochlorite (NaOCl). The study found that Etidronic acid and the combination of NaOCl with HEBP resulted in a significantly greater reduction in nano hardness than the other solutions. However, there was no significant difference in nano hardness reduction between samples irrigated with a single chelator and those irrigated with a chelator combined with NaOCl(42). A recent review confirms that EDTA is not the unique best option and, a mixture of tetracycline acid and detergent (MTAD) exhibits superior and faster smear layer removal compared to EDTA(43). After all, it is worth mentioning that EDTA is not capable of removing the smear layer completely and never can be used alone in the irrigation process(44,45), So always considered an adjuvant. About the dentinal tubule penetration depth of bioceramic root canal sealers, EDTA is a weaker substance in comparison to 10%citric acid and 7%maleic acid(46). Table 1 presents a detailed comparison of the effectiveness of EDTA alongside other alternatives, providing a comparative analysis of various chemical agents used in endodontics for their effectiveness in smear layer removal, antimicrobial properties, their impact on dentinal tubules and sealer penetration, and other properties. This table highlight the strengths and limitations of each agent, guiding the dentist to choose wisely based on the available evidence.

Complications and side effects associated with EDTA

Cytotoxicity

The biocompatibility of chelating agents and organic acids has been assessed using various methods, with recommendations for their use primarily based on clinical observations and physicochemical properties rather than biological considerations. For example, comparing 17% EDTA, 17% EDTA-T, and 10% citric acid in animal samples in a period revealed that 10% citric acid was a less aggressive tested solution at 14 days, but at 28 days, all solutions were similar(76).

Erosion of the dentinal tubules

It is widely agreed that extending the exposure time of EDTA beyond one minute and using NaOCl at concentrations higher than 2.5%, leads to erosion of the dentinal tubules(38,39,44,45). Additionally, according to the study by AlBatati et al., EDTA 17% induces less erosion of dentinal tubules compared to 40% citric acid or QMix(77).

Clinical Implementations

There is consensus that no single irrigant has been identified that effectively serves as an antimicrobial agent, a tissue dissolvent, and a smear layer demineralizer. Consequently, it is recommended to alternate between organic and inorganic solvents to achieve optimal results(78–81), therefore a final rinse is recommended. Based on the current evidence, until further research, the choice of the substance for the final rinse can be EDTA followed by NaOCL.

Future research directions

Future studies should focus on determining whether the addition of materials such as surfactants to EDTA is beneficial or not. Additionally, further research is necessary to evaluate MTAD and to ascertain whether it can be effectively used as a substitute for EDTA in endodontic treatments. This investigation will help clarify MTAD's advantages and potential risks, ultimately guiding clinical decision-making regarding the optimal final rinse agent.

CONCLUSIONS

Based on the aim of the final rinse, which is to address the limitations of the primary irrigating agent, the final rinse substance does not need to possess all the characteristics of the main irrigating solution. Instead, it suffices for this substance to excel in one or two areas where the primary agent falls short. Currently, NaOCl is widely used as the main irrigation protocol, yet it does not fully address smear layer removal and the thorough cleaning of dentinal tubules. EDTA effectively mitigates these shortcomings with minimal adverse effects, such as dentin erosion and cytotoxicity. However, concerns remain regarding its impact on dentin microhardness, which is not optimal and appears to exceed that of MTAD and CHD-FA. Although existing evidence suggests that EDTA may not be the ideal choice, it is insufficient to dismiss its use entirely. Therefore, further research is needed to definitively determine whether MTAD should be considered the gold standard for final rinses in endodontic procedures.

Author Contributions

Conceptualization, H.H. and C.G.; validation, S.G.; investigation, G.M.; writing—original draft preparation, A.G.; writing—review and editing,; M.V. supervision, S.G. All authors have read and agreed to the published version of the manuscript.

Funding

This research received no external funding.

Institutional Review Board Statement

Not applicable.

Data Availability Statement

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

Conflicts of Interest

The authors declare no conflicts of interest.

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