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Irrigation Solutions and Areas of Use in Endodontic Treatments

Mehmet Kutluhan UCUK[1]
[1]Department of Endodontics, Altinbas University, Istanbul, Turkey, kutluhan.ucuk@altinbas.edu.tr
(https://orcid.org/0000-0001-6719-9286)

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*Corresponding author

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Abstract
Continuous infection and recontamination are very important problems in root canal treatments. For this reason, to complete success, a key goal of root canal treatment is to remove microorganisms and tissue residues from infected root canals. Even though great progress has been made in the analysis of the root canal system, in light of contemporary research as opposed to past studies, indicates that the chemomechanical preparation process is unable to achieve complete cleaning and disinfection of the root canals due to their complex anatomical structure. Irrigation solutions are used in different varieties and for different purposes to dissolve the layer called smear and to reduce the bacterial population in infected root canals. The aim of this review is to summarize the literature information and collective data about irrigation solutions used in endodontic treatments.
Keywords: Endodontics, root canal irrigants, root canal preparation, smear layer

1. Introduction

The aim of endodontic treatment is to thoroughly eliminate vital or necrotic tissues, microorganisms, and their byproducts from the root canal system. Because, to believe to be have a successful root canal treatment is contingent upon the technique and quality of instrumentation, irrigation, sterilization, and 3-dimensional (3D) root canal obturation (Awati et al. 2024). Unique to endodontics is the focus on preventing or eradicating infections within the pulp space and addressing the subsequent inflammatory responses (Trope, M., & Bergenholtz, G. 2002). Destruction of organisms from the root-canal framework and avoidance of recurrent infection indicates the success of endodontic treatment (Haapasalo et al. 2010). It is not always possible to eliminate bacteria that settle in complex places as lateral canals of the root canal only by mechanical preparation. A mixed flora also plays a role in the formation of primary endodontic infections. From previous failed root canal therapies, its remarkable that the common recovered microorganism is E. faecalis (Sundqvist et al.1998). For this reason, this part is really necessary to use root canal irrigation solutions for eliminating bacteria and the root canal system’s disinfection. To achieve successful results during and after treatment, chemomechanical cleaning and irrigation are necessary, along with the elimination of the causes that need treatment. Over many years, research has consistently utilized existing substances to assess their effectiveness. In the future, experimenting with different substances in combination may offer promising results. For instance, a recent study (Ucuk and Ucuncu, 2024) achieved successful outcomes by combining boron with dental composite. Inspired by such research, new substances could be developed from the available irrigation materials.

2. Smear Layer

During the enlargement of the root canal space, organic and inorganic structure consisting of dentin called smear layer of necrosed pulp residues and microorganisms is formed on the canal walls. The endodontic tools create smear layers and smear plugs on the dentinal tubules, whether they are used manually or automatically (Ilhan et al. 2024). The root canal is formed with manual files and rotating devices beneath steady irrigation for evacuating the necrotic and inflamed tissue, microbes, and that type of debris from the root canal area. The main objective of instrumentation is to encourage successful irrigation, sanitization, and filling (Haapasalo et al., 2010). There's no clinical prove that the evacuation of smear layers progresses the clinical treatment result. In any case, evacuation of the smear layer empowers way better cleaning and cleansing of the canal walls and way better adjustment of root filling materials. (Orlowski, N. B., et al. 2020).

3. Features of Ideal Root Canal Irrigants

An ideal irrigation material cannot be mentioned without tissue dissolving properties or microorganism elimination. An ideal irrigation solution must be biocompatible, able to dissolve tissue, eliminate microorganisms present in the root canal, show lubrication properties and also remove the contaminated debris. In all irrigation solutions, the main objective is to obtain an ideally clean root canal for the root canal filling. Because it is broadly perceived that residual contamination in root canals could be a major reason for failure in endodontics (Williams et al.,2006). The root canal instrumentation should be supported by an effective irrigation always. In root canal treatments, alongside mechanical cleaning, root canals are irrigated to achieve biological cleaning. Irrigation is also performed to remove residual materials formed during canal preparation. Nowadays, it is known that the disinfection of root canals through irrigation is gaining much more importance as much as mechanical preparation (Ucuk M.K. 2023).

4. Root Canal Irrigants and Their Usage

Anatomical intricacies of the root canal complex, achieving success in endodontic procedures necessitates both mechanical and chemical preparation strategies to eliminate infected tissue and ensure thorough root canals' disinfection (Barakat et al. 2024).

Sodium Hypochlorite (NaOCl)

Currently, sodium hypochlorite (NaOCl) is favoured as the chemical irrigant of choice, attributed to its wide-ranging antibacterial effectiveness against pathogens implicated in endodontic infections (Barakat et al. 2024). NaOCl is the most popular irrigation solution (Whitten, et al. 1996). It possesses outstanding tissue dissolving capacity in addition to its antibacterial property (Rathi, 2021). NaOCl can work as a fat dissolvable that changes over them into glycerol and fatty acids, hence diminishing the surface pressure of the remaining arrangement (Estrela, C., et al. 2002). Its germicidal efficacy is attributed to the generation of hypochlorous acid upon contact with organic debris (Drews et al. 2023). In today's clinical practice, Dakin's solution has concentration rate 0.5% of sodium hypochlorite (Ueno et al. 2018). In some studies conducted with different concentrations, they did not came across with a difference comparing the concentrations in the disinfection of root canals (Siqueira Jr, J. F., et al., 2000 & Berber, V. B et al., 2006). However, in a study that compared the concentrations of 1%, 2.5%, 4%, 5.25%, and 10% NaOCl. A significant discrepancy was noted between 1% sodium hypochlorite (NaOCl) and all higher concentrations, in addition, no notable difference was found when comparing 2.5% NaOCl with higher concentrations (Li et al. 2022). The determination of the appropriate volume of NaOCl to administer, along with the requisite exposure duration, exchange frequency, and solution concentration, are interrelated factors significantly influenced by the diverse conditions present in the root canal complex. Therefore, the absence of universally agreed-upon guidelines for these parameters is to be expected (Boutsioukis, C., & Arias ‐ Moliz, M. T. 2022). Extrusion or perfusion beyond the apex of the root constitutes the primary scenario, and for an immediate diagnosis, it is crucial to identify the classic triad of sudden pain, copious bleeding within the accessed tooth, and almost instant swelling (Kartit et al. 2024). Moreover, NaOCl significantly reduces number of cycles to fracture (Alfawaz et al. 2022).

Chlor-XTRA

Chlor-XTRA comprises of a detergent and 5.85% NaOCl, which can diminish surface pressure. The color is straightforward pale green-yellow with a chlorine-like odour and is completely solvent in water. It is 2.5 times higher than ordinary NaOCl wetting capacity (Palazzi, F. et al. 2012).

Ethylenediaminetetraacetic Acid (EDTA)

EDTA is commonly used as an abbreviation for Ethylenediaminetetraacetic acid (CH2 (CH2 CO2 H)2)2. It is solid, soluble in water and produced colorless so that it can be used in most applications. Although sodium hypochlorite (NaOCl) is the primary preferred irrigant, lacks the ability to dissolve debris' hard-tissue generated during mechanical preparation or the inorganic part of the smear layer (Boutsioukis, C., & Arias ‐ Moliz, M. T. 2022). The primary indication for the use of EDTA is its chelating effect, essential for the smear layer removal (Haapasolo et al. 2010). EDTA is recommended to be used in concentrations between 15-17% (Hülsmann, M. et al.2003). The primary prescribed EDTA arrangement had a concentration of 15% and a pH of 7.3 (Loel, D. A. 1975). 17% EDTA is the most frequently utilized final irrigant in endodontic treatments (Mollashahi, Saberi & Karkehabadi, 2016). EDTA can be used alongside Ni-Ti instruments during canal instrumentation without adversely affecting the cyclic fatigue resistance (Alfawaz et al. 2022). The arrangement responds the calcium particles within the dentin and shapes dissolvable chelates of calcium. (von der Fehr& Ostby, 1963). Besides EDTA, there are also more variants known such as REDTA, which is EDTA buffered with sodium hydroxide in an aqueous carrier, 1% solution of cyclohexane-1,2-diaminetetraacetic acid (CDTA), ethylene glycol-bis(ß-aminoethyl ether)-N,N,N',N'-tetraacetic acid (EGTA), and solutions of diethylenetriamine pentaacetic acid known as EDTAC and DTPAC (Onay et al. 2013).In a study that compared EDTA and Citric acid, EDTA demonstrated significantly enhanced effectiveness in augmenting root dentin thickness in comparison to citric acid. (Farhad, Saatchi, & Bagherieh, 2022). Certain available formulations include a chelating agent, an antimicrobial, and also one or more surfactants. Although these kinds of mixtures are predominantly suggested for a last irrigation at the finishing of root canal preparation, replacing EDTA for eliminating the smear layer, also to enhance the antimicrobial effect of NaOCl, existing evidence indicates that they offer no definitive benefit over the combined application of EDTA and NaOCl following instrumentation (Boutsioukis, C., & Arias ‐ Moliz, M. T. 2022).

Chlorhexidine (CHX)

Chlorhexidine digluconate (CHX), the gluconate salt of chlorhexidine, is a biguanide compound used for its antiseptic properties and topical antibacterial action. Being positively charged, chlorhexidine digluconate interacts with the negative-charged surface of microbial cells, compromising the cell membrane's integrity (Drews et al. 2023). CHX, by absorbing into the cell wall of microorganisms, disrupts the cytoplasmic membrane whole and causes the size of intracellular components (Gomes, B. P. F. A et al., 2003). In a study it is found that CHX has shown similar toxicity as NaOCl to stem cells (Scott II et al. 2018).

Interactions Between NaOCl-CHX and EDTA-CHX

Due to their unique complementary characteristics, CHX and NaOCl are occasionally used for irrigation within the same tooth (Bueso et al. 2022). The majority of irrigants in use today are active chemical solutions, with directly get interaction between biofilm forming the basis of their antimicrobial efficacy. Nonetheless, these irrigants also engage in reactions with a range of other substrates within the root canal complex, such as dentine (Boutsioukis, C., & Arias ‐ Moliz, M. T. 2022). During irrigation, multiple cleaning agents may be utilized. Attention must be paid to the interaction between these substances. The combination of EDTA and CHX results in the formation of a white salt precipitate while between sodium hypochlorite and CHX results in the formation of PCA (para-chloroaniline), a red-colored toxic precipitate, (Ucuk M.K. 2023) which may impede the root canal obturation process (Bueso et al 2022). The combination of EDTA and CHX results in a white precipitate, with over 90% of the precipitate's mass being comprised of either EDTA or CHX. Efforts to prevent or dissolve the precipitate created by the interaction between chlorhexidine and hypochlorite have led to investigations for a suitable solvent. Measures to circumvent or lessen the formation of this precipitate include the utilization of irrigation with increased volumes of saline and distilled water to dilute NaOCl, as well as having absolute alcohol for irrigation prior to the application of CHX (Bernardi and Teixeria, 2015).

Bis-dequalinyum Asetat (BDA)

It is a chelating agent containing aminoquinolinedium diacetate. Its most significant properties are chelation, removal of organic debris, and bactericidal activity. Studies have specifically found it to effectively remove smear layer, especially at the apical 1/3 of the root tip. BDA is remarkably well accepted by periodontal tissues and features a low surface tension, thereby facilitating a high penetration capability. Its toxicity is lower than that of sodium hypochlorite (Napte, B., & Srinidhi, S. 2015).

Citric Acid (CA)

Citric acid, a mild organic acid, possesses the ability to remove calcium ions from dentin (Haznedaroğlu, F. 2003). In a research (Farhad, Saatchi, & Bagherieh 2022), investigators evaluated the impact of citric acid and EDTA on radiographic root development within the context of regenerative endodontic procedures using an animal model. The findings indicated no substantial variance in root length augmentation between the two irrigation solutions. Despite its enhanced antimicrobial efficacy relative to 17% EDTA, it exhibits inadequate chemical stability (Kaushik et al. 2013). The chelating capacity of citric acid is believed to facilitate the efficient elimination of the smear layer in root canals(Arslan et al. 2014).

Chlorine Dioxide (ClO2)

This substance, chemically similar to sodium hypochlorite, and used for whitening purposes in homes by patients (Topbas, C., & Adiguzel, O. 2017). In a study, it is found that ClO2 and NaOCl are equally efficient for dissolving organic tissue (Cobankara, and Terlemez, A. 2010).

Electrochemically Activated Water (ECA,Superoxidized Water)

ECA has been used in various synonyms such as super-oxidised water, electrolysed water (Al-Haq, M. I., et al., 2005). ECA solution is obtained by tap water and salt solution with a low concentration. ECA has been produced in 2 types of solutions, anolyte and catholyte. High oxidation potential and antimicrobial property is in Anolyte. On the other hand, catholyte, is a high reduction potential-had alkaline solution. It is based on the guideline of "Flow–through Electrolytic Module or FEM which suggests exchanging fluid into a metastable state by means of anode and cathode through the utilize of an component (Solovyeva & Dummer, 2000).

Glycolic Acid (GA)

The chemical composition of glycolic acid (GA) is C2H4O3; its application for the eradication of gram-negative and gram-positive bacteria. In the realm of aesthetic medicine, where GA is extensively used, proposes its use as an alternative irrigant. Following the application of NaOCl, glycolic acid exhibits the highest capacity for microbial reduction among the final irrigants, irrespective of the concentration used (Gambin et al. 2020).

Herbal alternatives (Triphala, Green Tea Polyphenols (GTP), Morinda Citrifolia (MC)

Over the years, numerous synthetic antibacterial substances have been utilized as endodontic irrigation solutions. Herbal products have emerged as a popular alternative in dental and medical applications due to their potent antimicrobial, biocompatible, anti-inflammatory, and antioxidant properties. In dentistry, these herbal preparations serve various roles, including as anti-inflammatory, antibiotic, analgesic, and sedative agents, as well as endodontic irrigants (Canavar et al. 2020).

Triphala

Tannic acid, a key component in Triphala, has a long history of use in Indian medicine for treating various diseases. Triphala is recognized as non-toxic and is attributed with additional anti-inflammatory and antioxidant properties

(Alghamdi et al. 2024). Triphala successfully eliminated 100% of E. faecalis in just 6 minutes, a testament to its efficacy that can be traced back to its unique formulation comprising three distinct medicinal plants in equal ratios: Terminalia bellerica, Terminalia chebula, and Emblica officinalis. Triphala includes fruits high in citric acid, potentially assisting in the removal of the smear layer (Agrawal Vineet et al. 2014).

Green tea

Tea is abundant in polyphenols, known for their antifungal, antibacterial, and antioxidant activities. In addition to their suppressive impact on specific oral pathogenic microorganisms and oral bacteria such as S. mutans. Predominantly, green tea, which is an unfermented product, is composed of a diverse array of catechins (Kharouf et al. 2020). In a study it was discovered that Green tea extract (Camellia Sinensis L) effectively inhibits the growth of E. faecalis. At a concentration of 75%, green tea extract exhibited the largest inhibitory zone in hindering the growth of Enterococcus faecalis (Asmah et al. 2023).

Morinda citrifolia (MC)

MC showcases a broad spectrum of therapeutic effects, including antibacterial, antiviral, antifungal, antitumor, antihelminthic, analgesic, hypotensive, anti-inflammatory, and immune-boosting properties. Among its constituents are L-asperuloside and alizarin, compounds recognized for their antibacterial efficacy. In a study, researchers assessed the efficacy of MC concentrated 6% and also NaOCl with 6% concentration, irrigation solutions in removal of smear layer. Following the use of both solutions, 17% EDTA was used as a final irrigant. The study found that both solutions demonstrated comparable capabilities in removing the smear layer (Murray et al. 2008). MTAD, triphala and green tea polyphenols demonstrated statistically higher antibacterial effects. Applying herbal alternatives as root canal irrigants could offer benefits, especially in light of the various unfavourable properties of NaOCl (Prabhakar et al. 2010).

Hydroxyethylidene bisphosphonate (HEBP), etidronic acid

HEBP (called 1-hydroxyethydylene-1, 1-bisphosphonate etidronic acid) is a chelator that can be used as a compound with NaOCI, apart from its effects that provide proteolytic and antimicrobial properties (Zehnder, M. 2006). A soft chelating irrigation protocol can be used.

HEBP has been suggested as a viable substitute for EDTA or the citric acid, owing to its chelating capacity as a final rinse. This approach is considered promising due to its minimal impact on the root canal-dentins mineral content. Nevertheless, the effect of HEBP on the microhardness of root dentin has yet to be evaluated in existing literature (Dineshkumar et al. 2012).

Hydrogen peroxide

Concentrations of hydrogen peroxide of 3% and 5% have long been used as an endodontic solution. It is active against bacteria, viruses and yeasts. The antibacterial mechanism of hydrogen peroxide (HP) involves the action of hydroxyl radicals. As a powerful oxidant, the hydroxyl radical can readily interact with macromolecules, including membrane lipids and DNA, thereby leading to bacterial cell death (Shahriari et al. 2010). The tissue dissolving capacity is clearly worse than the NAOCI. At the same time, its antibacterial effect is weak. When used in combination with NaOCI, foaming occurs because of the evaporation of oxygen that causes post-op pain. In a study, it is found that Sodium Hypochlorite proved to be significantly more effective than Hydrogen Peroxide in managing endodontic pain (Noor et al. 2022).

Iodine- potassium iodide (IPI)

The solution contains 2% iodine and 4% potassium iodide. The use of IPI is potentially risky due to allergic reactions to iodine and dentin staining. However, the harmful effects that occur as a result of IPI use are also quite rare in endodontics (Popescu et al., 1984). In a recent study (Alghamdi et al. 2024), it is found that another Iodine containing solution called povidone-Iodine, emerges as the most suitable alternative following the supremely effective sodium hypochlorite (NaOCl).

Maleic acid (MA)

It expels the smear layer successfully at of 5% and 7% concentration. In expansion, when utilized at of 10% concentration or higher, it provokes demineralization and disintegration of the space of root canal. MA could be a mellow natural corrosive utilized to roughen finish and dentin surfaces in cement dentistry. (Ballal et al., 2009).

MTAD

MTAD consists of a Tetracycline isomer, acetic acid and a deterrent encounter. This solution contains doxycycline with 3%, citric acid with 4.25% and 0.5% of Polysorbate 80, which is a detergent. In 2003, MTAD was first used (Torabinejad, M. et al. 2003).

Photoactivity disinfection (PAD)

PAD is an alternative, less toxic technology to chemical disinfection. In this method, a photosensitized dye and a specific wavelength of light are used together. This combination destroys the high bacterial population in planktonic suspension, collagen and infected dentin (Williams et al. 2006). PAD has been suggested as a supplementary approach to traditional endodontic treatment. Light of a specific wavelength activates a photosensitizing molecule that is bound to the bacterial/fungal membrane, which in turn leads to the generation of highly reactive oxygen species capable of destroying microorganisms (Schlafer et al. 2010). There are two molecular pathways included in photo-activated sanitization. (Ochsner, M. 1997). Within the to begin with pathway, irradiation of the photosensitizer molecule energizes this to a high vitality state, the tripletstate, where it exchanges energy to molecules other than oxygen. Second pathway, the photosensitizer molecule within the triplet state transfers energy to oxygen particles, creating singlet oxygen. This could quickly oxidize proteins, nucleic acids and lipids, causing harm to the microbial cell layers and to the nucleus and mitochondria (Girotti, A. W. 1990). The conclusion result of both pathways is inactivation and devastation of microorganisms. Many research facility considers have utilized planktonic microscopic organisms, or biofilms comprised of a single bacterial species as the challenge. There's as of now a restricted body of work from polymicrobial considers, counting research facility studies as well as clinical investigate (Sin, J. et al. 2021).

Silver Diamine Fluoride (SDF)

SDF with a 3.8% w/v solution (Ag (NH3)2F) has been formulated for use in intracanal irrigation, representing a 1:10 dilution of the initially used 38% Ag (NH3)2F solution for treatment of root canal infections (Agrawal Vineet et al. 2014).

Tetraclean

Tetraclean is mixture of 50 mg/ml doxycycline, acid, and polypropylene glycol (Giardino et al. 2006). The difference from MTAD is the concentration of antibiotics and the type of detergent. it contains 50 mg/ml of doxycycline and polypropylene glycol. Tetraclean exhibits significant efficacy against anaerobic and facultative anaerobic microorganisms. In comparison to MTAD, Tetraclean demonstrates greater effectiveness against planktonic cultures of E. faecalis and in vitro biofilms consisting of diverse species (Pappen et al. 2010).

Triclosan and gantrez

Triclosan acts as a broad-spectrum antimicrobial substance, showing efficacy against gram-negative and gram-positive bacteria, in addition to various fungi and viruses (Agrawal Vineet et al. 2014).

Ozonated water

Indeed at a concentration with 0.01 ppm, ozone (O3) can viably eliminate microbes, counting spores (Broadwater, W. T. et al., 1973). Ozone is a powerful antibacterial agent. In vivo studies, it has been estimated that it effectively disinfects the dentin tubules of bovine teeth. More studies are needed on the use of ozonated water as a root canal irrigant (Nagayoshi, M. et al. 2004).

QMIX

QMIX consists of CHX, EDTA and a detergent. QMIX is used as the final washing solution. In order to protection from the formation of PCA, physiological serum should be used for NaOCI rinsing. The effect of QMIX and 2% NaOCI on bacteria in biofilm is more effective than 1% NaOCI or 2% CHX. (Stojicic et al. 2012).

5. Conclusion

Considering the main purpose of endodontic treatment, the goal we will achieve is to make an effective cleaning and shaping. In addition, removing microorganisms from the root canal system is a result of effective irrigation and medication application. Today, many types of irrigation solutions, technological systems and devices are being used. Numerous studies have been conducted on this topic, and there is no 100% biocompatible or 100% effective for all microorganisms and that 100% dissolves both soft and hard tissue that can disinfect the entire root canal. What the clinician can do at this point is to establish a balance and use the most appropriate materials in root canal treatments in line with the goal and result. In order to develop solutions and techniques that will provide complete sterilization of root canals, it is necessary to review the existing literature and plan new studies.

CONFLICT OF INTEREST

Author declares no conflict of interests. There is no conflict of interest between the authors. In addition, no support or funding was received in this study.

References

Agrawal Vineet, S., Rajesh, M., Sonali, K., & Mukesh, P. (2014). A contemporary overview of endodontic irrigants–A review. J Dent App, 1(6), 105-15.

Alfawaz, H., Alqedairi, A., Alhamdan, M., Alkhzim, N., Alfarraj, S., & Jamleh, A. (2022). Effect of NaOCl and EDTA irrigating solutions on the cyclic fatigue resistance of EdgeTaper Platinum instruments. BMC Oral Health, 22(1), 1-6.

Alghamdi, N., Das, B., Hugar, S. I., Sarangi, P., Garg, G., Subramani, S. K., & Alghamdi Jr, N. (2024). Comparing the Biofilm Removal Capacity of NaOCl, Povidone-Iodine, Chlorhexidine, Curcumin, and Triphala as Endodontic Irrigants. Cureus, 16(1).

Al-Haq, M. I., Sugiyama, J., & Isobe, S. (2005). Applications of electrolyzed water in agriculture & food industries. Food Science and Technology Research, 11(2), 135-150.

Asmah, N., Mattulada, I. K., & Dodo, A. Z. A. (2023). Antibacterial Assay of Green Tea (Camellia Sinensis L) Against the Growth of Enterococcus faecalis. Journal of Syiah Kuala Dentistry Society, 8(2), 211-216.

Arslan, H., Barutcigil, C., Karatas, E., Topcuoglu, H. S., Yeter, K. Y., Ersoy, I., & Ayrancı, L. B. (2014). Effect of citric acid irrigation on the fracture resistance of endodontically treated roots. European journal of dentistry, 8(01), 074-078.

Awati, A. S., Dhaded, N. S., Mokal, S., & Doddwad, P. K. (2024). Analysis of the depth of penetration of an epoxy resin-based sealer following a final rinse of irrigants and use of activation systems: An in vitro study. Journal of Conservative Dentistry and Endodontics, 27(1), 87-94.

Ballal, N. V., Kandian, S., Mala, K., Bhat, K. S., & Acharya, S. (2009). Comparison of the efficacy of maleic acid and ethylenediaminetetraacetic acid in smear layer removal from instrumented human root canal: a scanning electron microscopic study. Journal of endodontics, 35(11), 1573-1576.

Barakat, R. M., Almohareb, R. A., Alsuwaidan, M., Faqehi, E., Alaidarous, E., & Algahtani, F. N. (2024). Effect of sodium hypochlorite temperature and concentration on the fracture resistance of root dentin. BMC Oral Health, 24(1), 1-6.

Berber, V. B., Gomes, B. P. F. A., Sena, N. T., Vianna, M. E., Ferraz, C. C. R., Zaia, A. A., & Souza-Filho, F. J. (2006). Efficacy of various concentrations of NaOCl and instrumentation techniques in reducing Enterococcus faecalis within root canals and dentinal tubules. International endodontic journal, 39(1), 10-17.

Bernardi, A., & Teixeira, C. S. (2015). The properties of chlorhexidine and undesired effects of its use in endodontics. Quintessence international, 46(7).

Broadwater, W. T., Hoehn, R. C., & King, P. H. (1973). Sensitivity of three selected bacterial species to ozone. Applied Microbiology, 26(3), 391-393.

Boutsioukis, C., & Arias-Moliz, M. T. (2022). Present status and future directions–irrigants and irrigation methods. International Endodontic Journal, 55, 588-612.

Bueso, V., Parikh, N., Terlier, T., Holland, J. N., Sarmast, N. D., & Jeong, J. W. (2022). Comparative evaluation of intermediate solutions in prevention of brown precipitate formed from sodium hypochlorite and chlorhexidine gluconate. Clinical and Experimental Dental Research, 8(6), 1591-1597.

Canavar, T., İrem, E. R. E. N., & Bayram, M. (2020). Endodontide İrrigasyon Solüsyonu Olarak Kullanilan Bitkisel Alternatifler. Dental and Medical Journal-Review, 2(3), 156-173.

Cobankara, F. K., Ozkan, H. B., & Terlemez, A. (2010). Comparison of organic tissue dissolution capacities of sodium hypochlorite and chlorine dioxide. Journal of endodontics, 36(2), 272-274.

Dineshkumar, M. K., Vinothkumar, T. S., Arathi, G., Shanthisree, P., & Kandaswamy, D. (2012). Effect of ethylene diamine tetra-acetic acid, MTAD™, and HEBP as a final rinse on the microhardness of root dentin. Journal of conservative dentistry: JCD, 15(2), 170.

Drews, D. J., Nguyen, A. D., Diederich, A., & Gernhardt, C. R. (2023). The Interaction of Two Widely Used Endodontic Irrigants, Chlorhexidine and Sodium Hypochlorite, and Its Impact on the Disinfection Protocol during Root Canal Treatment. Antibiotics, 12(3), 589.

Estrela, C., Estrela, C. R., Barbin, E. L., Spanó, J. C. E., Marchesan, M. A., & Pécora, J. D. (2002). Mechanism of action of sodium hypochlorite. Brazilian dental journal, 13, 113-117.

Farhad, A., Saatchi, M., & Bagherieh, S. (2022). Effect of citric acid versus EDTA on radiographic root development in regenerative endodontic treatment: An animal study. Journal of Endodontics, 48(4), 535-541.

Gambin, D. J., Leal, L. O., Farina, A. P., Souza, M. A., & Cecchin, D. (2020). Antimicrobial activity of glycolic acid as a final irrigant solution for root canal preparation. Gen Dent, 68(1), 41-4.

Giardino, L., Ambu, E., Becce, C., Rimondini, L., & Morra, M. (2006). Surface tension comparison of four common root canal irrigants and two new irrigants containing antibiotic. Journal of endodontics, 32(11), 1091-1093.

Girotti, A. W. (1990). Photodynamic lipid peroxidation in biological systems. Photochemistry and photobiology, 51(4), 497-509.

Gomes, B. P. F. A., Souza, S. F. C., Ferraz, C. C. R., Teixeira, F. B., Zaia, A. A., Valdrighi, L., & Souza-Filho, F. J. (2003). Effectiveness of 2% chlorhexidine gel and calcium hydroxide against Enterococcus faecalis in bovine root dentine in vitro. International endodontic journal, 36(4).

Haapasalo, M., Shen, Y., Qian, W., & Gao, Y. (2010). Irrigation in endodontics. Dental Clinics, 54(2), 291-312.

Haznedaroğlu, F. (2003). Efficacy of various concentrations of citric acid at different pH values for smear layer removal. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology, 96(3), 340-344.

Hülsmann, M., Heckendorff, M., & Lennon, A. (2003). Chelating agents in root canal treatment: mode of action and indications for their use. International endodontic journal, 36(12), 810-830.

Ilhan, H., Cakici, E. B., & Cakici, F. (2024). The comparative of chitosan and chitosan nanoparticle versus ethylenediaminetetraacetic acid on the smear layer removal: A systematic review and meta-analysis of in vitro study. Microscopy Research and Technique, 87(2), 181-190.

Kartit, Z., Delacroix, C., Clement, C., Beurrier, M., Mouton-Faivre, C., & Petitpain, N. (2024). Sodium hypochlorite accident diagnosis and management: Analysis from the literature and the French pharmacovigilance database. Fundamental & Clinical Pharmacology.

Kaushik, N., Rehani, U., Agarwal, A., Kaushik, M., & Adlakha, V. (2013). Antimicrobial efficacy of endodontic irrigants against Enterococcus faecalis and Escherichia coli: an in vitro study. International journal of clinical pediatric dentistry, 6(3), 178.

Kharouf, N., Haikel, Y., & Ball, V. (2020). Polyphenols in dental applications. Bioengineering, 7(3), 72.

Li, A. L. B., Markvart, M., & Abbott, P. V. (2022). Effect of different concentrations of sodium hypochlorite on the compressive strength of endodontically treated roots. Journal of Endodontics, 48(3), 370-374.

Loel, D. A. (1975). Use of acid cleanser in endodontic therapy. The Journal of the American Dental Association, 90(1), 148-151.

Mollashahi, N. F., Saberi, E., & Karkehabadi, H. (2016). Evaluation of cytotoxic effects of various endodontic irrigation solutions on the survival of stem cell of human apical papilla. Iranian endodontic journal, 11(4), 293.

Murray, P. E., Farber, R. M., Namerow, K. N., Kuttler, S., & Garcia-Godoy, F. (2008). Evaluation of Morinda citrifolia as an endodontic irrigant. Journal of endodontics, 34(1), 66-70.

Napte, B., & Srinidhi, S. (2015). Endodontic irrigants. Journal of Dental & Allied Sciences, 4(1).

Nagayoshi, M., Kitamura, C., Fukuizumi, T., Nishihara, T., & Terashita, M. (2004). Antimicrobial effect of ozonated water on bacteria invading dentinal tubules. Journal of endodontics, 30(11), 778-781.

Noor, N., Mujtaba, H., Humayoun, S., Umer, M. F., Javaid, M. M., & Rehman, A. (2022). Comparison of Endodontic Pain observed with Sodium Hypochloride, Hydrogen peroxide and Norman Saline based Root canal irrigants. Annals of PIMS-Shaheed Zulfiqar Ali Bhutto Medical University, 18(1), 3-8.

Ochsner, M. (1997). Photophysical and photobiological processes in the photodynamic therapy of tumours. Journal of Photochemistry and Photobiology B: Biology, 39(1), 1-18.

Orlowski, N. B., Schimdt, T. F., da Silveira Teixeira, C., Garcia, L. D. F. R., Savaris, J. M., Tay, F. R., & Bortoluzzi, E. A. (2020). Smear layer removal using passive ultrasonic irrigation and different concentrations of sodium hypochlorite. Journal of endodontics, 46(11), 1738-1744.

Önay, E. O., Ezgi, K. U. R. T., Kızılırmak, İ., Nuyan, D., Güran, Ç., & Erdoğa , T. (2013). Kök Kanal İrrigasyonunda Geleneksel ve Güncel Yaklaşımlar. ADO Klinik Bilimler Dergisi, 7(2), 1459-1468.

Palazzi, F., Morra, M., Mohammadi, Z., Grandini, S., & Giardino, L. (2012). Comparison of the surface tension of 5.25% sodium hypochlorite solution with three new sodium hypochlorite-based endodontic irrigants. International endodontic journal, 45(2), 129-135.

Pappen, F. G., Shen, Y., Qian, W., Leonardo, M. R., Giardino, L., & Haapasalo, M. (2010). In vitro antibacterial action of Tetraclean, MTAD and five experimental irrigation solutions. International endodontic journal, 43(6), 528-535.

Popescu, I. G., Popescu, M., Man, D., Ciolacu, S., Georgescu, M., Ciurea, T., ... & Ulmeanu, V. (1984). Drug allergy: incidence in terms of age and some drug allergens. Medecine interne, 22(3), 195-202.

Prabhakar, J., Senthilkumar, M., Priya, M. S., Mahalakshmi, K., Sehgal, P. K., & Sukumaran, V. G. (2010). Evaluation of antimicrobial efficacy of herbal alternatives (Triphala and green tea polyphenols), MTAD, and 5% sodium hypochlorite against Enterococcus faecalis biofilm formed on tooth substrate: an in vitro study. Journal of endodontics, 36(1), 83-86.

Rathi, S., Nikhade, P., Chandak, M., Ikhar, A., Motwani, N., Deshpande, M., & Chandak, M. (2021). Heat treatment of Sodium Hypochlorite: A Comprehensive Review. Indian Journal of Forensic Medicine & Toxicology, 15(2).

Shahriari, S., Mohammadi, Z., Mokhtari, M. M., & Yousefi, R. (2010). Effect of hydrogen peroxide on the antibacterial substantivity of chlorhexidine. International journal of dentistry, 2010.

Schlafer, S., Vaeth, M., Hørsted-Bindslev, P., & Frandsen, E. V. (2010). Endodontic photoactivated disinfection using a conventional light source: an in vitro and ex vivo study. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology, 109(4), 634-641.

Sin, J. H. M., Walsh, L. J., Figueredo, C. M., & George, R. (2021). Evaluation of effectiveness of photosensitizers used in laser endodontics disinfection: A systematic review. Translational Biophotonics, 3(1), e202000007.

Siqueira Jr, J. F., Rôças, I. N., Favieri, A., & Lima, K. C. (2000). Chemomechanical reduction of the bacterial population in the root canal after instrumentation and irrigation with 1%, 2.5%, and 5.25% sodium hypochlorite. Journal of endodontics, 26(6), 331-334.

Scott II, M. B., Zilinski, G. S., Kirkpatrick, T. C., Himel, V. T., Sabey, K. A., & Lallier, T. E. (2018). The effects of irrigants on the survival of human stem cells of the apical papilla, including endocyn. Journal of Endodontics, 44(2), 263-268.

Solovyeva, A. M., & Dummer, P. M. H. (2000). Cleaning effectiveness of root canal irrigation with electrochemically activated anolyte and catholyte solutions: a pilot study. International Endodontic Journal, 33(6), 494-504.

Stojicic, S., Shen, Y., Qian, W., Johnson, B., & Haapasalo, M. (2012). Antibacterial and smear layer removal ability of a novel irrigant, QMIX. International endodontic journal, 45(4), 363-371.

Sundqvist, G., Figdor, D., Persson, S., & Sjögren, U. (1998). Microbiologic analysis of teeth with failed endodontic treatment and the outcome of conservative re-treatment. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology, 85(1), 86-93.

Topbas, C., & Adiguzel, O. (2017). Endodontic irrigation solutions: A review: Endodontic irrigation solutions. International Dental Research, 7(3), 54-61.

Torabinejad, M., Khademi, A. A., Babagoli, J., Cho, Y., Johnson, W. B., Bozhilov, K., ... & Shabahang, S. (2003). A new solution for the removal of the smear layer. Journal of endodontics, 29(3), 170-175.

Trope, M., & Bergenholtz, G. (2002). Microbiological basis for endodontic treatment: can a maximal outcome be achieved in one visit?. Endodontic Topics, 1(1), 40-53.

Ueno, C. M., Mullens, C. L., Luh, J. H., & Wooden, W. A. (2018). Historical review of Dakin's solution applications. Journal of Plastic, Reconstructive & Aesthetic Surgery, 71(9), e49-e55.

Ucuk, M. K., & Ucuncu, M. K. (2024). The impact of incorporating five different boron materials into a dental composite on its mechanical properties. Applied Sciences, 14(3), 1054.

UCUK, M. K. (2023). Assesment of endodontic treatment administering dentists' views on their professional experience, complications and malpractise: a survey study (Doctoral dissertation).

von der Fehr, F. R., & Östby, B. N. (1963). Effect of EDTAC and sulfuric acid on root canal dentine. Oral Surgery, Oral Medicine, Oral Pathology, 16(2), 199-205.

Whitten, B. H., Gardiner, D. L., Jeansonne, B. G., & Lemon, R. R. (1996). Current trends in endodontic treatment: report of a national survey. The Journal of the American Dental Association, 127(9), 1333-1341.

Williams, J. A., Pearson, G. J., & Colles, M. J. (2006). Antibacterial action of photoactivated disinfection {PAD} used on endodontic bacteria in planktonic suspension and in artificial and human root canals. Journal of dentistry, 34(6), 363-371.

Zehnder, M. (2006). Root canal irrigants. Journal of endodontics, 32(5), 389-398.

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