Abstract
Microorganisms and their by-products play a critical role in pulp and periradicular pathosis. Therefore, one of the main purposes of root canal treatment is disinfection of the entire system of the canal. This aim may be obtained using mechanical preparation, chemical irrigation, and temporary medication of the canal. For this purpose, various irrigation solutions have been advocated. Common root canal irrigants, such as sodium hypochlorite, chlorhexidine, and a mixture of tetracycline, acid, and detergent have been extensively reviewed. The aim of this review was to address the less common newer root canal irrigation solutions, such as citric acid, maleic acid, electrochemically activated water, green tea, ozonated water, and SmearClear.

Keywords: Citric acid, Electrochemically activated solutions, Green tea, Maleic acid, Ozonated water, Root canal irrigants, SmearClear.


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Introduction
The important role of microorganisms in the pathogenesis of pulpo-periapical lesions has been proved. Decrease in amount of microorganisms inside the infected canal needs usage of the various instrumentation techniques, irrigation solutions, and intracanal temporary medicaments. Mechanical preparation of the canal alone cannot induce a bacteria-free canal, especially in cases with complex anatomy. On the contrary, ex vivo and clinical documents have indicated that mechanical preparation of the canal leaves large portions of the canal walls undebrided and complete removal of the bacteria by this mechanical procedure alone is unlikely to be seen. Therefore, some form of disinfection/irrigation is mandatory to kill the microorganisms and to remove the residual tissues. Common root canal irrigants, such as sodium hypochlorite (NaOCl), chlorhexidine (CHX), and mixture of tetracycline, acid, and detergent have been extensively reviewed. The aim of this review was to address less common newer root canal irrigation solutions.

Citric Acid
Structure and Characteristics
Citric acid is a weak organic acid with the appearance of white crystalline powder at room temperature. It can exist either in water-free form (anhydrous) or monohydrate form. The water-free form crystallizes from the hot water, whereas the monohydrate forms from the cold water. The latter may be converted to anhydrous form by heating more than 78°C.

Antimicrobial Activity
Yamaguchi et al showed that citric acid solution had antibacterial effects on all 12 root canal bacteria tested. Arias-Moliz et al evaluated the minimal bactericidal concentration (MBC) for Enterococcus faecalis. They showed that MBCs of citric acid and phosphoric acid were 20 and 2.5% respectively. They also showed that ethylenediaminetetraacetic acid (EDTA) has no bactericidal activity, even after 1 hour contact.
Smear Layer Removal

This acid has the ability of root canal irrigation and also smear layer removal. Different concentrations (1–50%) have been proposed. Gutmann et al concluded that 10% citric acid is better than ultrasound for smear layer removal from the root end cavities. Yamaguchi et al also assessed the chelating property of citric acid and EDTA and showed that powdered resin-dentin combination is more soluble in 0.5 to 2 M citric acid than in 0.5 M EDTA. Liolios et al showed that commercial EDTA is better than 50% citric acid for smear layer removal. In other studies, Di Lenarda et al and Scelza et al showed minor difference in the ability of smear layer removal with 15% EDTA and citric acid. In a recent study, Machado-Silveiro et al showed that 10% citric acid is more effective than 1% citric acid, which is more effective than EDTA in dentine demineralization. Takeda et al also concluded that irrigation with 6% phosphoric acid, 6% citric acid, and 17% EDTA cannot remove the whole smear layer from the canal walls. According to Reis et al, citric acid solutions removed the smear layer after 60 seconds of application.

Toxicity

Using the 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide assay (MTA), Prado et al revealed that 10% citric acid showed higher cell viability compared with other tested irrigation solutions. Marins et al assessed the capacity of some root canal irrigants to induce genetic damage and/or cellular death in marine fibroblasts in vitro. According to their findings, NaOCl, citric acid, and EDTA show dose-dependent cytotoxicity with no genotoxicity. Kang et al studied the biocompatibility property of MTA mixed with hydration accelerators, such as citric acid, calcium chloride, and calcium lactate gluconate. They showed that MTA mixed with 0.1 wt% citric acid shows the best results.

Effect on Fracture Resistance

Arslan et al evaluated the effect of citric acid on root fracture. According to their findings, using 50% citric acid for 10 minutes and 10% citric acid for 1 minute demonstrated highest and lowest fracture resistance respectively.

Effect on Calcium Hydroxide (Ca(OH)₂) Removal

Arslan et al showed that 10% citric acid is more effective for removal of Ca(OH)₂ combined with 2% CHX from the root canal than those of 17% EDTA and 1% NaOCl.

MALEIC ACID

Structure

Maleic acid (MA; C₃H₂O₄) is an organic composition; its nature is a dicarboxylic acid.
that there is no significant difference between EDTA and MA regarding the reduction of microhardness. The increase in roughness was greater with MA comparing EDTA. Kara Tuncer et al.\textsuperscript{41} revealed that MA produced the greatest reduction in dentin microhardness.

**Tissue Solubility**

Ballal et al.\textsuperscript{32} showed that 2.5% NaOCl dissolved the pulp tissue significantly more than 17% EDTA and 7% MA; however, there was no significant difference between 17% EDTA and 7% MA.

**ELECTROCHEMICALLY ACTIVATED SOLUTIONS**

Electrochemically activated (ECA) water is produced from tap water and low-concentrated salt solutions. Two kinds of ECA can be produced from the tap water and a saline solution by using a flow-through electrolytic module. The first is an antimicrobial anolyte with pH ranging between 2 and 9, and the latter is a catholyte can act as an alkaline detergent.\textsuperscript{42,43}

The ECA water is presented in a metastable state and contains some kinds of free radicals and also biocidal agents, such as sodium hydroxide and hydrogen peroxide.\textsuperscript{44}

Forty-eight hours after activation, the solution will return to a stable inactive state. Using ECA in dental unit water lines can effectively eliminate microbial biofilms.\textsuperscript{45} Solovyeva and Dummer\textsuperscript{46} showed that elimination of debris is equal for anolyte neutral cathodic solution and NaOCl. Gulabivala et al.\textsuperscript{47} assessed the effectiveness of EDTA. Kara Tuncer et al.\textsuperscript{41} revealed that MA produced the greatest reduction in dentin microhardness.

**Ozonated Water**

Ozone is considered as a naturally occurring compound consisting of three oxygen atoms. It can be found in the form of gas in the stratosphere being continually created from and destroyed into molecular oxygen.\textsuperscript{53} Both of these reactions are catalyzed by ultraviolet light from the sunlight.\textsuperscript{54} Ozone is also a powerful antibacterial agent.\textsuperscript{55,56} The oxidant potential of this component results in destruction of cytoplasmic membranes and cell walls of the bacteria.\textsuperscript{57} This may result in increases in membrane permeability and compromising the cell viability. Subsequently, ozone molecules can readily enter the cell and cause the microorganism to die.\textsuperscript{58,59} By oxidizing the biomolecules, ozone may show a great disruptive effect on cariogenic bacteria, and so eliminate the acidogenic bacteria.\textsuperscript{60-62}

Müller et al.\textsuperscript{63} compared the influence of ozone gas, photodynamic therapy, 2% CHX, and 0.5% and 5% NaOCl on a multispecies oral biofilm. They showed that only 5% NaOCl is able to eliminate all bacteria effectively. Baysan et al.\textsuperscript{64} evaluated the efficiency of ozone on Streptococcus mutans and Streptococcus sobrinus. Results indicated that exposing the mentioned bacteria to ozone for 10 to 20 seconds reduced the total levels of microorganisms in the primary root carious lesions to <1% of the control values.

Ten seconds application of ozone can also decrease the number of S. sobrinus and S. mutans in vitro.\textsuperscript{64} Polydorou et al.\textsuperscript{65} showed that 80 seconds treatment by ozone is a suitable choice for decreasing the microorganisms in deep cavities. This result can prove the effect of ozone on increasing the success rate of restorative treatments.

Nagayoshi et al.\textsuperscript{59} concluded that ozonated water is very effective in killing of Gram-negative and Gram-positive bacteria. Gram-negative bacteria were more sensitive to ozonated water than Gram-positive bacteria.

Aqueous ozone fulfills optimal cell characteristics in terms of biocompatibility for oral application.\textsuperscript{66} Hems et al.\textsuperscript{67} concluded that ozone in solution has antibacterial effect against planktonic E. faecalis; however, it was not effective in a biofilm environment unless displaced into surrounding medium by using agitation. It was also shown that gaseous ozone was not effective on biofilm of E. faecalis.

Estrela et al.\textsuperscript{68} also showed that gaseous ozone, ozonated water, 2.5% NaOCl, and 2% CHX had no antibacterial effect against E. faecalis over 20 minutes contact time.

Thanomsub et al.\textsuperscript{69} discovered that 0.167 mg/min/L ozone can sterilize water, which is contaminated with up to 105 cfu/mL bacteria within half an hour. This concentration had no effect on cell viability in bacterial cultures at higher concentrations.

Kronusová\textsuperscript{70} proposed usage of ozone for prepared cavities, postextraction complications, chronic gingivitis, and purulent periodontitis.

**SMEARCLEAR**

SmearClear (Sybron Endo, Orange, CA) is a product that was introduced for removing the smear layer. It is a 17% EDTA solution including a cationic CTR and an anionic surfactant. It has been shown that there were no
significant differences between SmearClear, 17% EDTA, and 10% citric acid regarding their smear layer-removing ability.71 Da Silva et al72 showed the ability of this material for removing the smear layer from canal. Nelson-Filho et al73 showed that there was no significant difference between EDTA and SmearClear in removing the smear layer from the root canals of primary teeth. On the contrary, Wu et al74 indicated that the efficacy of 17% EDTA was better than that of SmearClear, while Dunavant et al75 demonstrated that the efficacy of SmearClear on E. faecalis biofilms was significantly weaker than 1 and 6% NaOCl.

GREEN TEA

Green tea contains epigallocatechin gallate (EGCG) and tocopherols, carotenoids, vitamin C, and some minerals. Regarding the antioxidant property, it is more potent than black tea.76 It shows great antibacterial activity against E. faecalis biofilm and in 6 minutes, it can kill 100% of E. faecalis.77 Antibacterial activity of this material has been confirmed in other studies, which showed the efficacy of green tea extract in maintaining the viability of periodontal ligament cells higher than that of milk.78,79 Lee et al80 concluded that EGCG can suppress the progression of apical periodontitis. Recently, Lee and Tan81 showed that EGCG is an effective antimicrobial agent against both the planktonic and biofilm forms of E. faecalis and inhibiting bacterial growth. The antibacterial effect of EGCG on E. faecalis may occur during generation of hydroxyl radicals.

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