Irrigants in endodontic treatment

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Abstract

The aim of root canal treatment is to remove virulence factors from this system. Cleaning and shaping of the root canal are at the outmost importance in endodontic treatment. Canal irrigation during the process of cleaning and shaping can lead to the elimination of microorganism, which are not removable through physical methods. Moreover, during the preparation of root canal, manually and by rotary instruments, the smear layer is created that must be eliminated by irrigants. In the present review article, irrigants were investigated in terms of chemical and biological features and their effective and safe ways of usage, along with some information that have been proposed on recent developments of root canal solutions. Furthermore, this topic has been studied regarding its effect on microorganisms and smear layer. In the present article, a review has been conducted through libraries, PubMed, ISI Web of science, Scopus websites, and Google using keywords such as endodontic treatment, intracanal irrigant, anti-bacterial, chlorhexidine, smear layer, and sodium hypochlorite.

Different materials have been introduced as root canal irrigants. Although sodium hypochlorite is the most common material used in the endodontic treatment against root canal microorganism, it has certain disadvantages and limitations and could not entirely remove the smear layer. Therefore, there is no irrigant that is capable of providing all the features of an appropriate irrigant individually. To remove the smear layer, ethylene diamine tetra acetic acid is required as the final rinse. High-density sodium hypochlorite (NaOCl) is more effective than 1 and 2% solutions. In order to eliminate the microorganisms of the root canal and the smear layer, it is suggested to use two or more detergents with a proper frequency. Using chlorhexidine as the final detergent creates a lasting impact.

Keywords: Anti-bacterial materials, chlorhexidine, intracanal irrigant, root canal treatment, smear layer, sodium hypochlorite

Introduction

The success of endodontic treatment depends on the elimination of the existing bacteria in root canal system and preventing their regrowth.¹ Removing debris, biofilm, microbes, and necrotic tissues from the root canal system is performed manually or through rotary shaping, as well as frequently canal irrigation.²

The main objective of preparation and canal shaping is to facilitate canal irrigation, disinfection, and obturation. However, a study conducted by the advanced technique of micro-computed tomography indicated that, some areas might remain intact during canal shaping.³ This issue puts forward the significance of using chemical materials to clean and disinfection the root canal system.

In fact, since there is no irrigant that is capable of providing all the expected characteristics, ideal irrigation is feasible by using a combination of two or more appropriate solutions through a certain sequence.⁴ Accordingly, the chemical composition of canal irrigants has been changed to improve penetration and the effects of irrigation.

In this study, irrigants have been investigated in terms of chemical and biological properties and the effective and safe ways of application, along with data that were provided on recent developments in this field.

In the present article, a review has been conducted through libraries, PubMed, ISI Web of science, Scopus websites, and Google using keywords such as endodontic treatment, intracanal irrigant, anti-bacterial, chlorhexidine, smear layer, and sodium hypochlorite.

Aim of Irrigation

Irrigation plays a leading role in the root canal treatment. During and after canal preparation, through a pumping action, irrigants
perform an influential role in removing microorganisms, remaining tissues and dentin fragments found in the canal. In addition, irrigants prevent accumulation and compression of hard and soft tissue remnants at the apical end of the root canal and hinder the leakage of these pollutant materials toward the periapical area.\textsuperscript{[4]}

Some irrigants will dissolve both organic and inorganic tissues of the root canal while others contain antibacterial and anti-microbial properties and actively kill bacteria and fungi. Some of them, however, are toxic to cells and will cause severe pain if they gain access to the periapical tissues.\textsuperscript{[5]}

The resultant debris of preparing root canal manually or by rotary instruments will lead to the formation of smear layer on the root dentin, which includes organic and inorganic materials.\textsuperscript{[6]}

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Sodium hypochlorite is the most popular root canal irrigant that creates Na\(^+\) and OCl\(^{-}\) ions when combined with water, which are balanced with hypochlorous acid. Hypochlorous acid is an anti-bacterial agent that can be more effective than ClO\(^{-}\).\textsuperscript{[14]}

In acidic or neutral pH form of hypochlorous acid and in pH equal to 4 or more, the presence of OCl\(^{-}\) is dominant. Therefore, pH can affect the anti-bacterial property of a solution. By decomposing the vital activities of microbial cells, hypochlorous acid can lead to cell death.\textsuperscript{[15]}

Sodium hypochlorite is usually used in densities between 0.5\% and 6\%, which is a potential anti-bacterial agent, lethal in facing with most of the bacteria. Moreover, sodium hypochlorite is successful in dissolving organic compositions, cologne, and pulp remnants and it is the only irrigant capable of dissolving alive and dead organic tissues; hence, without this detergent, a satisfying root canal treatment seems to be difficult. In the case of removing smear layer, sodium hypochlorite is not applicable individually, but could affect the organic parts and provided a complete removal by using other irrigants such as ethylene diamine tetraacetic acid (EDTA) and citric acid.\textsuperscript{[16]}

There are different ideas about anti-bacterial properties of sodium hypochlorite. Some studies suggest that even in low densities, this substance is able to eliminate microorganisms within a few seconds,\textsuperscript{[14,17]} while some others state that much time is needed to reach this goal.\textsuperscript{[18,19]} These differences can be due to the existence of confounding factors in some studies. For example, the presence of organic materials could have negative effects on sodium hypochlorite activities.

Haapasalo et al.\textsuperscript{[20]} has indicated that the existence of dentin can cause a delay in the effects of 1\% sodium hypochlorite on Enterococcus faecalis. In previous studies, however, there were different amounts of organic materials in the root and pH was not under control. In fact, it can be said that when the confounding factors are limited or removed, even densities lower than 1\% sodium hypochlorite can exterminate the targeted microorganisms.\textsuperscript{[18,19,21]} Nevertheless, in clinical conditions, the presence of organic materials such as inflammatory exudate, tissue remnants, and microbial population can consume and weaken the sodium hypochlorite. Consequently, frequent irrigation and timing are important factors in the effectiveness of hypochlorite.\textsuperscript{[16]}

Bystrom and Sundqvist\textsuperscript{[22]} evaluated necrotic canal irrigation which are replete with anaerobic bacteria. They indicated that, comparing with normal saline, 0.5 or 5\% sodium hypochlorite with/without EDTA would lead to the reduction of considerable numbers of bacteria. Siqueira et al.\textsuperscript{[23]} presented the same results about canals that are contaminated with E. faecalis as well. All three papers found no significant difference between anti-bacterial effects of low-density and high-density sodium hypochlorite. Contrary to these results, Clegg et al.\textsuperscript{[24]} reported an enormous difference between 3\% and 6\% densities of sodium hypochlorite, in terms of being applicable on bacterial biofilm and illustrated that higher densities are more effective. Besides its great advantages, sodium hypochlorite has many disadvantages such as unpleasant odor and taste, toxicity, and the inability to remove the smear layer. In fact, sodium hypochlorite is only capable of dissolving the organic materials of the smear layer.\textsuperscript{[25]}

Among other disadvantages of this substance is its limited anti-bacterial effect at “in vivo” condition, due to the inability of penetrating into the surrounding area of the root canal such as apical anastomosis, lateral canal, and dentinal tubule. In addition, the existence of non-activator materials including exudate, collagen pulp tissue, and microbial populations can interfere with the function of sodium hypochlorite and reduce its effectiveness.\textsuperscript{[20]}

According to Liu et al., compared with the living cells, the biofilms of E. faecalis starved cells were more resistant to 5.25\%
NaOCl and the effect of that amount on them is reduced by the biofilm growth.\cite{26} Ozdemir et al. indicated that a mixed application of EDTA and NaOCl decreases the amount of root canal biofilms, significantly.\cite{27}

In summary, sodium hypochlorite is the most significant solution and the only option, which capable of dissolving the organic tissues such as biofilm and the organic parts of the smear layer that must be used during canal preparation a complete process of cleaning the root canal system requires an irrigant that is competent to dissolve the organic and mineral materials. Although sodium hypochlorite could properly dissolve the organic substances, other irrigants must be employed to remove the smear layer and dentinal debris, completely. Citric acid, EDTA, and tetracycline contain this functionality.\cite{28-30}

**EDTA**

This substance is subtle or has no effect on organic contents of the root, along with no anti-bacterial impact. However, there are some reports suggesting that direct and long contact of a bacterium with this substance leads to the release of bacterial proteins and subsequently cellular death. Furthermore, some studies illustrated that removing smear layer by this irrigant, increases the anti-bacterial effects of disinfecting factors in deeper layers.\cite{31,32} This irrigant is mostly presented as 17% neutral solution (disodium EDTA, pH7), but as it is stated in a study, lower densities like 10, 5, or even 1 percent could have a similar effect after irrigation with sodium hypochlorite, as well. Since EDTA is expensive, lower densities can be practical.\cite{33}

**Citric acid**

Citric acid is accessible in various densities from 1% to 50%, although its 10% solution is more prevalent. As it is demonstrated in a study, its 10% density compared with 1%, can remove the smear layer more effectively.\cite{34} By removing the smear layer, the composition improves the anti-bacterial effect of topical antiseptics factors in deeper layers of the dentin. Khademi and Feizianfard\cite{35} claimed that EDTA is more effective in removing the smear layer from citric acid, especially in third apical and middle, however, both materials have removed the smear layer in third middle and cervical better than third apical. It is suggested by another study that, compared with ultrasonic 10%, citric acid has the potential to remove the smear layer in third apical more effectively.\cite{36} It is much better to use EDTA and citric acid for 2-3 min at the end of the preparation phase and after irrigation by hypochlorite.\cite{37}

Citric acid and EDTA are available in liquid and gel form. It is probable that the limited capacity of the root canal may lead to rapid saturation of the chemical solution and decreases its effectiveness. In this case, using liquid products is recommended in frequent irrigation.\cite{38,39}

**Tetracycline**

This substance has some specific properties including low pH. Its acidic property causes it to function as calcium chelator and demineralize enamel and dentin.\cite{40} This mineralization is comparable by what is gained through citric acid.\cite{41} Furthermore, tetracycline has retention property absorbed by dentin and cementum and freed gradually;\cite{42} however, its retention is less than chlorhexidine.\cite{43} In contrary to the two previous irrigants, this substance has broad anti-bacterial (bacteriostatic) property,\cite{44} which are used through the inhibition of protein synthesis. In high densities, tetracycline can have a bactericidal impact. Among other specific properties of tetracycline is its ability to decrease the root resorption by affecting the osteoclast activity and reducing collagenase;\cite{45} although tooth color is a harmful side-effect of this irrigant.\cite{46}

**Chlorhexidine**

Due to its anti-bacterial property, chlorhexidine digluconate has widespread disinfecting functionality in dentistry.\cite{47,48} This product is free of unfavorable characteristics of sodium hypochlorite such as taste, odor, and severe irritation of periapical tissues, but cannot dissolve the tissue and replace it.\cite{49} Chlorhexidine permeates through microbial cell walls or external membrane, hits the cytoplasm or internal membrane of the bacterium, and exterminates them. In high densities, this substance can result in the coagulation of intercellular components.\cite{49}

Retention is one of the favorable characteristics of chlorhexidine since it sticks to the hard tissues and remains in place. However, like other antiseptic agents of root canal treatment, the functionality of chlorhexidine is contingent to pH and reduces considerably in the presence of organic materials.\cite{50} Various studies compared the anti-bacterial effect of sodium hypochlorite and chlorhexidine, indicating that there is no significant difference between them.\cite{51-54} Consequently, although bacteria will be killed by chlorhexidine, biofilm, and other organic debris might not be removed and may affect the quality of permanent obturation seal of the root canal.\cite{53,54} This problem points out the significance of using hypochlorite during root canal preparation.

Accordingly, due to dentinal erosion, sodium hypochlorite cannot be used as the final detergent after the EDTA, but it is not the case about 2% chlorhexidine and it can be employed for accessing the most anti-bacterial effect in the final phase of mechanical and chemical preparation of the canal.\cite{55} Most studies, however, on using chlorhexidine in root canal treatment has been in the form of *in vitro* or *in vivo* and on Gram-positive organisms such as *E. faecalis*.\cite{14,56} Chlorhexidine is available in forms of the solution in water, gel, and liquid combined with surface activator factors. According to a study, chlorhexidine gel has better functionality, but the reason is not identified.\cite{57} Regarding the current drawbacks, there are increasing evidences confirming that 2% chlorhexidine (liquid or gel) as an irrigant is appropriate for endodontic treatment.\cite{58}

In an *in vitro* study, Gomes et al.\cite{14} compared the antimicrobial function against root pathogens in three densities (0.2%, 1%, and 2%) of two modes of CHX (Gel and liquid)
and five densities of NaOCl (0.5%, 1%, 2.5%, 4%, and 2.25%). All these irrigants are effective in killing E. faecalis, but the required impact time is different. However, the required time for 0.2% liquid CHX and 2% gel CHX for increasing the negative growth is 30 and 1 min, respectively. Even if all these tested irrigants have an antibacterial function, the required time for elimination of E. faecalis depends on density and kind of irrigant. On the other hand, Siqueira et al. [59] found that, 4% NaOCl was statistically better than 0.2% and 2% CHX against four aerobic antimicrobial Gram-negative with black pigments and four non-aerobic optional bacteria. For the first time, Ferraz et al. [57] entered 2% CHX gel as a root canal irrigant. They evaluated the CHX gel ability in disinfection of infected root canal with E. faecalis and cleaning compared with the obtained results from other tested irrigants, such as NaOCl and liquid CHX. The results indicated that, compared with other yielded outcomes from tested irrigants, the CHX gel produced more cleanly root canal level and significantly had more antibacterial capabilities. Consequently, CHX gel is capable of being used as a root irrigant. Sena et al. [60] investigated the antimicrobial function of 2.5% and 5.25% NaOCl gel and 2.0% liquid CHX, as a root canal irrigant against selected single-species biofilms. Results have shown that, mechanical simulation improved the antibacterial properties of chemicals by a biofilm model, which is indicative of the existence agents in liquid cases, especially the 2.25% NaOCl and 2% CHX.

Iodine potassium iodide

2% and 4% iodine potassium iodide has anti-bacterial properties as well, but it is not capable of dissolving the tissues. [61] The current iodine is less active than chlorine in sodium hypochlorite; however, it dispatches the microorganisms immediately and has bactericidal functionality. Moreover, the substance is effective in fungus, tuberculosis, virus, and even spirochetas. [62] The antiseptic role of potassium iodide iodine on the tooth surface is well-documented. [63] Similar to chlorhexidine, it can be used at the end of mechanical and chemical preparation. According to a study, irrigation by this substance, after a typical mechanical and chemical preparation, will decrease number of negative implants in infected canals before the treatment. [64] On the other hand, some studies have shown that irrigation by potassium iodide iodine will not cause the shaping of microorganism-free canals. [65,66] These studies consider the deactivation of iodine compositions by dentin and necrotic tissues inside the canal, as the most significant factors. Several allergic patients to these materials have emphasized on this issue to be taken into consideration. [58]

Other irrigants

Other applicable irrigants in endodontic treatment are distilled water, physiological saline, hydrogen peroxide, and urea peroxide. When used individually, these materials have no antibacterial activity and cannot dissolve the tissues. Hence, there is no cogent reason to use them as common irrigant. Furthermore, distilled water and saline increase the risk of infection when used from bottles or containers that were unbolted more than once. [33,67]

Interaction between irrigants

Sodium hypochlorite and EDTA are the most prevalent irrigants. They have various features and functionalities, which cause them to be used as a composition. EDTA, however, in combination with sodium hypochlorite decreases the amount of chlorine and finally reduces the sodium hypochlorite activity. Accordingly, these two solutions should not be combined together. [68]

Chlorhexidine is not tissue soluble and can be mixed with sodium hypochlorite to get useful features, yet these two solutions are not soluble and the resultant becomes orange-brown sediment. Maybe the properties of this sediment and the liquid phase have not been tested so far, yet it seems that its existence made the clinical function of this composition impossible. Atomic absorption spectrophotometry has shown that iron-included sediments can be the reason of orange color. [69]

It is proved that the presence of para chlorine in sediments could have Mutagenic properties, as well. [70,71]

The combination of chlorhexidine and EDTA also creates white sediment promptly. Although the characteristics of this sediment have not been studies so far, but it seems that, the ability to remove the smear layer of EDTA is affected and reduced. Most dentists mix the sodium hypochlorite with hydrogen peroxide that due to the formation of excessive bubbles, it does not seem to be better than sodium hypochlorite. [53] Therefore, the combination of chlorhexidine and Hydrogen peroxide in “in vivo” conditions leads to increase of combined anti-bacterial activity, however it appears that there are no information available on the effects of this combination in clinical conditions.

Synthetic Irrigants

New compositions of root irrigants include MTAD (tetracycline, citric acid, and irrigant compound) and Tetra clean, which contain antibiotic (doxycycline) [72-74] and have been developed to remove the smear layer and create anti-bacterial property. Both comprise citric acid and irrigant, and their difference is in citric acid density and the type of irrigant. These two materials do not dissolve the organic tissue, and it is better to be used at the end of mechanical and chemical preparation after sodium hypochlorite. While former studies were the indicator of the appropriate anti-bacterial activity of MTAD, [56,57] recent studies have shown that MTAD-sodium hypochlorite composition are as effective or less effective as EDTA - sodium hypochlorite. [77,78]

A comparative study between MTAD and Tetra clean has also demonstrated that the latter has more anti-bacterial effect. [79]

Though an antibiotic composition can have short and long-term effects, there are still some concerns about using tetracycline (doxycycline), due to the increase of bacterial resistance and formation of pigment in hard tissues. According to an in vitro study, pigment formation in hard tissues elaborated
in light exposure, but it seems that there is no report available of its occurrence in in vivo conditions.

**Conclusion**

Irrigation plays a significant role in a successful root canal treatment and to achieve a proper root canal irrigation, it is crucial to have accurate information about the functionality of irrigants. Although sodium hypochlorite is the most important irrigant, yet there are no options that can provide all the required characteristics individually. Tissue dissolution and antimicrobial effect are two significant features of irrigation. To secure the optimal results in an apical third of the canal, small, 30 gauge side-vented needles and/or negative pressure irrigation with NaOCl and EDTA are suggested.

**References**

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