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REVIEW

Endodontic irrigants from a comprehensive perspective

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Abstract

This review article explores the fundamental principles of modern endodontics with a focus on root canal cleaning and shaping. It reviews commonly used endodontic irrigant, namely sodium hypochlorite (NaOCl), herbal extracts, chlorhexidine (CHX), and chelating agents, highlighting their properties, applications, and potential drawbacks. NaOCl, a key antimicrobial agent, demonstrates effectiveness against various microorganisms but poses challenges such as high cytotoxicity. Herbal extracts, gaining recognition in endodontics, present an alternative with potential advantages in preserving dentin integrity. CHX, known for its broad-spectrum antimicrobial activity, is discussed in both liquid and gel formulations, emphasizing its role in reducing smear layer formation and preserving hybrid layer durability. Chelating agents, specifically ethylenediaminetetraacetic acid and citric acid, play a vital role in removing the smear layer, enhancing dentin permeability, and facilitating the penetration of antimicrobial agents. The review article underscores the importance of careful application and consideration of each irrigant's properties to ensure safe and effective endodontic procedures. It serves as a valuable guide for clinicians in selecting appropriate irrigants based on specific treatment requirements.

Key Words: Root canal irrigants; Sodium hypochlorite; Chlorhexidine; Chelating agents; Plant extracts

Core Tip: To increase the effectiveness of mechanical preparation and bacterial removal, irrigation is necessary. The dentist must be familiar with their different modes of action, indications, advantages, and disadvantages. This article provides an overview of the characteristics of the main endodontic irrigants for the professional class. The primary irrigants used in the field of endodontics include sodium hypochlorite, chlorhexidine, ethylenediaminetetraacetic acid, tetracycline antibiotics, TetraClean, calcium hydroxide, distilled water, and herbal irrigants. It was concluded that none of these irrigants are ideal, making it necessary to evaluate each case individually for their use and conduct further research to identify the best candidate.

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INTRODUCTION

Schilder is credited with establishing the fundamental principles of modern endodontics, focusing primarily on two essential elements: “cleaning” and “shaping.” The process of shaping the root canal system serves a dual purpose of both cleaning and disinfection. This preparatory step is pivotal for ensuring effective three-dimensional filling with obturating materials[1]. The concept of cleaning stands as the paramount objective in root canal treatment, adapting to the specific condition of the pulp[2]. In instances of vital pulp diseases, the primary objective is the removal and cleaning of inflamed tissues. Conversely, in cases of necrotic pulp diseases, the goal extends to the removal, cleaning, and disinfection of necrotic tissues[3].

Achieving this cleanliness involves the use of mechanical instruments, which not only shape the root canal system but also mechanically remove bacteria and their by-products. Simultaneously, endodontic irrigants are employed to lubricate the root canal system, dissolve organic tissues, and, most importantly, to clean and disinfect the canal[4-11].

In this review article, we provide a concise summary of the most employed endodontic irrigants. These solutions play a pivotal role in achieving the high standard of cleanliness required in modern endodontic procedures, underscoring their critical importance in the field.

SODIUM HYPOCHLORITE

Sodium hypochlorite (NaOCl) is obtained through the electrolysis of sodium chloride, with its relative value determined by the chlorine content released, known as active chlorine[12,13]. It is classified as a halogenated compound, it can be found in a series of products, containing varying concentrations and additives (Table 1).

Numerous studies have provided substantial evidence supporting the antimicrobial effectiveness of NaOCl against a diverse range of microorganisms commonly found in the oral cavity such as *Escherichia coli*[14], *Enterococcus faecalis*[15], different anaerobic bacteria[16,17], and *Candida albicans*[18]. In addition, it is also effective against microorganisms’ endotoxins including lipopolysaccharides and lipoteichoic acid[4,11,19,20], and against matrix metalloproteinases (MMPs)[5]. While there may be ongoing debates regarding the exact mechanisms of its antimicrobial activity, the prevailing theory suggests that active chlorine hinders enzymatic processes, disrupts metabolic activities, and ultimately results in cell death[21]. This multifaceted evidence underscores the valuable role of NaOCl as a potent antimicrobial agent in oral healthcare.

NaOCl possesses remarkable properties in the context of root canal treatment. It demonstrates a unique functionality in that it not only exhibits the capacity to dissolve organic tissues within the root canal, such as pulp tissue and collagen[10, 22], but also serves as an effective lubricating agent within the canal. This lubricating action enables the mechanical removal of debris and other contaminants from the canal, contributing to a more thorough cleaning process[23]. Furthermore, NaOCl exhibits an interesting characteristic in terms of its pH (potential of hydrogen). Initially, it is alkaline in nature, which can be beneficial for its antimicrobial and tissue-dissolving properties. However, over time, its alkalinity gradually diminishes[24]. This dynamic pH change over the course of treatment may have implications for its overall effectiveness and the evolving chemical environment within the root canal.

Nonetheless, it is crucial to acknowledge the drawbacks associated with the use of NaOCl. Notably, NaOCl exhibits high cytotoxicity and relative genotoxicity[17,25,26], which are both are related to its concentration[27]. Furthermore, its ability to dissolve organic tissues can lead to the distortion of dentin collagen, ultimately resulting in reduced bond strength within the dentin-resin system[28]. This effect can have implications for the overall mechanical properties of root

Table 1 Sodium hypochlorite types and concentrations

Solution	Concentration	Parts per million
Dakin's solution	0.5% NaOCl solution	Equivalent to 5000 ppm, and is neutralized with boric acid to bring the pH close to neutral
Dausfrene solution	0.5% NaOCl solution	Equivalent to 5000 ppm, that has been neutralized using sodium bicarbonate
Milton's solution	1% NaOCl solution	Equivalent to 10000 ppm, that is stabilized with 16% sodium chloride
Labarraque Liqueur	2.5% NaOCl solution	Equivalent to 25000 ppm
Chlorinated soda	4%-6% NaOCl solution	Equivalent to 40000-60000 ppm
Sanitary water	2%-2.5% NaOCl solution	Equivalent to 20000-25000 ppm

NaOCl: Sodium hypochlorite; ppm: Parts per million.

canal-treated teeth, potentially leading to compromised structural integrity[29]. These considerations underscore the importance of careful and precise application of NaOCl in endodontic procedures to mitigate these potential disadvantages.

It is worth mentioning that the NaOCl concentration has effect on its efficacy, in which lower concentrations (0.5%-1%) are indicated in biopulpectomy and pulpotomy; however, higher concentrations (2.5% and higher) are indicated for necropulpectomy as in periapical periodontitis and periapical abscess[30,31]. These indications are highly attributed to its antimicrobial, anti-endotoxin, and organic tissue capacity, in addition to its biocompatibility[4,5,10], in which lower concentrations are safer for tissues and have a lower risk of irritation or chemical burns but are less effective in dissolving organic matter, and require a longer exposure time[32]. Conversely, higher concentrations are more effective in dissolving organic matter and disinfecting the canal, but have a higher risk of tissue irritation and potential for damage to surrounding structures if not used cautiously[32].

HERBAL EXTRACTS

The integration of herbal extracts, or phytotherapy, in dentistry is steadily gaining recognition[33] particularly within the specialized domain of endodontics[34]. Different extracts of herbal medicine were introduced to be used as endodontic irrigants or intracanal medications[35,36] primarily due to their demonstrated antimicrobial properties and biocompatibility[37]. This highlights the growing recognition of herbal remedies in dental care, especially within endodontics, due to their potential therapeutic benefits. Still, most of the reported studies have been performed as laboratorial research not *in vitro* or even *in vivo* studies.

Numerous in tooth model studies have indicated herbal medicines extracts as endodontic irrigants. *Artocarpus lakoocha* (monkey jack or monkey fruit) extract might be a useful alternative for antimicrobial medication in endodontic treatment because of its efficacy against *E. faecalis*[38]. In addition, *Allium sativum* (garlic) extract is as effective as 5.25% NaOCl, and more biocompatible with good dentinal penetration property[39]. Similarly, *Camellia sinensis* (green tea) extract is indicated as a potential antimicrobial root canal irrigant because of its antimicrobial action against *E. faecalis*[40].

Furthermore, numerous laboratory studies have also supported the use of herbal medicine extracts as endodontic irrigants. These include extracts from *S. officinalis*, *Glycyrrhiza glabra* (liquorice), Brazilian green propolis, *Rosmarinus officinalis* (Rosemary), *Pfaffia paniculata* (Brazilian ginseng), *Hamamelis virginiana* (American witch-hazel), *Stryphnodendron barbatiman* (Stryphnodendron), *Gymnema sylvestre* (Gurmar), *Curcuma longa* (turmeric), *Persea americana* (avocado), and others[36,41-45].

While the efficacy of herbal medicine extracts has been established and several extracts have been identified for their safety, ease of use, extended shelf life, affordability, and limited microbial resistance[46,47], it is important to note that certain studies have suggested caution regarding their use as the primary irrigant for canal disinfection[48]. Unless subjected to thorough preclinical and clinical testing, as well as evaluations of potential interactions with other materials [49], the adoption of herbal extracts as main irrigants should be approached with careful consideration.

Nonetheless, it is essential to acknowledge that the capacity of these herbal irrigants in removing the smear layer is relatively lower compared to chelating agents such as ethylenediaminetetraacetic acid (EDTA) and tetracycline antibiotics (MTAD, a combination of a tetracycline isomer, an acid, and a detergent)[50,51]. However, certain studies have reported that natural irrigants can effectively remove the smear layer while causing minimal harm to the mechanical and chemical properties of radicular dentin in contrast to synthetic agents, as they have a less detrimental impact on dentin's mechanical properties[52]. This underlines the potential advantages of natural irrigants in preserving dentin integrity, despite their less robust smear layer removal compared to their synthetic counterparts, suggesting that herbal irrigants may offer unique advantages, encouraging further exploration of their potential in improving endodontic treatments.

CHLORHEXIDINE

Chlorhexidine (CHX) has been extensively utilized in the field of endodontics as a substance for irrigation or as a medicament within the root canal. This is due to its possession of a broad spectrum of antimicrobial activity, as well as its ability to sustain residual antimicrobial activity. Moreover, CHX exhibits a lower level of cytotoxicity compared to NaOCl while still demonstrating effective clinical performance, lubricating properties, and rheological action. The gel presentation of CHX aids in suspending debris and it also acts as an inhibitor of metalloproteinase. Additionally, CHX is known for its chemical stability, lack of staining on fabric, lack of odor, and water solubility, among other notable properties[53].

The structure of the compound consists of two symmetric 4-cholorophenyl rings and two biguanide groups, connected by a central hexamethylene chain[54]. In the context of endodontic applications, CHX can be utilized either in a liquid form or as a gel. The CHX gel formulation consists of a gel base containing 1% natrosol, a hydroxyethylcellulose, with a range from 6 to 9 and CHX gluconate, in an optimal pH range of 5.5 to 7.0. Natrosol gel is a biocompatible carbon polymer[55], that is a water-soluble substance, and therefore can be easily removed from the root canal with a final flush of distilled water[56,57].

The CHX gel provides lubrication to the walls of the root canal, minimizing friction between the file and the dentin surface. This, in turn, eases the instrumentation process and lowers the chances of instrument breakage within the canal. Moreover, by aiding in instrumentation, the CHX gel enhances the removal of organic tissues, addressing its inability to dissolve them[56,57]. Another advantage of CHX gel is the reduction of smear layer formation[57], which does not occur with the liquid form. CHX gel maintains almost all the dentinal tubules open because its viscosity keeps the debris in suspension (rheological action), reducing smear layer formation. Furthermore, the gel formulation may keep the “active principle” of CHX in contact with the microorganisms for a longer time, inhibiting their growth[58].

The pH-dependent nature of the antimicrobial activity of CHX is observed, with the optimal range falling between 5.5 and 7.0, encompassing the pH values characteristic of body surfaces and tissues. At physiological pH levels, CHX undergoes dissociation, resulting in the release of the positively charged CH component. The ability of the CHX molecule to penetrate bacterial cells and exert toxic effects is facilitated by the interaction between the positively charged molecule and the negatively charged phosphate groups present on the bacterial cell wall[59]. Consequently, the antimicrobial activity of CHX is independent of its pH, which remains within the range of 5.5 to 7.0.

In terms of its range of activity, CHX exhibits a broad spectrum of antimicrobial properties and demonstrates effectiveness against both Gram-positive and Gram-negative bacteria, as well as facultative and strict anaerobes[57,58,60-68], yeast, and fungi, particularly *Candida albicans*[58,69-71]. Furthermore, it demonstrates activity against certain viruses such as respiratory viruses, herpes, cytomegalovirus, and human immunodeficiency virus, while remaining inactive against bacterial spores when at room temperature[72,73].

One of the primary benefits of CHX is associated with its antimicrobial substantivity. The cations with a positive charge that CHX emits can adhere to dentin and hinder the establishment of microorganisms on the dentin surface for a duration that extends beyond the actual application period[74], thereby sustaining an extended period of antimicrobial efficacy for multiple hours[53].

CHX has the ability to preserve the durability of the hybrid layer and adhesive strength both *in vitro* and *in vivo*[75,76]. This is likely attributed to its effectiveness as an MMP inhibitor[77], leading to reduced degradation of collagen fibrils in the hybrid layer and sub-hybrid layer. This notable property is relevant because the gradual deterioration of the integrity of resin-dentin bonds over time is often linked to the breakdown of exposed collagen fibrils within inadequately infiltrated hybrid layers[78]. This breakdown is associated with an endogenous proteolytic process, primarily involving the action of MMPs present in dentin[79].

CHX has been recommended as an irrigant alternative to NaOCl, especially because of its broad-spectrum antimicrobial action, substantivity and low toxicity[80]. However, CHX's incapacity of tissue dissolution has been pointed out as its major disadvantage. Some attempts have been made to assess the ability of CHX to dissolve organic matter, and the findings indicate that neither the aqueous solution nor the gel formulations of this substance were effective in dissolving pulp tissues[81,82]. In this context, it has been recommended to combine NaOCl and CHX to amplify their antimicrobial efficacy. The benefit of concluding the procedure with a CHX final rinse lies in the sustained antimicrobial activity attributable to CHX substantivity[83]. On the other hand, when NaOCl is combined with CHX, it produces an orange-brown precipitate, forming a chemical smear layer that envelops dentinal tubules and could potentially disrupt the sealing of the root filling[56,84]. Moreover, this precipitate alters the tooth color[85], and exhibits cytotoxicity[86]. Hence, it is crucial to eliminate any remnants of the substances employed within the root canals through intermediate flushes with distilled water to prevent interactions between them.

CHELATING AGENTS

The instrumentation of the root canal walls leads to the formation of a smear layer[87], which consists of both inorganic and organic components such as dentin filings, remnants of odontoblastic processes, pulp tissue and in circumstances where root canals are infected, bacteria[88,89]. The presence of the smear layer poses a hindrance to effective disinfection by preventing the penetration of antimicrobial agents such as NaOCl, calcium hydroxide and other intracanal medicaments into the dentinal tubules[90]. Furthermore, if not removed, the smear layer has the potential to interfere with the seal between the filling material and the root canal wall, thus compromising the success of endodontic treatment [88,91].

Although NaOCl appears to be the most appropriate endodontic irrigant, when used alone, it is ineffective in smear layer removal as it cannot dissolve inorganic dentin particles[92]. In addition, calcifications hindering mechanical preparation are frequently encountered in the canal system. In this context, the use of demineralizing agents has been recommended as adjuvants in root canal therapy. Chelators such as EDTA[93] and citric acid[94] are highly efficient in chemically softening the root canal dentin and dissolving the smear layer, increasing the dentin permeability[95].

The most common chelating solutions are based on EDTA which functions through the establishment of a steadfast compound with calcium ions. Upon the binding of all accessible ions, a state of equilibrium materializes, thereby precluding any subsequent disintegration. Using gravimetrical analyses, Schilder[1,96] demonstrated that the properties of EDTA exhibited a self-limiting nature. This restriction is believed to be attributed to alterations in pH during the demineralization process of dentine. Under neutral circumstances, most chelators possess a pH in close proximity to the neutral benchmark, with 99% of the EDTA existing in the form of EDTAHNa3. The process of calcium removal from the dentine by hydrogen leads to a subsequent decline in pH. Due to the liberation of acid, the efficacy of EDTA decreases over time; conversely, the interaction of the acid with hydroxyapatite influences the solubility of dentine.

Although the antiseptic capacity of EDTA irrigant is relatively limited[97], it is significantly superior to saline in the reduction of intracanal microbiota[98]. This phenomenon can be attributed to its capability to detach biofilms that are adhered to the root canal walls[99]. While a randomized clinical trial has yet to demonstrate this, there is a consensus that utilizing an alternating irrigation regimen of NaOCl and EDTA may prove to be more effective in reducing bacterial loads in root canal systems than using NaOCl alone[100].

Antimicrobial agents, such as quaternary ammonium compounds (EDTAC)[101] or MTAD[102], have been incorporated into EDTA and citric acid irrigants, respectively, to enhance their ability to combat microorganisms. Nonetheless, the clinical significance of this practice remains uncertain. Although EDTAC exhibits comparable efficacy in removing smears compared to EDTA, it possesses a higher degree of causticity[97]. In the case of MTAD, bacteria isolated from root canals frequently exhibit resistance to tetracycline[103]. In general, the use of antibiotics, as opposed to biocides like hypochlorite or CHX, seems unjustifiable, as the former were primarily developed for systemic administration rather than localized wound debridement. Furthermore, antibiotics have a much narrower range of effectiveness compared to the latter[104].

One essential aspect regarding the currently accessible irrigation solutions, particularly EDTA and citric acid, is their powerful interaction with NaOCl[105]. Both citric acid and EDTA promptly diminish the chlorine readily available in the solution, thus rendering the NaOCl irrigant ineffective against bacteria and necrotic tissue[101]. Hence, the combination of citric acid or EDTA with NaOCl must be strictly avoided. The substances employed for disinfecting infected canals should be administered in a manner that enables them to fully exploit their potential on their intended targets within the root canal, rather than exerting an influence on one another.

Thus, it is crucial to employ a NaOCl solution during the instrumentation process, without incorporating any modifications such as the addition of EDTA or citric acid. It is essential to ensure that the canals are consistently filled with NaOCl, as this will effectively extend the duration of the irrigant's activity. In the intervals between instrument usage, it is recommended to irrigate the root canals using substantial quantities of the hypochlorite solution. Once the shaping procedure has been successfully executed, the root canals can be thoroughly cleansed by means of an aqueous solution containing EDTA or citric acid.

Generally, each canal is flushed for a minimum of one minute using a volume of 5 to 10 mL of the chelator irrigant. It is important to exercise caution, as extended exposure to potent chelators like EDTA could potentially compromise the integrity of the root dentin[106]. This is because the hardness and elastic modulus of dentin are influenced by the mineral composition of the dentin[107]. Following the procedure to remove smear layer, a concluding rinse with an antiseptic solution seems to offer advantages[108]. The choice of the ultimate irrigant is contingent upon the subsequent step in treatment, specifically whether an intervisit dressing is intended.

In this communication, we intended to provide a simple exposition of root canal irrigants that are cost-effective materials and currently accessible to the clinician. It is important to note that this does not preclude the existence of other biologically acceptable options for cleansing root canal systems. Nevertheless, it is crucial for the reader to acknowledge the tendency for novel concepts to be excessively praised in preliminary investigations, in contrast to the established benchmark[102].

CONCLUSION

This review concludes by highlighting the importance of selecting appropriate root canal irrigants based on their properties and applications. It emphasizes the need for careful consideration and precise application of these irrigants to ensure effective and safe endodontic procedures. The information presented serves as a guide for clinicians in choosing irrigants that meet the specific requirements of root canal treatments.

FOOTNOTES

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