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Review Article

A Contemporary Overview of Endodontic Irrigants – A Review

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Abstract

The goal of endodontic therapy is the removal of all vital or necrotic tissue, microorganisms, and microbial by-products from the root canal system. This may be achieved through chemomechanical debridement of root canal. In this review article, the specifics of the pulpal microenvironment and the resulting requirements for irrigating solutions are spelled out. Sodium hypochlorite solutions are recommended as the main irrigants. This is because of their broad antimicrobial spectrum as well as their unique capacity to dissolve necrotic tissue remnants. Chemical and toxicological concerns related to their use are discussed, including different approaches to enhance local efficacy without increasing the caustic potential. In addition, chelating solutions are recommended as adjunct irrigants to prevent the formation of a smear layer and/or remove it before filling the root canal system. Along with traditional irigants, newer irrigants are also studied for potential replacement of sodium hypochloride. This article reviews the potential irrigants with their advantages and limitations with their future in endodontic irrigation. Based on the actions and interactions of currently available solutions, a clinical irrigating regimen is proposed. Furthermore, some technical aspects of irrigating the root canal system are discussed, and recent trends are critically inspected.

Keywords: Root canal irrigants; Sodium hypochlorite; Chelators; Chlorhexidine; Iinteractions; E.Faecalis

Introduction

The goal of endodontic therapy is the removal of all vital or necrotic tissue, microorganisms, and microbial by-products from the root canal system. This may be achieved through chemomechanical debridement of root canal. The root canal system is highly complex and variable and has limited our ability to clean and disinfect it predictably. Shaping of root canals is performed almost entirely by using hand and rotary instrumentation techniques [1]. Peters et al. [2] using micro computed tomography scans before and after mechanical instrumentation found that, regardless of the instrumentation technique, 35% or more of the root canal surfaces (including canal fins, isthmi and cul-de-sacs)remained uninstrumented. Therefore, irrigation is an essential part of root canal debridement because it allows for cleaning beyond what might be achieved by root canal instrumentation alone. In addition to disinfection, irrigants can also help remove the smear layer from the radicular wall. For this review article we performed a Medline search for all English-language articles published from January 2006 to March 2014. We used the keywords 'root canal irrigants' and 'endodontic irrigants' and mainly the META analysis and systemic review were included.

Characteristics of an ideal endodontic irrigant [3].

1. Effective germicide and fungicide.
2. Non-irritating to the periapical tissues.
3. Stable in solution.
4. Prolonged antimicrobial effect and a sustained antibacterial effect after use.
5. Active in the presence of blood, serum, and protein derivatives of tissue.
6. Able to completely remove the smear layer.
7. Low surface tension.
8. Able to disinfect the dentin/dentinal tubules.
9. Does not interfere with repair of periapical tissues.
10. Does not stain tooth structure?
11. Inactivation in a culture medium.
12. Does not induce a cell-mediated immune response. Is non antigenic, non toxic, and non-carcinogenic to tissue cells surrounding the tooth.
13. Has no adverse effects on the physical properties of exposed dentin.
14. Has no adverse effect on the sealing ability of filling materials.
15. Easy to use/apply.
16. Inexpensive.

Classification of the commonly used irrigating solutions

A) Instrumentation auxiliary substances (used during instrumentation, do not needs the optimal physical properties, only the chemical one)

- NaOCl (Sodium Hypochlorite)

- CHX (Chlorhexidine)

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- EDTA (Ethylene Diamine Tetra Acetic Acid)

- Qmix

B) Irrigating substances (Used during irrigation aspiration procedure, have optimal physical properties, such as lower tension surface and lower viscosity).

- NaOCl,

- Saline,

- Distilled Water

- MTAD (Mixture of Tetracycline, Acid and Detergent)

- Tetraclean

- Qmix

- Herbal Alternatives – Green Tea, Triphala.

However, there is currently no unique irrigant that meets all of the requirements for an optimal irrigating solution [4-16]. Using a combination of products in the correct irrigation sequence and technique contributes to a successful treatment outcome.

This article summarizes the chemistry, biology, and procedures for safe and efficient irrigation and provides cutting-edge information on the most recent developments.

NaOCl

Of all the currently used substances, sodium hypochlorite appears to be the most ideal, as it covers more of the requirements for endodontic irrigant than any other known compound.

Natural Occurrence

Chlorine is one of the most widely distributed elements on earth. It is not found in a free state in nature, but exists in combination with sodium, potassium, calcium, and magnesium.

History

Potassium hypochlorite was the first chemically produced aqueous chlorine solution, invented in France by Berthollet (1748-1822). Starting in the late 18th century, this solution was industrially produced by Percy in Javel near Paris, hence the name "Eau de Javel". First, hypochlorite solutions were used as bleaching agents. Subsequently, sodium hypochlorite was recommended by Labarraque to prevent childbed fever and other infectious diseases. Based on the controlled laboratory studies by Koch and Pasteur, hypochlorite then gained wide acceptance as a disinfectant by the end of the 19th century. In World War I, the chemist Henry Drysdale Dakin and the surgeon Alexis Carrel extended the use of a buffered 0.5% sodium hypochlorite solution to the irrigation of infected wounds, based on Dakin's meticulous studies on the efficacy of different solutions on infected necrotic tissue [5,17]. Beside their wide-spectrum, nonspecific killing efficacy on all microbes, hypochlorite preparations are sporicidal, virucidal, and show far greater tissue dissolving effects on necrotic than on vital tissues. These features prompted the use of aqueous sodium hypochlorite in endodontics as the main irrigant as early as 1920. Furthermore, sodium hypochlorite solutions are cheap, easily available, and demonstrate good shelf life. Other chlorine-releasing compounds have been advocated in endodontics, such as chloramine-T and sodium dichloroisocyanurate. These, however, have never gained wide acceptance in endodontics, and appear to be less effective than hypochlorite at comparable concentration [5].

Mechanism of action

Pécora et al. reported that NaOCl exhibits a dynamic balance as is shown by the reaction [18].

$NaOCl + H_2O \leftrightarrow NaOH + HOCl \leftrightarrow Na^+ + OH^- + H^+ + OCl^-$

The chemical reactions between organic tissue and NaOCl are shown in Schemes [1–3] [18,19]:

SCHEME 1: SAPONIFICATION REACTION

O O

|| ||

R – C – 0 – R + NaOH ↔ R – C – 0 – Na + R – OH

Fatty acid Sodium Soap Glycerol

Hydroxide

Estrela reported that NaOCl exhibits a balance that acts as an organic and fat solvent degrading fatty acids, transforming them into salts (soap) and glycerol (alcohol), that reduces the surface tension of the remaining solution (saponification reaction) [20].

SCHEME 2 : Amino acid neutralization reaction

H O H O

| ‖ | ‖

R – C – 0 – C + NaOH ↔ R – C – 0 – C + $H_2$0

| |

NH_2OH NH_2ONa

amino acid sodium salt water

hydroxide

NaOCl neutralizes amino acids forming water and salt [Scheme 2]. With the exit of hydroxyl ions, there is a reduction of pH.

SCHEME 3: Chloramination reaction

H O Cl O

| ‖ | ‖

R – C – 0 – C + HOCl ↔ R – C – 0 – C + $H_2$0

| |

NH_2OH NH_2ONa

amino acid Hypochlorous Chloramine water

acid

When hypochlorous acid, a substance present in NaOCl solution, comes in contact with organic tissue it acts as a solvent and releases chlorine, which combines with the protein amino group to form chloramines that interfere in cell metabolism. [Scheme 3]. Hypochlorous acid (HOCl–) and hypochlorite ions (OCl–) lead to amino acid degradation and hydrolysis [20].

Thus, the saponification, amino acid neutralization, and chloramination reactions that occur in the presence of microorganisms and organic tissue lead to the antimicrobial effect and tissue dissolution process [20].

Antimicrobial property – Concentration and time

Hypochlorite preparations are sporicidal and virucidal and show far greater tissue dissolving effects on necrotic than on vital tissues. These features prompted the use of aqueous sodium hypochlorite in endodontics as the main irrigant as early as 1920. NaOCl was moderately effective against bacteria but less effective against endotoxins in root canal infection [21]. There has been much controversy over the concentration of hypochlorite solutions to be used in endodontics.

The presence of organic matter (inflammatory exudate, tissue remnants, microbial biomass) weakens its effect. NaOCl in higher concentrations has a better tissue-dissolving ability, but even in lower concentrations when used in high volumes it can be equally effective [22,23]. Higher concentrations of NaOCl are more toxic than lower concentrations [24]; however, due to the confined anatomy of the root canal system, higher concentrations have successfully been used during root. It must be realized that continuous irrigation to all areas of the root canal for optimum time is important factor (rather than concentration) for the effectiveness of hypochlorite. Based on the currently available evidence, there is no rationale for using hypochlorite solutions at concentrations over 1% wt/vol.

Tissue dissolution capacity

Hypochlorite has the unique capacity to dissolve necrotic tissue [25-27]. It depends on its concentration, temperature & time of application.

Biofilm

If thick layers of biofilm grow on predentin, they may interfere with the effectiveness of NaOCl irrigation in these areas.

Effect on dentin

When NaOCl is used as the first irrigant, the hydroxyapatite coating on collagen seems to protect the collagen fibers and the effect of the NaOCl on dentin is limited. However, when decalcifying solution is used, the hydroxyapatite is quickly dissolved exposing the underlying collagen fibers. If NaOCl is used again at this stage, it can directly attack the protein (collagen) and in a relatively short time cause considerably destruction of the collagen of surface dentin which impairs flexural and elastic strength of dentin [28]. Recently, it has been shown by in vitro studies that long-term exposure of dentin to a high concentration sodium hypochlorite can have a detrimental effect on dentin elasticity and flexural strength. This Short-term irrigation with hypochlorite after EDTA or CA at the end of chemomechanical preparation causes strong erosion of the canal-wall surface dentin [6].

Increasing the efficacy of NAOCL

Possible ways to improve the efficacy of sodium hypochlorite preparations in tissue dissolution are the temperature of the solutions, ultrasonic activation, and prolonged working time [5].

Temperature

One alternative approach to improve the effectiveness of hypochlorite irrigants in the root canal system could be to increase the temperature of low-concentration NaOCl solutions. This improves their immediate tissue-dissolution capacity. The capacity of a 1% NaOCl at 45°C to dissolve human dental pulps was found to be equal to that of a 5.25% solution at 20°C [29]. The systemic toxicity of preheated NaOCl irrigants is lower than the one of more concentrated nonheated counterparts

Altering the pH[4]

The antibacterial properties and tissue-dissolving properties of 5.25% NaOCl decrease when it is diluted [14–16]. When NaOCl is added to water, the following reaction takes place:

$NaOCl + H2O \rightarrow NaOH + HOCl$ (hypochlorous acid) (1)

In aqueous solution, hypochlorous acid partially dissociates into the anion hypochlorite (OCl–):

$HOCl \leftrightarrow H+ OCl-$ (2)

HOCl is considered to be a stronger oxidant than the hypochlorite ion. HOCl dissociation [Equation 2] depends on pH, with the clinical equilibrium between HOCl and OCl– being maintained as HOCl is consumed through its germicidal function. At pH 10, basically all chlorine is in the OCl– form; the reverse occurs at a pH of 4.5, when all chlorine is in the form of HOCl. The disinfecting properties decrease with higher pH, paralleling the concentration of dissociated HOCl. Hypochlorites at a lower pH possess greater antimicrobial activity.

Mechanical agitation

The impact of mechanical agitation of the NaOCl solutions on tissue dissolution was found to be very important by Moorer & Wesselink who emphasized the great impact of violent fluid flow and shearing forces caused by ultrasound on the ability of NaOCl to dissolve tissue [22].

Surface tension

Some investigators have proposed adding a biocompatible surfactant (e.g. polysorbate) to sodium hypochlorite, so as to lower its surface tension and improve its penetrative ability in canal but this concept was no more accepted [30].

Ultrasonic

The use of ultrasonic agitation increased the effectiveness of 5% NaOCl in the apical third of the canal wall [31] as this would "accelerate chemical reactions, create cavitational effects, and achieve a superior cleansing action" [32]. If ultrasonic activation of the hypochlorite irrigant is to be used, it appears important to apply the ultrasonic instrument after the canal preparation has been completed. A freely oscillating instrument will cause more ultrasound effects in the irrigating solution than a counterpart that binds to canal walls (122) [33]. Passive ultrasonic irrigation with a nickel-titanium tip produced superior tissue-dissolving effects as compared to sonic irrigant activation [34].

Effect on resin bonding

The reduction of the bond strength seen between adhesive systems and dentin walls may be because of the removal of collagen fibrils from the dentin surface by NaOCl, impeding the formation of a consistent hybrid layer [35]. It requires a reversal agent (ascorbic acid or sodium ascorbate) because of its ability to affect the polymerization of the resin sealer [36,37].

Interaction of NaOCl and chlorhexidine

The reaction between NaOCl and CHX produces a carcinogenic product, parachloroanaline (PCA), the potential leakage of which into the surrounding tissues is a concern. The presence of PCA was confirmed by the Beilstein test for the presence of chlorine and the HCl solubility test for the presence of aniline. This reaction coats the canal surface and significantly occludes the dentinal tubules and affects the seal of the root canal [38].

A study conducted by Mortenson D et al in 2012 on the effect of using an alternative irrigant between sodium hypochlorite and chlorhexidine to prevent the formation of para-chloroaniline within the root canal system concluded that citric acid used as the intermittent irrigant had the least amount of PCA formation in the canal system as compared to sterile saline and EDTA [39].

Interaction of NaOCl & EDTA

Grawehr concluded that EDTA retained its calcium complexing ability when mixed with NaOCl, but however it instantaneously reduces the amount of chlorine of NaOCl & ultimately NaOCl loses its tissue-dissolving capacity [40]. Short-term irrigation with hypochlorite after EDTA or CA at the end of chemomechanical preparation causes strong erosion of the canal-wall surface dentin [6].

Interaction with H_2O_2

Many clinicians mix NaOCl with hydrogen peroxide for root-canal irrigation. Despite more vigorous bubbling, the effectiveness of the mixture has not been shown to be better than that of NaOCl alone [41].

As a final rinse

As a final sodium hypochlorite rinse after EDTA increase erosion of dentin, it is not recommended.

Safety

Several mishaps during root canal irrigation range from damage to the patient's clothing, splashing the irrigant into the patient's or operator's eye, injection through the apical foramen, and allergic reactions to the irrigant, to inadvertent use of an irrigant as an anesthetic solution were described [42].

Furthermore, sodium hypochlorite solutions are cheap, easily available, and demonstrate good shelf life [43].

EDTA

Complete cleaning of the root-canal system requires the use of irrigants that dissolve organic and inorganic material. As hypochlorite is active only against the former, other substances must be used to complete the removal of the smear layer and dentin debris. In addition, calcifications hindering mechanical preparation are frequently encountered in the canal system. Demineralizing agents such as ethylenediamine tetraacetic acid (EDTA) [44] and citric acid [45] have therefore been recommended as adjuvants in root canal therapy. Chelating agents were introduced into endodontics as an aid in preparation of narrow and decalcified canals by Nygaard –Ostby in 1957 who recommended the use of 15% EDTA at pH 7.3.

Mechanism of action

EDTA reacts with the calcium ions in dentine and forms soluble calcium chelates. It has been reported that EDTA decalcified dentin to a depth of 20–30 µm in 5 min [46]. The decalcifying process is self-limiting, because the chelator is used up.

Smear layer

A continuous rinse with 5 ml of 17% EDTA, as a final rinse for 3 min efficiently removes the smear layer from root canal walls [47]. EDTA is most commonly used as a 17% neutralized solution (disodium EDTA, pH 7), but a few reports have indicated that solutions with lower concentrations (eg, 10%, 5%, and even 1%) remove the smear layer equally well after NaOCl irrigation.

Biofilm

In addition to their cleaning ability, chelators may detach biofilms adhering to root canal walls.

Dentinal property

Calt and Serper demonstrated that 10 mL irrigation with 17% EDTA for 1 minute was effective in removal of smear layer, but a 10-minute application caused excessive peritubular and intertubular dentinal erosion [48]. Increasing contact time and concentration of EDTA from 10% to 17% as well as a pH of 7.5 versus pH 9.0 has been shown to increase dentin demineralization.

Ultrasonics

A 1-min application of 17% EDTA combined with ultrasonics is efficient for smear layer and debris removal in the apical region of the root canal [49].

Form

Although there are no comparative studies about the effectiveness of liquid and gel products to demineralize dentin, it is possible that the small volume of the root canal (only a few microliters) contributes to a rapid saturation of the chemical and thereby loss of effectiveness. In such situations, the use of liquid products and continuous irrigation should be recommended [5,50].

Interaction with CHX

CHX is not degraded by EDTA under normal conditions. The precipitate is most likely a salt formed by electrostatic neutralization of cationic CHX by anionic EDTA. The suspected net ionic equation is:

$$2HEDTA^{3-}{}_{(aq)} + 3H_2CHX^{2+}{}_{(aq)} \leftrightarrow (HEDTA)_2(H_2CHX)_{3(S)}$$

The clinical significance of this precipitate is largely unknown [51]. It seems that the ability of EDTA to remove the smear layer is reduced.

Citric acid (CA)

CA is also marketed and used in various concentrations, ranging from 1% to 50%.

Smear layer

The use of 10% citric acid as final irrigation has shown good results in smear layer removal [52]. Although citric acid appears to be slightly more potent at similar concentration than EDTA, both agents show high efficiency in removing the smear layer [53].

Cytotoxicity

In vitro studies have shown their cytotoxicity, and 10% citric acid has proven to be more biocompatible than 17% EDTA [54,55].

Antimicrobial action

The use of 25% citric acid was found to be ineffective in eradication of biofilms of E faecalis after 1, 5, and 10 min of exposure [56].

HEBP

Hydroxyethylidene bisphosphonate (HEBP) (1-hydroxyethylidene- 1, 1-bisphosphonate), also known as etidronic acid or etidronate, is a decalcifying agent that shows only little short-term interference with sodium hypochlorite. It has recently been suggested as a possible alternative to citric acid or EDTA [53,57]. HEBP prevents bone resorption and is used systemically in patients suffering from osteoporosis or Paget's disease [58]. However, whether this agent will improve or abbreviate endodontic irrigation will have to be shown in future studies. The demineralization kinetics promoted by both 9% HEBP and 18% HEBP were significantly slower than those of 17% EDTA [59]. De-Deus et al. reported that the soft chelating irrigation protocol (18% HEBP) optimized the bonding quality (3.1–6.1 MPa) of Resilon/Epiphany® [60].

Chlorhexidine

Chlorhexidine is a potent antiseptic, which is widely used for chemical plaque control in the oral cavity [61]. Aqueous solutions of 0.1 to 0.2% are recommended for that purpose, while 2% is the concentration of root canal irrigating solutions usually found in the endodontic literature [36].

Structure and mechanism of action

CHX is a synthetic cationic bis-guanide that consists of two symmetric 4-chlorophenyl rings and two biguanide groups connected by central hexamethylene chains.

CHX is a positively charged hydrophobic and lipophilic molecule that interacts with the negatively charged phosphate groups on microbial cell walls [62,63], which alters the cells' osmotic equilibrium. As a consequence, the cytoplasm becomes congealed, with resultant reduction in leakage. CHX antimicrobial activity is pH dependant, with the optimal range being 5.5–0.7 [64]. CHX at low concentration will result in bacteriostatic effect but at higher concentrations, it is bactericidal due to extensive cell damage, coagulation of cytoplasm, and precipitation of proteins and nucleic acids [65].

Form

CHX is marketed as a water-based solution and as a gel (with Natrosol). Some studies have indicated that the 2% CHX gel has a slightly better performance than the 2 % CHX liquid.[66] This has been found to be more effective in the least time.

Antimicrobial activity

CHX is active against Gram-positive and Gram-negative bacteria, bacterial spores, lipophilic virus, yeast, and dermatophytes [67]. The antimicrobial action is related to type, concentration, and presentation form of the irrigants as well as the microbial susceptibility. In vivo, it inhibits experimentally induced inflammatory external root resorption when applied for four weeks [68].

CHX and bioflim

However, similar to other endodontic disinfecting agents, the activity of CHX depends on the pH and is also greatly reduced in the presence of organic matter [38]. Although bacteria may be killed by CHX, the biofilm and other organic debris are not removed by it.

Final rinse

2% CHX may be a good choice for maximized antibacterial effect at the end of the chemomechanical preparation [69].

Intracanal medicament (With CaOH)

It has gained considerable popularity in endodontics as an irrigating solution and as an intracanal medicament with $Ca(OH)_2$.

Substantivity

One of the reasons for the popularity of CHX is its substantivity (ie, continued antimicrobial effect), because CHX binds to hard tissue and remains antimicrobial. Antimicrobial substantivity depends on the number of CHX molecules available to interact with the dentine [70]. White et al. evaluated the antimicrobial substantivity of a 2% CHX solution as an endodontic irrigant and reported that the substantivity lasted 72 h to upto 12 weeks [71,72].

Tissue dissolution capacity

Chlorhexidine gluconate has been recommended as a root canal irrigant because of its broad spectrum antimicrobial action, substantivity and low toxicity. However, CHX's incapacity of tissue dissolution has been pointed out as its major disadvantage. Some attempts have been made to evaluate the activity of CHX to dissolve organic matter, demonstrating that both preparations of this substance, aqueous solution or gel, were not able to dissolve pulp tissues [73].

CHX and dentin bonding (Anticollagenolytic Activity)

CHX known to have a broad-spectrum MMP inhibitory effect [74] & so significantly improved the integrity of the hybrid layer in a 6-month clinical trial. Adsorption of CHX by dentin improves the resin infiltration in dentinal tubules and thereby increasing bond strength.

CHX and coronal microleakage

Canals medicated with CHX alone or in combination with CH retard the entrance of microorganisms through the coronal portion of the tooth into the root canal system, due to its wide antimicrobial activity and substantivity. Such a finding is interesting, especially if the coronal restoration becomes defective or if it is lost.

CHX and apical fluid penetration

Canals irrigated or medicated with CHX do not affect negatively the ability of root fillings to prevent fluid penetration into the root canal system through the apical foramen.

Cytotoxicity of CHX

The toxic potency of CHX is dependent on the length of exposure and the composition of the exposure medium [75]. While Chlorhexidine does not appear to cause any long-term damage to host tissues, it may still cause an inflammatory response in these tissues if expressed beyond root canal.

Allergic reactions to CHX

CHX may have a number of rare side effects, such as desquamative gingivitis, discoloration of the teeth and tongue, or dysgeusia [70].

Temperature

As with sodium hypochlorite (see below), heating a chlorhexidine irrigant of lesser concentration could increase its local efficacy in the root canal system while keeping the systemic toxicity low [76].

Disinfection of obturation cones

Comparing the two solutions, CHX was a better disinfectant compared with NaOCl, that is, presented high values of surface free energy. Cones disinfected with CHX presented smaller contact angles than NaOCl, favoring the interaction between the solid surface (cone) and the liquid, in this case, the sealer (144).

Versions

The antibacterial activity of a chlorhexidine product with surface-active agents (CHX-Plus have shown superior killing of planktonic and biofilm bacteria by the combination product [77,78]. There are no studies about whether adding surface-active agents increases the risk of the irrigants escaping to the periapical area in clinical use.

Q MIX

Q mix is an irrigation solution used as a final rinse. It is a combination of CHX with EDTA and a surfactant solution to improve penetration in dentinal tubules. It is in the market for very short time, so, there is no research available yet.

MTAD

It was introduced as an alternative to EDTA to remove the smear layer by Torabinejad et al. It is a mixture of 3% doxycycline, 4.25% citric acid and detergent-Tween 80. It has a combined chelating and antibacterial properties [79]. They do not dissolve organic tissue and are intended for use at the end of chemomechanical preparation after sodium hypochlorite.

Antibacterial activity and smear layer removal

MTAD is composed of three constituents that are expected to act synergistically against bacteria [79]. The bactericidal effect of MTAD was inferior to 1%–6% NaOCl against E faecalis biofilms [80]. The antibacterial activity of MTAD might also be inhibited by the buffering effect of dentin and the serum albumin present in the root canal [81]. In the MTAD preparation, the citric acid may serve to remove the smear layer, allowing doxycycline to enter the dentinal tubules and exert an antibacterial effect [82].

Final rinse

The recently revised protocol for clinical use of MTAD advises an initial irrigation for 20 min with 1.3% NaOCl, followed by a 5-min final rinse with MTAD [82].

Bond strength

The use of MTAD as a final rinse with gutta-percha/AH Plus® resulted in a significant reduction in bond strength (1.76±1.67 Mpa) when compared with EDTA [83] due to the precipitate formation [84].

As for MTAD, resistance to tetracycline is not uncommon in bacteria isolated from root canals [85]. Generally speaking, the use of antibiotics instead of biocides such as hypochlorite or chlorhexidine appears unwarranted, as the former were developed for systemic use rather than local wound debridement, and have a far narrower spectrum than the latter [86].

Tetraclean

Tetraclean (Ogna Laboratori Farmaceutici, Muggiò (Mi), Italy), like MTAD, is mixture of an Citric Acid, doxycycline, and a detergent. However, the concentration of the antibiotic (doxycycline-50 mg/ml), and the type of detergent (polypropylene glycol) differ from those of MTAD [15]. Tetraclean is a mixture of doxycycline hyclate (at a lower concentration than in MTAD), an acid, and a detergent [15,79]. They do not dissolve organic tissue and are intended for use at the end of chemomechanical preparation after sodium hypochlorite.

Antimicrobial action

It shows a high action against both, strictly anaerobic and facultative anaerobic bacteria [87]. It is also more effective than MTAD against E. faecalis in planktonic culture and in mixed species in vitro biofilm [88].

Comparative studies on MTAD and Tetraclean have indicated better antibacterial effects by the latter [89].

Smear layer

It is able to eliminate microorganisms and smear layer in dentinal tubules of infected root canals with a final 5-min rinse.

Surface tension

It has low surface tension which enables a better adaptation of the mixtures to the dentinal walls. 37

Maleic Acid

Maleic acid is a mild organic acid used as an acid conditioner in adhesive dentistry [90]. It efficiently removes the smear layer at 5% and 7% concentration. However, at 10% or more concentration it can result in demineralization and damage to root canal wall.34 Ballal et al. reported that final irrigation with 7% maleic acid for 1 min was more efficient than 17% EDTA in the removal of smear layer from the apical third of the root canal system [90]. Also 7% Maleic acid produces maximum surface roughness on root canal walls as compared to 17% EDTA. This surface roughness produces an important role in micromechanical bonding of resin sealers [91]. However, the technique of use and biologic effects of Maleic acid on periapical tissues needs evaluation, before it is routinely employed for clinical use.

Chlorine Dioxide

Chlorine dioxide (ClO2) is chemically similar to chlorine or hypochlorite, the familiar household bleach. An In vitro study compared organic tissue dissolution capacity of NaOCl and ClO2. It was concluded that ClO2 and NaOCl are equally efficient for dissolving organic tissue [92]. ClO2 produces little or no trihalomethanes [93]. A study showed that trihalomethane is an animal carcinogen and a suspected human carcinogen [94]. ClO2 might therefore be a better dental irrigant than NaOCl [95].

Silver Diamine Fluoride

A 3.8% w/v silver diamine fluoride ($Ag[NH_3]_2F$) solution has been developed for intracanal irrigation. This represents a 1:10

dilution of the original 38% Ag $[NH_3]_2F$ solution used for root canal infection [96]. The study on the antibacterial effect of 3.8% Ag $[NH_3]_2F$ against a E faecalis biofilm model concluded that $Ag[NH_3]_2F$ for 60 min has potential for use as an antimicrobial root canal irrigant or interappointment medicament to reduce bacterial loads [97]. The silver deposits were found to occlude tubular orifices after removal of the smear layer.

Triclosan and Gantrez

Triclosan is a broad spectrum antimicrobial agent, active against gram-positive and gram-negative bacteria as well as some fungi and viruses [98,99]. Nudera et al. evaluated the minimum inhibitory concentrations (MIC) and minimum bactericidal concentrations (MBC) of triclosan and triclosan with Gantrez® against P intermedia, F nucleatum, A naeslundii, P gingivalis, and E faecalis [100]. The MBC of triclosan ranged from 12–94 µg/ml. The MBC of triclosan with Gantrez® ranged from <0.3–10.4 µg/ml. The addition of Gantrez® enhanced the bactericidal activity of triclosan. Both triclosan and triclosan with Gantrez® demonstrated bactericidal activity against the five specific endodontic pathogens.

Herbal

Triphala

Triphala consists of dried and powdered fruits of three medicinal plants Terminalia bellerica, Terminalia chebula, and Emblica officinalis [101]. Triphala achieved 100% killing of E faecalis at 6 min. This may be attributed to its formulation, which contains three different medicinal plants in equal proportions; in such formulations, different compounds may help enhance the potency of the active compounds, producing an additive or synergistic effect [102]. Triphala contains fruits that are rich in citric acid, which may aid in removal of the smear layer. The major advantages of using herbal alternatives are easy availability, cost-effectiveness longer shelf life, low toxicity, and lack of microbial resistance [103].

Green tea

Green tea polyphenols, the traditional drink of Japan and China is prepared from the young shoots of the tea plant Camellia sinensis [104]. Green tea polyphenols showed statistically significant antibacterial activity against E faecalis biofilm formed on tooth substrate. It takes 6 min to achieve 100% killing of E faecalis [102].

Dimethyl sulfoxide (DMSO) is used as a solvent for Triphala and GTP, although they are readily soluble in water. DMSO is a clean, safe, highly polar, aprotic solvent that helps in bringing out the pure properties of all the components of the herb being dissolved [105,106].

Although Triphala and green tea polyphenols (GTPs) exhibited similar antibacterial sensitivity on E. faecalis planktonic cells, Triphala showed more potency on E. faecalis biofilm. This may be attributed to its formulation, which contains three different medicinal plants in equal proportions. In such formulations, different compounds may be of help in enhancing the potency of the active compounds resulting in an additive or synergistic positive effect. According to Prabhakar et al. 5% of sodium hypochlorite exhibited excellent antibacterial activity in both 3-week and 6-week biofilm, whereas Triphala and MTAD showed complete eradication only in 3-week biofilm [102].

Triphala and GTPs are proven to be safe, containing active constituents that have beneficial physiologic effect apart from its curative property such as antioxidant, antiinflammatory, and radical scavenging activity and may have an added advantage over the traditional root canal irrigants [107-110].

Morinda citrifolia

Morinda citrifolia (MCJ) has a broad range of therapeutic effects, including antibacterial, antiviral, antifungal, antitumor, antihelmintic, analgesic, hypotensive, antiinflammatory, and immune-enhancing effects [110-113]. MCJ contains the antibacterial compounds L-asperuloside and alizarin [113]. Murray et al. proved that, as an intracanal irrigant to remove the smear layer, the efficacy of 6% MJC was similar to that of 6% NaOCl in conjunction with EDTA [113]. The use of MCJ as an irrigant might be advantageous because it is a biocompatible antioxidant and not likely to cause severe injuries to patients as might occur through NaOCl accidents [113].

Electrochemically Activated Solutions

Electrochemically Activated (ECA) solutions are produced from tap water and low-concentrated salt solutions [114-116].

Electrochemical treatment in the anode and cathode chambers results in the synthesis of two types of solutions: that produced in the anode chamber is termed an Anolyte, and that produced in the cathode chamber is Catholyte. Anolyte solutions containing a mixture of oxidizing substances demonstrate pronounced microbiocidal effectiveness against bacteria, viruses, fungi, and protozoa [114,117]. Anolyte solution has been termed Superoxidized Water or Oxidative Potential Water [118-119]. Acidic anolyte was used initially but in recent years the neutral and alkaline solutions have been recommended for clinical application. Under clean conditions, freshly generated superoxidized solution was found to be highly active against all these microorganisms giving a 99.999% or greater reduction in two minutes or less. That allowed investigators to treat it as a potent microbiocidal agent [118,120]. It is nontoxic when being in contact with vital biological tissues [121,122]. The quality of debridement was better in the coronal and middle parts of canal walls where only scattered debris was noted in the apical part [123]. Solovyeva and Dummer studied the cleaning effectiveness of root canal irrigation with ECA solution and found that it was more effective than NaOCl in smear layer removal [114]. ECA is showing promising results and the potential to be an efficient root canal irrigant.

Ozonated Water

Ozone (O3) at low concentration, 0.1 ppm, is sufficient to inactivate bacterial cells including their spores [124]. It can be easily produced by ozone generator. When introduced in water, ozone dissolves rapidly and dissociates rather quickly. The concentration of ozone in ozonated water can be measured using a dissolved ozone meter.

Nagayoshi et al. found that killing ability of ozonated water and 2.5% of sodium hypochlorite was almost comparable when the specimen was irrigated with sonication [125]. Ibrahim and Abdullah studied that 1.31% NaOCI might allow passage of oxidation of ozonated water, thus increasing their antibacterial effect compared to 1.31% NaOCI or ozonated water alone [126,127]. Cardoso concluded that ozonated water was not able to neutralize E. coli and lipopolysaccharide (LPS) inside root canals and the remaining amount of LPS may have biological consequences such as apical periodontitis. There is need for further studies and modifications in ozonated water before it could be used as a root canal irrigant.

Suggested irrigation regimen

A hypochlorite solution should be employed throughout instrumentation, without altering it with EDTA or citric acid. Between instruments, canals should be irrigated using copious amounts of the hypochlorite solution. Once the shaping procedure is completed, canals can be thoroughly rinsed using aqueous EDTA or citric acid. Generally each canal is rinsed for at least 1 min using 5 to 10ml of the chelator irrigant. After the smear layer removal procedure, a final rinse with an antiseptic solution appears beneficial. Chlorhexidine appears to be the most promising agent for use as a final irrigant in this situation. It has an affinity for dental hard tissues and, once bound to a surface, it has prolonged antimicrobial activity, a phenomenon called substantivity. After the introduction of MTAD irrigant, newer irrigating regimen followed was initial rinse with 1.3% NaOCl for 20 min and followed by final rinse with MTAD for 5 min. Future research on irrigants needs to focus on finding a single irrigant that has tissue dissolving capacity, smear layer removal property, and antibacterial efficacy.

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