Review Article

The Advancement in irrigation solution within the field of endodontics, A Review

Fatima Fahad [1], Raghad Abdulrazzaq Al-Hashimi [2*], Munther Jaffar Hussain [3]

1 Ministry of health, Baghdad, Iraq
2 Professor, Department of Conservative Dentistry, Faculty of Dentistry, University of Baghdad, Baghdad, Iraq. Bab-Almoadham, P.O. Box 1417, Baghdad, Iraq.
2 Faculty of life science and Medicine Kings college london, UK
*Corresponding author: Raghadalhashimi@codental.uobaghdad.edu.iq

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Abstract: The purpose of endodontic treatment is to eliminate all germs, microbial by-products, and vital tissues from the root canal system. Root canals can be mechanically and chemically used for this purpose. The needs and details of the irrigation solutions are described in this article. Because of its wide range of antibacterial activities and its ability to dissolve organic tissues, sodium hypochlorite is suggested as the main irrigation. On the contrary, chelation solutions are recommended as supplemental treatments to either eliminate the smear layer or prevent it from forming on the dentin surface. Data: Only articles that were published electronically were searched within the review. Sources: 'Google Scholar' and "Pub-med" websites were used to search data, The most papers related to the topic were chosen, specifically original articles , including only articles from 1999 to 2023.Journal papers that weren't published in a highly regarded publication, irrelevant studies, editorials, personal viewpoints, and social media sources were all disqualified from consideration. 98 articles were retained after the filtering procedure. In conclusion, this article reviews many types of new irrigations that may be used in endodontic practice in the future.

Keywords: antibacterial, biofilm, drawback, sodium hypochlorite.

Introduction

The primary aspect of cleaning is carried out by endodontic irrigation and cleaning of the mechanical root canal system, while instrumentation is mostly a method of gaining access to the apical structure (1). The two biggest obstacles to irrigation are the complexity of human anatomy and the existence of bacteria as surface-attached biofilm formations for irrigation (2).

The biofilm growth mode has several benefits compared to its planktonic counterparts, such as increased resistance to antimicrobial agents (2). The antibacterial effect is influenced by several factors. Resistance of extracellular polymeric substances (EPS) blocks the dispersion of and prevents penetration of the antimicrobial activity [2]. When nutrients are scarce, cells enter a slow-growing or starving metabolic state in the inner layers, reducing their susceptibility to antimicrobial agents. Existing 'persisted cells' exhibit a phenotype that is extremely persistent when in contact with antimicrobial agents(1). The numerous and diverse bacteria allow the transfer of genes that can result in antibiotic and antimicrobial resistance (1).

Numerous types of bacteria are found in biofilms, forming a diverse community. Although it is one of the most commonly isolated species in the community, Enterococcus faecalis may be a factor in persistent endodontic infections due to its built-in antibacterial properties (3, 4). Capacity for resistance to invasion and flexibility in coping with extreme environmental changes. The penetration tubules in the root are challenging to treat because they are protected from endodontic irrigation (5).

Endodontic irrigations including sodium hypochlorite (NaOCl), ethylenediaminetetraacetic acid (EDTA), chlorhexidine (CHX) and MTAD have been tested for their antibacterial effectiveness against *E. faecalis* biofilms in a number of investigations, although EDTA is important in irrigation, it does not have antibacterial activity (3). The general goal is to reduce the bacterial burden to a subcritical level so that the injury can heal naturally as a result of the patient's immune system (5). The goal of endodontic research has always been to create techniques and endodontic irrigations that can completely eliminate bacterial biofilm entirely with the least possible negative effects (5).

NaOCl, the most popular root canal irrigation in the industry, provides a wide range of antibacterial action against microorganisms, as well as the capacity to eliminate organic components (5). However, as a result of its high surface tension, it might not be able to penetrate the depth within the dentinal tubule and reach bacteria there (6). It was given the name 'Eau de Javel' because Percy industrially introduced it close to Paris at Javel. As a disinfectant, NaOCl has had considerable acceptance since the turn of the twentieth century (7).

The first chlorine aqueous solution was created by Berthollet in France around the end of the 18th century(7). The weakness of sodium Hypochlorite NaOCl entering within dentinal tubules up to 300 micron depending on the contact time, concentration, and temperature. Bacteria can exist up to 1000 micrometres. Microorganisms can enter dentin tubules of surrounding tissues and root canal infection, acting as a reservoir to trigger reinfection (8). When its biological matrix, NaOCl may alter the mechanical characteristics of dentine, making it brittle. Collagen type 1, which makes up 22% of dentin, is the primary component of the hydrated organic matrix of dentin. The inorganic phase of carbonated apatite is embedded in collagen and contributes to its mechanical qualities. The proteolytic agent NaOCl, depending on its concentration, can remove carbonate ions from dentine, cause collagen depletion, leave hydroxyapatite unbounded, and result in a rich apatite subsurface with sparse collagen (9). The cytotoxicity of NaOCl is another flaw. The discomfort it causes as it passes through the apical foramen can be severe and linger for a while. When NaOCl is administered incorrectly, it can cause ecchymosis, paresthesia, tissue necrosis, and even potentially fatal accidents (10-11) .

Nanoparticles ,can be used in dentistry, because of their reactivity, special physicochemical characteristics ultrasmall diameters, high surface area to mass ratio, and improved chemical features, nanoparticles have sparked innovative research on the treatment and prevention of oral infections (6). Nanoantimicrobial agents are prospective agents to reduce the number of infections due to their ability to penetrate bacteria and the supporting structures of biofilms (5).

The purpose of this review is to focus on the irrigation of NaOCl and the possibility of using other materials to overcome the problem of NaOCl.

Methods search strategy

A thorough electronic search was carried out on the following websites: Google Scholar and the PubMed database. The most papers related to the topic were chosen, specifically the original articles, including only English-language articles from 1999 to 2023 by utilising the following keywords: short coming NaOCl, Nanoparticles, chitosan, propolis, types of irrigation. Journal articles that were not published in a highly regarded publication, irrelevant studies, editorials, personal views, and social media sources were disqualified from consideration. 96 articles were retained after the filtering procedure.

Factor effect on activity of irrigation solution

1. Viscosity

One of the most crucial variables related to the properties of fluid flow is dynamic viscosity. The low viscosity of a fluid, which is determined by temperature, means that it is easy to be widely recognised as key to be more effective. Few researchers have addressed this issue of viscosity of fluid of irrigation (12). As a typical liquid parameter, the coefficient of viscosity is affected by the makeup and temperature. This parameter defines the internal friction forces that exist between different layers of liquid under laminar flow circumstances. Laminar flow is defined as the absence of interruption between layers, while the fluid travels in parallel layers. This situation occurs when a liquid flows through a narrow conduit at moderate speed without creating vertices inside the liquid [13].

2. Temperature

The elimination of pulp and its remnants from the ability of the canal system depends on the irrigation solution to disintegrate tissue. The effectiveness of irrigation on pulp tissue may be enhanced by increasing its concentration or temperature. Exposing a substantial amount of the sample surface area to sodium Hypochlorite before submerging organic tissue samples in it could improve sodium hypochlorite's ability to dissolve organic tissue [14. 15]. Heating 1% hypochlorite to a high temperature enhances the substance's ability to destroy germs and dissolve tissue. As a result, low cytotoxic concentrations can be utilised effectively by preheating NaOCl syringes in a water bath prior to use. According to a previous study, 2.6% solutions of NaOCl at 37 ° C can be as effective as 5.2% at 22 ° C [16].

3. Surface tension

NaOCl has a high surface tension, which could alter its wettability because wettability depends on surface tension [17] . The solution can easily diffuse through a small dentinal tubule if its surface tension decreases. The solution may have entered the dentin tubules by capillary forces or diffusion/flow. By lowering the surface tension, different surface-active agent detergents can increase the wettability and bactericidal activity of antimicrobial solutions, allowing for improved irrigation adaptation to dentin and penetration into dentinal tubules [18]. When surface-active agents (surfactant) are introduced into solutions, a zero-degree contact angle is created, and the dentine surface spreads immediately [17].

4. Wettability

The capacity of liquids to spread, or wettability, is influenced by the surface tension and dentine characteristics of the liquid. Surfaces that are chemically homogeneous, flat, nonreactive, and undeformable are the best for wetting. The surface energy of the substrate must be high, and the surface tension of the liquid coming into contact with the substrate must be low to achieve ideal wettability. Heat can also be used to decrease surface tension [17]. Wettability is crucial for antimicrobial treatments to reach abnormalities in the root canal system and dentinal tubules [18].

5. Substantivity

A chemical solution for endodontic application should be sufficiently moist in the non-instrumented portions of the root canal to improve the the solvent capacity and improve antibacterial action. Substantivity Given its capacity to attach negatively charged of tooth surfaces. chlorhexidine (CHX) possesses a substantivity that can be released over time [19].

6. Volume

A high volume of NaOCl must be employed to achieve optimal cleaning and compensate for the chlorine loss that occurred during the interaction of NaOCl with pulpal tissues and bacteria within the root canal. This requirement causes irrigating flushing and improves debris effectiveness of the debridement created during the instrumentation procedure. The total duration of solution with root canal is directly correlates with the amount of germs and biofilms eliminated [20]. The complexity of the root canal provides additional support for increasing the volume and duration of the interaction of NaOCl with dentine to improve root canal disinfection [21]. The authors hypothesised that a particular NaOCl solution used with a contact duration (mean 26 min) causes 30% root weakening through its proteolytic effect. The increased length of contact and the volume of NaOCl cause a large amount of dentin to be proteolyzed. which increases the negative impact on the organic dentin scaffold and increases the susceptibility to root fractures [22].

7. Concentration

Higher NaOCl concentrations are more cytotoxic than lower ones, causing extensive irritation to the periapical tissue as a result of inevitable extrusions brought on by high apical extrusion of debris. Therefore, NaOCl concentration can influence the intensity of postoperative pain. A high concentration causes dentin erosion, collagen degradation, decalcification, deproteination, and stress on the tooth surface but lowers the elastic modulus, flexural strength, and micro-hardness of the dentin [23. 24].

8. Activation

Historically, irrigations are injected into the root canal using a syringe and needle. Various irrigation methods are available, including manual dynamic agitation with gutta-percha points or files, brushes, and dynamic agitation with gutta-percha. These methods are mechanical. Rotating irrigation systems are also used, including rotary brushes, sonic and ultrasonic devices, continuous watering through instrumentation, and the use of negative pressure irrigation [25]. When shaping and cleaning canals, flushing them with NaOCl lengthens the period that can be used for irrigation, thereby improving the effectiveness of the instrument's cutting action. Another method of improving root canal debridement is laser light, which causes canal bacteria to become fatally photosensitised [26].

Types of irrigations

Irrigation solutions were largely categorised into two categories: synthetic and natural.

1. Synthetic

Normal saline is a typical irrigating solution that is isotonic to bodily fluids and is used in surgical and endodontic operations. It is best used in conjunction with or between irrigation with other solutions, such as sodium hypochlorite NaOCl [27] without negative effects when injected into the periapical tissues. The most used endodontic solution is NaOCl due to its broad antibacterial spectrum action and its ability to dissolve organic tissue. Increases in pH, concentration, and temperature of solutions are required to enhance tissue dissolution by NaOCl [28].

EDTA, tetracycline, and citric acid are utilised as chelating agents to remove the inorganic components of the smear layer. NaOCl is used to remove organic components. The most popular technique for removing the smear layer involves using EDTA with a 17% solution for 1 min of irrigation; little or no bactericidal activity was detected in EDTA [29].

A new solution called Smear Clear was created to remove the smear layer (SybronEndo). It is comparable to the EDTA solution, but contains the cat ionic surfactant cetrimide. Compared to 17% EDTA and 10% citric acid, this novel product demonstrated the same capacity to remove the smear layer [30].

MTAD is a substitute for EDTA that has features similar to those offered by EDTA, such as the elimination of smear layers. Since tetracycline is an antibiotic, its fundamental distinction from EDTA is its antibacterial action. Citric acid provides MTAD with its ability to remove smear layers, and detergent is used in its formulation to lower the surface tension of the solution. When NaOCl solution is added to MTAD as a final rinse, it improves the ability to remove the smear layer. MTAD provides prolonged antimicrobial action, improves bond strength, and is a biocompatible solution [29].

Tetraclean is a type of irrigation. The ingredients in Tetraclean (Muggi'o (Mi), Italy) are the same as those of MTAD, with the exception of the type of antibiotic used, which is doxycycline at a concentration lower than that used for tetracycline, the type of detergent used (polypropylene glycol) as opposed to MTAD and the concentration of the acid used [18]. An irrigation called QMix 2in1 is a mixture of EDTA and CHX with an unidentified surfactant. It removes the smear layer as effectively as 17% EDTA [31]. Its antibacterial activity has also been discovered to be equivalent to that of CHX and NaOCl [32].

Chlorhexidine(CHX) solution is utilised for root canal disinfection because it causes less irritation than NaOCl and has substance, which is the ability to release an antibacterial agent continuously when bonded to dentin. It is not able to bleach or having a terrible odor. The fundamental concern with CHX is that it cannot disintegrate tissue [33]. Hydrogen peroxide(H_2O_2) is an odourless, colourless liquid that is transparent.

H_2O_2 is a peroxide that has antibacterial, antiviral, and antifungal properties. It produces hydroxyl free radicals, which can damage DNA and proteins in addition to other parts of the cell. As a result, H_2O_2 is popular for removing residual tissue and blood from pulp and sanitising it. Given that it is unstable and easily broken down by heat and light, H_2O_2 has the ability to quickly split into water and nascent oxygen (H_2O+O). The bactericidal effects of the released oxygen are momentary because they are weakened by the presence of organic waste. When H_2O_2 is in contact with organic tissue, the increased release of nascent oxygen causes bubbling, which helps with mechanical debridement. In mechanical debridement, H_2O_2 cannot eliminate the smear layer by itself [34].

Electrochemically activated solutions comprise anionic and cat ionic aqueous solutions. The apparatus is a custom-made electrolysis machine with an anode and a cathode chamber with built-in platinum electrodes. A proton-permeable membrane with 0.45-micron pore diameters is positioned between the two chambers to facilitate ion exchange during electrolysis. For a 50 ml chamber, electrolysis is carried out at 500 MA current and 10.8V DC for 8–20 min. The solutions that fill the two chambers are as follows. The first solution is room-temperature water in the cathode compartment. In the anode compartment, the second solution, namely a 10% sodium chloride salt solution, is kept at room temperature. When a circuit is turned on and an electric current flows through water, a series of red ox reactions occur on the surfaces of the cathode and anode [35].

Ozonation is a chemical method of purification of water that involves injecting ozone into the water. Three oxygen atoms (O3) are the main components of ozone, a chemical molecule with greater energy than oxygen with two atoms (O2), known as atmospheric oxygen [36]. Ozone is utilised for disinfection because of its incredible ability to eliminate bacteria as a bactericidal agent. It is a volatile gas that can oxidize any living organism. It may inactivate bacterial cells even at low concentrations such as 0.1 ppm and is produced by ozone-generating equipment. Ozone is also present in natural air [33].

The idea of dry laser therapy inside the root canal without the use of irrigation solution was developed. Er, Cr-YSGG lasers (2780 nm) and Er:-YAG lasers (2940 nm) can remove smear layers and debris from the dentin walls of the root canal. Both are capable of cutting hard tissue and permitting direct ablation of root canal walls [37]. Such a direct ablative technique cannot replace NaOCl, but it can be utilized as a supplement to the outlined root canal irrigation systems. Research into employing laser energy to create cavitation within irrigations and acoustic flow for intracanal irrigations has resulted in the creation of many clinical regimens for fluid agitation by lasers [38].

Hydroxylethylidene bisphosphonate, commonly known as etidronate, is used to inhibit bone resorption; it is used systemically for the treatment of Paget's disease or osteoporosis [39]. Given its low effect on structure, etidronate has been used as an alternative to various chelators in many states. When combined, their antibacterial activities are unaffected by interaction with NaOCl. However, this technique requires 300 s to completely remove the smear layer [40].

According to previous research, when silver nanoparticle solution (AgNP) touches the dentin biofilm, which is mainly composed of E. faecalis, the bacterial burden is dramatically reduced due to its potent bactericidal effects [41]. Ag NP has been reported to be noncytotoxic to human periodontal ligament stem cells, as well as mouse fibroblasts [42]. It exhibited polycationic/poly anionic characteristics with a large surface area and a positive charge density, which improves its antibacterial activity [41]. Ag NP mixed with NaOCl mixing can increase cell lysis and toxins release[94], another study found that the antimicrobial effect was achieved by mixing of 15 μg/ml Ag NP and a 2% CHX solution [95].

2. Natural irrigation

Natural irrigation made from a variety of plant species, shrimp and crab shells, including chitosan, miswak, and propolis, to determine whether or not they can function as a disinfectant within root canals. Propolis is an suitable irrigation for the removal of Enterococcus faecalis and Candida albicans, and can be used instead of other canal irrigation, The antibacterial action of propolis has been related to the chemical compounds found in it, such as chrysin, volatile compounds (coumaric acid), flavonoid, tropenoid, and protocatechuic acid [(42)]. Generally, the comparison between sodium hypochlorite and propolis as irrigation material showed a similar effect as antibacterial properties [(5).]

Comparisons of propolis with chlorhexidine also showed that the former has no superiority over the latter in removing bacteria; however, propolis irrigation significantly lower the number of cultivable bacteria The study showed that propolis is effective against Candida albicans, and it is comparable with chlorhexidine and sodium hypochlorite, even in the presence of smear layer [(43 ,44)]. Other plant-based treatments require further testing. These materials were used as a root canal irrigation for a variety of reasons, including the fact that they are less toxic than synthetic solutions, simple to obtain, inexpensive, and leave no microbial resistance. Despite the fact that calcium hydroxide has some disadvantages, such as the long time to effectiveness and failure to remove all microorganisms, it is still considered a standard intracanal medication in research [(45)].

Additionally, incorporating ethanolic propolis extract into calcium hydroxide paste increases its antibacterial activity [(46)]. Studies have shown that propolis has slightly better results than calcium hydroxide and its antimicrobial activity is more related to the flavonoid present in it. Compared to calcium hydroxide, propolis is an appropriate intracanal medication and is also very effective in Enterococcus faecalis after seven to ten days and can be used as an intracanal medication [(47)]. Compared to chlorhexidine gel as an intracanal drug, propolis gel is not as effective as bacterial reduction , However, more studies are needed to evaluate the effect of propolis on other anaerobic bacteria involved in endodontic infections [(48)]. Propolis and calcium hydroxide have physical properties as an intracanal medication, but the toxic effects of propolis on periodontal ligament (PDL) fibroblasts and dental pulp are 10 times less than calcium hydroxide and can be removed more easily from canals than calcium hydroxide [(42])]. According to a study, the use of propolis as an intracanal medication can change the clinical colour of the tooth crown. Also, different method of application methods have no effect on the amount of discolouration [(42)].

Chitosan has gained interest in dentistry research because it is a non-toxic, biocompatible, biodegradable, and bioadhesive natural polysaccharide [(49)]. As a result of its low production cost and abundance in nature, chitosan, which is produced via chitin deacetylation and found in shrimp and crab shells, has become environmentally appealing for usage in a variety of applications. In dentistry, 0.1% has been shown to be effective against Candida albicans; when added to calcium hydroxide paste as intracanal treatment, it produces sustained calcium ion release [(49).] Chitosan has been used in many endodontic investigations as a chelating and for its antimicrobial effect. Several studies discussed the efficiency of chitosan as a chelation agent in removing the smear layer from the dentinal walls of the root canal compared to EDTA and cetric acid. All results are promising regarding the removal of that smear layer; they found the chitosan irrigation caused less erosion than EDTA to dentin. Subsequently, it may increase the bond strength of the sealers to the radicular dentin. [(50 – 51)].

The antibacterial activity of chitosan showed broad spectrum antibacterial activity on Gramme positive and Gramme negative bacteria [(52)]. Chitosan properties such as antibacterial, biocompatibility, and availability may be good alternative for many conventional root canal irrigations either as separated irrigation or mixed with other irrigations [(53)]. Furthermore, the high chemical activity and functionality of chitosan contributed to the combination of different substances to increase their antibacterial properties, such as the addition of chitosan to zinc oxide eugenol, calcium hydroxide, and some types of photosensitiser to increase the antibacterial effect of these materials against endodontic pathogen [(54)]. The antimicrobial mechanisms of chitosan were ambivalent. The most suitable mechanism is related to the positive charge of the amine group in chitosan and interactions with the negatively charged bacterial cell wall that causes rupture and leakage of cell components (55). Another mechanism is related to nanosized chitosan nanoparticles which can penetrate the cell wall and bind to DNA and inhibit cell replication (56).

Types of endodontic infections and their related microbiota:

Primary root canal infections can be considered the first line of infection that causes necrotic pulpal tissue. The type of microorganisms in the infection species, either the early introduction alone or mixed with another species that arrive later due to low immunity after pulpal necrosis (57). Anaerobic bacteria are widely spread in primary root canal infections and consist of 10 to 30 types / canal. The number of all bacteria can differ from 103 to 108 species in each canal during infection (58).

The microbiota of primary root canal infections is mainly control. by Gram- negative species of the genus, *Porphyromonas, Treponema, Fusobacterium, Dialister, Tannerella, Prevotella* and *Campylobacter.* Gram-positive anaerobes are *Olsenella Filifactor, Actinomyces, Pseudoramibacter and Parvimonas, and also facultative streptococci (Streptococcus salivarius, Streptococcus mutants, Streptococcus oralis, Streptococcus mites, Streptococcus sanguinis)* are commonly present in this kind of infection. Archaea, viruses, and fungi are other kinds of microorganisms that play a significant role in primary endodontic infection in addition to bacteria (59).

The main sources of nutrition for microorganisms in this period of infections are necrotic pulp tissue, saliva, and exudates that enter the pulp space from the lateral and apical foramen (60).

In secondary infection microorganisms that at some time move to the root canal system secondary to orderly treatment cause what is generally known as secondary infection. This can occur at any time, including between appointments, during treatment sessions, or after filling the root canal due to leakage [61]. Secondary infection is established when microorganisms survive and flourish in the new environment. The type of microorganism involved in secondary infection depends on the source of contamination, which may be oral or non-oral species. Non-oral species included Staphylococcus species, Candida species, enteric rods, *Pseudomonas aeruginosa,* and *Enterococcus faecalis*. The oral species may enter from coronal leakage or from any cause that allows saliva to inter root canal space (62).

Persistent infection is a general term in endodontic infection , This type of endodontic infection was developed due to the resistance to chemo-mechanical cleaning procedures and periods of reduced nourishment in treated canals. Persistent endodontic infections are considered the main cause of failure in root canal treatment, distinguished by the persistence or evolution of apical periodontitis after treatment (61). Commonly well-known microorganisms in these infections are Gramme-positive bacteria or fungi, especially candida species (63). The most prevalent bacterial species are *Enterococcus faecalis, Staphylococcus aureus, and Pseudomonas aeruginosa* with candida fungal species. The aetiology of persistent periapical lesions occurs by E. faecalis, and is considered the reason for failed root canal treatment (64).

Enterococcus faecalis is a Gramme-positive Enterococcus that can grow in the absence or presence of oxygen (facultative anaerobic). It is considered commensal bacteria existed in the large numbers in human intestine without any harmful effect. They are often found in genital tract and mucosal tissue of the oral cavity. *Enterococcus* appears as short chains, in pairs, or single (63). The species with *E. faecalis* was the most persistence that is recognised in samples taken from teeth treated with ally treated teeth with apical periodontitis. *E.faecalis* was the microorganism most often isolated from root canal re treatment cases for prosthetic cause and without apical periodontitis (65). *E. faecalis* was shown to be more resistant to many root canal medications and irrigations, such as calcium hydroxide and NaOCl. Furthermore, many studies converse about the resistance of clinical isolates of *E.faecalis* to many antibiotics recommended for dental procedures, such as ampicillin, clindamycin, tetracycline,benzylpenicillin, cephalosporins, erythromycin and azithromycin (66 67).

E. faecalis can make extracellular polysaccharide which encompassed the bacterial cells, and this may play an important role in biofilm formation, antibiotic resistance, adherence, and act as a barrier against host defence [67,68]. *E. faecalis* is a strong microorganism having various virulence elements such as aggregation substance, lipoteichoic acid, lytic enzymes, pheromones, and cytolysin. *E. faecalis* is capable of forcing its way into the dentinal tubules and staying alive in the tubules for a long time, it can initiate a biofilm due to its ability to stick to dentine under various ecological conditions, resist root canal medicament, and continue to live in difficult circumstances within root canal-treated teeth [69].

The ultimate goals of root canal treatment are to prevent apical periodontitis and to create adequate conditions for the healing of periradicular tissue by eliminating microorganisms from the root canal space. The second goal is to prevent reinfection by three-dimensional hermetic seal obturation [70].

The anatomy of the root canal must be studied thoroughly to suggest a new and enhance conventional therapeutic modalities that can handle the microorganisms which dwelt in difficult-to-reach intraradicular anatomical spaces such as dentinal tubules, accessory canals and ramifications [71]. The main root canal contains the majority of microorganisms that are the leading cause of apical periodontitis and inflammatory response after treatment [72].

Chemomechanical planning for the treatment of the infected root canal such as endodontic irrigations and filling procedures is considered the main root canal cleaning techniques, but some areas of the main root canal space remain unclean by the irrigations and intracanal instruments, so bacteria and soft tissue will remain uneradicated [73]. Untouched locations provide remote sites for endodontic tools to clean. Dentinal tubules, isthmus, apical ramifications, and lateral canals; these areas are usually not affected by the treatment procedure due to the inherent physical shortcomings of instruments and the limited contact duration with irrigations within the network spaces of the root canal [73].

The instrumentation of flattened, oval, or C shaped canals is challenging because these canals have two cross sections, maximum and minimum. Round rotary instrumentation will sculpt inside these canals, leaving an area untouched by instrumentation at the ends of the largest canal diameter [74, 75]. In flattened or oval canals, the areas of the walls of the root canal untouched during the instrumentation procedure range from 10% to 80% [76]. Another anatomical factor that affects the cleaning of the main canal is the curvature of the roots. In this type of root canals, the cleaning instruments try to straighten themselves inside the canals so that some areas of the canal walls (the outer wall coronal to the curvature and the inner wall apical to the curvature) will be uncleaned properly by the instruments [76].

Isthmus is another anatomical complexity which is difficult to clean. They are commonly found in teeth with two or more canals with different frequency of incidence. Some researchers reported an incidence of isthmus in molar teeth up to 80% especially in the apical 3-5 mm [77].

The isthmus is difficult to clean with the conventional chemomechanical endodontic procedure. Several studies investigated the cleaning efficiency of different instruments and different irrigation protocols microbiologically, microCT, and histologically [78].

They concluded that the isthmus was difficult to clean [79, 80-82]. Other locations of microorganisms in the root canal system that are difficult to clean are ramifications, including apical ramifications, lateral canals, and furcation canals [81].

Ramifications can be located anywhere along the root canal, but are frequently located in posterior teeth and the apical portion of the root. In general, they were observed in 75% of the teeth and were distributed as 73% apically, 11% in the the middle and 15% in coronal thirds Ramifications and apical deltas are the main anatomic complexities in the apical third of the root canal system [81] .the presence of the lateral canals in the apical three mm of 204 permanent teeth morphologically. They found that there were 178 lateral canals in 93 tested canals, and the ramifications ranged from 1-7 per each canal in the apical segment and the median diameter of the ramification was 67.0μm. The biofilm removal activity of active or passive irrigation protocols from lateral canals by a three-dimensional simulated root canal system. The results showed that the percentages of biofilm removal were 66.76%, 45.49% and 43.97% for the ultrasonic agitation, sonic and passive irrigation groups, respectively [83].

Many studies discussed the difficulty of cleaning the lateral canal with a conventional endodontic procedure and the high rate of recurrent infection associated with the presence of these implications [84]. Dentin tubules harbour microorganisms at the base of a biofilm. In teeth with apical periodontitis, bacterial penetration can occur in about 70% to 80% of cases. The penetration depth ranging from a few microns to 300 μm in some teeth and the chemomechanical preparation of the intraradicular space alone are not enough to eliminate these penetrated bacteria [84].

The ability of *E. faecalis* and C. Albicans to penetrate the dentin tubules of the root canal system, and they found that these microorganisms can penetrate the dentinal tubules with a maximum depth of 244 μm in case of *E. faecalis* penetrates the instrumented root canal system. For the removal of these microorganisms from the dentin tubules, the conventional chemomechanical procedure for root canal system is not sufficient. Therefore, new and adjuvant strategies are needed to help eliminate bacteria from the dentinal tubules [85].

Several studies evaluated the effect of manual dynamic activation, sonic, and ultrasonic activation of irrigation solution on the penetration depth of these fluids inside dentin tubules. They found that the penetration depth increased with different types of activation compared to conventional irrigation [86]. Additionally, other studies evaluated more than one type of laser to activate an endodontic irrigation solution. They concluded that laser activated irrigation groups penetrated deeper than other activation methods [87]. Post-treatment apical periodontitis develops mainly due to persistent endodontic infection. Bacteria may resist root canal disinfectants, but the main reason for the persistence is the inability of current chemical and mechanical procedures and medications to disinfect the entire anatomical complexity of the root canal system [84].

Several anatomical studies confirm that persistent bacterial infection in the lateral canals, apical ramifications, isthmus, recesses, and dentinal tubules is the main cause of endodontic treatment failure (post-management apical inflammation). [84]. Current chemomechanical cleaning techniques fail to reach and touch all the walls of the root canal system and complex anatomies. Therefore, new strategies to improve the disinfection process for the entire root canal system.

Improvement of irrigation solution

In 2020 Mukhlif and Al-Hashimi found that NaOH has more penetration within the dentin tubules than NaOCl, and adding poloxamer surfactant to both solutions results in greater penetration inside the dentin tubules than without the surfactant. When the concentration was reduced, the surface tension of NaOH also decreased [88]. Jihad and Al-Huwaizi in 2020 studied the antimicrobial effect of a new solution of glycine functionalized iron oxide nanoparticles coated with glycine and coated with chitosan as final root canal final irrigation had found that Chi-IONP was a potent antimicrobial agent against the microorganisms studied, with antifungal activity greater than NaOCl 5.25% and antibacterial activity equivalent to NaOCl 5.25% [89].

Aydin et al. in 2018 reported that irrigation solutions are cytotoxic depending on the dose and duration. After 4 and 24 h of exposure, NaOCl was the most hazardous solution ($p < 0.05$). Chitosan and propolis may be a better irrigation solution than NaOCl because they are less toxic and cause less oxidative DNA damage than the latter [90].

Jaiswal et al., in 2017 found that root canal therapy with 0.2% high molecular nanochitosan and the addition of PUI activation demonstrated substantial antibacterial properties against *E. faecalis.* Their research implied that nanochitosan might be used in future bio material applications [91]. Three irrigating solutions, namely, chitosan, chlorhexidine and propolis, were determined their antibacterial efficacy in the biofilm of *E. faecalis* biofilm; they found that combinations of 1% chitosan+1% chlorhexidine, 0.2 chitosan + 2% chlorhexidine, and 2% chitosan+2% chlorhexidine could be used as an alternative to NaOCl for endodontic infections [92].

Parolia *et al*., in 2021[5] in the other study used a human tooth model and E. faecalis isolates collected from patients with unsuccessful root canal therapy, and they found that propolis nanoparticles 300 (PN300) as endodontic irrigation are similarly efficient to 6% NaOCl and 2% CHX in lowering *E. faecalis* CFU. As a result, PN300 can be recommended as an alternative endodontic irrigation. At all time intervals and depths, PN100 as endodontic irrigation is more effective than saline and P100 in reducing the CFU of *E. faecalis.* At 1 and 5 min, PN100 is similar to P300 but less effective than 6% NaOCl and 2% CHX at all time intervals and depths. Compared to performance at 1 and 5 min, PN300 and PN100 as endodontic irrigations were the most efficient in reducing the CFU of *E. faecalis* at 10 min [93]. Chitosan nanoparticles added to Glide gel are efficient in eliminating *E. faecalis* and *Staphylococcus aureus*. In plank tonic bacteria, the degree of antibacterial activity is higher than 5.25% NaOCl and 2% gel form, and this can yield a different result when utilised in biofilm bacteria. However, it is a promising substance that is used in rotational instruments as both a lubricant and an antimicrobial material [94].

Adham and Ali in 2023 found that continuous chelating with the NaOClHEDP protocol increase the bond strength of the Bio-C Sealer96- [95]. Fahad et al., in 2023 presented a study to improve NaOCl 2.5% antibacterial and cytotoxic properties by adding the nanoparticles propolis and chitosan separately. The result of study showed significant improvement in NaOCl 2.5% irrigation solution [96].

Conclusion

Although sodium hypochlorite (NaOCl) and EDTA remain the preferred choices in endodontic irrigation due to their unparalleled tissue-dissolving abilities and removing dentin chips. Despite its efficacy, NaOCl falls short in completely eliminating root canal microbes and poses toxicity risks when extruded beyond the apex. To enhance safety and efficacy in root canal disinfection, nanoparticles and other substances can be promising additional irrigation materials and alternative solutions and they can enhance the cleaning effectiveness of root canal systems.

Conflict of interest

The authors have no conflicts of interest to declare.

Authors' contributions

R A; Supervision. F.F and MJH; Writing- review and editing. All authors reviewed the manuscript and approved the final version of the manuscript to be published.

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Informed consent

Informed consent was obtained from all individuals or their guardians included in this study.

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العنوان: التقدم في محلول الري في مجال علاج جذور الأسنان، مراجعة

الباحثون: فاطمة فهد، رغد عبد الرزاق الهاشمي، منذر الكاضمي

المستخلص

الخلفية: هدفت هذه المراجعة إلى شرح الطرق المختلفة والمواد لعلاج العصب والقضاء على جميع الجراثيم ويمكن تنضيف القنوات كيميايا وميكانيكيا لتحقيق هذا الغرضز ويعتبر صوديوم هايبوكلورايت هو العنصر الرءيسي بالاضافه الى عناصر اخرى يمكن ان تعمل بكفاء افضل الطرق: تم إجراء البحث قواعد بيانات مختلفة ، بما في ذلك PubMed Central و Science Direct و Wiley Online Library ومكتبة Cochrane والكتب المدرسية و Google Scholar و Research Gate والبحث اليدوي النتائج: بعد استبعاد المقالات المكررة ، تم تضمين الأوراق التي تصف طرق ومواد المستخدمه.لتنضيف الجذر. الاستنتاجات: تم شرح طرق مختلفة لتنضيف القنوات بالتفصيل فيما يتعلق بمزاياها وعيوبها , واقتراح مواد بديلة