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Review Article

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New Technologies to Improve Root Canal Disinfection

Gianluca Plotino[1], Teresa Cortese[1], Nicola M. Grande[2], Denise P. Leonardi[3], Gianni Di Giorgio[1], Luca Testarelli[1], Gianluca Gambarini[1]

[1]Department of Endodontics, Sapienza University of Rome, Rome, Italy
[2]Catholic University of Sacred Heart, Rome, Italy
[3]Department of Dentistry, Universidade Positivo, Curitiba, PR, Brazil

Correspondence: Dr Gianluca Plotino, Via Tommaso Salvini, 57, 00197 Roma, Italia. Tel: +39-064202-0595. e-mail: endo@gianlucaplotino.com

Effective irrigant delivery and agitation are prerequisites to promote root canal disinfection and debris removal and improve successful endodontic treatment. This paper presents an overview of the currently available technologies to improve the cleaning of the endodontic space and their debridement efficacy. A PubMed electronic search was conducted with appropriate key words to identify the relevant literature on this topic. After retrieving the full-text articles, all the articles were reviewed and the most appropriate were included in this review. Several different systems of mechanical activation of irrigants to improve endodontic disinfection were analysed: manual agitation with gutta-percha cones, endodontic instruments or special brushes, vibrating systems activated by low-speed hand-pieces or by sonic or subsonic energy, use of ultrasonic or laser energy to mechanically activate the irrigants and apical negative pressure irrigation systems. Furthermore, this review aims to describe systems designed to improve the intracanal bacterial decontamination by a specific chemical action, such as ozone, direct laser action or light-activated disinfection. The ultrasonic activation of root canal irrigants and of sodium hypochlorite in particular still remains the gold standard to which all other systems of mechanical agitation analyzed in this article were compared. From this overview, it is evident that the use of different irrigation systems can provide several advantages in the clinical endodontic outcome and that integration of new technologies, coupled with enhanced techniques and materials, may help everyday clinical practice.

Key Words: root canal preparation, endodontic disinfection, biomechanical disinfection, root canal irrigants, activation systems.

Introduction

The major causative role of microorganisms in the pathogenesis of pulp and periapical diseases has clearly been demonstrated (1). The main aim of the endodontic therapy is to disinfect the entire root canal system, which requires elimination of microorganisms and microbial components and prevention of its re-infection during and after treatment. This goal is pursued by chemo-mechanical debridement, where the mechanical systems are associated with the irrigating solutions.

1. Standard Endodontic Irrigation Protocols

1.1 Sodium Hypochlorite (NaOCl)

Sodium hypochlorite (NaOCl) is the main endodontic irrigant used, due to its antibacterial properties and its ability to dissolve organic tissues (2). NaOCl is used during the instrumentation phase to increase as much as possible its time of action within the canal without being chemically altered by the presence of other substances (3). Its effectiveness has been shown to depend on its concentration, temperature, pH solution and storage conditions (3). Heated solutions (45-60 °C) and higher concentrations (5-6%) have greater tissue-dissolving properties (2). However, the greater the concentration the more severe is the potential reaction that may happen if some of the irrigant is inadvertently forced into the periapical tissues (4). To reduce this risk, use of specially designed endodontic needles and a technique of injection without pressure are recommended (5).

1.2 Ethylene-diamine-tetra-acetic Acid (EDTA)

The main disadvantage of NaOCl is its inability to remove the inorganic portion of smear layer. For this reason, it is advised the combination of NaOCl with EDTA (2). EDTA has the ability to decompose the inorganic component of intracanal debris and is generally used at 17% concentration. EDTA seems to reduce the antibacterial and solvent activity of hypochlorite and so these two liquids should not be in the canal at same time (6). For this reason, during mechanical preparation abundant and frequent washing with sodium hypochlorite is used, while EDTA is used at the end of the preparation phase to completely remove the inorganic debris and smear layer from the canal walls.

1.3 Ultrasonic Activation of Sodium Hypochlorite

The use of ultrasound during and at the end the root canal preparation phase is a necessary step to improve endodontic disinfection. The range of frequencies used in the ultrasonic unit is between 25 and 40 kHz (7). The effectiveness of ultrasound in the irrigation is determined by its ability to produce "cavitation" and "acoustic streaming". The cavitation is minimized and limited to the tip of the used instrument, while the effect of the acoustic streaming is more significant (7). Ultrasound creates bubbles of positive and negative pressure in the molecules of the liquid with which they come into contact. They become unstable and then they collapse and cause an implosion similar to a vacuum decompression. Exploding and imploding they release impact energy responsible for its detergent effect. It has been demonstrated that ultrasonic activation of sodium hypochlorite dramatically enhances the effectiveness of cleaning the root canal space. Besides, it greatly increases the flow of liquid and improves both the solvent and antibacterial capacities and the removal effect of organic and inorganic debris from the root canal walls (7).

Ultrasonic activation of NaOCl from 30 s to 1 min for each canal with 3 cycles of 10-20 s (with constant irrigant renewal) seems to be a sufficient time to obtain cleaned canals at the end of the preparation (7). Ultrasound appears to be less effective to enhance the activity of EDTA, although it may contribute to a better removal of the smear layer (7,8). Accumulation of debris produced by mechanical instrumentation in the inaccessible areas is preventable by ultrasonic activation of NaOCl even during the preparation phase (9). Therefore, use of ultrasonic continuous irrigation system might be advantageous. It involves the use of a needle activated by ultrasound. In this way, the irrigant is released into the canal and it is also activated by the action of ultrasonic needle at the same time (10).

1.4 Chlorhexidine (CHX)

A final flush with 2% CHX after NaOCl and EDTA has been proposed to ensure good results in cases of persistent infection, due to its broad spectrum of action and its property of substantivity (5,11). However, CHX is hindered by its interaction with NaOCl, which tends to create products that may discolor the tooth and precipitates that may be potentially mutagenic (12). For this reason, CHX should not be used together with or immediately after sodium hypochlorite (13). This interaction has been prevented or minimized by an intermediate wash with absolute alcohol, saline or distilled water (14).

2. Activation Systems

Mechanical instrumentation by itself could reduce microorganisms from root canal system even without using irrigants and intracanal dressings (15), but it is not able to assure an effective and complete cleaning (16). Irrigating solutions by themselves without a mechanical preparation, are not able to significantly reduce the intracanal bacterial infection (17). For these reasons, the systems that can improve root canal disinfection through mechanical activation of endodontic irrigants as sodium hypochlorite have been currently researched. Multiple techniques and agitation systems of irrigants have been used over time (18) demonstrating more or less positive results (19).

2.1 Manual Agitation Techniques

The simplest of all mechanical activation techniques is the manual irrigant agitation, which can be performed with different systems. The easiest way to achieve this effect is moving vertically and passively the endodontic file within the root canal. The file promotes the irrigant penetration (20) and reduces the presence of air bubbles in the canal space (21), but does not improve the final cleaning (19). Another similar technique advises to move vertically a gutta-percha cone until reaching the working length while the canal is fill with irrigant. Even this method, however, does not improve the intracanal cleaning (,19,22). Endodontic brushes and specific needles for endodontic irrigation with bristles on their surface is another technique suggested in order to move the irrigant more effectively within the canals. These systems have shown to be valid in the removal of smear layer from root canal walls (23,24), thus they can be indicated during irrigation with EDTA to improve their efficacy at the end of the preparation.

2.2 Machine-Assisted Agitation Systems

The evolution of the manual systems led to the introduction of instruments that may be rotated by hand-pieces at low speed inside the canal fill with irrigant. Instruments such as plastic files can show a smooth surface and increased taper (25-27), or even a surface with lateral plastic extensions (28-30). Studies on these systems have shown conflicting results. There are better results for the machine-assisted agitation systems than for the conventional irrigation technique with syringe, but worse than other more effective systems (18).

2.3 Continuous Irrigation during Instrumentation

Recently a new system for root canal preparation was introduced on the market. This system uses a particular instrument with abrasive surface that enlarges the canal by friction and in a vibrating motion allows the irrigant to flow through the file itself. This system has shown excellent results in terms of anatomy preservation and cleaning ability. It can reach anatomical areas of difficult access as isthmuses, oval canals or C-shaped canals (31). The low cutting efficiency of this system in some cases may limit its use in the root canal preparation. On the other hand, its characteristics make it an excellent additional technique to enhance the cleaning and disinfecting of the root canal system at the end of the preparation (32). The concept of continuous irrigation was already developed in the past with mechanical instruments for sonic and ultrasonic preparation (33,34) that could contextually clean by continuous release of irrigant.

2.4 Sonic Activation

Sonic activation has shown to be an effective method to disinfect the root canals (35). Most actual systems have smooth plastic tips of different sizes activated at sonic frequency by a hand piece (36). This system seems to be able to effectively clean the main canal, to remove the smear layer and to promote the filling of a greater number of lateral canals (19,37). Another recently introduced technique uses a syringe with sonic vibration that allows the delivery and activation of the irrigant in the root canal at the same time. Sonic activation differs from the ultrasonic because it operates at a lower frequency (1-6 kHz) (38), and for this reason it is generally found to be less effective in removing debris than the ultrasonic systems (19,39-41).

2.5 Apical Negative-Pressure Irrigation

In order to deliver the irrigant into the root canal for the entire length and to obtain a good flow of fluid, apical negative-pressure systems have been introduced to simultaneously release and remove the irrigant. These systems comprise a macrocannula for the coronal and middle portions and a microcannula for the apical portion, which are connected to a syringe for irrigation and the aspiration system integrated with the dental unit (42). During irrigation, a tip connected to a syringe delivers the irrigant in the pulp chamber, while the cannula placed in the canal pulls irrigant into the canal, through the aspiration system to which it is connected, and evacuates it through the suction holes. This system has the purpose to ensure a constant and continuous flow of new irrigant in the apical third, with safety and a lower risk of extrusion (43). Most of the studies on this technique have shown that it is very effective to ensure a greater volume of irrigant in the apical third (44) and excellent removal of debris in this area (45) and in inaccessible areas (46), with results in most cases similar to those of the ultrasonic activation techniques (47-49).

2.6 Laser Activation

The interaction between laser and the irrigant in the root canal outlines a new area of interest in the field of endodontic disinfection. This concept is the base of the Laser Activated Irrigation (LAI) and the so-called PIPS technology (Photon-Initiated Photoacoustic Streaming) (50). The mechanism of this interaction has been attributed to the effective absorption of laser light by sodium hypochlorite. This leads to the vaporization of the irrigant and to formation of vapor bubbles, which expand and implode with secondary cavitation effects. The PIPS technique is based on the power of Erbium:YAG laser to create photoacustic shock waves within the irrigant introduced in the canal. When activated in a limited volume of liquid, the high absorption of the laser in hypochlorite combined with the high peak power derived from the short pulse duration (50 μs) determines a photomechanical phenomenon (50). A study showed that there was no difference in bacterial reduction achieved by hypochlorite sodium activated by laser compared to sodium hypochlorite only (51). Another study found that it did not completely remove the biofilm from the apical third of the root canal and infected dentinal tubules (52). However, the finding that laser activation generated a higher number of samples with negative bacterial cultures and a lower number of bacteria in the apical third was a promising result on the effectiveness of the technique, also confirmed by more recent studies (53).

3. Additional Disinfection Systems

In addition to the above-mentioned systems, endodontic research is also oriented towards the identification of alternative solutions that could further refine the disinfection and assist the destruction of biofilms and elimination of microorganisms.

3.1 Photo-Activated Disinfection (PAD)

A new method recently introduced in endodontics is the Photo-Activated Disinfection (PAD). This technique is based on the principle that the photosensitizing molecules (photosensitizer - PS) are able to bind to the membrane of the bacteria. PS is activated at specific wavelength and produces free oxygen, which causes the rupture of the bacterial cell wall on which the PS is associated with, determining a bactericidal action (54). An endodontic system called Light-Activated Disinfection (LAD) was developed. It is based on a combination of a PS and a special light source. The PS attacks the membranes of microorganisms and binds to their surface, absorbs energy from light and then releases this energy in the form of oxygen (O_2), which is transformed into highly reactive forms that effectively destroy microorganisms. The LAD is not only effective against bacteria, but also against other microorganisms including viruses, fungi and protozoa (55). The PSs have far less affinity for the cells of the body; therefore toxicity tests carried out did not report adverse effects of this treatment (56).

Clinically, after the root canal preparation, PS is introduced into the canal until working length with an endodontic needle and is left *in situ* for 60 s. The specific endodontic tip is then inserted into the root canal up to the depth that can be reached and the light irradiation is performed for 30 s in each canal. This technique was proven effective in laboratory studies to eliminate high concentrations of bacteria present in artificially infected root canals (57). Care should be taken to ensure maximum penetration of the PS, since it is important that it comes in direct contact with the bacteria, otherwise the process of photosensitivity does not occur (58). In addition, LAD seems to be effective not only against the bacteria in suspension, but also against biofilm (5,59). Currently LAD is not considered as an alternative, but rather as a possible supplement to standard protocols of root canal disinfection already in use (5).

3.2 Laser

In the Endodontics area several types of laser have been used to improve root canal disinfection: diode laser, gas laser (CO_2), erbium: YAG laser, neodymium: YAG laser. Bactericidal action of the laser depends on the wavelength and energy, and in many cases it is due to thermal effects that produce alteration of the cell wall of the bacteria, leading to changes in osmotic gradients up to cell death. Some studies have concluded that the laser irradiation is not an alternative, but rather a possible integration to existing protocols to disinfect root canal (60). The laser energy emitted from the tip of the optical fiber is directed along the canal and not necessarily lateral to the walls. To overcome this limitation, a delivery system that allows lateral emission of the radiation aimed to improve the antimicrobial effect (61), but a complete elimination of the biofilm and bacteria was not yet possible (62). In conclusion, there is still no strong evidence to support the application of high-power lasers for direct disinfection of root canals (63).

3.3 Ozone

Ozone (O_3) rapidly dissociates in water and releases a reactive form of oxygen that may oxidize cells, thus having antimicrobial efficacy without inducing drug resistance (64). The results of the available studies on its effectiveness against endodontic pathogens are inconsistent, especially against biofilms (65).

4. Alternative Antibacterial Systems

4.1 Nanoparticles

Nanoparticles of magnesium oxide, calcium oxide or zinc oxide are microscopic particles that have antibacterial properties (66). Nanoparticles synthesized from powders of silver, copper oxide and zinc oxide are currently used and may generate active oxygen species. They are responsible for the anti-bacterial effect by the electrostatic interaction between positively charged nanoparticles and negatively charged bacterial cells (67). In addition, nanoparticles may change the chemical and physical properties of dentin and reduce the bacterial strength of adhesion to the dentin itself (68).

4.2 Bioactive Glass

Recently, the bioactive glass or bioactive glass-ceramics have been the object of considerable interest for endodontic disinfection due to their antibacterial properties, but with conflicting results (69).

4.3 Natural Plant Extracts

A current trend directed to the use of natural plant extracts takes advantage of the antibacterial activity of polyphenolic molecules generally used for storing food (70) These compounds have a poor antibacterial efficacy, but a little significant ability to reduce the formation of biofilms, although the mechanism by which this occurs is not clear. (5,71).

4.4 Non-Instrumentation Techniques

The first trial of a method of cleaning without canal preparation was the Non-Instrumentation Technique (NIT) conceived by Lussi et al. (72). This technique did not provide for the enlargement of the root canals because there was no mechanical instrumentation of root canal walls. In fact, root canal cleaning was obtained exclusively with hypochlorite at low concentration, introduced and removed from the canal by a vacuum pump and an electric piston that created fields of alternating pressure inside the canal. This caused the implosion of the produced bubbles and hydrodynamic turbulence that facilitated the penetration of hypochlorite into the root canal ramifications.

A method for cleaning the entire root canal system has recently been developed using a broad spectrum of sound waves transmitted within an irrigating solution to quickly remove pulp tissue, debris and microorganisms (73). One study showed that this technique is able to dissolve the tested tissues at a significantly higher rate compared to conventional irrigation (4).

From a biological point of view, endodontic therapy must be directed to the elimination of microorganisms and prevention of a possible reinfection. Unfortunately, the root canal system with its anatomical complexity is a challenging environment for the effective removal of bacteria and biofilm adhered to the canal walls. The chemo-mechanical preparation involves mechanical instrumentation and antibacterial irrigation and it is the most important phase for disinfection of the endodontic space. The technological advances of instruments brought significant improvements in the ability to shape the root canals, with less procedural complications. Various anti-microbial agents have been employed in the management of infected root canal systems. Furthermore, some clinical