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Review Article

Current Developments in Endodontic Irrigation

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Abstract

The importance of irrigation in endodontic treatment cannot be overstated. On the one hand the anatomical features of the root canal system and the limitations of instrumentation make impossible complete removal of the dental pulp, dentin mineral debris, smear layer and, most importantly, microorganisms; the endodontic system may only be cleaned and disinfected by proper irrigation. On the other hand, root canal instruments should never be used in dry canals. With both chemical and mechanical effects, efficient irrigation based upon the continuous advancement of irrigants and endodontic irrigation techniques is thus of utmost importance. Throughout the entire evolution of the field of endodontics, irrigation methods experienced a permanent development to enhance effectiveness, safety, and ease of use.

Keywords: Endodontic Irrigation; Endodontic System Complexity; Microbial Biofilm; Root Canal Disinfection

Introduction

The American Association of Endodontists (AAE) views endodontics as a field that includes the study of the biology of the normal pulp as well as the genesis, diagnosis, treatment, and prevention of disorders affecting the pulp and related periradicular ailments [1].

The main goal of root canal therapy is to avoid the infection or reinfection of the periapical tissues and manage the infection that already exists in the root canal system [2]. To achieve this, the use of specific chemical disinfection during endodontic treatment is mandatory. This implies that, apart from shaping the root canals, complete and effective irrigation must be performed to address the entire endodontic anatomy and reach all the areas in which microbial biofilms are potentially harbored.

As early as 1889 Willoughby Miller demonstrated the microbial nature of dental caries and how infections could spread via the root canal into the periapical area [3].

In the endodontic environment microorganisms are both present as free-floating cells in planktonic state and embedded in biofilms. Because they give bacteria a protective environment against stresses, immune responses, antibacterial agents, and antibiotics, biofilms have significant clinical relevance [4].

The process of biofilm formation is tightly controlled in response to the environment and starts when cells attach to a surface [5]. Biofilms are complex microbial communities and are one of the main reasons for the persistence of infections [6].

The complex anatomy of the endodontic system, characterized by a multitude of recesses, fins, isthmuses connecting individual canals, C-shaped canals, accessory canals and frequently an irregularly shaped apical area with various ramifications makes chemo mechanical debridement to be particularly challenging. In these areas biofilms can easily develop and have been observed to adhere to the inner walls of complex apex anatomies and accessory canals [7,8]. Ensuring thorough cleaning and disinfection of all canal spaces is more difficult in complex configurations.

The development of the micro-computed tomography (μCT) imaging technology has made possible to investigate and visualize the root canal complexity and report on new unclassified anatomical variations.

Figure 1: Complexity of the endodontic system.
Marco Versiani - Endodontic applications of microcomputed tomography for studying root canals [9].

The movement of rotary files during the action of shaping root canals are not be able to follow all the irregularities of the root canal walls. The inaccessible regions of the root canal system remain unshaped by instruments and host many microorganisms potentially leading to persistent infection or reinfection [10].

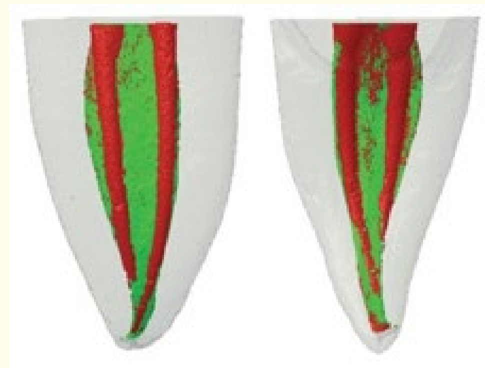

Figure 2: Superimposition of the root canals before (green) and after (red) preparation [11].

Endodontic irrigation plays therefore a crucial role in eliminating biofilm bacteria from the root canals.

An important number of research papers approached the evaluation of microbial biofilm structure, development and implications for the endodontic pathology.

The biofilm matrix can be seen as a common space for closed microbial cells, which comprises a wide variety of extracellular polymeric substances (EPS), such as polysaccharides, proteins, amyloids, lipids and extracellular DNA (eDNA) and microbial refractory substances of humic type [12].

The increased resistance of bacteria in biofilm formation is thought to have multiple reasons, and there is currently no unanimously agreed upon specific mechanisms for this. It appears that resistance depends on various factors including the substrate, microenvironment, and age of the biofilm [4].

Various intracanal medications, root canal instrumentation methods and endodontic irrigation techniques have been implemented to eliminate biofilm in root canals. Successful treatment of persistent and recurrent endodontic infections depends on the eradication of residual microorganisms in the root canal system.

Numerous studies in endodontic literature compared the immediate and residual antimicrobial results against biofilms present on the root canal walls and into dentinal tubules [13-21].

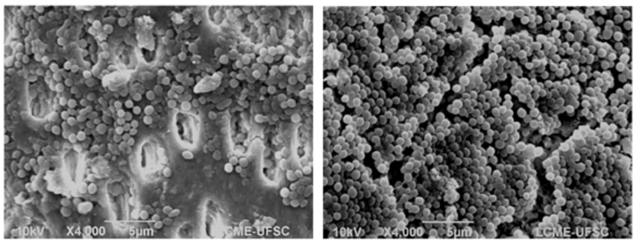

Figure 3: The presence of Enterococcus faecalis biofilm on root canal walls [22].

It is a very well-known fact that multispecies biofilms cause endodontic infections, with interactions between different microorganisms leading to apical periodontitis [23], and therefore, it must be emphasized that the endodontic treatment focuses on removing bacterial biofilm from the root canal system.

Since the 19th century, once the evidence of the existence of microbes was demonstrated, research was carried out to discover substances that could be used for bactericidal purposes.

In a controlled laboratory setting, German bacteriologist Robert Koch showed in 1881 that hypochlorite can destroy pure bacteria cultures [24]. In 1936 Walker recommended the use of sodium hypochlorite to irrigate the root canals, followed by Grossman, in 1943, who talked about the use of sodium hypochlorite and hydrogen peroxide, Nygaard-Ostby, in 1957, who introduced the ethylenediaminetetraacetic acid (EDTA) solution [25]. Chlorhexidine digluconate has also been introduced as an endodontic irrigant during the 1970's [26].

The main endodontic irrigants clinically used today are sodium hypochlorite, ethylenediaminetetraacetic acid, and chlorhexidine digluconate. An important number of solutions are commercially available: BioPure MTAD Antibacterial Root Canal Cleanser (containing doxycycline, citric acid and Polysorbate), Tetraclean, Salvizol, Solvidont, Hyposol, QMiX, Dual Rinse HEDP, EndoWize, BioPure MTAD, citric acid.

There are many requirements and functions of irrigants: dissolve organic and inorganic tissues, remove smear layer, disinfect and clean areas inaccessible to endodontic instruments, dissolve necrotic pulp tissue, facilitate the removal of debris, effective on biofilm, inactive endotoxins have low surface tension, act as lubricant, have low surface tension and low viscosity, do not weaken the tooth structure, do not interfere with the physical properties of dentin, do not interfere with dentin adhesion, be non-toxic, be biocompatible with periapical tissues, permit gutta-percha disinfection, be colorless, do not stain tooth structure [27,28].

On the one hand there is no single irrigant to fulfill all these necessary properties. On the other hand, regardless of their qualities, no irrigant per se can play its role in the endodontic system by simply flushing it along the root canals.

The effectiveness of root canal irrigation is based both on the mechanical washing action of the irrigation solution and on its biological effects - but only IF it reaches the entire endodontic system. Experimental research has shown that the irrigant is not effective at a distance greater than 1 mm apical from the needle tip [27,29], and an increase in the volume of the irrigant does not significantly improve the cleaning action and the effectiveness regarding the elimination of organo-mineral debris.

There are two main issues regarding the effectiveness of irrigation:

- If the irrigation solution reaches the level of the entire endodontic system, and especially in its apical third
- If the irrigant can have a debridement action at the level of all the areas untouched by instrumentation - lateral canals, isthmuses, fins, etc.
- At the apical level of the root canal there is:
- An "air pocket" that prevents the penetration of the irrigation solution
- A mixture of ammonia and carbon dioxide produced by hydrolysis due to the interaction of sodium hypochlorite with organic substances.

The accumulation of these gases creates the so-called "vapor lock" effect (apical vapor lock - AVL) in the apical third of the root canals, impeding irrigation efficacy. This critical problem has been researched using multiple methods, including CBCT investigation

[30], that proved it cannot be solved by conventional syringe irrigation and requires the use of various kinetic energy irrigation systems [28,30].

Multiple activation techniques and devices have been proposed to address the apical vapor lock and increase irrigation canal debridement efficiency: manual dynamic activation MDA, intermittent passive ultrasonic irrigation (IPUI), continuous ultrasonic irrigation CUI, continuous apical negative ultrasonic irrigation (CANUI), passive ultrasonic irrigation PUI, sonic irrigation (EndoActivator, Vibringe), hydrodynamic activation (RinsEndo), plastic finishing file PFF, the use of self-adjusting file SAF, apical negative pressure ANP (EndoVac, GentleWave), remotely generated high-intensity ultrasound irrigation system (RS), photoactivated disinfection PAD, and laser activation (Er: YAG, PIPS).

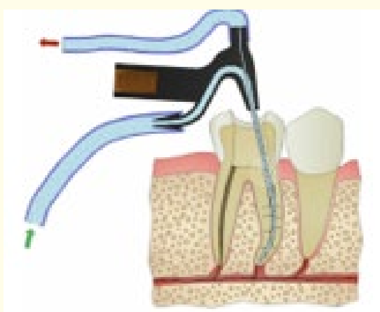

Figure 4: Representation of CANUI design and mode of operation. Castelo-Baz., *et al*. 2021 [31].

Dissolving organic tissue and removing biofilms that are attached to the dentine in the complex endodontic anatomy not only requires irrigation to reach the entire endodontic system with sufficient concentration and contact time, but also to perform physical energizing irrigation. The main objectives are to change the flow pattern, increase the intensity of rinsing, improve the shear stress of the dentinal walls and activate the chemical composition of the irrigant, thus promoting the access of the irrigant into the complexity of the root canal system and the exertion of better biochemical effects [28].

This kinetic energy irrigation includes different methods of activation mainly ultrasonic irrigation, sonic irrigation, negative pressure irrigation and laser activated irrigation.

Ultrasonic irrigation currently uses the concept of Passive Ultrasonic Irrigation (PUI), first proposed by Weller in 1980 [32]. Two modes of PUI are presently used: continuous, in which the irrigant is continuously flowing into the root canal simultaneously during ultrasonic activation, and intermittent which consists in the injection of irrigants into the root canal, followed by the insertion of an ultrasonic file, and intermittently activate the static irrigant in the root canal.

Figure 5: UC One Cordless Passive Ultrasonic Irrigation and metal tip. (DoWell Dental Products) [33,34].

During ultrasonic activation irrigants form a circular or vortex-like motion that rolls rapidly, creating the effect of acoustic streaming. Shear stress thus generated along the root canal wall facilitates the removal of tissue and biofilm attached, as well as debris and bacteria suspended in the canal. The bubbles caused by acoustic streaming continue to grow and become unstable, and eventually collapse in a violent implosion - the cavitation effect.

Figure 6: Acoustic streaming around a size 15 endosonic file. Depiction of the waves generated around the vibrating ultrasonic file (ACTEON North America/Clinical Research Dental) [35].

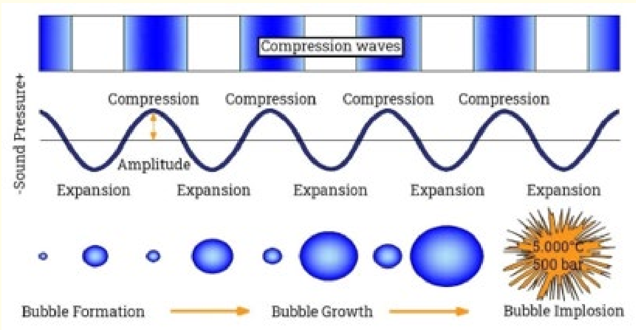

Figure 7: Principle of ultrasonic cavitation [36].

Acoustic streaming is defined as a rapid movement of the irrigant in a circular or vortex shape around the vibrating ultrasonic file.

The cavitation effect consists in the creation, growth and implosion of bubbles formed when a liquid is subject to a pressure wave.

The microscopic bubbles generated by the shear forces due to the passing acoustic waves result in micro-streaming and micro-cavitation effects, thus permeating root canal ramifications and even dentinal tubules and leading to disruption of the microbial biofilm.

Sonic irrigation was introduced by Tronstad in 1985 [37]. Sonic activation has a lower frequency but a greater amplitude than the ultrasonic one [28]. The second generation EndoActivator, appeared in 2023, showed an increase of the vibration frequency from a maximum of 190 Hz for the first generation to 300 Hz. The high-frequency sonic device EDDY, has a much higher frequency of 5 000-6 000 Hz. However, neither high-frequency nor low-frequency sonic activation lead to the complete removal of bacteria present in the root canal, especially in the deep dentinal tubules of the apical wall of the root canal [38].

Negative pressure irrigation. The use of combined positive-pressure irrigation and negative-pressure suction allowes the irrigants to reach the apical region without extruding the through the apical foramen [28]. The EndoVac system uses this approach and has a better effect of irrigation in the apical area than the one using conventional positive pressure irrigation.

Figure 8: SmartLite EndoActivator (Dentsply Sirona) [39].

Figure 9: EndoVac Pure system (Kerr Endodontics) [40].

The newer GentleWave system, launched in 2015, uses multi-frequency sound waves, and is capable of cleaning and disinfecting complex root canal systems and producing enriched cavitation microbubbles and broad-spectrum sound fields. Extrusion of the irrigant into the apical foramen is prevented by the negative pressure at the apex. Improved solubilization of organic tissue with sodium hypochlorite is possible, and its bacterial biofilm removal effect proved to be superior to that of ultrasonic irrigation in the middle third of the root canal and isthmuses [41].

Laser activated irrigation (LAI) mainly uses erbium (Er) family lasers: Er: YAG laser (2940 nm) and Er, Cr: YSGG laser (2780 nm). Having a high affinity for water and hydroxyapatite, erbium lasers can produce a strong activation effect and shock waves during irrigation and simultaneously reactive oxygen which destroys biofilms and accelerates bacterial death. Another type of laser

Figure 10: The GentleWave G4 System (Sonendo) [42,43].

activation irrigation system, photon-initiated photoacoustic streaming (PIPS), has been created from the traditional erbium laser. It transmits during root canal irrigation low energy (20-50 mJ) with extremely short pulses (50 μs), generating shock waves which causes violent movement of the irrigant, insuring predictable debridement with minimally invasive access. Endodontic tips used are end firing and/or radial firing tips (conical and modified conical tips) for LAI and, in particular, radial and stripped tips (the last 3 mm), in order to increase the lateral emission of laser photons for PIP technique.

Figure 11: Laser activated irrigation (a) and photon-initiated photoacoustic streaming (b) [44].

New technologies were recently developed to increase the disinfection efficiency of the PIPS method. Shock wave-enhanced emission photoacoustic streaming (SWEEPS) uses positioning a laser fiber tip which sends pulse pairs in the access cavity filled with irrigant [45].

Figure 12: Waterlase iPlus (a) and EdgePRO Laser Microfluidic irrigation (b) both with Er,Cr:YSGG 2780 nm wavelength [46,47].

It is important to emphasize that both ultrasonic and laser assisted methods can increase the penetration of antimicrobial solutions into the restricted regions of the complex canal systems and the dentinal tubules.

Conclusions

Every method of endodontic irrigation implies knowing and using specific final irrigation protocols, which decisively contribute to elimination of the bacterial biofilm.

The goal of safely delivering the irrigants into the entire endodontic system to remove all the microbial contaminants is the key towards achieving treatment success.

Though the "gold standard" irrigant concerning antimicrobial efficacy remains the sodium hypochlorite, and the most used method of activation is the ultrasonic one, given the complex nature of root canal anatomy and the variety of infections encountered, it is imperative to develop safer and more efficient irrigants, to innovate more practical and feasible operative techniques and procedures, and to develop enhanced irrigation devices for root canal irrigation. Every step forward will certainly enhance our ability to eliminate microorganisms from the root canal and consequently make endodontic treatment more predictable and successful.

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