TRABAJO DE FIN DE GRADO

Grado en Odontología

ACTIVATION OF IRRIGANTS IN ENDODONTICS

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1.Resumen

Introducción

El objetivo del tratamiento del conducto radicular es eliminar las bacterias, el tejido infectado y los microorganismos, sin embargo, a veces el tratamiento no tiene éxito debido a la falta de una adecuada inclinación y desinfección, a la complejidad anatómica del conducto radicular, a las soluciones de irrigación y a las técnicas de instrumentación. Por tanto, la técnica adecuada, una buena solución de irrigación y un buen diagnóstico del tratamiento de conducto son la clave del éxito. Como a veces la instrumentación mecánica no toca muchas superficies y no puede llegar a la zona apical, se introduce diferentes técnicas y equipos de irrigación para mejorar la desinfección química y mejorar la limpieza del canal a través de la instrumentación.

Materiales y métodos

Con el fin de llevar a cabo este estudio, aprovechamos como base de datos PubMed, Medline, Google scholar, Cochrane para encontrar información basada en la evidencia para este artículo utilizando palabras clave como ¨ conducto radicular¨, ¨activación de irrigantes¨, ¨soluciones de riego¨, ¨ técnica de riego¨, ¨Biopelícula microbiana¨, ¨ Eliminación de la capa de frotis¨. Con el propósito de enfocar en este estudio, contamos con los artículos que contenían estas palabras claves . Además, analizamos 65 artículos y un libro para realizar este trabajo de investigación.

Discusión y conclusión

Conocer las ventajas y desventajas de cada técnica de activación y solución irrigante fue la clave principal para elegir la mejor técnica y la más frecuente de activación que se puede utilizar en la clínica dental para tener una limpieza óptima y un tratamiento exitoso. Estudiamos y analizamos las múltiples técnicas en diferentes situaciones y utilizamos distintas soluciones como la Técnica de Activación Dinámica Manual (MDA) con hipoclorito de sodio (NaOCl) y el ácido Etilendiaminotetraacético (EDTA) que es una de las técnicas más comunes y rentables utilizada en la odontología, y luego, en un segundo lugar concluimos que el sistema de activación por ultrasonidos es el líder en este campo. Además, la Terapia Fotodinámica para la desinfección del conducto radicular (TFD) se concluyó como una novedosa técnica de irrigación.

1. Abstract

Introduction

The objective of the root canal treatment is to eliminate the bacteria , the infected tissue and microorganisms and sometimes the treatment is not successful because of lack of the proper cleaning and disinfecting due to anatomical complexity of the root canal, irrigation solutions and instrumentation techniques. Therefore, the proper technique ,good irrigation solution and the good diagnosis of the root canal treatment is the key to success. Introduced different techniques and irrigation equipment to improve the chemical disinfection and improve the cleanliness of the canal through the instrumentation as sometimes mechanical instrumentation will not touch many surfaces and cannot reach the apical area.

Materials and Methods

Data bases such as PubMed, Medline, Google scholar, Cochrane were used in order to find evidence-based information for this paper using keywords such as ¨root canal¨, ¨activation of irrigants¨, ¨irrigation solutions¨, ¨irrigation technique¨, ¨microbial biofilm¨,¨ smear layer removal¨. Articles than contained these keywords were used in an effort to focus this study. 65 articles and one book were used to write this paper.

Discussion and Conclusion

Understanding the advantages and disadvantages of each activation technique and irrigant solution were key to choose the best and most common activation technique that can be used

in the dental clinic in order to have better cleaning and successful treatment. Multiple techniques were studied and analyzed in a different situations and different irrigation solution were used, such as Manual Dynamic Activation Technique (MDA) with Sodium Hypochlorite (NaOCl) and Ethylenediaminetetraacetic acid (EDTA) that is one of the most common and inexpensive technique used in the dentistry and after that in a second place the Ultrasonic activation system were concluded to be leading in this field. In addition ,the Photodynamic Therapy for the root canal disinfection (PDT) were concluded as a Novel irrigation technique.

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2. Introduction

2.1. Background

The objective of the root canal irrigation is to eliminate the pulp tissue residues and microorganisms, eliminate the smear layer and dentine debris during the treatment. These microorganisms colonize the canals by attaching to the dentin walls in the whole canal; this accumulation of the microorganisms is called a biofilm and can be seen in the inner walls of the apical anatomy and the lateral canals.(1) These microorganisms have surface associated growth which can cause the most common endodontic infection.(2)

Irrigation is one of the major parts in the endodontic treatments, during root canal treatments (RCT) various parts of the tooth canal surfaces are not affected by mechanical instrumentation. Therefore, a good and proper root canal irrigation solution and technique is the essential for the success in RCT. Various techniques and irrigation devices have been introduced to enhance the impact of the chemical disinfection and enhance the cleanliness of the canals with the mechanical instrumentation. Sufficient cleansing of the root canal is influenced by elimination of debris and smear layer; however shaping of the whole root canal still poses a challenge even with improvements in mechanical instrumentation with rotatory systems; a smear layer is almost always present in the apical third, which depending on anatomical complexity, may further complicates the process.(3)

2.2 Irrigation solutions

2.2.1 Sodium Hypochlorite (NaOCl)

One of the most widely utilized and typical root canal irrigation solutions is Sodium Hypochlorite (NaOCl), it is the only solution that eliminates organic matter and necrotic tissue residues along with the biofilm; however, this solution works best as an antiseptic and tissue dissolving solvent but has no influence on the inorganic part of the smear layer. Studies showed that a great concentration of NaOCl has higher impact than the 1-2% solution.(4)

2.2.2 Ethylenediaminetetraacetic acid (EDTA)

The other irrigant is called Ethylenediaminetetraacetic acid (EDTA), it influences the inorganic sector of the dentin and smear layer (hydroxyapatite). EDTA has small to no antimicrobial effects but certain studies have described some antifungal effect; however, EDTA is known to react with NaOCl and cause staining among other undesirable effects such as eliminating the anti-bacterial effect of the NaOCl and these effects must be avoided in all the situations. To remedy this, Saline water/Saline solution is be utilized between the application of the two solutions to prevent the chemical reaction between them, but saline cannot be used as a principal disinfectant because they have neither tissue-dissolving attributes nor a disinfecting effect. (3)(5)

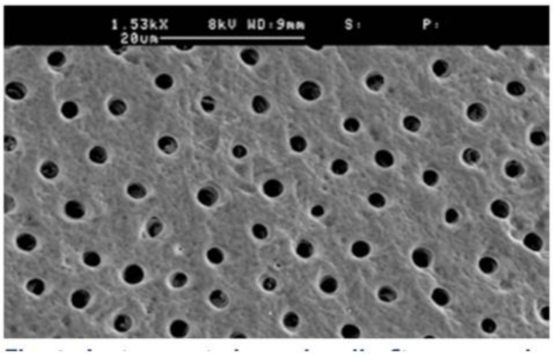

Figure 1 : Instrumented canal wall after elimination of smear layer with NaOCl and a final rise by EDTA.

2.2.3 Citric acid

Citric acid is one of the oldest irrigants used in RCTs and some studies showed that it can be used as a substitute for EDTA in the final irrigation step to eliminate the smear layer and other debris, however Citric Acid is more aggressive than EDTA and can produce erosion of the root canal walls if used after NaOCl without using a buffer such as saline solution between them.(6)

2.2.4Chlorhexidine Gluconate (CHX)

The other irrigant solution Chlorhexidine Gluconate (CHX) is commonly utilized in preventative dentistry to control plaque formation and in endodontics it is used for disinfection because of its great antimicrobial action; it could be used as last irrigant after the use of EDTA. CHX cannot dissolve organic matter nor inorganic matter, therefore it shall not be utilized as an irrigant solution alone. (7)

2.3. Activation Techniques

Different methods and techniques have been utilized in endodontic irrigation to increase the effectiveness of irrigants in RCTs from traditional syringe-needle delivery to diverse machine-driven systems that use sonic and ultrasonic energy, negative and positive pressure, irrigation of the root canal by Laser Activation (LAI), Self-Adjusting File system (SAF), Photodynamic therapy for root canal disinfection, Photon-induced Photoacoustic Streaming (PIPS) and the Manual Dynamic Activation technique (MDA).(8)(9)

2.3.1 The Manual Dynamic Activation technique (MDA)

The Manual Dynamic Activation technique (MDA) is one of the most common, inexpensive, safe, fast and the appropriate rinsing fluid operation methods aftercompletion of the shaping procedure, it can be operated by hand files, brushes and very suitable tapered gutta-percha point. According to the current research, we have to analyse between two methods of the irrigation process: static (or passive) and dynamic (or active); the static irrigating process is done with the syringe and it relies on the penetration depth of the irrigating needle; the dynamic irrigation consist of two parts:

- The depth of the penetration of the irrigation fluid by any type of instrument and the movement used by the instrument..

-The function of the taper and the size of the canal is to interchange the irrigation fluid.

Both of the parameters are related with the penetration depth of the endodontic needle.(9)

2.3.2 Syringe irrigation

Syringe irrigation is extensively used method in the Endodontic treatments, the fluid dynamics is one of the most important factor to facilitate the disinfecting procedure.(3)To enhance the effectiveness of the syringe irrigation different models of needles have been utilized to transfer irrigants into the root canals, these needles principally alter in the existence of an open or closed tip and one or more outlets.(10) (11)

There are various forms of needles which are used in the irrigation delivery, the open-ended needles have different types such as flat, bevelled and notched, the close-ended needles also have different types which are side-vented, double-vented and multi-vented. However, the multi-vented needle is not available in the market currently to utilize with the syringe. Like all the medical needles system the irrigation needles also measured with a system call “Gauge”.(12) Previously large needles (21-25G) were used to deliver the irrigants, these needles couldn’t pass beyond the coronal third of the root canals, because of this problem recently needles with the narrower diameter (28G-30G or 31G) are used because they can reach the working length (WL).

The open-ended needles (flat, beveled, notched) system , the high speed fluid flow extrude from a small diameter opening which is called ¨Jet¨ is very strong and intense toward apical part of the root, however the close-ended needles although the jet is directed apically but has a slight deliver and even though the irrigant can between one vortex to the other , the velocity will decrease toward the apex.(13)

2.3.3 The Vapor Lock phenomenon

The vapor lock phenomenon happens when an air or gas bubble are formed within the close ended system and prevents the irrigant´s actions such as osmosis. Recent studies showed that the methods used for activating of the Sodium hypochlorite are effective in elimination of the vapor lock are passive ultrasonic irrigation (PUI), manual dynamic agitation (MDA), a sonic endoactivator, continuous ultrasonic irrigation (CUI), and photon-induced photoacoustic streaming (PIPS); but the major issue during the irrigant activation in the MDA technique is the risk of apical ejection in the apical area and can be prevented via apical negative pressure.(14)(15)

2.3.4 Apical negative pressure system (ANP)

Apical negative pressure system of irrigation has the potential to aspirate and passively transport the irrigant to the apical area. The EndoVac system is a negative pressure irrigation system which contains three active sections: The Master Delivery Tip (MDT), the macrocannula and the microcannula. The MDT concurrently transfer and remove the excess of the irrigant from the pulp chamber. The macrocannula is suctioning the irrigant from the pulp chamber to the coronal and middle part of the canal, that the irrigant is directed toward the axial wall and never direct the flow toward the canal´s orifice because of the possible accident.(11)(16)(17)

2.3.5 Self-Adjusting File (SAF) System

The other system which is introduced recently is called Self-Adjusting File (SAF), is created for minimally invasive endodontic treatment combined with effective irrigation. This system eliminates a homogeneous dentin layer from the canals compare to the rotatory file which are removing excessive healthy dentin. The self-adjusting file is used with RDT handpiece head and an irrigation pump that brings a constant flow of irrigation solution through file without clinically positive pressure because of the metal mesh which allows constant circulation of the irrigant. This type of file adopts to the canal three dimensionally and to the cross-section of the canal. SAF it can be used in immature teeth, cleaning during retreatment, challenge of Isthmuses and disinfection of Oval canals. The lattice threads of the file has abrasive surface that allows to eliminate the dentin with a back-and-forth grinding motion.(18)(19)

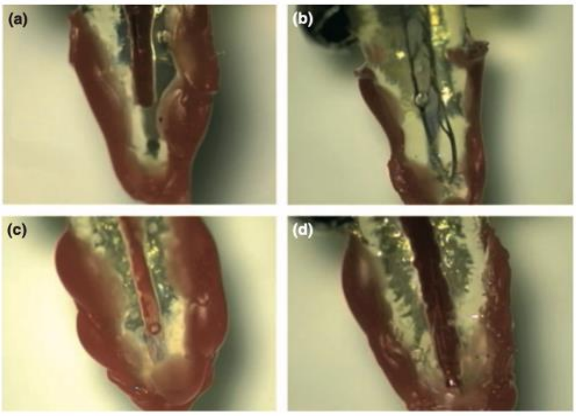

Figure 2: Representive sample of four different techniques: (a) Positive Pressure , (b) SAF without packing motion; (c) SAF with packing motion ; (d) Apical negative pressure.

2.3.6 Sonic and Ultrasonic activation systems

Ultrasonic activation systems like other techniques, have increased cleaning and disinfecting actions inside the canals; studies attributed the effectiveness to the ultrasonic ‘energy’ and the irrigating solution employed. This is named the ¨synergic system¨, that activates biological-chemical effects of the irrigant when the solution undergoes ‘ultrasonation’, the wave applied to a liquid by an ultrasonic device. When this wave is applied to a liquid it creates a negative pressure which causes ‘cavitation’, the liquid fractures and bubbles are created. The cavitation of the irrigant can affect surfaces that the conventional irrigant systems cannot reach. (20)(21)

The Ultrasonically activated irrigant (UAI) in the clinically usage has different tips which allows the insertion of the hand file or specially designed hand file-type with different lengths and diameters to improve the cleaning at the levels of the 1-3 mm from the apex with less operator fatigue.(22) Some authors concluded that the ultrasonic instrumentation can be used as a complementary technique after hand instrumentation to increase debridement efficacy in a more passive way and without instrument or influence the walls of the root canal ; therefore the term passive ultrasonic irrigation (PUI) were used. PUI/UAI the time for the technique and irrigant became a problem of this technique, which lead to evolution of an ultrasonically activated irrigating needle that can concurrently actualize and refill irrigant deep in the canals, this system called continuous ultrasonic irrigation (CUI).(23)(21)

The Sonic equipments usually oscillate at a frequency of 20-20,000 Hz. By definition, a second frequency is anything within the audible range of humans. The main system that can be used to generate sonic/subsonic mixing is the Micromega® , Sonic Air®1500 handpiece with an attached Rispi-Sonic® file.(3) EndoActivator® is a battery-powered handheld mobile handpiece with a 3-speed motor. The handpiece obtains one of three different sizes, disposable and polymer tip (15/.02, s5/.04, 35/.04). The surface of the polymer tip is smooth. The tip agitates the irrigation solution positioned within the root canal and flushes through the needle into the opening.(3)

2.3.7 Photon-induced photoacoustic streaming or PIPS

One of the newest techniques that is used is Photon-induced photoacoustic streaming or PIPS; it creates a strong photoacoustic wave which make the currents of the irrigants flow through the canal three dimensionally, affecting the entire anatomy. The tapered and stripped tips used in the PIPS system need to be positioned in the pulp chamber rather than inside the canal; waves generated by this technique can remove healthy and necrotic tissue, destroy bacteria, eliminate biofilm and even decontaminate dentin tubules.(24)

2.3.8 Photodynamic therapy (PDT)

Photodynamic therapy (PDT) is considered as one of the most effective treatments of localized infections in RCTs regardless of the type of microorganism that has caused it. The combination of PDT with the conventional root canal cleaning techniques (manual files, etc) has a better degree of bacterial elimination than other irrigation methods. Four different studies combined of this method with cleaning and shaping of the canals resulted in 82% to 96.7% bacterial removal. (25)

2.3.9 Laser Activation irrigation (LAI)

Laser Activation irrigation (LAI) with an erbium laser has been found as a system for activating the irrigant, the result is based upon cavitation in water which can lead to a formation of large elliptical vapor bubbles that enlarge and implode. Only two studies studied the using of the (LAI) in the removal of dentin residues from the root canal, that Er,Cr:YSGG laser and Er:YAG have better effect on removing the dentin residues and smear layer from the apical part. Er,Cr:YSGG (erbium, chromium: yttrium-scandium-gallium-garnet) laser frequency is absorbed by water and penetrates into dentin surface which has a good antimicrobial effect on the dentinal tubules, this type of laser which is approved by the FDA for using not only in Endodontical treatment but also in Periodontal surgery. The Er:YAG laser release the infrared light which is highly absorbed by water unlike Nd:YAG laser.(26)(27)

There are several forms of lasers which are used in dentistry with different wavelengths, they all work principally by conduct radiation of light energy to the tooth surface which makes the thermal reaction. The Nd:YAG laser is commonly utilized in dentistry that generates radiation in near and far infrared electromagnetic spectrum, this type of the laser has good antimicrobial effect but showed an increased in temperature which is considered as an undesirable effect.(28)

As we mentioned before in this thesis, we are going to discuss more in detail about the PIPS Technique which is one of the newest techniques which is used now a days and the other LAI such as Nd:YAG laser and Er,Cr:YSGG Laser will be mention briefly in this paper and the other techniques which are mentioned in the introduction will be discussed later on this Trabajo Fin de Grado.

3. OBJECTIVES

The main objective of this thesis is informing about most common irrigation techniques, focusing on their main advantages, disadvantages.

A secondary objective is to provide information about Novel activation techniques and their role in the future.

4. MATERIALS AND METHODS

This review of literature, results in some relevant studies about activation of irrigations, different activation techniques and their effectiveness.

Only articles, journals, reviews of recent studies were taken into account. Taking in consideration the principal objective, date and degree of evidence of those studies. The main electronic databases such as PubMed, Medline, Google scholar, Cochrane were used in order to find evidence-based information. Apart from using the online library “Biblioteca CRAI Dulce Chacón” of the university “Universidad Europea de Madrid”, books and papers in physical form were used and the online shopping platform “Amazon” was helpful for buying further books with limited access in order to complete my literature research.

Including criteria:

Recent literature that was certified by Journal Citation Report.

Articles in language like Spanish and English.

Excluding criteria:

Literature older than 20 years were excluded. Studies with low static value like clinical case studies were disqualified.

Key words: root canal, activation of irrigants, irrigation solutions, irrigation technique, microbial biofilm, smear layer removal, Novel activation.

5. RESULTS AND DISCUSSION

5.1. Irrigation Solutions

5.1.1 Sodium Hypochlorite (NaOCl)

The objective of root canal treatment is to avoid or treat periapical periodontitis, which is the consequence of bacterial infection of the root canal system; studies have shown that the use of disinfectant irrigant solutions in the chemo-mechanical preparation process plays an important role in helping to eradicate bacteria inside the canals.(29)

Nonetheless, contempt long-term achivements to expand new irrigation equipment and solutions and new instrument technology, it is still to completely sterilize the root canal system; therefore , the clinical goal is to minimize the threshold of bacterial load so that the host defense system can be repaired; so far, the efficiency of choosing endodontic irrigant is not as good Sodium hypochlorite (NaOCl). (6)

The most popular irrigation salutation that is utilized daily in the dental clinic is Sodium Hypochlorite, studies showed that the effective concentration of the Sodium Hypochlorite is within 0.5-6% and to increase the effect of the irrigation solution the NaOCl need to be replenish continuously and kept in motion by agitation, therefore with an effective agitation the tissue disintegration will increase , however several recent studies confirmed that the lower and higher concentration of the solution equitably productive in decreasing the amount of bacteria in the affected root canal system but the tissue dissipating effect has a direct relation to the concentration. (7), to prove this point the other author Clegg et al.(30) analyzed the different concentrations of the NaOCl under the Scanning electron microscope (SEM) and the

3% and 6% NaOCl demonstrated absence of the biofilm and the 1% NaOCl only demonstrated disruption of the biofilm. Thus the 2.5-6% concentration should be used during the instrumentation for one to two minutes after finishing the instrumentation.(31), Studies showed that to have a better irrigation and cleaning of the root canal EDTA used as a chelator (30) after NaOCl as a final irrigant , because studies showed the moment that NaOCl is used as last irrigation solution can alter the connection between the dentin and the sealer and may cause discoloration of the root canal and has an unpleasant smell. (32)

5.1.2. Ethylenediaminetetraacetic acid (EDTA)

Generally, EDTA itself cannot effectively eliminate the smear layer, therefore proteolytic components such as NaOCl should be combined to eliminate the organic components because this solution alone can only remove the inorganic matter during the root canal treatment, most of the studies showed that EDTA is commonly utilized at a concentration of 17% and while it is in touched with the root canal walls not more than one minute can remove a thin smear layer and for the thick smear it requires more time up to two minutes to have an effective removal, even though few studies showed that 5% or even 1% solution is sufficient to remove the smear layer, (3) and EDTA is utilized after completion of instrumentation to complete the smear layer removal.(5)(33) However, another study demonstrated that the clinical concentration of the EDTA solution is 17% and can remove the smear layer while it is in direct contact with the canal walls for 1 minute.(34)

Some studies suggested the clinical use of EDTA and NaOCl in RCT, After the using NaOCl during the entire cleaning and shaping process, must be rinse with EDTA for one minute to erase the smear layer; in order to increase the penetration the EDTA will be activated for few seconds, in order to avoid the adverse interaction between EDTA and NaOCl we need to carefully clear away the NaOCl with an abundant amount of EDTA; EDTA can leave a layer of the collagen which is important for binding bacteria for that reason the last rinse with a small concentration of NaOCl can be used at their time; as the author Wei Qian et al. (35) reported the clinician must be cautious because the higher concentrations may cause dentin erosion, and some collagens or proteins that are in touched with EDTA can be eliminated by a brief exposure to Sodium hypochlorite(36)

5.1.3.Citric acid

According to the research, Citric Acid is one of the oldest irrigation solutions in the root canal treatment. It shall be utilized after NaOCl place of last rinse with EDTA to remove the smear layer (37); according to research , Citric Acid is more erosive than EDTA. If NaOCl is used after Citric Acid, the corrosion is more obvious than the EDTA-NaOCl sequence. (35)

5.1.4. Chlorhexidine digluconate (CHX)

Chlorhexidine digluconate (CHX) has good antibacterial activity and is used for prevention and disinfection of dental plaque and also used after EDTA, it has also been used in root canal treatment as the final irrigant (38), Several early studies showed that CHX can bind to hard tissues and presrve antimicrobial properties (substantivity), which is one of the reasons for its use; however, the possible influence of the continuous antibacterial action of the CHX on the root canal has not been investigated very well (39) ; Enterococcus faecalis is the majority of research on CHX root canal treatment. Therefore, the research is too optimistic to prove that CHX has antibacterial effect in endodontic treatment ; Ng et al. (40) suggested in the outcomes of the study that adding 0.2% CHX to NaOCl would significantly reduce the success rate of non-surgical treatments; CHX lacks tissue dissolving ability (41), which is an fundamental aspect for the root canal irrigation.

Nonetheless, another recent study reported that the use of CHX for final irrigation may actually have a adverse influence on recovering of apical periodontitis; more research needed to determine the best irrigation options for different endodontic treatment (40)

5.2. Activation Techniques

In order to better clean, disinfect and eliminate biofilms, several activation techniques and equipment can be used, including manual dynamic activation (MDA), Laser Activation (LAI), Self-Adjusting File system (SAF), Photodynamic therapy for root canal cleanliness , Photon-induced Photoacoustic Streaming (PIPS).

All these technologies and equipments have been broadly investigated and compared; undoubtedly, these techniques have limitations and the results are uncertain due to various models (mostly plastic and extracted teeth), various assessment methods, different tapers, different apical sizes , and different volumes and time; however, regardless of the activation technique used, it must not forget that agitation is a main element that helps disperse and replacement solutions in the root canal space and improve the effectiveness of antiseptic and solvents.

Consequently, an overall concession on the advantages of using irrigation fluid activation at the final step of the canal instrumentation, compared with syringe delivery this method seems to enhance the canal cleaning and disinfection.(42)

5.2.1 Manual Dynamic Activation Techniques (MDA)

The Manual Dynamic Activation Technique (MDA) is the most common technique that it is done with manual files, brushes and very suitable cone-shaped guta-percha point.(43)

MDA is a simple method that helps the irrigant to reach to the apex and extricate the vapor lock effect. This technique produces bigger intracanal pressure changes all along the gutta-percha cone in-and-out action; some studies showed that the recurrence of the strokes build turbulence and increase dispersal by shear stresses; it is very important to have a weak backflow space between the cone and the canal wall, so that the irrigant flows back together with the cone and produces an effective hydrodynamic effect.(3)

Certainly, MDA helps to mix in active fluid with the motionless solution in the apical millimeters.(42) The effectiveness of the MDA technology has been proven through a number of studies. Huang et el (44) used a stained collagen biofilm model and demonstrated in his study that manual agitation of the main cone more effectively removes biofilm or stained collagen on the surface of the root canal compared with static irrigation. However, another study analysed the difference between ANP (EndoVac) and MDA by using the scanning electron microscopy (SEM) in both closed and an open system, results demonstrated that the ANP in the narrow isthmuses and closed apieces could eliminate more debris than MDA due to wall shear stress.(9)

Nevertheless, another study assimilated MDA with tapered and non-taperd guta-percha cones, the Safety irrigator, Continuous Ultrasonic Irrigation (CUI) and ANP, concluded that the most effective technique is CUI.(45)

In 2013, Caper and Aydinbelgehave (46) showed that the final irrigation activation program including MDA will not change the mineral content of the root surface and in addition, they also concluded that the mixing of the mixuture of NaOCl with EDTA for 1 minute does not change mineral level of the dentin surface. On the other hand, the same study showed that the usage of SAF with distilled water can change the ratio between organic and inorganic components and also will alter the dentin permeability, microhardness and solubility of dental materials to hard tissue.

The main problem in the process of irrigation fluid activation is the risk of apical compression.(3) According to studies, all the tested devices including MDA, except ANP, seem to excrete a certain irrigation agent, but the safest is ANP (but ANP should be regarded as a delivery device, not an activation system). Nonetheless, it is worth knowing that in clinical situations, the resistance of the periapical tissue plays a role in limiting the occurance of compression. Proper use of MDA technology can prevent irrigant extrusion.(9)

5.2.2 Syringe Irrigation

Today, the main purpose of the most publications is to assess advanced activation of irrigations techniques, syringe irrigation is often used, like treating controls as a *priori* invalid and introducing avoidable bias ; it will soon be impossible to completely replace syringe irrigation with other delivery techniques. Syringe irrigation is a long-established method in endodontic treatment, and fluid dynamic is one of the most important factors to promote the disinfection process.(10)

A liquid is a substance that would not endure any risk to convert its shape at the moment that is at rest. They involved liquids and gases because they both have the ability to flow.(17)

Recent studies recommended for irrigation to use syringes with quantity ranging from 1 to 20 ml. (47), despite little attention is paid to the capacity of the used syringe, it will influence the tactile force appropriate to irrigant at a convinced flow rate. (48) When using syringes of different sizes, even if the pressure generated within the syringe is the same, the clinician needs to apply different forces and will encounter varying degrees of difficulty when pushing the plunger. This stems from the description of stress. Bigger syringes are very hard to depress and control; and because of the same story, clinicians would not be able make a trustworthy conclusions about stress.(47)

When the plunger is depressed, the pressure within the syringe is still greater than the environment pressure around the needle tip (almost atmospheric pressure). The difference between pressures directs the irrigation fluid straight to the needle within the root canal, this is the reason that syringe irrigation is classified as a positive pressure technique. (49)

A typical mistake between clinicians is that delivering irrigant at high flow rates incorrectly referred to as force delivery or delivery under pressure. Furthermore, it must be claimed that the pressure of the irrigation fluid deposited into the root canal is regularly much smaller than the pressure within the syringe due to significantly falling pressure that occurs along the needle.(3)

A 5ml syringe is approved, which is an acceptable accommodation amongst less frequent refilling and ease of operation. Even when combined with a narrow irrigation needle, the syringe can be used to reach a flow rate of not less than 0.20-0.25 ml/s , and in addition it is necessary that the syringe have a Luer Lock (Fig. 3) threaded fitting to prevent unexpected detachment of the needle during irrigation due to a strong pressure generated inside the syringe.(48)

Figure 3: Syringes with different capacities for root canal irrigation, from top to bottom : 20, 12, 5 and 2.5 mL.
All of the syringes have a Luer Lock threaded fitting (arrow).

The needle type also has a great influence on the primary flow design built in the root canal at the same time as syringe irrigation, while other parameters such as needle insertion depth, root canal size and taper have limited impact.(50) According to the needle design and the flow rate, the available needle types can be divided into two groups, particularly open-ended and close-ended.(10) For open-ended (flat, bevelled, notched), the jet is very strong and extends along the root canal to the root apex. Within the certain distance (depending on root canal geometry, needle insertion depth and flow rate), the jet seems to have continuous ruptures. In the free zone of the root canal wall, a flowback to the canal orifice occurs. The jet built with a flat and bevelled needle is relatively stronger than that of a notched needle and extends further at the tip.(51)

Furthermore, open-ended needle can be placed inside the root canal 2-3 mm shorter than WL.(10)

Meanwhile using a close-ended needle (lateral, bilateral ventilation), the jet will form close to the point of the outlet (the side near the outlet of the bilateral needle), there is a slight difference. The irrigation fluid mainly follows an arched pathway which surrounds the end of the needle and then towards the coronal aperture.(51)

Moreover, this type of needle are obliged to be installed within the canal 0-1 mm shorter than WL as it has limited area close to the apical part of the root which the irrigation fluid cannot reach that area .(10) The distal opening of the double-side-vented needle has little effect on the entire flow pattern, since most of the irrigation fluid (93.5%) moves from the proximal opening, therefore, it does not produce any extensive advantages.(51)

Further, multi-ended needles are a limited model of close-ended needles and were promoted for root canal irrigation in the old days. Despite the fact that this needle is unavailable on the market currently, it seems to have developed a unique flow sequence; various small jets are made by irrigation fluid following out the needle from the outlet near the needle tip, which is perpendicular to the tube wall.(51)

Syringe irrigation does not seem to be able to eliminate hard tissue fragments or soft tissue residues from the isthmus among the mandibular molars mesial root canals or from the artificial grooves and cavities in the apical area of the canal. Along the irrigation process, the needle should have a longitudinal movement in the root canal to the maximum insertion point so the limited area influences as much as the root canal wall as possible. Likewise, the root canal must be widened to 30 or 35 gauge and increased taper, to permit the irrigation fluid to penetrate into working length. And also, higher flow rate almost 0.25mL/s appears to improve the chemical and mechanical effects of irrigation.(3)
Unfortunately, studies showed that traditional needle irrigation cannot clean the isthmus and lateral canals completely.(52)

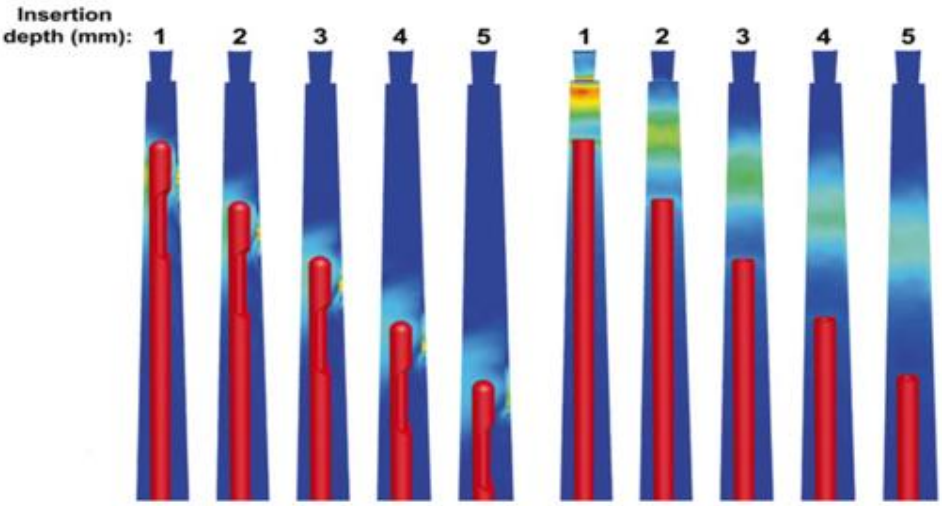

Figure 4: Close-ended on left and an open-ended needle on right positioned at 1-5 mm short of the WL in a size of 45, 0.06 tapered root canal, according to the computer simulation. Only half of the root canal wall is shown to allow simultaneous evaluation of the needle position.

5.2.3 The Vapor Lock phenomenon

Vapor lock phenomenon happens as bubbles or air form inside the closed system and prevent the insertion of the irrigation fluid; the presence of air bubbles leads to the creation of a two-phase (irrigant- air), however other studies demonstrated that during the syringe irrigation process, bubble allurement does not seem to be the main problem.(53)

Another recent study claims that the development and amount of apical vapor lock depends on the equal parameters that generally influence the permeation of the irrigation fluid, increased flow rate, using an open-ended needle, introduction of the needle near to the ¨Working Length¨, and degree of enlargement of the root canal all appear to cause a tinier vapor lock.

Additionally, by briefly inserting the close ended needle into WL, residual air bubbles can be eliminated smoothly along the syringe irrigation. Therefore, it seems unnecessary to use negative pressure system or mixing technology to achieve this goal. (54) (14)

A reach by Boutsioukis et al. (55) also demonstrated the same results and suggested the used of fine needle near the working length can prevent or eliminate this phenomenon. In the same study he presented that the penetration depth of the needle tip is the main factor affecting the penetration of the irrigation fluid, followed by the taper of the apical part of the canal, the needle tip design and the volume of the irrigation fluid. As a result, it can be admitted that at the end of the shaping process, it is clinically feasible to use a syringe and a fine needle or ANP for static irrigation to completely flush the root canal.(55)

However, if the final objective is to disseminate and interchange the irrigation fluid inside the complex part of the root anatomy, additional agitation of the solution is required.(3)
On the contrary, another study found that eliminating the Vapor lock phenomenon is challenging, so other techniques such as activation or use of apical negative pressure (ANP) are contemplated valuable aids to solve this problem.(56)

5.2.4 Apical Negative Pressure Technique (ANP)

Recently, it was described that the use of negative apical pressure irrigation technology is superior to positive pressure irrigation. The negative pressure technique has been proven to cautiously and efficiently carry the irrigation fluid to the apical part of the root canal system; however, it is as well suggested that, regardless of the amount of irrigation prepared , negative pressure can better control microorganisms than traditional irrigation delivery system.(49)

ANP has capability to distribute irrigation fluid to working length (WL) and eliminate any risk of apical compression. In addition, studies has shown that compared with traditional irrigation, the effectiveness of the ANP system in delivering irrigation solution to (WL) is also related to the phenomenon of Vapor lock.(57)

In addition other study showed that by rising the delivery flow rate, significant amount of irrigation solution can be gathered from the apical area while applying the apical negative pressure and this will permit to replenish fresh irrigant fluid at WL and possibly disinfect the canals; the affecting factors are identified as apical preparation size, taper, root curvature and type of needle.(58)

Furthermore, during the ANP irrigation process, the clinician should ensure that there is always irrigant solution in the reservoir to preserve a continuous flow and the flow rate can significantly change in conformity with the gender of the controller which is greater in male.(58)
The EndoVac system passively delivers the selected irrigation fluid to the apical part of the root and actively solves the problem of the irrigation fluid entering the periapical tissue through the apex, which may lead to treatment complications.(3)

Basically, the EndoVac ANP system consists of four main components: Multiport Adapter (MPA), Master Delivery Tip (MDT), Large Cannula and Micro Cannula. The MDT is designed to deposit solution in the inlet and pulp chamber and automatically drain any excess solution. The purpose of the large cannula and the micro cannula is to suck the irrigation fluid into the tube and generate a dynamic flow under the condition of constantly renewing the solution, thereby reducing the effectiveness loss of the irrigation fluid in contact with organic and inorganic residues. This allows us to use a large amount of irrigant without the danger of causing damage to the apical area.(57) Additionally, while using the MDT, the irrigant flow must direct opposite to the chamber wall and never direct the needle toward the canal aperture and must be used in an up and down motion, because of the pressure of the irrigation fluid may cause accidents.(32)

An exact and properly monitored investigation conducted by Gondim et al. found that when performing Apical Negative Pressure irrigation (EndoVac system), patients measured objectively and subjectively had less post-operative pain than positive apical pressure irrigation.(59)

5.2.5 The Self-Adjusting File (SAF) System

The Self-adjusting file system is a shaping and washing system created for less aggressive RCT, the system includes a Self-Adjusting file with a dedicated RDT handpiece and an irrigation pump that provides constant irrigation fluid throughout the empty file.(19)

The file is modelled as an empty tube, the wall of that is built of slim nickel-titanium mesh and a coarse outer surface, which the tip of the tube is asymmetric and it has a very high compressive force, so it can compress the 1.5 mm SAF diameter toward the root canal where solely a #20 K file can enter, this flexibility also allows the file to adjust to the cross-sectional form of the canal.(60) This feature allows the clinician to work easily in an oval canals without being aware of the shape of the canal.(32)

Studies showed that SAF system with the proper irrigation can remove the materials and disinfect the oval canals and isthmuses 50% more than using the Passive Ultrasonic Irrigation system; although the SAF cannot clean the isthmuses that are narrower than 0.2 mm and may show limits in the narrower and long isthmuses.(32)
Moreover, Lin et al. found by using a unique model to study that using the SAF system with unceasing Sodium Hypochlorite irrigation solution, only 3% biofilm was left on root canal walls and grooves.(61)

On the other hand, SAF system as studies showed can be used in immature teeth with an open apex because the MDA technique and the typical instrumentation techniques are not advisable and secure, therefore using SAF was recommended by studies to remove the biofilm and bacteria without lowering the dimension of the dentin walls of the roots as the immature teeth has thinner dentin wall than the normal mature teeth, therefore the narrower SAF were used to produce lower pressure on the walls and passing the apex.(19)

When the SAF system is used the glide path was needed to permit the SAF to reach working length at the ¨onset¨ of the process, however, the concept of reaching the WL is at the ¨end¨ of the procedure in the other instrumentation techniques. This system is used with continuous irrigation fluid such as active NaOCl and used for approximately 4 min with up and down movement to reach to the WL. Additionally , the other cleaning feature of this system is ¨scrubbing¨, this feature helps the sodium hypochlorite remove the biofilm easier, however, when NaOCl removes the inner layer of the root canal wall the irrigation fluid became deactivated and cannot remove pulp tissue properly. To help the SAF to reach the cleaning goal the Direct mechanical action is recommended to eliminate residues from the canal.(60)

In another study showed when using SAF system, interchanging among NaOCl and EDTA, in all the samples there was no debris on the root canal and in 65% of the cases there was zero smear layer.(62)

Moreover, while using rotatory file a great proportion of the canal wall was not touched with the instrumentation technique and showed 70% in oval canals and 40-45% in the curved canals, on the contrary this percentage dropped to 23% while using SAF system, and secondarily shows that any material that may have adhered to the root canal wall is more efficiently removed.(63)

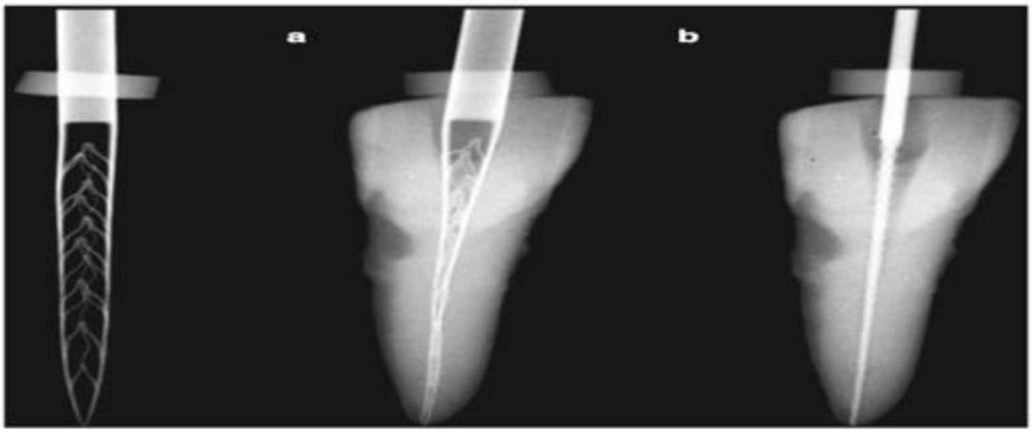

Figure 5: SAF compressed into a narrow canal. Left: the SAF in its relaxed form.

(a) The same SAF inserted into a narrow canal, which was prepared with a #20 K file.
(b) A #20 K file that fits into the same canal.

5.2.6 Sonic and Ultrasonic Activation system

Richman in 1957 was one of the first ones who reported the application of ultrasound in endodontic treatment. He tested Ultrasonic equipment and accomplished that since those cases have no treatment for adverse postoperational consequence, the utilisation of ultrasound in root canal treatment has broad prospects.(64)

According to reports, the use of ultrasonically files can more effectively and quickly instrument the canal wall and can reduce the clinician fatigue. "Ultrasonic activation" irrigation fluid helps clean and decontaminate the root canal system; nevertheless, other study found no dissimilarity in tissue elimination between ultrasound and manual instruments.(3)
Similarly, during evaluation of the antibacterial effect, no differences were found between the two instrument technologies. The total action of ultrasound as a major instrument measurement system has not been established to be better than handheld instruments (65); however, the authors determined that ultrasonic instruments are not a substitute to hand cleaning but help to improve the efficacy of hand instruments after debridement. In the current studies, ultrasound equipment is used as an auxiliary tool for canal preparation.(66)(67)

A recent study analyzed the results of the bacteria and biofilm removal and showed that the Sonic Activation results are superior to needle activation however, it is inferior to PUI/UAI ; in fact none of these techniques can remove all the bacteria from the canal wall.(65)
Regarding the biofilm removal two studies showed that both Sonic activation and needle irrigation under the SEM microscope study has no difference in results and these two techniques are lower to the PUI/UAI and PIPS activation techniques.(53)

Additionally, in terms of eliminating the smear layer, the results were different, more studies have shown that PUI/UAI helps to eliminate the smear layer. These different outcomes can be attributed to the utilization of various forms and concentrations of irrigation solution. When only NaOCl was used, an investigation describes that the smear layer was almost completely eliminated from the root canal at all levels.(3)

Moreover, the same study, used different concentrations of NaOCl (from 0.5% to 12%) and different exposure periods to ultrasonic energy (10 seconds to 5 minutes). While NaOCl is used in combination with EDTA, studies have shown that a considerable enhancement in smear layer removal.(3)

Unluckily the time of the exposure to the irrigation solution is the criticizing factor as it needs extra time to entirely flush the canals in an uncontrolled way, thus Lev et al. in 1987 announced that, with regard to cleaning, using PUI/UAI for 1 minute for each canal is equal to 3 minutes for each canal cleanliness, however, when using a continuous flushing system, 3 minutes can make the isthmus cleaner.(32)

In addition, De Gregorio et al. described that when using PUI/UAI, the lateral canal was much better with artificial irrigant diffusion than using the needle irrigation or negative pressure.(68)

Moreover, the study by Al-Jadaa et al. announced similar results between PUI/UAI and needle irrigation when controlling the increase in temperature of NaOCl irrigant solution (about 30 ° C) as a result of ultrasonic activation (elimination of the debris from artificial lateral canals was enhanced).(69)

Studies have demonstrated that refreshing NaOCl along with PUI/UAI can increase the irrigant response and increase the cleaning of the canal; these studies also showed that in the in vitro model, increasing he time of the canal is exposed to PUI/UAI can improve the cleanliness.(70)(71)

Furthermore, the effect of canal curvature on the efficacy of PUI/UAI has also been stated. Compared with the needle irrigation, the cleansing of the root canal and the isthmus at 5 mm of the apex of the curved canal has been significantly improved.(72)(73)

The studies from Ahmed et al. and Lumely et al. in 1992 reported that the curative effect was improved when the pre-curved file was used for PUI/UAI.(3)

Amato et al. (74) showed that the use of PUI/UAI in straight and curved tubes can better clean artificial teeth compared to needle flushing. However, better cleansing was observed in straight canals. This may be caused by the fact that the ultrasonic file is positioned within 1 mm of the root tip and touches the innermost part of the canal wall and the outer wall near the root tip at the curvature, resulting in weakened or limited ultrasonic activation of the irrigation fluid.

In addition, Stojicic et al. reported the effectiveness of NaOCl's sonic agitation on tissue dissolution. They reported that rising the NaOCl concentration has an impressive impact, followed by agitation (sonic) that had the second impressive impact more than rising the temperature of the irrigation solution.(75)

Furthermore, De Gregorio et al. (53) found that when using EDTA, the use of EndoActivator® for sonic activation is equivalent to the effect of PUI/UAI moving the irrigation fluid from the root tip to the 2–4.5 mm lateral canal of the root tip. In a later study, de Gregorio et al. (4) reported that EndoActivator® is better than needle irrigation in obtaining the irrigation fluid for the root canal preparation apex and lateral canal.

Moreover, Sonic activation also has different results when removing the smear layer. Paragiola et al. (76) it is reported that the use of EndoActivator® is better than needle irrigation in eliminating the smear layer, but not as good as PUI/UAI. Uroz-Torres and others. (77) reported that when using EDTA and NaOCl, there was no difference between needle rinsing and EndoActivator® to clear the smear layer.

They pointed out that when only NaOCl is used, no smear layer will be removed. Rödig et al. (78) reported that the addition of PUI/UAI or EndoActivator® activated rinsing fluids (NaOCl and EDTA) in the curved canal developed an excellent smear removal, particularly in the root tip.

Likewise, a study from Ordinola-Zapata et al. found that EndoActivator® agitation and needle irrigation results are equal, and both are lower than PUI/UAI and PIPS irrigation techniques.(79)

A recent study by Seet et al. (80) specified that EndoActivator® agitation reduced the number of bacteria and removed *Enterococcus faecalis* biofilm from the root canal wall instead of the dentin tubules. Acoustic activation is worse than needle irrigation, but not as efficient as LAI.

The irrigating fluid activated by Sonic, Ultrasound or Laser equipment demonstrated great progression in cleansing and disinfecting the root canal system, and should be regarded as an significant basic point in non-surgical endodontic treatment.(3)

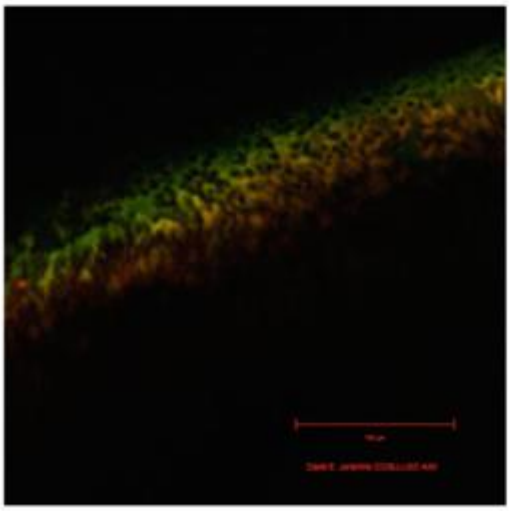

Figure 6: Backlight (live/dead) confocal staining technique. After root canal irrigation with PIPS, the root canal Wall and dentinal tubules are free of either live (Green) or dead (red) bacteria.

5.2.7 Photon-Induced Photoacoustic Streaming (PIPS)

PIPS is a form of laser-activated irrigation. It acts secondarily by activating the irrigation fluid without thermal actions. The mechanism of action is to generate an intense photoacoustic shock wave to make the irrigation fluid three-dimensionally flow all over the root canal system. Unlike other traditional laser applications, there is no need to place the unique tapered and deprived PIPS tip within the canal system itself, but only in the pulp cavity. This minimises the need to use bigger files and rotating instruments to make a bigger shape canals to open the system, so that treatment with irrigant can efficiently reach the fine tip of the apex, isthmus and lateral root canal one third. This non-thermal pressure wave has been shown to be effective in removing healthy and necrotic tissues, killing bacteria, removing biofilms, and indeed disinfecting dentin tubules.(81)

Peters et al. (82) analysed the cleansing and destruction effects of the biofilm in the third canal of the root tip. Compared with the Passive Ultrasonic Irrigation technique group, PIPS cannot entirely eliminate bacteria from infected dentin tubules, however, it produces fewer infections and has a better biofilm removal effect. It can even disinfect dentin tubules.

Furthermore another study found the mixture of irrigation for 20 seconds with Er:YAG laser by use of PIPS photoacoustic delivery technology and 6% NaOCl was more efficacious in suppression of bacterial growth; hence during endodontic treatment, PIPS system can be used as an effective additional tool for sterilisation of infected canals.(3)

Fincham et al. (83) researched the movement of irrigant fluid produced by PIPS and Ultrasonic irrigation and concluded that PIPS results in a higher average fluid velocity near and away from the instrument compared to PUI. Therefore, this huge speed difference between these two instruments, is indicating a clinical advantage in disinfection and probable biofilm removal of the main canal. However, this cannot solve the problem of contamination of the dentinal tubules; in this case, it is necessary to conduct different studies and experiments to check the result of activation on irrigants.(3)

In addition, Ordinola et al. (79) analysed the effect of using 6% NaOCl solution to eliminate biofilm from the root canal, the author found that the group that used PIPS technique has better result in cleaning and disinfecting the canals compare to the PUI group. An exceptional result of this particular experiment was that PIPS tip was positioned 22 mm far from the target area when Ultrasonic, Sonic and Passive irrigation were performed on the precise target area.

Additionally, Alshahrani et al. reported that the mixture of PIPS + NaOCl 6% was more efficient than water + PIPS or irrigation with only 6% NaOCl.(84) However, as mentioned by

Ordinola et al. and Alshahrani et al. , the mixture of PIPS and NaOCl 6% can achieve a better disinfection rate.(79)(84)

5.2.8 Photodynamic Therapy for Root Canal Disinfection (PDT)

Recently, a new type of disinfection method for dental caries and root canal treatment has emerged. This is the light activated disinfection PDT. Its working principle is that the photosensitizer molecules are attached to the bacterial membrane. Light irradiation of a specific wavelength that matches the peak absorption of the photosensitizer will cause the production of singlet oxygen, that will cause the bacterial cell wall to rapture and kill the bacteria.(85)
Photodynamic therapy (PDT) is also thought-out to be one of the possible treatments for local infections, and has nothing to do with pathogenic microorganisms, counting those that are not satisfied with traditional antimicrobial treatment. (86)

Compared with the two treatments alone, the combination of PDT and conventional root canal disinfection methods can significantly improve the effect of bacteria removal. Throughout the years, numerous attempts have been made to enhance the parameters linked with PDT in endodontic applications. A great number of *in vitro* and *in vivo* studies have shown that PDT can eliminate biofilm inside the root canal. (87)
At present, PDT is not considered as a substitute for the current root canal disinfection program, but as a possible adjuvant to advance the anti-biofilm efficacy in the root canal treatment process.(3)

Meire et al. (57) and George et al.and Kishenet al. (88) (89) utilized antibacterial PDT to improve root canal disinfection. They demonstrated that antibacterial PDT can adequately kill the biofilm of *Enterococcus faecalis* through photosensitizers for example methylene blue (MB) and toluidine blue (TBO) and red light. Soukos et al. PDT investigations were performed on a series of dental pulp pathogens (methylene blue as photosensitizer) and stated that all bacteria except *Enterococcus faecalis* (53%) have been completely eliminated.(90)

Moreover, among the most important benefits of PDT is targeted antibacterial impact. Selecting photosensitizers with great affinity for microbial cells and irradiating distinct areas of infection may lead to the targeting effect of antimicrobial PDT.(3)

In addition, when a great concentration and volume of photosensitizer is enforced to the tissue to acquire a most important feedback, the toxicity of the photosensitizer usually occurs. The immediate antimicrobial activity provides extra advantages since antibiotics need couple of days to generate similar efficiency.(3)

Moreover, because PDT has multiple targets on bacterial cell, the possibility of bacterial resistance to this treatment is almost considered impossible.(86)

In addition to the limitations correlated with bacterial biofilm communication/absorption of photosensitizers in the canal , tissue-specific limitations in the performance of the PDT in pulp disinfection also require significant attention. Couple of the tissue-specific constraints used by PDT in pulp disinfection include limited penetration of light energy within the infected tissue, lack of an optimal photosensitizer concentration in the infected tissue, low oxygen tension in the root canal, and dentin discoloration through photosensitization agent. Before confirming PDT as a definitive treatment stage for root canal treatment, these issues need to be addressed.(3)

Bonsor et al.(85) concluded that the when the right photosensitizer and the right energy dose combination are used, and both light ad photosensitizer reach the bacteria, PDT system can successfully eliminate 96.7% of bacteria. It emphasizes that care must be taken when using the emitter to ensure that it is not bent too tight or get stuck in the canal.
On the other hand, the same author demonstrated the combination of 20% citric acid and PDT can cause 91% of samples to completely kill bacteria, however; 20% citric acid and 2.25% NaOCl can cause 82% of samples to completely kill bacteria.(91)

The current study from Garcez et al. evaluated the antibacterial impacts of PDT and endodontic treatment in two different sections ; first section was cleaning and shaping with PDT and after completion of the treatment the root canal is packed with $Ca(OH)_2$; that generated 98.5% bacterial removal, and the second section was took over with PDT, one week after the first section and resulted 99.9% bacterial removal from the canals; which concluded that the second PDT is more efficient than the first. Additionally, after using traditional endodontic chemo-mechanical treatment, antibacterial PDT can provide an effective non-toxic method to eliminate microorganisms remaining in the root canal system.(92)
However, the light source was used as antimicrobial in PDT and the choice of the source depends on the location, the compulsory light dosage and the slecetion of photosensitizer. The laser provides monochromatic , coherent and collimated light and can provide a wide range of output power. The laser can be simply coupled into the fiber optic cable, and it can be used as a transmission system (probe) when irradiating complex anatomical structures for instance root canals. (92) the basic principle of using the optical fiber is to enhance the distribution of light energy through the infected root canal or dentin. Notched fiber is also provided to allow 360°

light distribution and in addition the Optical fiber decreasing the bacterial biofilm more than the laser tip with PDT in the canal aperture (93)

Current study aimed to enhance the antibiofilm efficacy of PDT by making new photosensitizers and combining photodynamic effects with bioactive antimicrobial particles and nanoparticles.(94)

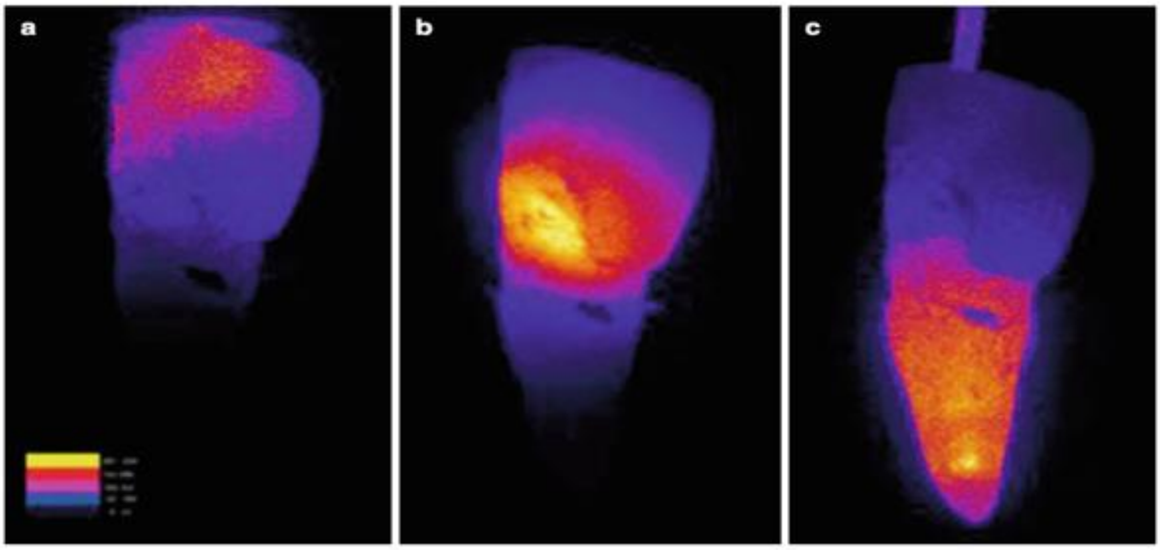

Figure 7: Representative image of the light-scattering intensity of each group. Image J software transforms the black-white image in a false color image according to the light intensity between values minimum of 0 for no light and 256 for maximum light intensity. **(a)** Irradiation with the larger laser tip; **(b)** Irradiation with the smaller laser tip; and **(c)** Irradiation with the laser optical fiber/diffuser

5.2.9.Laser Activation Irrigation (LAI)

There are various studies where many authors such as Hess et al. (95),Weine et al. (96), and Vertucci et al. (97) confirmed the complication of the root canal system. Root canals can demonstrate problems with accessibility, and in a few zones of the root canal system, reachability by instrumentation, irrigation, or even intra-canal medication is impossible.

Because of this unreachability, various irrigation techniques have been recommended with the intention of acquiring greater disinfection rates.

However, there have been problems with the possible harm to the dentin of the root canal, overheating of the root canal and periodontal tissue, entry near the curvature of the root canal and the size of the laser head.(3)

Nowadays, many types of lasers utilized in dentistry including diodes, Nd: YAG, erbium and CO2 that have different wavelengths. They all work by directly radiating light energy to the surface of the tooth to generate a thermal reaction. Nd: YAG (neodymium-doped yttrium aluminium garnet) laser is usually used in the dental field and can produce near-infrared and far-infrared electromagnetic spectrum radiation. This type of laser has good antibacterial effect, but the temperature increases, which is considered to be an unfavorable effect.(28)

An old study in 1992 analysed the difference between Nd: YAG laser and conventional disinfecting and shaping the canals, and reported the canals that used LAI were more polished and cleaner than the conventional technique, however, there were no difference in the taper of the canals, moreover, found that the temperature of the external side of the root did not increase.(3)

A new study by Gordon et al. (98) described the Er,Cr:YSGG laser (erbium, chromium:yttrium-scandium-gallium-garnet) has a great antibacterial impact on dentin tubules infected by *Enterococcus faecialis*. Hence, the frequency of this type of laser is extremely absorbed by water and therefore has a major influence on the bacterial cells themselves. The laser is working by piercing toward dentin surface through a variety of factors.

Furthermore, Blanken and Verdaasdok et al. (99) first described the effect of using the Er,Cr:YSGG laser on irrigation fluids. They reported that there was a fluid movement instantly after every laser pulse, and they observed cavitation effects.

At the same time, the authors found that when the Er.Cr:YSGG laser was used without water, the reduction in bacterial load was greatest caused by radiation energy, however , the elevated in the temperature may have an adverse effect, together with the other negative effect that the NaOCl used as an irrigant was not deactivated after the operation ,that could result in incorrect outcomes.(3)(100)

However, a study by Peeters and Mooduto et al. stated that after Er.Cr:YSGG LAI, there is no irrigation fluid injected outside the apex of the treated tooth.(101)

In addition, it has been proven that the combination of Nd: YAG laser and hand file can generate clean canals without leaving smear layer and tissue residues. Attributable to the influence of laser wavelength and flexible conductor, Nd: YAG laser can be utilized to cease the bleeding after treatment to enhance root canal cleaning, eliminate smear layer and seal dentin tubules, thereby lowering dentin permeability.(102)

Moreover, in the recent studies showed after Nd: YAG laser treatment, the smear layer may fuse with the root canal dentin and re-solidify, which can be used as a single substrate.(102)

Guidotti et al. reported that after LAI with Er: YAG (erbium-doped yttrium aluminium garnet) laser, the internal temperature raised very little below 4 °C, while the outer surface of the root only increased by an average of 1.3°C.(103)

It is announced that the elimination of the smear layer by laser such as Er: YAG and Er,CrYSGG is higher than removal advocated by Nd: YAG lasers.(104)

Even in the deeper dentin layer, only Nd: YAG can obtain a significant degree of disinfection effect; contrary to higher wavelength radiation such as Er: YAG and Er,Cr:YSGG lasers, the radiation of Nd: YAG laser is difficult to be consumed by hard dental materials, so it can be expected to have deeper penetration in the tissue.(102)

A current study, it has been proven that if the laser material is utilized following the correct parameter range and the temperature increase of the root surface does not surpasses 10 °C for more than 1 minute at the temperature higher than body temperature, it will not damage the surrounding Periodontal tissue.(102)

6. CONCLUSION

- Among all the techniques the Manual Dynamic Activation technique (MDA) is inexpensive ,most common, easy to perform and does not require specific instruments or equipment, in addition this technique allows the clinician to mix the irrigant fluid in the canal.

  On the other hand, this MDA is not able to disinfect and clean narrow and anatomically complex area such as narrow isthmuses and close apices, thus the risk of apical expression and accidents are high in this system. The effectiveness and the success rate of this system relies on the penetration of the irrigation solution and the size and type of the needle.
- The syringe and needle irrigation technique is widely used in endodontic treatments, using the syringe irrigation has some disadvantages such as the clinician needs to apply different forces and will encounter varying degree of difficulty when pushing the plunger, the big needle cannot distribute the irrigation solution to the apex, the flow rate

will drop as the solution passes through needle, and also the close-ended needles have a limited area which the irrigation cannot reach that zone. Moreover, the open-ended needle increasing the risk of ejection of the irrigant into the apex area and can cause Vapor Lock phenomenon.

But in contrary, has advantages such as narrow needles (28G-30G or 31G) can reach the WL, the syringe has Leur Lock to prevent accidental detachment of the needle, and in addition, the usage of the close-ended needles can prevent the Vapor Lock phenomenon inside the canal.

- Apical negative pressure technique is safe, can effectively deliver irrigant, eliminate the risk of apical compression and the patients showed less post-operative pain, moreover, the EndoVac system is constantly renewing the irrigation fluid inside the canal that concluded as an effective technique.

  In contrary, the flow rate in this technique can easily change according to the sex of the clinician that is more in male than female.

- The Self-adjusting file system can be used in minimally invasive RCT and the hollow file which is flexible can adjust itself to the shape of the canal and reach the apical zone at the ¨onset¨ of the procedure, this feature helps the file to compress the 1.5 mm inside the root canal, in addition, the shape of the file can ease the work for clinician to reach and disinfect the isthmuses, oval and curved canals. Moreover, this technique showed good results in immature teeth as it does not reduce the dentinal wall and with the continuous irrigation of NaOCl with EDTA demonstrated almost no smear layer in the SEM samples.

Contrarily, this technique showed limits in the narrow and long isthmuses, and the NaOCl became deactivated as the solution removed the inner layer of the root canal and could not eliminate the pulp tissue properly.

- Sonic and Ultrasonic irrigation technique was concluded as one of the most effective and leader in RCT and non-surgical endodontic treatment, because this technique could clean the lateral canals and isthmuses at the 5 mm of the curved canal apex, in addition, the UPI technique showed better disinfecting result as it increased the temperature of the irrigant solution and removed the debris and biofilm successfully. The Sonic activation technique, EndoActivator showed superior results in obtaining the irrigation fluid for the root canal preparation apex and lateral canal.

  Furthermore, the combination of UPI and EndoActivator showed excellent smear removal by activating the irrigation fluid such as NaOCl and EDTA in the curved canal. On the other hand , the time of the exposure to the irrigation solution concluded as criticizing factor as it needs extra time to irrigate the whole canal in an uncontrolled way.

- Photon-Induced Photoacoustic Streaming (PIPS) technique is irrigating the canal three dimensionally; and in addition, it is placed in the pulp cavity rather than inside the canal. Furthermore, this technique doesn’t show the need to use big files and rotatory instrument, so effectively reached the apex, isthmus and lateral canal, additionally, PIPS non-thermal pressure wave shown to be effective in removing healthy and necrotic tissues, killing bacteria, removing biofilm, and of course disinfecting the dentinal tubules.

  Thus, PIPS can be utilized as an effective supplementary tool for sterilization of infected canals.

- Photodynamic Therapy for Root Canal Disinfection (PDT) was concluded as a Novel activation technique as had antimicrobial activity which could kill adequately the biofilm, and the immediate antimicrobial activity after each laser pulse provides extra advantages since antibiotics takes days to generate comparable effect.

  Furthermore, antibacterial PDT can produce an effective non-toxic method to remove microorganisms remaining in the root canal.

  However, the toxicity of the photosensitizers happens when great concentration of the photosensitizer was employed to have more accurate treatment response.

  In addition, in the existence of tissue inhibitors , further research must be conducted to enhance the antibiofilm efficiency of PDT, optimize light transmission in the root canal and optimize new photosensitizers and/or preparation for use in the root canal. Standardized protocols for photosensitivity and photoactivation are essential for pulp disinfection using PDT.

- Laser activated technique has a disadvantage that made the authors to face limitations that is rising the temperature while within the root canal and additionally, the NaOCl that used as an irrigant was not inactivated after operation. However, laser-activated irrigation concluded to be more efficient in removing dentin debris from the root canal apex and in addition, can stop the bleeding after treatment, reducing dentin permeability, eliminate the smear layer and seal dentin tubules and the usage of this technique made the canals more polished and cleaner.

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ANNEXES

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Figure 1: Becker TD, Woollard GW. negative pressure book. Gen Dent. 2001;49(3):272–6.
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Responsibility:

- The author declares that no experiments were performed on humans or animals for this study.
- The author declare that they have followed the protocol of the university on the publication of data.
- The author declares that no patient data appear in this article.

First page of the articles:

8. Root Canal Irrigation

Summary

The aims of root canal irrigation are the mechanical detachment of pulp tissue, dentin debris, smear layer (instrumentation products), micro-organisms (planktonic or biofilm) and their products from the root canal wall, their removal out of the root canal system and their chemical dissolution or disruption. Each of the endodontic irrigation systems has its own irrigant flow characteristics, which should fulfill these aims. Without flow (convection), the irrigant would have to be distributed through diffusion, which is the result of the random movement of individual particles in the fluid. This process is slow and depends on temperature and concentration gradients. On the other hand, convection is a faster and more efficient transport mechanism in which molecules/ions are transported by the motion of fluid which facilitates delivery throughout the root canal system and mixing of the irrigant. During irrigant flow, frictional forces will occur, for example between the irrigant and the root canal wall (wall shear stress). In this chapter the irrigant flow and wall shear stress produced by different irrigation systems will be described. Furthermore, the effect of the flow on the biofilm and the chemical effect of irrigants on the biofilm will be discussed.

8.1 Introduction

Root canal irrigation can be defined as the procedure to deliver a liquid or irrigant in the root canal system before, during and after instrumentation of the root canal. The aims of this procedure are the *mechanical* detachment of pulp tissue, dentin debris, smear layer (instrumentation products), micro-organisms (planktonic or biofilm) and their products (all together hereafter named substrate) from the root canal wall, their removal out of the root canal system and their *chemical* dissolution or disruption.
The objectives of irrigation are to induce a flow of irrigant:
= to the full extent of the root canal system, in order to come in close contact with the substrate, carry away the substrate and provide lubrication for the instruments.
= which ensures an adequate delivery throughout the root canal system, refreshment and mixing of the irrigant, in order to retain an effective concentration of the active chemical component(s) and compensate for its rapid inactivation.
= which ensures a force on the root canal wall (wall shear stress), in order to detach/disrupt the substrate.

1.

Root Canal Irrigants

Matthias Zehnder, Dr. med. dent., PhD

Abstract
Local wound debridement in the diseased pulp space is the main step in root canal treatment to prevent the tooth from being a source of infection. 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. 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. *(J Endod 2006;32: 389–398)*

Key Words
Chelators, chlorhexidine, interactions, irrigants, review, sodium hypochlorite

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We are living in the age of evidence-based medicine. Any new concepts and techniques to be used in the clinic should ideally be assessed in randomized controlled clinical trials against their respective gold standards. This, however, poses a major problem in endodontic research. A favorable outcome of root canal treatment is defined as the reduction of a radiographic lesion and absence of clinical symptoms of the affected tooth after a minimal observation period of 1 yr (1). Alternatively, so-called surrogate outcome (dependent) variables yielding quicker results, such as the microbial load remaining in the root canal system after different treatment protocols, can be defined. However, these do not necessarily correlate with the "true" treatment outcome (2). Endodontic success is dependent on multiple factors (3), and a faulty treatment step can thus be compensated. For instance if cultivable microbiota remain after improper canal disinfection, they can theoretically be entombed in the canal system by a perfect root canal filling (4), and clinical success may still be achieved (5). On the other hand, in a methodologically sound clinical trial, single treatment steps have to be randomized and related to outcome. Otherwise, the results do not allow any conclusions and no causative relationships may be revealed (6).

The above issues may be viewed as the reason (or as an excuse) for the fact that no randomized controlled clinical trials exist on the effect of irrigating solutions on treatment outcome in the endodontic literature. As of yet, we largely depend on data from in vitro studies and clinical trials with microbial recovery after treatment as the surrogate outcome. Clinical recommendations based on such findings are merely deductive and need to be interpreted with care. Nevertheless, individual problems can be singled out in these investigations and basic information can be gained.

It was the purpose of this article to present an overview on irrigating solutions in endodontics, their actions and interactions. Based on data derived from basic science studies, results obtained in clinical investigations are discussed and some general recommendations are given.

Facing the Challenge

There can be no doubt today that microorganisms, either remaining in the root canal space after treatment or re-colonizing the filled canal system, are the main cause of endodontic failure (7, 8). The primary endodontic treatment goal must thus be to optimize root canal disinfection and to prevent re-infection.

Infection of the root canal space occurs most frequently as a sequela to a profound carious lesion (9). Cracks in the crown structure extending into the pulp chamber can also be identified as a cause of endodontic infection (10). Regardless of the microbial entryways, it should be differentiated between vital and nonvital cases (11). Pulpitis is the host reaction to opportunistic pathogens from the oral environment entering the endodontium (12). Vital pulp tissue can defend against microorganisms and is thus largely noninfected until it gradually becomes necrotic (9). In contrast, the pulp space of nonvital teeth with radiographic signs of periapical rarefaction always harbors cultivable microorganisms (13). Consequently, the treatment of vital cases should focus on *asepsis*, i.e. the prevention of infection entering a primarily sterile environment, which is the apical portion of the root canal. *Antisepsis*, which is the attempt to remove all microorganisms, is the key issue in nonvital cases. Vitality cannot always be predictably assessed with current sensitivity tests and radiologic methods before treatment (14). Once the pulp space is entered during access cavity preparation, however, the clinician can clearly discern between vital and nonvital pulp tissue (15), and further treatment decisions can be made accordingly.

Aseptic principles such as correct rubber dam placement and coronal disinfection of the tooth to be treated have long been accepted (16). Although asepsis is not the topic

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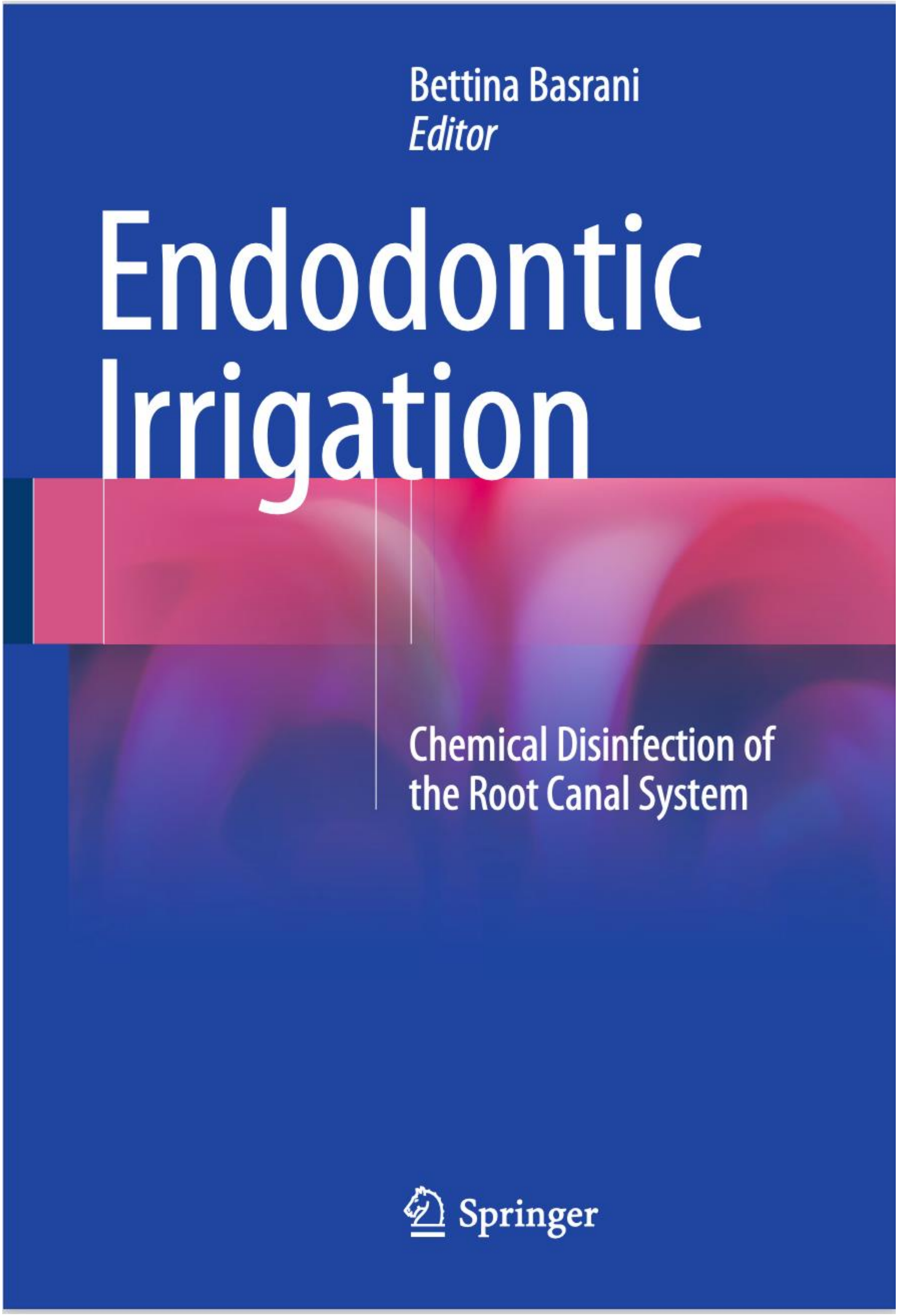
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Efficacy of irrigation systems on penetration of sodium hypochlorite to working length and to simulated uninstrumented areas in oval shaped root canals

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Abstract

de Gregorio C, Paranjpe A, Garcia A, Navarrete N, Estevez R, Esplugues EO, Cohenca N. Efficacy of irrigation systems on penetration of sodium hypochlorite to working length and to simulated uninstrumented areas in oval shaped root canals. *International Endodontic Journal.*

Aim To assess the ability of sodium hypochlorite (NaOCl) to penetrate simulated lateral canals and to reach working length (WL) when using the self-adjusting file (SAF).

Methodology Seventy single-rooted teeth with oval-shaped canals were used. Upon access, presence of a single canal was confirmed by direct visualization under a dental-operating microscope. Canal length and patency were obtained using a size 10 K-file and root length standardized to 18 mm. Pre-enlargement was restricted to the coronal one-third. The apical size of each canal was gauged at WL and samples larger than size 30 were excluded. Canals were instrumented for 5 min using the SAF system while delivering a total of 20 mL of 5.25% NaOCl and 5 mL of 17% EDTA. Then, the apical diameters were standardized to size 35 using hand files. Four hundred and twenty simulated lateral canals were then created during the clearing process and roots coated with wax to create a closed system. All samples were then cleared and randomly assigned to four experimental groups: 1 (n = 15) positive pressure; 2 (n = 15) SAF without pecking motion; 3 (n = 15) SAF with pecking motion; 4 (n = 15) apical negative pressure (ANP) irrigation and (n = 10) control groups. Samples were scored on the basis of the ability of the contrast solution to reach WL and permeate into the simulated lateral canals to at least 50% of the total length. The Kruskal–Wallis test was used to analyse irrigant penetration and the Tukey test to determine statistical differences between groups ($P < 0.05$).

Results All samples irrigated with ANP were associated with irrigant penetration to WL (Table 1). The differences between group 4 (ANP) and all other groups were significant in penetration to WL ($P < 0.05$). The pecking motion allowed for further penetration of the irrigant when using the SAF system but failed to irrigate at WL. None of the experimental groups demonstrated predictable irrigation of simulated lateral canals.

Conclusions In this laboratory model, ANP was the only delivery system capable of irrigating consistently to full WL. None of the systems tested produced complete irrigation in artificial lateral canals.

Keywords: irrigation, penetration, SAF.

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Introduction

Adequate instrumentation combined with effective irrigation is required to achieve sufficient disinfection during root canal treatment (Bystrom & Sundqvist

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A Review: The Applications of EDTA in Endodontics (Part I)

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Abstract : *EDTA is a frequently used irrigant in root canal treatment. Its main activity is toward smear layer removal because of its chelating power which makes it effective in removing the inorganic component of dentin. But it cannot remove the smear layer effectively; a proteolytic component, such as NaOCl, should be added to remove the organic components of the smear layer. EDTA contributes to the elimination of bacteria in the root canal.*

Keywords: *Anti-microbial, Chelating, EDTA, MTAD, NaOCl, Smear layer.*

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I. History Of EDTA

Alfred Werner 1893 developed the theory of coordination compounds, today referred to as chelates. For this turning point in reclassifying inorganic chemical compounds, Werner received the Nobel Prize in 1913. He went on to create accounting for the process by which metals bind to organic molecules, which is the basis for chelation chemistry. In the mid 1930's Germany developed its own chelating material. The synthetic substance they invented was EDTA (Ethylene-diamine-tetra-acetate). Chelating agents were introduced into endodontics as an aid for the preparation of narrow and calcified root canals (1).

II. Chemical Formula Of EDTA

It is a polyaminocarboxylic acid with the formula [CH2N (CH2CO2H) 2]2. Nowadays, EDTA is mainly synthesized from ethylenediamine (1,2-diaminoethane), formaldehyde (methanal), and sodium cyanide (2).

III. Mechanism Of Action Of EDTA

EDTA is a complex molecule with a claw-like structure, which binds and seizes divalent and trivalent metal ions such as calcium and aluminum to form a stable ring structure. EDTA removes bacterial surface proteins by combining with metal ions from the cell envelope leading to bacterial death (1). EDTA forms a stable complex with calcium. When all available ions have been bound no further dissolution takes place; therefore, EDTA is self-limiting (1).

IV. Applications Of EDTA In Endodontics

4.1. Smear layer removal

It has been reported that EDTA decalcified dentine to a depth of 20–30 µm in 5 min (3). The paste type chelating agents do not remove the smear layer effectively when compared to liquid EDTA. EDTA is normally used in a concentration of 17% and can remove the smear layers when in direct contact with the root canal wall for less than 1 minute. Addition of surfactants to liquid EDTA did not result in better smear layer removal (4). A quaternary ammonium bromide has been added to EDTA solutions to reduce surface tension and increase penetrability of the solution. When this combination (REDTA) was used during instrumentation, there was no smear layer remaining except in the apical part of the root canal (5). The ideal working time of EDTAC (EDTA and cetavlon) was suggested to be 15 min in the root canal and no further chelating action could be expected after this (6). Takeda et al reported that irrigation with 17% EDTA, 6% phosphoric acid, and 6% citric acid did not remove the entire smear layer from the root canal system (7). Both EDTA and citric acid can effectively remove the smear layer when used together with NaOCl. 17% EDTA, 18% Etidronic acid, and 7% maleic acid removed the smear layer from different tooth levels (coronal, middle, and apical)(8). A study found that 5% and 7% maleic acid can be an alternative to routine use of 17% EDTA (9). MTAD is an efficient solution for the

5.

Antagonistic Interactions between Sodium Hypochlorite, Chlorhexidine, EDTA, and Citric Acid

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Abstract

Introduction: Root canal irrigants play a significant role in the elimination of microorganisms, tissue dissolution, and the removal of debris and smear layer. No single solution is able to fulfill these actions completely; therefore, their association is required. The aim of this investigation was to review the antagonistic interactions occurring when sodium hypochlorite (NaOCl), chlorhexidine (CHX), EDTA, and citric acid (CA) are used together during endodontic treatment. **Methods:** A search was performed in the electronic database Medline (articles published through 2011; English language; and the following search terms or combinations: "interaction AND root canal irrigant or endodontic irrigant or sodium hypochlorite or chlorhexidine," "sodium hypochlorite AND EDTA or ethylenediaminetetraacetic acid or citric acid or chelating agent or chlorhexidine," and "chlorhexidine AND EDTA or ethylenediaminetetraacetic acid or citric acid or chelating agent") to identify publications that studied unwanted chemical interactions between NaOCl, CHX, and EDTA and CA. **Results:** The search identified 1,285 publications; 19 fulfilled the inclusion/exclusion criteria of the review. Their research methodology was classified as either *in vitro* or *ex vivo*. **Conclusions:** Antagonistic interactions included the loss of free available chlorine for NaOCl when in contact with chelators, which consequently reduced the tissue dissolution capability and to a lesser extent antimicrobial activities. When CHX and NaOCl are mixed, a precipitate forms that can present detrimental consequences for endodontic treatment, including a risk of discoloration and potential leaching of unidentified chemicals into the periradicular tissues. CHX and EDTA mixtures cause a precipitate, whereas CHX and CA do not exhibit interaction. *(J Endod 2012;38:426–431)*

Key Words

Chlorhexidine, citric acid, EDTA, endodontic irrigant, interaction, root canal irrigants, sodium hypochlorite

Root canal cleaning and disinfection during chemomechanical preparation relies heavily on irrigants because of the anatomic complexities of the pulp canal system. Irrigants should ideally have antimicrobial and tissue-dissolution actions as well as other advantageous properties, such as lubrication, demineralization, and the ability to remove debris and the smear layer (1).

Sodium hypochlorite (NaOCl) is recommended as the main endodontic irrigant because of its ability to dissolve organic matter together with its broad antimicrobial action (2). NaOCl is commercially available as aqueous solutions with concentrations ranging from 1% to 15% and having an alkaline pH with values around 11 (3). Among other salts, they also contain sodium hydroxide salts in order to increase their stability (3), and they might contain surfactants as well as other components that are not always disclosed by the manufacturer (4).

No irrigation solution has been found capable of demineralizing the smear layer and dissolving organic tissue simultaneously (5). Therefore, the adjunctive use of chelating agents such as EDTA or citric acid (CA) is suggested in order to remove and prevent the formation of the smear layer associated with root canal instrumentation (2).

EDTA is a polyprotic acid whose sodium salts are noncolloidal organic agents that can form nonionic chelates with metallic ions (2, 6). Its solutions are normally used at concentrations between 10% and 17%, and its pH is modified from its original value of 4 (7) to values between 7 and 8 to increase its chelating capacity (2, 6). Like many well-known chelating agents, EDTA exists in aqueous solutions as an equilibrium mixture of both protonated and unprotonated forms. CA is an organic acid normally used in endodontics at concentrations between 10% and 50% (2) with a pH value between 1 and 2 (8).

Although the role of smear layer removal has been widely debated, endodontic literature concerning the antimicrobial action of irrigants suggests that the combined use of EDTA and NaOCl is more efficient than NaOCl alone when measuring bacterial survival after multiple appointments (9); bacterial survival analysis is a surrogate measure of treatment outcome. A recently published outcome investigation indicated that 2.5% to 5% NaOCl followed by 17% EDTA had a profoundly beneficial effect on secondary nonsurgical root canal treatment success while having a marginal effect on the original treatment (10).

It has been suggested that variations of NaOCl pH will modify the antimicrobial and tissue-dissolution activities (11). A reduction of the pH to values around 6.0 to 7.5 has been found to improve the antimicrobial efficacy (11–13) but hinders tissue-dissolution action (11, 13–15). If the pH is lowered to values below 4, then the amount of chlorine gas in the solution will increase (16). Chlorine in gas form is volatile and therefore unstable (17). If NaOCl is mixed with other irrigants possessing low pH values, there is a possibility of altering its properties.

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6.

Irrigation in endodontics

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IN BRIEF

- Highlights the importance of irrigation in endodontics.
- Provides an overview of solutions used in the irrigation of the root canal.
- Outlines old and new equipment for irrigation.

PRACTICE

Irrigation is a key part of successful root canal treatment. It has several important functions, which may vary according to the irrigant used: it reduces friction between the instrument and dentine, improves the cutting effectiveness of the files, dissolves tissue, cools the file and tooth, and furthermore, it has a washing effect and an antimicrobial/antibiofilm effect. Irrigation is also the only way to impact those areas of the root canal wall not touched by mechanical instrumentation. Sodium hypochlorite is the main irrigating solution used to dissolve organic matter and kill microbes effectively. High concentration sodium hypochlorite (NaOCl) has a better effect than 1 and 2% solutions. Ethylenediaminetetraacetic acid (EDTA) is needed as a final rinse to remove the smear layer. Sterile water or saline may be used between these two main irrigants, however, they must not be the only solutions used. The apical root canal imposes a special challenge to irrigation as the balance between safety and effectiveness is particularly important in this area. Different means of delivery are used for root canal irrigation, from traditional syringe-needle delivery to various machine-driven systems, including automatic pumps and sonic or ultrasonic energy.

INTRODUCTION

Irrigation is a key part of successful root canal treatment as it fulfils several important mechanical, chemical and (micro) biological functions. Irrigation is also the only way to impact those areas of the root canal wall that are not touched by mechanical instrumentation. Much of the research on endodontic irrigation has focused on the effect of irrigation on the smear layer.[1–4] However, smear layer removal can be accomplished relatively easily when correct protocols are followed. A bigger challenge for irrigation may be the areas untouched by the files, such as fins, isthmuses and large lateral canals.[5] Also, large areas in the oval and flat canals may remain untouched despite careful instrumentation. These areas contain tissue remnants and biofilms that only can be removed by chemical means using irrigation. The apical root canal poses a special challenge to irrigation as the balance between safety and effectiveness is particularly important in this area (Fig. 1).[6] Negative pressure irrigation was introduced to endodontic treatment several years ago as a safe method to effectively irrigate the most apical canals.[7,8] Comparative studies on negative pressure and positive pressure irrigation have indicated that the negative pressure method can improve the quality of cleaning of the apical root canal without the risk of extrusion of the solution.[7,9]

Different means of delivery are used for root canal irrigation, from traditional syringe-needle delivery to various machine-driven systems, including automatic pumps, vibrating tips and sonic or ultrasonic energy.[10–13] The goal of the various ways to improve irrigation is to secure optimal spreading of the irrigants throughout the root canal system for more predictable cleaning of the difficult-to-reach areas. Ultrasonic irrigation using ultrasonic tips to deliver the solutions directly into the canal space have shown promising results for cleaning even the most difficult areas such as long and narrow isthmuses between two canals.[14–16]

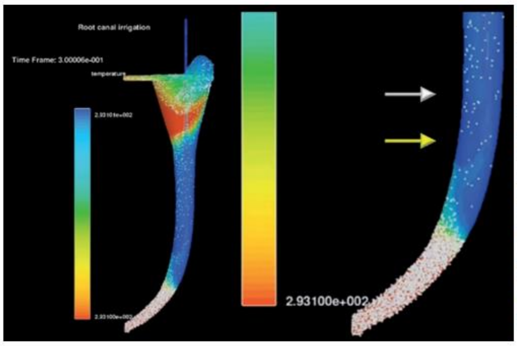

Fig. 1 Particle tracking during irrigation simulated by a computational fluid dynamics model (left), with the high magnification of the root canal (right). The simulation illustrates the weak effect irrigation has on the apical canal. Yellow arrow shows the position of the tip of the irrigation needle, the white arrow shows the place of the side vent

This review is a summary of the present knowledge of effective and safe endodontic irrigation and will include recommendations for optimal irrigation with regard to different solutions, concentration, irrigant sequence and methods of delivery.

GOALS OF IRRIGATION

Irrigation is often regarded as the most important part of endodontic treatment,

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7.

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Root Canal Irrigation

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Abstract The aims of root canal irrigation are the chemical dissolution or disruption and the mechanical detachment of pulp tissue, dentin debris and smear layer (instrumentation products), microorganisms (planktonic or biofilm), and their products from the root canal wall, their removal out of the root canal system. Each of the endodontic irrigation systems has its own irrigant flow characteristics, which should fulfill these aims. Without flow (convection), the irrigant would have to be distributed through diffusion. This process is slow and depends on temperature and concentration gradients. On the other hand, convection is a faster and more efficient transport mechanism. During irrigant flow, frictional forces will occur, for example, between the irrigant and the root canal wall (wall shear stress). In this chapter the irrigant flow and wall shear stress produced by different irrigation systems will be described. Furthermore, the effect of the flow on the biofilm and the chemical effect of irrigants on the biofilm will be discussed.

1 Introduction

Root canal irrigation can be defined as the procedure to deliver a liquid or *irrigant* in the root canal system before, during, and after instrumentation of the root canal. The aims of this procedure are the *chemical* dissolution or disruption and the *mechanical* detachment of pulp tissue, dentin debris and smear layer (instrumentation products), microorganisms (planktonic or biofilm), and their products

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8.

Manual Dynamic Activation (MDA) Technique

8

Pierre Machtou

Abstract

Highest canal disinfection has to be achieved in endodontics in order to expect a predictable successful outcome. So far, following chemomechanical preparation, passive irrigation followed by some type of activation technique has proved to be effective to reduce bacteria counts. Data on the efficiency of current activation systems are inconclusive. Therefore, until a new activation protocol has proven to be the best and although MDA may be perceived by some clinicians as laborious, it is a fast, cost-effective, safe, and convenient method to perform irrigant agitation at the end of the shaping procedure.

Static Versus Dynamic Irrigation

The aim of endodontic treatment is to prevent or treat apical periodontitis which is the result of a bacterial infection of the root canal system. It has been shown that using an antiseptic irrigant during chemo-mechanical preparation plays a major role to help eradicate intracanal bacteria [7]. Nevertheless, despite long efforts to develop new irrigation devices and solutions and new instrumentation techniques, complete sterilization of the root canal systems is currently impossible to achieve. Therefore, the clinical goal is to reduce at best the threshold of the bacterial load to allow the host defenses to repair [33]. When it comes to select an endodontic irrigant, so far, nothing is as efficient as sodium hypochlorite (NaOCl) [42]. In a recent survey among AAE members, more than 90 % of them use it as the primary irrigant [15]. To be effective, NaOCl must be used in large amounts [37], be in contact with the tissues [38], be *mechanically agitated* [26], and be exchanged [2]. Furthermore, NaOCl has to penetrate the full extent of the root canal space since the bacteria involved in the development and continuation of apical periodontitis are located in the last apical 2 ml [25, 27]. But, according to experimental available data, the apical third appears to be the most difficult area to clean [32], implying that irrigant penetration and exchange with the syringe are not easy to occur in this area. It is obvious that a better knowledge of the behavior

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9.

Evaluation of Irrigant Flow in the Root Canal Using Different Needle Types by an Unsteady Computational Fluid Dynamics Model

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Abstract

Introduction: The aim of this study was to evaluate the effect of needle tip design on the irrigant flow inside a prepared root canal during final irrigation with a syringe using a validated Computational Fluid Dynamics (CFD) model. **Methods:** A CFD model was created to simulate the irrigant flow inside a prepared root canal. Six different types of 30-G needles, three open-ended needles and three close-ended needles, were tested. Using this CFD model, the irrigant flow in the apical root canal was calculated and visualized. As a result, the streaming velocity, the apical pressure, and the shear stress on the root canal wall were evaluated. **Results:** The open-ended needles created a jet toward the apex and maximum irrigant replacement. Within this group, the notched needle appeared less efficient in terms of irrigant replacement than the other two types. Within the close-ended group, the side-vented and double side-vented needle created a series of vortices and a less efficient irrigant replacement; the side-vented needle was slightly more efficient. The multi-vented needle created almost no flow apically to its tip, and wall shear stress was concentrated on a limited area, but the apical pressure was significantly lower than the other types. **Conclusions:** The flow pattern of the open-ended needles was different from the close-ended needles, resulting in more irrigant replacement in front of the open-ended needles but also higher apical pressure. *(J Endod 2010;36:875–879)*

Key Words

Computational Fluid Dynamics, irrigation, needle, tip

The irrigation of root canals with antibacterial solutions is considered an essential part of chemomechanical preparation (1). Irrigation with a syringe and a needle remains the most commonly used procedure (2, 3). However, there is an uncertainty about the efficiency of this procedure in the apical part of the root canal (4–6).

To increase the efficiency of syringe irrigation, different needle types have been proposed (7–13). Previous studies of the resulting flow (7, 8, 10, 12) were limited because an indirect or a macroscopic approach can only provide a coarse and incomplete estimation of the irrigant flow. Consequently, there is still no consensus on the superiority of any of these types.

Computational Fluid Dynamics (CFD) represents a powerful tool to investigate flow patterns by mathematical modeling and computer simulation (14, 15). CFD simulations can provide details of the velocity field, shear stress, and pressure in areas in which experimental measurements are difficult to perform. Recently, a CFD model was proposed for the evaluation of irrigant flow in the root canal (16) and was subsequently validated by comparison with experimental high-speed imaging data (17). The aim of this study was to evaluate the effect of needle tip design on the apical irrigant flow inside a prepared root canal during final irrigation with a syringe using this validated CFD model.

Materials and Methods

The root canal and apical anatomy were simulated similarly to a previous study (16), assuming a length of 19 mm, an apical diameter of 0.45 mm (ISO size 45), and 6% taper. The apical foramen was simulated as a rigid and impermeable wall.

Six different needle types were modeled using commercially available 30-G needles as a reference (Fig. 1). The needle types can be divided in two main groups: open-ended (Fig. 1*A-C*) and close-ended (Fig. 1*D-F*). The external and internal diameter and the length of all needles were standardized (D_{ext} = 320 μm, D_{int} = 196 μm, l = 31 mm, respectively) in order to isolate the effect of needle tip design. These values correspond closely to the real geometry of the needles, which was determined according to a previous study (18). The two outlets of the double side-vented needle were modeled identical to the outlet of the side-vented needle to exclude the possible effect of the outlet design. The needles were fixed and centered within the canal, 3 mm short of the working length (WL).

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10.

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REVIEW

Apical negative pressure irrigation versus syringe irrigation: a systematic review of cleaning and disinfection of the root canal system

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Abstract

Konstantinidi E, Psimma Z, Chávez de Paz LE, Boutsioukis C. Apical negative pressure irrigation versus syringe irrigation: a systematic review of cleaning and disinfection of the root canal system. *International Endodontic Journal*, **50**, 1034–1054, 2017.

The aim of this study was to systematically review and critically analyse the published data on the treatment outcome (primary outcome) and on the cleaning and disinfection of root canals (secondary outcomes) achieved by negative pressure irrigation as compared to syringe irrigation. An electronic search was conducted in EMBASE, LILACS, PubMed, SciELO, Scopus and Web of Knowledge using both free-text keywords and controlled vocabulary. Additional studies were sought through hand searching of endodontic journals and of the relevant chapters of endodontic textbooks. No language restriction was imposed. The retrieved studies were screened by two reviewers according to predefined criteria. Included studies were critically appraised and the extracted data were arranged in tables. The electronic search and hand search retrieved 489 titles. One clinical study and 14 *in vitro* studies were finally included in the review; none of these studies assessed treatment outcome, four studies assessed the antimicrobial effect, seven studies evaluated the removal of pulp tissue remnants, and four studies investigated the removal of hard tissue debris or both hard tissue debris and pulp tissue remnants. Poor standardization and description of the protocols was evident. Inconclusive results were reported about the cleaning and disinfection accomplished by the two irrigation methods. Negative pressure irrigation was more effective under certain conditions when compared to suboptimal syringe irrigation; however, the variability of the protocols hindered quantitative synthesis. There is insufficient evidence to claim general superiority of any one of these methods. The level of the available evidence is low, and the conclusions should be interpreted with caution.

Keywords: cleaning, disinfection, irrigation, needle, negative pressure, syringe.

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Introduction

Irrigation is considered an essential part of root canal treatment as it reinforces the cleaning and disinfection of areas of the root canal system that have been insufficiently affected by instruments (Peters *et al.* 2001, Gulabivala *et al.* 2005, Paqué *et al.* 2010). Additional cleaning and disinfection are achieved through the chemical and mechanical disruption and removal of bacteria and especially biofilm, pulp tissue remnants, dentine debris and of the smear layer by the irrigant, provided that it can reach them (Gulabivala *et al.* 2005, Zehnder 2006, Boutsioukis & van der Sluis 2015). Multispecies microbial biofilms in remote areas of the root canal system are

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RESEARCH ARTICLE

Role of the confinement of a root canal on jet impingement during endodontic irrigation

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Abstract During a root canal treatment the root canal is irrigated with an antimicrobial fluid, commonly performed with a needle and a syringe. Irrigation of a root canal with two different types of needles can be modeled as an impinging axisymmetric or non-axisymmetric jet. These jets are investigated experimentally with high-speed Particle Imaging Velocimetry, inside and outside the confinement (concave surface) of a root canal, and compared to theoretical predictions for these jets. The efficacy of irrigation fluid refreshment with respect to the typical reaction time of the antimicrobial fluid with a biofilm is characterized with a non-dimensional Damköhler number. The pressure that these jets induce on a wall or at the apex of the root canal is also measured. The axisymmetric jet is found to be stable and its velocity agrees with the theoretical prediction for this type of jet, however, a confinement causes instabilities to the jet. The confinement of the root canal has a pronounced influence on the flow, for both the axisymmetric and non-axisymmetric jet, by reducing the velocities by one order of magnitude and increasing the pressure at the apex. The non-axisymmetric jet inside the confinement shows a cascade of eddies with decreasing velocities, which at the apex does not provide adequate irrigation fluid refreshment.

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List of symbols

u, v	velocity in r and y direction
ρ	fluid density
ν	fluid dynamic viscosity
R, D	jet radius, diameter
Q	flow rate
$Re = \frac{vD}{\nu}$	Reynolds number
d	distance between the needle tip and the apex or wall
d_{stag}	distance from the plate or apex where stagnation flow holds
θ	angle under which flow exits the needle
α	(root canal) cone angle
μ	eigenvalue of the stream function inside a cavity

1 Introduction

A root canal treatment is a dental therapeutic procedure, which is necessary when bacteria cause an inflammation of the bone around the tip of the tooth. During a treatment, the root canal is irrigated and disinfected with an antibacterial solution (the 'irrigant') using a syringe and a needle (Haapasalo et al. 2005). This irrigant needs to be refreshed frequently for optimal reaction with the bacteria. However, the flow created by a syringe and needle has been shown to be marginally effective in entirely cleaning the root canal systemy (Nair 2004), due to the flow of irrigant not being

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Efficacy of Four Irrigation Needles in Cleaning the Apical Third of Root Canals

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This study aimed to evaluate the influence of irrigation needle gauge and design, and the final root canal diameter on the apical cleaning efficacy. Twelve human mandibular incisors were used. At different stages of root canal widening (sizes 20, 30 and 40 K-files), root canals were filled with radiopaque contrast medium. Four different needles were evaluated: 23G with side opening, 22G with apical opening, 30G with side opening and 30G with apical opening. Irrigation was carried out with 2 mL distilled water. The same tooth was radiographed with a digital system several times to assess the four types of needle in those three stages of canal widening. Pre-irrigation (canals filled with contrast) and post-irrigation (canals with remaining contrast) images were submitted to digital subtraction using the Adobe Photoshop CS4 program. Pre-irrigation (filled with contrast) and subtracted (cleaned by irrigation) areas were outlined by a trained and blinded operator using the Image Tool 3.0 software. Their ratio was calculated to express the percentage of apical cleaning in each stage of canal widening (sizes 20, 30 and 40 K-files) with each of the four needles. Data obtained were subjected to one-way ANOVA and Tukey's tests. The 30G needles with side and apical opening promoted better apical cleaning at all stages of root canal widening ($p<0.05$). In conclusion, smaller diameter needles were more efficacious in cleaning the apical third of the root canals, regardless of their design.

Key Words: endodontics, digital radiography, root canal irrigants, root canal preparation.

Introduction

Root canal irrigation and instrumentation promote cleaning and disinfection of the root canal, contributing for the success of endodontic therapy (1). The ideal irrigation solution should remove debris, lubricate the root canal walls, dissolve organic tissues and eliminate bacteria. Regardless of the used irrigating solution, the endodontic microbiota is significantly reduced by the mechanical action of irrigation (2).

Efficacy of root canal irrigation depends on several factors, such as depth of needle insertion into the canal (3), final diameter of the prepared canal (4), canal curvature (5), as well as volume and properties of the used solution (6).

Greater approximation of the irrigating device to the contaminated area favors its effectiveness (3). Thus, penetration of the irrigating needle into the apical portion of the root canal is important for complete removal of debris and endodontic microorganisms (7,8). Consequently, irrigation needle gauge and the amount of root canal widening may affect the cleaning efficacy. The widely used "gauge" unit is not directly comparable to the size of endodontic instruments. According to the ISO 9626 1991/2001 standard, needles with gauges of 21, 23, 25, 27 and 30 present external diameter of 0.8, 0.6, 0.5, 0.4 and 0.3 mm, respectively (9).

Radiography has been employed to evaluate the cleaning efficacy of irrigation, by analyzing the clearance of radiopaque contrast medium from the root canals (7,10). Subtraction of images using conventional software is also an important evaluation tool (11). This method is used to evaluate irrigant penetration and renewal during root canal preparation (12). Moreover, digital radiography provides good image quality (13), with advantages of reducing radiation exposure, saving time and producing standardized images that can be manipulated with different tools (14).

The aim of this study was to evaluate, by means of digital radiography, the influence of the gauge and design of the irrigation needle and the size of root canal widening on the apical cleaning efficacy of endodontic irrigation.

Material and Methods

After approval of the research by the institutional Ethics Committee (Protocol# 20/09), 12 freshly extracted human mandibular incisors with a single and straight root canal, fully formed root and initial diameter corresponding to a #15 K-file or smaller were selected. Coronal access was performed with a #1012 spherical diamond bur (KG Sorensen, São Paulo, SP, Brazil) and complemented with a #1 Largo drill (Dentsply Maillefer, Ballaigues, Switzerland). Following that, root canal length was determined by introducing a #10 K-file (Dentsply Maillefer) until its tip was visible at the apical foramen. Working length was established by subtracting 1 mm from the total length.

The root canals were hand-instrumented and widened up to size 20, 30 or 40 K-files at the working length. Next,

13.

Effect of Vapor Lock on Root Canal Debridement by Using a Side-vented Needle for Positive-pressure Irrigant Delivery

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Abstract

Introduction: This study examined the effect of vapor lock on canal debridement efficacy by testing the null hypothesis that there is no difference between a "closed" and an "open" system design in smear layer and debris removal by using a side-vented needle for irrigant delivery. **Methods:** Roots in the closed system were sealed with hot glue and embedded in polyvinylsiloxane to restrict fluid flow through the apical foramen during cleaning and shaping. For the open system, the apical foramen was enlarged and connected to the external environment via a channel within the polyvinylsiloxane to permit unrestricted fluid flow. Smear and debris scores were evaluated by using scanning electron microscopy and analyzed by using Cochran-Mantel-Haenszel statistic. **Results:** No difference in smear scores was detected between the 2 systems at all canal levels. Significant differences in debris scores between the 2 systems were found at each canal level: coronal ($P < .001$), middle ($P < .001$), and apical ($P < .001$). **Conclusions:** The null hypothesis was rejected; presence of an apical vapor lock effect adversely affects debridement efficacy. Thus, studies with unspecified or questionable mechanisms to restrict fluid flow through the apical foramen have to be interpreted with caution. *(J Endod 2010;36:745–750)*

Key Words

Debris, irrigation, root canal, side-venting syringe delivery, smear layer, vapor lock

Thorough debridement is crucial for long-term success in root canal treatment (1–4). The mechanical debridement efficacy of an irrigation delivery/agitation system is dependent on its ability to deliver the irrigant to the apical and noninstrumented regions of the canal space and to create a strong enough current to carry the debris away from the canal walls (5–9). Because the root is enclosed by the bone socket during *in vivo* cleaning and shaping (10–12), the canal behaves as a closed-end channel, which results in gas entrainment at its closed end (13–15), producing a vapor lock effect during irrigant delivery (16, 17). Studies that were designed to simulate such a closed system by embedding the root in a polyvinylsiloxane impression material (PVS) to restrict fluid flow through the apical foramen demonstrated incomplete debridement from the apical part of the canal walls with the use of a syringe delivery technique (18–20).

If not optimally designed or meticulously executed, a closed system behaves as an open system that challenges the creditability of the results. For example, a hypothetical closed system that consists of stabilizing the longitudinal bottom half of a completely demineralized root in soft silicone and covering the top half with methyl salicylate to prevent the cleared root from opacifying functions as an open system, even when the apex remains covered by silicone. This permits flow of a dye-containing irrigant through the lateral canals and apical foramen when it is delivered under positive pressure. Likewise, a hypothetical scenario that consists of postextraction flushing of an irrigant through an unsealed apical foramen to remove blood that enters the canal space during tooth extraction bleaches the original *in vivo* vapor lock and revokes the goal of examining debridement efficacy in a closed system.

Because the debridement quality between a closed versus an open system design has not been evaluated simultaneously in a single study, it is dubious whether conclusions derived from studies with unspecified or ambiguous mechanism to restrict fluid flow through the apical foramen are as clinically relevant as those that adopted a robust closed system design. This study attempted to resolve this issue by testing the null hypothesis that there is no difference between a closed and an open system design in smear layer and debris removal by using a side-vented needle for irrigant delivery.

Materials and Methods

Twenty-eight extracted human single-rooted teeth were radiographed to ensure that each tooth contained 1 canal, and that an equal number of narrow (33%) and

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14.

applied sciences

MDPI

Article

Effectiveness of Vapor Lock Effect Removal in Endo Training Blocks: Manual Dynamic Agitation versus Passive Ultrasonic Irrigation

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Abstract: Root canal cleaning plays an important role in endodontics. In most cases, root canal cleaning is performed using irrigants, such as sodium hypochlorite or EDTA (ethylenediaminetetraacetic acid). The efficacy of these irrigants may be compromised by different phenomena, such as vapor lock. Different methods can be used to overcome this problem; in this paper, we compare the efficacy of two such methods: manual dynamic agitation (MDA) and passive ultrasonic irrigation (PUI). We shaped 50 endo training blocks, which were divided into two groups of 25 samples each, into MDA or PUI groups. In both groups, the vapor lock was produced by delivering a watery solution using a disposable syringe with a tip-opened needle. Using the MDA technique, vapor lock was removed in 15/25 cases. The PUI technique produced the same results in 17/25 cases, where vapor lock was only reduced, not removed. The MDA method produced an average reduction in vapor lock of 80%, whereas the PUI method yielded a 55% reduction. The differences among groups were assessed through a Mann–Whitney U test, and the results had a *p*-value of 0.0013, which was considered to be statistically significant. The MDA method was able to effectively remove vapor lock. PUI, however, was only able to reduce but not remove vapor lock.

Keywords: manual dynamic agitation; passive ultrasonic irrigation; vapor lock; endodontics; endo training blocks; endodontic irrigation; ultrasonic activation; root canal irrigants

1. Introduction

Endodontic treatment involves a procedure composed of the following sequence of steps: tooth anesthesia, operative field isolation, opening of the pulp chamber, canal scouting, shaping and cleansing of the canals, and three-dimensional (3D) obturation [1]. These phases lead to root canal disinfection, shaping [2,3], and filling [4]. All the steps are important for achieving endodontic success, but cleansing has an essential role in reducing the bacterial load inside the root canal system [5]. Cleansing can be

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10 Apical Negative Pressure Irrigation (ANP)

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Introduction

It has been well established for the past several years that the etiology for endodontic disease is microbial pathogens. Toxic metabolites and by-products released from microorganisms within the canal diffuse into apical tissues and elicit inflammatory responses and bone resorption (1, 2). The host immune response plays an important role at this time by preventing the infection from spreading into the various parts of the body. However, because of the lack of blood supply in a necrotic tooth, the host response cannot affect the bacteria that are present in the root canal system. Hence it is necessary to mechanically and chemically remove these microorganisms during root canal treatment procedures. Irrigation along with the instrumentation of the canal can help achieve the goal of disinfection of the root canals. Irrigation supports mechanical instrumentation along with killing and removing any residual microbes left back in the canal. Currently, there are numerous irrigation solutions and irrigation techniques available and many of them have showed improvement even in the most complex canal systems. This chapter focuses on the apical negative pressure (ANP) irrigation system's unique abilities, advantages, and benefits, one of which is exemplified in Figure 10.1.

Positive pressure (PP) irrigation is still widely used by many clinicians. However, a review of the literature shows that PP irrigation systems have their limitations—inadequate debridement and disinfection in the apical area. Previous studies have demonstrated that PP irrigation had virtually no effect on the orifice of the needle (3). Furthermore, some more recent studies have demonstrated the effectiveness of other irrigation systems over the traditional PP systems (4–6). In addition to debridement and disinfection, safety is another

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16.

Apical Negative Pressure: Safety, Efficacy and Efficiency

9

Gary Glassman and Karine Charara

Abstract

The objective of dentistry is to prevent oral disease and retain the natural dentition, hopefully for the lifetime of the patient. The objective of endodontic treatment is to prevent and/or treat apical periodontitis. In order for an endodontic irrigant delivery system to be mechanically effective and satisfy the objective of endodontics, it must reach the apical terminus, create a current along the root canal wall and have the ability to remove debris, tissue and bacterial contaminants. Currently, the irrigant of choice to achieve this objective is full-strength sodium hypochlorite (NaOCl).

During endodontic irrigation, the organic component of pulpal tissue consumes NaOCl rapidly as the reaction of hydrolysis occurs forming water and releasing ammonia and carbon dioxide as the by-products. In very short order, a column of gas develops at the apical one third of the root canal (apical vapour lock). The conundrum that the clinician faces is to safely and effectively deliver the irrigants to the apical terminus, break the apical vapour lock and allow constant exchange of irrigant and thereby continual hydrolysis of pulpal tissue by the NaOCl, without the risk of apical extrusion.

This chapter will outline the scientific evidence surrounding apical negative pressure as a safe and reliable method to deliver irrigants to the apical terminus, thereby satisfying the objectives of endodontic treatment.

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17.

Instrumentación tridimensional de sistemas de conductos mediante el sistema *self adjusting file* (SAF). A propósito de un caso

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RESUMEN

Algunas de las dificultades que nos encontramos en los retratamientos son la eliminación del material de obturación intraconducto y la presencia de dentina muy contaminada por microorganismos resistentes, en muchas ocasiones asociados en biofilms. En el caso que presentamos nos ayudamos en la última fase del retratamiento de un nuevo sistema que combina instrumentación e irrigación simultáneamente, cuya principal característica es la de adaptarse a la sección transversal de los conductos y de este modo permitir alcanzar áreas en las que la instrumentación rotatoria presenta grandes limitaciones. Facilitándonos, de este modo, la eliminación de cemento y gutapercha remanentes así como dentina contaminada, respetando la anatomía original. El caso ejemplifica esta técnica clínica sobre la que hemos realizado una discusión a partir de la literatura revisada. El diente tratado, un segundo molar inferior, presenta una periodontitis apical aguda producida por una subextensión del material obturador y una deficiente condensación del mismo. Su anatomía inusual formada por un único y amplio conducto es desobturada y desinfectada para proceder a su obturación termoplástica. La evolución del caso a los 6 meses indica una mejora de la sintomatología sin signos radiográficos que indiquen patología periapical.

PALABRAS CLAVE

AF; Retratamiento; Periodontitis apical; Áreas sin instrumentar; Biofilms.

ABSTRACT

Some of the difficulties we can find in a retreatment are the removal of the filling material and the presence of intracanal dentin heavily contaminated with resistant organisms, often associated in biofilms. In this case report we help in the last phase of treatment that combines a new simultaneously instrumentation and irrigation system whose main characteristic is to adapt to the cross section of the canals and thus allow to reach areas in which the rotary instrumentation has great limitations. In retreatments, this system provide us thereby removing residual cement and gutta percha and most infected dentin, respecting the original anatomy. The present case illustrates the clinical technique on which we have made a discussion from the literature reviewed. The treated tooth presents a acute apical periodontitis with a subextension of the root canal treatment and a poor condensation. Its unusual anatomy consists of a single large canal which is desobturated and disinfected to proceed with thermoplastic seal. The evolution of the case at 6 months indicates an improvement of symptoms without radiographic signs of apical periodontitis.

KEY WORDS

SAF; Retreatment; Apical periodontitis; Uninstrumented áreas; Biofilms.

18.

The Self-adjusting File (SAF). Part 2: Mechanical Analysis

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Abstract

Introduction: The study was designed to explore the mechanical properties of the self-adjusting file (SAF) and its application in the root canal using continuous irrigation. **Methods:** The compressibility of the SAF file and the resulting peripheral force were measured using specially designed systems. The abrasivity of the file was tested on dentin blocks representing a flat root canal. The durability of the SAF file was tested using a functional fatigue-to-failure assay. Degradation of the file was evaluated by using files that were previously used for 10, 20, and 30 minutes and comparing their efficacy with that of new, unused files. The potential of extruding irrigant beyond the apex was explored in roots with an open apical foramen. **Results:** The SAF file was elastically compressible from a diameter of 1.5 mm to dimensions similar to those of a #20 stainless steel K-file. This compression resulted in an evenly applied force to the root canal walls. The in-and-out vibration of the file and the peripheral force, combined with its abrasivity, allow for hard-tissue removal. Under the conditions of the experiment, no mechanical failure was observed with up to 29 minutes of operation in the root canal. The file loses its efficacy after prolonged use, with a 40% reduction after 30 minutes of operation. The operation of the file with continuous irrigation did not push the irrigant beyond an open apical foramen. **Conclusions:** The SAF file is an elastically compressible file that effectively removes dentin and can mechanically endure use under its recommended mode of operation with a minimal loss of efficacy. *(J Endod 2010;36:691–696)*

Key Words

Cleaning and shaping, cyclic fatigue, endodontic files, fatigue, mechanical properties, SAF, self-adjusting file

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Rafael Hof, Valery Perevalov, Moshe Eltanani, and Dr. Raviv Zary are employed by ReDent-Nova, manufacturer of the SAF file. Dr Zvi Metzger serves as a scientific consultant to the same company.

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The biological objectives of root canal treatment have not changed over the recent decades, but the methods to attain these goals have been greatly modified. The introduction of nickel-titanium rotary files represents a major leap in the development of endodontic instruments, with a wide variety of sophisticated instruments presently available (1, 2).

The superelastic alloy has made it possible to manufacture highly efficient instruments that can be rotated safely, even in curved root canals with a reasonable centingability, reasonably maintaining the long axis of the canal in its original location. Since then, many file designs have been tested and introduced with variations in rake angle, radial lands design, helical pitch, or thickness of the core (3–5). Some designs are highly aggressive and some are more flexible, whereas others offer safe tips or an interrupted helical angles (3–8). Recent advances in nickel-titanium metallurgy are also promising a potential for more elastic instruments (9). Whatever their modification or improvement, all of these instruments have one thing in common: they consist of a metal core with some type of rotating blade that machines the canal with a circular motion using flutes to carry the dentin chips and debris coronally. Consequently, all rotary nickel-titanium files will machine the root canal to a cylindrical bore with a circular cross-section if the clinician applies them in a strict boring manner.

When operated in narrow canals or those with a round cross section, this mode of operation may be adequate. The situation is quite different for flat root canals that have an oval or even ribbon-shaped cross-section.

Several reports have indicated that in oval or flat root canals, rotary files alone fail to perform adequate cleaning and shaping. Untreated "fins" may remain on the buccal and/or lingual aspects of the bore created by the rotary file (10–12). The new self-adjusting file (SAF) represents a totally different approach in endodontic file design and mode of operation that was specially designed to overcome this problem (13).

The SAF is a hollow file designed as a compressible, thin-walled, pointed cylinder, 1.5 mm in diameter, composed of a thin nickel-titanium lattice (Fig. 1A). During its operation, the file is designed to be compressed while inserted into a narrow root canal. The file then attempts to regain its original dimensions, thus applying a constant delicate pressure on the canal walls. When inserted into a root canal, it adapts itself to the canal's shape, both longitudinally (as will any nickel-titanium file) and also along the cross-section (13, 14). In a round canal, it will attain a round cross-section, whereas in an oval or flat canal it will attain a flat or oval cross-section, thus providing three-dimensional adaptation during the cleaning and shaping process (13, 14). Thus, its name, SAF, expresses this unique behavior during its application.

The surface of the SAF lattice threads is lightly abrasive, designed for the removal of dentin with a back-and-forth grinding motion. A single SAF file is used throughout the procedure, starting as a compressed file that gradually enlarges in size during dentin removal with close adaptation to the canal walls.

The SAF is operated using a dental handpiece that provides a vertical (in-and-out) vibration, with 3,000 to 5,000 vibrations per minute and a 0.4-mm amplitude (13). A light manual in- and-out motion of 3 to 5 mm is applied by the operator. The hollow SAF file also allows for continuous irrigation throughout the procedure. Irrigation is performed via a silicon tube that is attached to a rotating hub on the shaft of the file (Fig. 1A). The irrigant goes into the file, freely escapes into the canal through the lattice wall, and then flows back coronally and escapes through the access cavity. The aim of this study was to mechanically analyze the SAF and to characterize the parameters of its performance, mode of action, and durability.

19.

Antibacterial Efficacy of a New Sonic Irrigation Device for Root Canal Disinfection

Klaus W. Neuhaus, DMD, MMA, MAS, Melanie Liebi, DMD,* Simone Stauffacher, DMD,* Sigrun Eick, DMD,† and Adrian Lussi, DMD**

Abstract

Introduction: Passive ultrasonic irrigation (PUI) is the most widespread method used to activate irrigation solutions. Concerns have been raised that PUI is less effective in curved root canals and is not passive at all. Our aim was to compare a novel passive sonic irrigation (PSI) device (6000 Hz) with PUI and manual irrigation (MI) with respect to their efficiency in removing different endodontic microorganisms from curved and straight root canals. **Methods:** We performed 2 experiments as follows. In a 3-day infection model, we included 8 groups of single or dual microbial species that were rinsed with 0.9% sodium chloride using PSI, PUI, or MI. Colony-forming units (CFUs) were counted after incubation, and log_{10} transformations were performed for statistical comparisons. In a 21-d infection model, we tested the same irrigation protocols on 4 groups of microorganisms and used 1.5% sodium hypochlorite as an irrigant. Infection control samples were taken at day 0, 3, 5, and 7 after treatment and were subsequently reincubated. **Results:** Using sodium chloride as an irrigant, the amount of reduction in CFUs compared with the negative control was approximately 3 log_{10} units for PSI at 6000 Hz, 2 log_{10} units for PUI, and 1 log_{10} unit for MI. PSI reduced the microorganism CFUs significantly better than PUI. Using sodium hypochlorite led to a significant reduction in microorganism CFUs even with MI. After 3 days, compared with MI, microorganism regrowth significantly reduced after PSI and PUI treatment, but in these groups, in at least half of the samples, microorganisms were detectable after 7 days. **Conclusions:** PSI at 6000 Hz might be at least equal to PUI with respect to reduction of the microbial load in curved and straight root canals. *(J Endod 2016;■:1–5)*

Key Words

Disinfection, oral bacteria, root canal, sonic irrigation, ultrasonic irrigation

Significance

Passive sonic irrigation at 6000 Hz seems to perform equal to or better than passive ultrasonic irrigation.

Root canal infections are caused by a variety of mainly anaerobic gram-positive bacteria (1). A persistent intraradicular presence of bacteria after chemomechanical treatment is considered to be a possible cause of endodontic failure (2). Although facultative anaerobes such as *Streptococcus gordonii*, *Fusobacterium nucleatum*, and *Actinomyces oris* have been isolated in primary endodontic infections (3), the persistence of *Enterococcus faecalis* (4) or *Candida albicans* (5) has been associated with persistent periapical lesions and the need for endodontic retreatment. Sodium hypochlorite is considered a suitable disinfecting irrigation solution, but it has been shown that ultrasonic activation of sodium hypochlorite (NaCl) enhances its effectiveness (6). Nowadays, passive ultrasonic irrigation (PUI) seems to be the predominant activation method for endodontic irrigation solutions (7). The main reason for the additional effectiveness via ultrasound has been shown to be caused by acoustic streaming effects that increase wall shear stress and enhance rupturing of intraradicular biofilm (8). However, several limitations have been identified that impose procedural problems when using ultrasonic activation. Wall contact with the oscillating instrument dampens the energy and constrains the file movement (9). Therefore, in curved root canals, ultrasonic instruments are less likely to oscillate freely. It has been shown that even in straight root canals an ultrasonic instrument comes into contact with the wall during at least 20% of the working time (10). Furthermore, although ultrasonic irrigation instruments usually possess a noncutting design, they are made of a metal alloy that is harder than root dentin, and, therefore, their use risks changing root canal morphology. Consequently, Boutsioukis et al (10) suggested that PUI be replaced by ultrasonically activated irrigation.

In order to avoid the detrimental effects caused by ultrasonic activation, activating the irrigation solution with sonically driven noncutting plastic tips was suggested. Among the devices using this technique, the EndoActivator (Dentsply, Tulsa, OK) device appears to be the best-documented system (11). The principle is to use a polyamide tip to activate the solution and thus to prevent active cutting of the root canal walls or opening of the apical constriction. Passive sonic activation at low frequency was shown to be inferior to PUI with respect to bringing irrigation solution to the apex in variously tapered and curved canals (12). Furthermore, using simulated lateral canal models, no difference in cleaning efficacy was detected between PUI and passive sonic activation at low frequency (13). The maximum frequency of the aforementioned sonic irrigation system was measured to be 190 Hz (14).

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20.

Antibacterial Efficacy of a New Sonic Irrigation Device for Root Canal Disinfection

Klaus W. Neuhaus, DMD, MMA, MAS, * *Melanie Liebi, DMD,* * *Simone Stauffacher, DMD,* * *Sigrun Eick, DMD,*† *and Adrian Lussi, DMD**

Abstract

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21.

Efficacy of Ultrasonic *versus* Laser-activated Irrigation to Remove Artificially Placed Dentin Debris Plugs

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Abstract

Introduction: The study assessed the efficacy of laser activated irrigation (LAI) with Erbium: Yttrium Aluminum Garnet (Er:YAG) and Erbium Chromium: Yttrium Scandium Gallium Garnet (Er,Cr:YSGG) wavelengths as compared with passive ultrasonic irrigation (PUI). Previously proposed irrigation times were used for LAI (4× 5 seconds) and the intermittent flush technique (3× 20 seconds). **Methods:** We used a split root model with an artificial root canal wall groove. Roots were prepared to an apical size # 40 with ProFiles 0.06 (Dentsply Maillefer, Baillaigues, Switzerland). Five groups of 20 straight canine roots were evaluated as follows: Group 1: hand irrigation for 20 s with 2.5% NaOCl (CI); Group 2: PUI performed once for 20 s with the #20 Irrisafe (Satelec Acteon group, Merignac, France) (PUI 1); Group 3: PUI for 3x 20 s with the Irrisafe (PUI 2); Group 4: LAI with the Er,Cr:YSGG laser and Z2 (200 μm) Endolase tip (Biolase, San Clemente, USA) at 75 mJ for 4x 5 s (LAI 1); Group 5: LAI with the Er:YAG laser (HoYa Versawave, Cortaboeuf, France) and a 200 μm endodontic fiber at 75 mJ for 4x 5 s (LAI 2). Images from the groove were taken before and after irrigation. The quantity of dentin debris in the groove after the experimental protocols was evaluated. **Results:** Statistically significant differences ($p < 0.05$) were found between CI and all other groups and between PUI 1 and the other groups. **Conclusion:** LAI techniques using erbium lasers (Er:YAG or Er,Cr:YSGG) for 20 seconds (4× 5 seconds) are as efficient as PUI with the intermittent flush technique (3× 20 seconds). *(J Endod 2010;36:1580–1583)*

Key Words

Irrigation, laser, root canal, ultrasound

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Effective endodontic treatment requires the combination of physical and chemical agents to eradicate soft-tissue debris, smear layer, and microorganisms because buildup of debris in the root canal system makes effective cleaning and disinfection impossible. The use of lasers at different wavelengths has been proposed to supplement conventional endodontic cleaning procedures (1–4). A considerable limitation, however, is the unidirectional emission of the laser beam, which makes it difficult to access the entire root canal wall with the laser. The laser fiber must be moved repeatedly in a spiraling motion along the root canal walls in order to maximize the area exposed to the laser beam, but even this is not completely efficient and the entire root canal wall will not be exposed to the laser beam (2, 4). Alternative approaches such as side-firing tips have limited use because of their size (4) or require further investigation before clinical application (5, 6).

Laser-activated irrigation (LAI) with an erbium laser has been introduced as a method for activating the irrigant (5–10). The effect is based on cavitation; in water, activation of the laser at subablative settings may result in the formation of large elliptical vapor bubbles, which expand and implode. These vapor bubbles may cause a volumetric expansion of 1,600 times the original volume, which increases pressure and drives fluid out of the canal. When the bubble implodes after 100 to 200 microseconds, an underpressure develops and sucks fluid back into the canal, inducing secondary cavitation effects. Therefore, the laser works as a fluid pump. Another technique, passive ultrasonic irrigation (PUI), is also based on the principle of cavitation and acoustic streaming (11). The ultrasonic activation of irrigants therefore plays a pivotal role in contemporary endodontics (12, 13).

The removal of dentin debris from the root canal using LAI has been investigated in only two studies (10, 11). Both studies, de Moor et al (10) with an Er,Cr:YSGG laser (2,780 nm) and de Groot et al (11) with an Er:YAG laser (2,940 nm), have shown that LAI is significantly more effective in removing dentin debris from the apical part of the root canal than PUI or hand irrigation when the irrigant was activated for 20 seconds. It remains unknown (1) whether the use of PUI for more than 20 seconds (3× 20 seconds according to van der Sluis et al [14]) is as effective as 20 seconds of LAI , and (2) whether there is a difference between the efficacy of LAI performed with an Er:YAG laser or Er,Cr:YSGG laser (both erbium lasers, with different wavelengths, 2,780 nm and 2,940 nm, respectively). Therefore, the aim of the present study was to evaluate *ex vivo* the removal of artificially placed dentin debris in standardized root canals by (1) active hand irrigation for 20 seconds, (2) PUI with an Er:YAG or Er,Cr:YSGG laser, and (3) LAI for 20 seconds and 3 × 20 seconds.

Material and Methods

Sample Selection and Preparation

For the setup of this study, an experimental root canal model described by Lee et al (15) was used (Fig. 1). One hundred maxillary canines with straight roots were selected. These roots were mounted and prepared as described in de Moor et al (9). After verification of the location of the apical foramen with an ISO size 15 file through the apical foramen, the teeth were decapitated at 19 mm of the location of the apical foramen with a diamond disc (Horico, Berlin, Germany). The coronal 3 mm of the canals were enlarged by a round bur with a diameter of 2.3 mm (Komet, Düsseldorf, Germany, 340.202.001.001.023, American size 8) and simulating the

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REVIEW

Passive ultrasonic irrigation of the root canal: a review of the literature

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Abstract

van der Sluis LWM, Versluis M, Wu MK, Wesselink PR. Passive ultrasonic irrigation of the root canal: a review of the literature. *International Endodontic Journal*, **40**, 415–426, 2007.

Ultrasonic irrigation of the root canal can be performed with or without simultaneous ultrasonic instrumentation. When canal shaping is not undertaken the term passive ultrasonic irrigation (PUI) can be used to describe the technique. In this paper the relevant literature on PUI is reviewed from a MEDLINE database search.Passive ultrasonic irrigation can be performed with a small file or smooth wire (size 10–20) oscillating freely in the root canal to induce powerful acoustic microstreaming. PUI can be an important supplement for cleaning the root canal system and, compared with traditional syringe irrigation, it removes more organic tissue, planktonic bacteria and dentine debris from the root canal. PUI is more efficient in cleaning canals than ultrasonic irrigation with simultaneous ultrasonic instrumentation. PUI can be effective in curved canals and a smooth wire can be as effective as a cutting K-file. The taper and the diameter of the root canal were found to be important parameters in determining the efficacies of dentine debris removal. Irrigation with sodium hypochlorite is more effective than with water and ultrasonic irrigation is more effective than sonic irrigation in the removal of dentine debris from the root canal. The role of cavitation during PUI remains inconclusive. No detailed information is available on the influence of the irrigation time, the volume of the irrigant, the penetration depth of the instrument and the shape and material properties of the instrument. The influence of irrigation frequency and intensity on the streaming pattern as well as the complicated interaction of acoustic streaming with the adherent biofilm needs to be clarified to reveal the underlying physical mechanisms of PUI.

Keywords: biofilm, cleaning, dentine debris, irrigation, review, root canal, ultrasound.

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Introduction

With the endodontic procedures at our disposal it is impossible to shape and clean the root canal completely. This is mainly due to the complex anatomy of the root canal system (Ricucci & Bergenholtz 2003, Peters 2004, Naïr *et al.* 2005). Irregularities of the root canal wall in particular are a major concern, including oval extensions, isthmuses and apical deltas (Wu & Wesselink 2001, Ricucci & Bergenholtz 2003, Peters 2004, Naïr *et al.* 2005). In fact, within oval canals only 40% of the apical root canal wall area can be contacted by instruments when a rotating technique is used (Wu *et al.* 2003). Therefore, irrigation is an essential part of a root canal treatment as it allows for cleaning beyond the root canal instruments.

The goal of irrigation is to remove pulp tissue and/or microorganisms (planktonic or biofilm) from

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23.

Photodynamic Therapy Associated with Conventional Endodontic Treatment in Patients with Antibiotic-resistant Microflora: A Preliminary Report

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Abstract

Introduction: This study reports the antimicrobial effect of photodynamic therapy (PDT) combined with endodontic treatment in patients with necrotic pulp infected with microflora resistant to a previous antibiotic therapy. **Methods:** Thirty anterior teeth from 21 patients with periapical lesions that had been treated with conventional endodontic treatment and antibiotic therapy were selected. Microbiological samples were taken (1) after accessing the root canal, (2) after endodontic therapy, and (3) after PDT. **Results:** All the patients had at least 1 microorganism resistant to antibiotics. PDT used polyethylenimine chlorin(e6) as a photosensitizer and a diode laser as a light source (P = 40 mW, t = 4minutes, E = 9.6 J). Endodontic therapy alone produced a significant reduction in numbers of microbial species but only 3 teeth were free of bacteria, whereas the combination of endodontic therapy with PDT eliminated all drug-resistant species and all teeth were bacteria-free. **Conclusions:** The use of PDT added to conventional endodontic treatment leads to a further major reduction of microbial load. PDT is an efficient treatment to kill multi-drug resistant microorganisms. *(J Endod 2010;36:1463–1466)*

Key Words

Antibiotic resistant bacteria, endodontic re-treatment, laser, photodynamic therapy

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In the case of endodontic treatment failure, retreatment, surgical treatment, or extraction usually is carried out with the use of antibiotics and antiseptics as adjunctive therapies, but the long-term use of these agents can be rendered ineffective by resistance developing in the target organism (1). Currently, there is an emergence of bacteria with multiple resistances, and there is a need for alternative antimicrobial approaches (2–6).

The combination of conventional endodontic therapy and photodynamic therapy (PDT) has been shown as an effective approach in reducing bacterial load in *in vitro* and *in vivo* models (7–11).

This study investigated the combination of PDT with endodontic treatment in patients with necrotic pulp harboring microflora resistant to a previous antibiotic therapy.

Materials and Methods

Thirty teeth from 21 patients with periapical lesions who had been previously treated with endodontic treatment associated with antibiotic were selected. The patients were in good health and between the ages of 17 and 52 years. All the teeth presented sights and symptoms of periapical periodontitis and apical bone lesion detected by radiography, and some patients had pain by vertical percussion and/or local edema, all requiring root canal retreatment on teeth with closed apices. The same practitioner carried out this study in a private dental office in São Paulo, Brazil. The protocol was approved by the Institutional Review Board of the São Paulo University, and all procedures were conducted according to the principles of the Declaration of Helsinki.

Endodontic Treatment

Thirty root canals from anterior teeth were re-treated and received endodontic treatment followed by PDT. Microbiological samples were taken after accessing the root canal, after endodontic therapy, and after PDT. The first microbiological sample confirmed that all the patients had at least 1 microorganism resistant to antibiotic medication.

A periapical radiograph was taken for each case to determine the presence of apical lesion, the canal morphology, and its length.

The access to the pulp chamber was gained after installation of a rubber dam, and then the surrounding area received prophylactic asepsis and was irrigated with 5 mL of chlorhexidine solution at 2% to ensure that the crown of the tooth had minimal microbial load (8).

Once the canal was accessed, a Hedström file #15 (Maillefer Instruments SA, Ballaigues, Switzerland) was inserted inside the canal to remove the gutta-percha and root canal sealer obturation; then the root canal was irrigated with 1 mL of sterile saline solution. The canal was dried with 3 sterile paper points (Dentsply Latin America, Petropolis, Brazil) and left inside the root canal for 1 minute each. All 3 paper points were combined for microbiological analysis. This procedure was the first microbiological sampling representing the initial contamination. The paper points were deposited in a fresh sterile bottle with sterile nutrient broth.

24.

The Effect of Photodynamic Therapy in Root Canal Disinfection: A Systematic Review

Vanessa Chrepa, DDS, Georgios A. Kotsakis, DDS,† Tom C. Pagonis, DDS, MS,‡ and Kenneth M. Hargreaves, DDS, PhD**

Abstract

Introduction: Effective root canal disinfection is a fundamental component of successful root canal treatment. Photodynamic therapy (PDT) has been proposed as a new adjunctive method for additional disinfection of the root canal system with the possibility of improved treatment outcomes. The aim of this systematic review was to investigate the effect of PDT on bacterial load reduction during root canal disinfection. **Methods:** Two reviewers independently conducted a comprehensive literature search using a combination of medical subject heading terms and key words to identify studies relevant to the Population Intervention Control Outcome question. The selection of articles for inclusion was performed in 2 phases based on predetermined eligibility criteria according to Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Inter-reviewer agreement for each phase was recorded. The effect of PDT on bacterial load reduction during root canal disinfection was evaluated as the primary outcome variable during data extraction. **Results:** The literature search provided 57 titles and abstracts. Three articles met the inclusion criteria and were selected for this systematic review. The reasons for study exclusion in each phase were recorded. Because of the heterogeneity in clinical indications and PDT protocols among the included studies, a meta-analysis could not be performed. All included studies showed a positive effect of PDT in the reduction of microbial load in root canal treatment ranging from 91.3%–100%. **Conclusions:** Limited clinical information is currently available on the use of PDT in root canal disinfection. If supported by future clinical research, PDT may have efficacy for additional root canal disinfection, especially in the presence of multi–drug-resistant bacteria. *(J Endod 2014;■:1–8)*

Key Words

Antibacterial, bacteria reduction, light-activated disinfection, photodynamic therapy, reactive oxygen species, root canal disinfection

Effective root canal disinfection is undoubtedly a fundamental component of successful root canal treatment. Contemporary techniques include the mechanical debridement and shaping of the root canal system with emphasis on various nickel-titanium (NiTi) rotary systems, intracanal irrigation with antimicrobial/tissue dissolving agents, and interappointment dressings. However, several studies have reported that rotary and hand instruments are equally effective in bacteria reduction, and despite the improved efficiency of NiTi systems, there is no difference in antimicrobial reduction (1, 2). Regarding chemotherapeutic agents, sodium hypochlorite (NaOCl) has been considered as the "gold standard" because of its antibacterial and tissue dissolution properties (3, 4). Nevertheless, numerous studies have verified that complete elimination of bacteria from the root canal system cannot be consistently achieved with any of the currently used techniques and combinations (1, 5–9).

In search of new methods to provide additional disinfection for the root canal system and presumably improve treatment outcome, novel techniques including various laser wavelengths (10); hydraulic (eg, Endo-Vac; SybronEndo Corporation, Orange, CA) (11), sonic (12), and ultrasonic (13, 14) irrigation; and gaseous ozone (15) and photodynamic therapy (PDT) (16) have been proposed in the literature. PDT is an antimicrobial strategy defined as "light induced inactivation of cells, microorganisms and molecules" (17). In principle, it uses a nontoxic photosensitizer that is selectively absorbed in a target tissue and a low-intensity light source. Upon photo-induced activation of the photosensitizer, in the presence of oxygen, a series of reactions produce free radicals and singlet oxygen molecules leading to bacterial eradication. Singlet oxygen diffuses to a distance of approximately 100 nm with a half-life of <0.04 microseconds (18). The photodynamic effect or the extent of tissue/cell damage depends on the type, dose, incubation time, and localization of the photosensitizer; the availability of oxygen; the wavelength of light (nm); the light power density measured in mW/cm^2; and the light energy fluency. Of all the PDT dosimetry parameters, fluency appears to cause some confusion. Some authors use the cross-sectional area of the light source, whereas others use a light effect on a determined area. In either case, fluency represents the rate of deposited energy in a specified area and is expressed in J/cm^2. Because of its high antibacterial potential, PDT has been suggested as an adjunct to conventional endodontic disinfection protocols.

Currently, the use of PDT in endodontic therapy has been tested in terms of bacterial load reduction *in vivo* (16, 19, 20) as well as *in vitro* (21, 22) and *ex vivo* (23) and has shown promising results. A recent systematic review of PDT against *Enterococcus faecalis* provides a direct comparison of these studies (24). Despite recent research efforts to study the effect of PDT on the disinfection of the root canal system, no effort has been made to evaluate the efficacy of this approach by means of a system-

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25.

SCIENTIFIC REVIEW

Laser Use in Endodontics: Evolution from Direct Laser Irradiation to Laser-Activated Irrigation

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J Laser Dent 2013;21(2):58-71

SUMMARY

Laser technology applied to endodontics, initially investigated in 1971,[1] expanded in the 1990s with the development of fiber-optic delivery systems, and lately has undergone an important evolution. New technologies (including impulses of reduced length, radial-firing and stripped tips) and techniques (such as laser-activated irrigation [LAI] and photon-initiated photoacoustic streaming™ [PIPS™]) have simplified laser use in endodontics while minimizing undesirable thermal effects on the dentinal walls. The use of very low energy to activate (i.e., warm and agitate) the common endodontic irrigants, such as ethylenediaminetetraacetic acid (EDTA) or sodium hypochlorite, has proven effective for the LAI technique, enhancing both the smear layer cleaning ability and the bacterial reduction activity.

INTRODUCTION

Given the complex root canal anatomy and the limited ability of chemical irrigants to three-dimensionally clean and disinfect the entire endodontic space,[2-3] the use of lasers was seen as a possible means of adjunctively enhancing the effectiveness of endodontic treatment.[1, 4-7]

Many laser wavelengths (from 532 nm to 10,600 nm) clinically or experimentally used in dentistry have bactericidal capabilities because of their thermal effect which generates structural modifications in bacteria cells.[8-11] With the different penetration depths of various wavelengths and the varied morphological alterations of the root canal surface commonly observed after laser irradiation, an overall consensus on the positive effects of lasers in endodontics still has not been reached.

Conventional endodontics utilizes different types of activation of the irrigants. Sirtes *et al.* reported that warming the sodium hypochlorite from 20°C to 45°C enhanced the killing efficacy of sodium hypochlorite.[12] Stojicic *et al.* reported that the effect of agitation of irrigants on tissue dissolution was greater than that of temperature, and continuous agitation of sodium hypochlorite resulted in the fastest tissue dissolution.[13] Accordingly, different agitation techniques have been proposed to improve the efficacy of irrigation solutions, including hand agitation and sonic and ultrasonic devices.[13-14] Other studies have investigated the ability of some laser wavelengths to activate the commonly used irrigant solutions within the canal. This technique, called laser-activated irrigation (LAI), has been shown to be statistically more effective in removing debris and smear layer in root canals compared to traditional techniques (hand irrigation and passive ultrasonic irrigation).[15-17] Recent studies have also reported how the use of an Er:YAG laser, used at very low energy (20 to 50 mJ, 10 to 15 Hz, with a 400-micron tip in the so-called PIPS technique), in combination with commonly used irrigants, resulted in a superior debris and smear layer removal and bacterial reduction, without thermal damage to the organic dentinal structure, when compared to traditional and ultrasonic techniques.[18-20]

This manuscript describes and reviews the evolution of laser techniques and technologies in the cleaning and bacterial reduction of the endodontic system.

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Laser-activated irrigation within root canals: cleaning efficacy and flow visualization

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Abstract

de Groot SD, Verhaagen B, Versluis M, Wu M.-K, Wesselink PR, van der Sluis LWM. Laser-activated irrigation within root canals: cleaning efficacy and flow visualization. *International Endodontic Journal*, **42**, 1077–1083, 2009.

Aim To test *ex vivo* the efficiency of laser-activated irrigation in removing dentine debris from the apical part of the root canal and to visualize *in vitro* the fluid dynamics during the activation of the irrigant by laser, using high-speed imaging at a relevant timescale.

Methodology Root canals with a standardized groove in one canal wall filled with dentine debris were irrigated with syringe irrigation, ultrasonically or laser-activated irrigation (LAI) using 2% sodium hypochlorite as irrigant. The quantity of dentine debris after irrigation was determined. Visualization of the fluid dynamics during activation was achieved using a high-speed camera and a glass model.

Results Laser-activated irrigation was significantly more effective in removing dentine debris from the apical part of the root canal than passive ultrasonic irrigation or hand irrigation when the irrigant was activated for 20 s.

Conclusions The *in vitro* recordings suggest that streaming, caused by the collapse of the laser-induced bubble, is the main cleaning mechanism of LAI.

Keywords: irrigation, laser, root canal, ultrasound, visualization.

Received 16 April 2009; accepted 18 August 2009

Introduction

An important procedure during root canal treatment is the irrigation of the root canal. Syringe irrigation is the standard procedure but unfortunately, syringe irrigation is not effective in the apical part of the root canal (Ram 1977, Salzgeber & Brilliant 1977, Abou-Rass & Patonai 1982, Druttman & Stock 1989) and in isthmuses or oval extensions (Lee *et al.* 2004, Burleson *et al.* 2007). Therefore, acoustic and hydrodynamic activation of the irrigant have been developed (Weller *et al.* 1980, Lumley *et al.* 1991, Lussi *et al.* 1993), which have been shown to contribute to the cleaning efficiency (Lumley *et al.* 1991, Lussi *et al.* 1993, Roy *et al.* 1994). The physical mechanisms underlying these cleaning procedures, however, are not well-understood (van der Sluis *et al.* 2007a).

Laser-activated irrigation (LAI) has been introduced as a powerful method for root canal irrigation (Blanken & Verdaasdonk 2007, George & Walsh 2008, George *et al.* 2008). The laser radiation produces transient cavitation in the liquid through optical breakdown by strong absorption of the laser energy (Blanken & Verdaasdonk 2007). LAI can result in smear layer removal from the root canal wall, but also cause extrusion of irrigant through the apex (George & Walsh 2008, George *et al.* 2008). However, the removal of dentine debris from the root canal by LAI has not yet been studied. Furthermore, Blanken & Verdaasdonk (2007) suggested repeating

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Effectiveness of Nd:YAG Laser on the elimination of debris and Smear Layer. A comparative study with two different irrigation solution: EDTA and QMix® in addition to NaOCl

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Abstract

Background: The aim of this study was to evaluate the effectiveness in dentin debris and smear layer removal from root canal walls using EDTA and QMix® alone and also activated with Nd:YAG laser.

Material and Methods: 50 single-rooted teeth were instrumented and divided in 5 groups according to irrigation protocol: 17% EDTA, QMix®, Nd:YAG laser alone, and combination of 17% EDTA - Nd:YAG laser and QMix® - Nd:YAG laser. Samples were evaluated using SEM. Statistical analysis was done using Chi-Square Fisher exact test and McNemar test.

Results: Dentinal debris analysis showed statistically significant differences when comparing 17% EDTA vs Laser and Laser vs QMix® in combination with Laser at the apical third. The Smear Layer analysis also showed statistically significant differences at the apical third when comparing 17% EDTA vs Laser, QMix® vs QMix® in combination with Laser and Laser vs QMix® in combination with Laser.

Conclusions: 17% EDTA was the most efficient irrigant showing the best results. Laser alone was not effective removing either dentinal debris or smear layer.

Key words: *Laser, endodontics, Smear Layer.*

Introduction

The smear layer is a microscopic layer formed after root canal instrumentation and located along the root canal walls. It blocks dentinal tubule orifices and creates an interface between filling material and root canal wall, affecting sealing ability of the root canal system. The width of this layer is between 1 to 2 microns (1) and it reduces penetration of irrigants and sealers into dentinal tubules (2,3).

Some studies have shown that mechanical instrumentation and chemical action of NaOCl are not enough to remove the smear layer totally from the root canal wall (4,5). Chelating agents are used for its removal. QMix® (Denstply-Maillefer, Tulsa, USA) has been recently launched, composed of an antimicrobial agent, Chlorhexidine, mixed with a chelating agent, EDTA, and a surfactant (6).

Laser technology has been developing for several years

28.

The Effect of QMix, an Experimental Antibacterial Root Canal Irrigant, on Removal of Canal Wall Smear Layer and Debris

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Abstract

Introduction: This study examined the ability of two versions of QMix, an experimental antimicrobial irrigant, on removal of canal wall smear layers and debris using an open canal design. **Methods:** Cleaned and shaped single-rooted human root canals were irrigated with NaOCl as the initial irrigant and one of the following as the final irrigant: (1) QMix I (pH = 8), (2) QMix II (pH = 7.5), (3) distilled water, (4) 17% EDTA, and (5) BioPure MTAD (Dentsply Tulsa Dental Specialties, Tulsa, OK). Smear and debris scores were evaluated in the coronal, middle, and apical thirds of longitudinally fractured canal spaces using scanning electron microscopy and analyzed using Cochran-Mantel-Haenszel statistic. **Results:** Smear scores, when the overall canal was considered, differences were observed among groups except groups 1 versus 4 and groups 2 versus 4. After adjusting for canal levels, all groups differed significantly from each other ($p < 0.005$) with the exception of groups 2 versus 5. For the debris scores, no significant difference was observed among the treatment groups when the overall canal was considered and after adjusting for the effect of canal level. **Conclusion:** Within the limitations of an open-canal design, the two experimental QMix versions are as effective as 17% EDTA in removing canal wall smear layers after the use of 5.25% NaOCl as the initial rinse. *(J Endod 2011;37:80–84)*

Key Words

Antimicrobial, canal level, chelation, debris, root canal irrigant, smear layer, surfactant

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It is impossible to create a sterile space in infected root canals with mechanical preparation alone because of the complexity of root canal systems (1–3). Pulpal tissue remnants and inorganic debris remain even in well-shaped canals, especially in those areas with which the instruments do not come in contact (4). Rotary instruments that used a conventional single-shaft design, regardless of the instrumentation technique, never contacted canal walls completely (5). The amount of residual tissues was much more in canals that were treated without irrigation than those in which root canal irrigants were used (6). Thus, irrigants are essential for successful debridement of the root canals after mechanical shaping procedures (7). Although canal wall smear layers may reduce dentin permeability and prevent bacterial penetration into dentinal tubules (8, 9), they may prevent irrigants and medications from accessing infected dentinal tubules (10). An infected smear layer containing bacteria and necrotic tissue may also act as a substrate for the multiplication of those bacteria (11, 12).

The use of NaOCl and EDTA has been reported to be effective in removing pulpal tissue remnants and the organic and inorganic components of the smear layer (13, 14). BioPure MTAD (Dentsply Tulsa Dental Specialties, Tulsa, OK), has shown promise as an antimicrobial against *Enterococcus faecalis* (15–18) and as a smear layer removal agent (19–21) after the use of 1.3% NaOCl as the initial rinse. However, the antimicrobial efficacy and substantivity of this irrigant combination has been challenged (22–24). BioPure MTAD is also relatively ineffective against *E. faecalis* biofilms (25–27), which are more difficult to eliminate and more resistant to antimicrobial agents than planktonic bacteria (28, 29). It is effective in removing canal wall smear layers but demineralizes intraradicular dentin (30).

An experimental antimicrobial root canal irrigant (QMix) and its modifications containing a mixture of a bisbiguanide antimicrobial agent, a polyaminocarboxylic acid calcium-chelating agent, saline, and a surfactant have been found to be more effective than BioPure MTAD against bacterial biofilms (Dr Markus Haapasalo, personal communication, August 2010). As little information is available on the ability of QMix in removing pulpal debris and canal wall smear layers, the objective of the present study was to evaluate its effectiveness in removing canal wall debris and smear layer from the coronal third, middle third, and apical third of root canals. The null hypothesis tested was that there are no differences in the ability of two versions of QMix, BioPure MTAD, and 17% EDTA as final irrigants to remove canal wall debris and smear layer from different parts of the root canals.

Materials and Methods

Fifty extracted human single-rooted teeth were radiographed to ensure that each tooth contained one canal and that an equal number of narrow (33%) and wide canals (67%) were present in the experimental groups. Each tooth was decoronated at 17 mm from the anatomic apex. Working length was established at 1 mm short of the apical foramen. Each tooth was prepared using a crown-down technique to size 50, 0.06 taper using the stainless steel hand files and ProTaper Universal nickel titanium rotary instruments (Dentsply Tulsa Dental Specialties).

Because the objective of the study was to evaluate the effectiveness of the irrigants instead of the efficacy of root canal irrigation (20, 21), an "open-system" design (31) with an unsealed root apex (13) that permits air and vapor communication between the

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REVIEW

Apical negative pressure irrigation versus syringe irrigation: a systematic review of cleaning and disinfection of the root canal system

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Abstract

Konstantinidi E, Psimma Z, Chávez de Paz LE, Boutsioukis C. Apical negative pressure irrigation versus syringe irrigation: a systematic review of cleaning and disinfection of the root canal system. *International Endodontic Journal*, **50**, 1034–1054, 2017.

The aim of this study was to systematically review and critically analyse the published data on the treatment outcome (primary outcome) and on the cleaning and disinfection of root canals (secondary outcomes) achieved by negative pressure irrigation as compared to syringe irrigation. An electronic search was conducted in EMBASE, LILACS, PubMed, SciELO, Scopus and Web of Knowledge using both free-text keywords and controlled vocabulary. Additional studies were sought through hand searching of endodontic journals and of the relevant chapters of endodontic textbooks. No language restriction was imposed. The retrieved studies were screened by two reviewers according to predefined criteria. Included studies were critically appraised and the extracted data were arranged in tables. The electronic search and hand search retrieved 489 titles. One clinical study and 14 *in vitro* studies were finally included in the review; none of these studies assessed treatment outcome, four studies assessed the antimicrobial effect, seven studies evaluated the removal of pulp tissue remnants, and four studies investigated the removal of hard tissue debris or both hard tissue debris and pulp tissue remnants. Poor standardization and description of the protocols was evident. Inconclusive results were reported about the cleaning and disinfection accomplished by the two irrigation methods. Negative pressure irrigation was more effective under certain conditions when compared to suboptimal syringe irrigation; however, the variability of the protocols hindered quantitative synthesis. There is insufficient evidence to claim general superiority of any one of these methods. The level of the available evidence is low, and the conclusions should be interpreted with caution.

Keywords: cleaning, disinfection, irrigation, needle, negative pressure, syringe.

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Introduction

Irrigation is considered an essential part of root canal treatment as it reinforces the cleaning and disinfection of areas of the root canal system that have been insufficiently affected by instruments (Peters *et al.* 2001, Gulabivala *et al.* 2005, Paqué *et al.* 2010). Additional cleaning and disinfection are achieved through the chemical and mechanical disruption and removal of bacteria and especially biofilm, pulp tissue remnants, dentine debris and of the smear layer by the irrigant, provided that it can reach them (Gulabivala *et al.* 2005, Zehnder 2006, Boutsioukis & van der Sluis 2015). Multispecies microbial biofilms in remote areas of the root canal system are

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30.

Effectiveness of Endodontic Disinfecting Solutions against Young and Old *Enterococcus faecalis* Biofilms in Dentin Canals

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Abstract

Introduction: *Enterococcus faecalis* is a species commonly isolated from persistent root canal infections. The purpose of this study was to compare the antibacterial effects of different disinfecting solutions on young and old *E. faecalis* biofilms in dentin canals using a novel dentin infection model and confocal laser scanning microscopy (CLSM). **Methods:** The bacteria were introduced into the dentinal tubules by centrifugation. After 1 day and 3 weeks of incubation, 40 infected dentin specimens were subjected to 1 and 3 minutes of exposure to disinfecting solutions, which included 2% sodium hypochlorite (NaOCl) (EMD Chemicals Inc, Darmstadt, Germany), 6% NaOCl, 2% chlorhexidine (CHX) (Sigma Chemical Co, St Louis, MO), and QMiX (Dentsply Tulsa Dental, Tulsa, OK). The proportions of dead and live bacteria inside the dentinal tubules after exposure to these disinfectants were assessed by CLSM using a LIVE/DEAD bacterial viability stain. **Results:** Significantly fewer bacteria were killed in the 3-week-old dentin biofilm than in the 1-day-old biofilm. Three minutes of exposure resulted in more dead bacteria than 1 minute of exposure for both biofilms in all experimental groups ($P < .05$). Six percent NaOCl and QMiX were the most effective disinfecting solutions against the young biofilm, whereas against the 3-week-old biofilm, 6% NaOCl was the most effective followed by QMiX. Two percent NaOCl was equally effective as 2% CHX. All the disinfecting agents killed significantly more bacteria than the sterile water used as a negative control ($P < .05$). **Conclusions:** Within dentin canals, bacteria in established biofilms are less easily killed by endodontic medicaments than bacteria in young biofilms. *(J Endod 2012;38:1376–1379)*

Key Words

Biofilm, confocal laser scanning microscopy, dentin, disinfection, *Enterococcus faecalis*

Apical periodontitis is an inflammatory reaction of periradicular tissues caused by microbial infection in the root canal (1, 2). Free-floating microorganisms in the root canal space can attach to each other and grow into biofilm as a microbial community on the dentin walls (3). The maturity of the biofilm is known to influence its resistance to being killed by antibacterial agents (4). Bacteria in mature biofilm can resist the action of antibacterial irrigants and are remarkably difficult to eradicate, even though the reason for this resistance is not completely understood (5).

Enterococcus faecalis is a commonly isolated species that may play a role in persistent endodontic infections (6). The development of these infections may be caused by *E. faecalis* having inherent antimicrobial resistance, the ability to adapt to harsh environmental changes, and the ability to invade into the dentinal tubules where they are protected from endodontic medicaments and are therefore difficult to eliminate (7, 8). A number of laboratory studies have evaluated the efficacy of antimicrobial agents used in root canal treatment against *E. faecalis* biofilms at different stages of growth and on planktonic culture (4, 9–11). Shen et al (3) studied the susceptibility of multispecies biofilms to chlorhexidine (CHX) at different phases of growth from 2 days to several months on a hydroxyapatite disk model and found that bacteria in mature biofilms are much more resistant to being killed by CHX than bacteria in young biofilms. Most of the previous studies have used young biofilms only, and, therefore, the good results noted in the laboratory may not correlate well with the clinical reality (12–14). Variables such as the properties of dentin and the degree of bacterial invasion into the dentinal tubules are difficult to standardize (15, 16).

Recently, a novel dentin infection model was introduced to allow a standardized and deep penetration of *E. faecalis* into dentinal tubules using the power of centrifugation (17). Previous results from studies using this model showed that various antibacterial solutions differed in their ability to kill 1-day-old *E. faecalis* biofilm in dentin. However, it is likely that root canal biofilms are usually several weeks or months old when the treatment is started (18, 19). Presently, little, if anything, is known about the effect of biofilm age on the effectiveness of disinfecting agents against bacteria in dentin canals. The aim of the present study was to measure the killing of 1-day- and 3-week-old *E. faecalis* biofilms in dentinal tubules by different disinfecting solutions using a new dentin infection model and confocal laser scanning microscopy (CLSM).

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Dr Markus Haapasalo has financial affiliation (royalty from patent licensing arrangements between the University of British Columbia and Densply International), related to Qmix, one of the tested solutions in the study.

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31.

32.

Continuous Instrumentation and Irrigation: The Self-Adjusting File (SAF) System

11

Zvi Metzger and Anda Kfir

Abstract

The recently introduced self-adjusting file (SAF) system is the first of its kind, performing continuous and simultaneous instrumentation and irrigation. As an instrumentation device it adapts itself to the shape of the canal, including its cross section, as opposed to most rotary file systems that machine the canal to the shape of the file. The SAF system removes a uniform dentin layer from all around the canal as opposed to rotary files which are using excessive removal of sound dentin in attempt to include the whole canal within the preparation. Combined with its effective irrigation, it allows a new concept of minimally invasive endodontics. The SAF system is a no-pressure irrigation system combined with an added mechanical scrubbing effect. The effective cleaning of oval canals enables more effective disinfection and better obturation than can be achieved with rotary files. Its scrubbing effect is also useful in the final stage of retreatment as well as in the treatment of root canals of immature teeth.

The Role of Irrigants in Endodontic Treatment

If the simple idea that "the file shapes; the irrigant cleans" was always true, there would be no need for special irrigation systems. Shaping a canal with rotary files to the extent that a thin irrigation needle can be inserted to a working length would always provide clean, ready-to-fill canals. Unfortunately, this simple concept, which may be effective in narrow, straight canals with a round cross section, fails to deliver the desired result in oval canals [23, 59, 72, 77, 100]. Such canals represent 24 % of the total number of root canals, and in certain types of teeth, the incidence of oval canals can reach 90 % [29, 50, 58, 99].

Furthermore, the assumption that the above concept provides adequate cleaning of the whole canal has led to an oversimplified approach to root canal treatment: one only has to machine the canal to a certain shape to accommodate a similarly

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Irrigation: beyond the smear layer

MARKUS HAAPASALO, WEI QIAN & YA SHEN

Traditionally, much of the attention placed on irrigation in endodontics has focused on smear layer removal. While the smear layer continues to be a relevant topic, other areas related to irrigation and irrigants have emerged that also require a more in-depth analysis and understanding. This review starts with the smear layer, partially from a new angle, and expands into other topics such as uninstrumented root canal areas, and effect of irrigation in lateral canals and dentin canals. Advanced microbiological models for irrigation research will be presented and discussed. The effect of sodium hypochlorite and decalcifying solutions on dentin structure and dentin strength has become an important topic, which is related to the possible harmful effects of irrigation such as dentin erosion and even vertical root fracture. The impact of irrigant sequence and time of exposure will also be discussed, and recommendations for irrigation protocols will be made.

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Introduction

Irrigation is regarded as a centrally important part of successful root canal treatment. Irrigation and irrigating solutions have a variety of different physical/mechanical, chemical, biological, and microbiological effects, most of which have been discussed in other articles of this volume of *Endodontic Topics.* Because of the importance of irrigation, for decades it has been a continuous focus of interest in endodontic research. Table 1 shows the results of a Medline search using keywords describing several topics related to root canal irrigation. Although this search was far from exhaustive, it gives a rough view of the relative popularity of these topics. It is clear that while some areas have been extensively studied, others have gained much less attention. Removal of the smear layer, for example, has been thoroughly explored, whereas topics such as dentin erosion, uninstrumented root canal areas, predentin, and endodontic biofilm are addressed only in a limited number of studies. The purpose of this review is to present a summary of the effects of irrigation in the various parts of the root canal environment, starting from the smear layer and then extending beyond the smear layer to the lesser known areas of root canal irrigation.

Smear layer

A smear layer always forms when a metallic endodontic instrument touches a mineralized dentin wall within a root canal (Fig. 1). Therefore, the smear layer always consists of mineralized dentin, but often also of predentin, remnants of pulp tissue, bacteria, and biofilm (1–3). The smear layer is caused by hand and rotary stainless steel and NiTi files as well as by ultrasonic tips and various burs that are used in the root canal. However, the smear layer is not created by instruments which are softer than dentin; for example, an EndoActivator tip hitting a canal wall at high frequency does not create a smear layer. The smear layer is a thin, amorphous layer, ca. 0.5–2 μm thick, that covers the dentin surface and thus hides the openings of the dentin canals (Figs. 2 and 3). Sometimes, part of the smear layer/dentin debris has been pushed into the dentin canals by instruments to a depth of even several micrometers. The smear layer that forms in teeth with pulpitis has one important difference from the smear layer that forms in teeth with apical lesions: bacteria and antigenic material are present only in the latter. This difference may affect a dentist's decision regarding the necessity of smear layer removal.

The smear layer should be removed for the following reasons: (i) it may contain microbial cells and antigens

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Effects of mechanical and chemical procedures on root canal surfaces

KISHOR GULABIVALA, BINA PATEL, GLYNIS EVANS & YUAN-LING NG

Root canal treatment may be performed on teeth with irreversibly inflamed dental pulps to prevent apical periodontitis or on teeth with apical periodontitis to treat it. The presenting condition of the root canal surface may therefore vary from that of an intact pulp–dentine complex, through partially degraded pulp tissue with infection, to a dentine surface coated with a mature bacterial biofilm (1). Subsequent treatment procedures will alter the surface in ways that depend upon the root canal anatomy, the instruments used, the strategy and mode of their use, and the chemicals used to facilitate debridement. The effects range from displacement and/or deformation of soft and/or hard tissue components, to changes in the biological, mechanical, and chemical properties of the root canal dentine surface. These changes may have a profound effect on the survival of the tooth, both in terms of progression of apical periodontitis and the long-term integrity of the tooth. An evidence-based synthesis of the literature on the chain of events associated with the effects of root canal treatment, on the internal dentine surfaces, has required subjective assimilation. The mass of published, largely laboratory data, relevant to the topic is heterogenous and contradictory, leaving room for conjecture, differences of opinion, and further questions. The original questions posed in laboratory studies were not guided by clinical outcome data and therefore lacked relevant focus. The synthesized view presented below is based on the authors' interpretation of the literature findings, sought systematically by hand and electronic search methods.

Presenting condition of root canal surfaces before treatment

Before the effects of treatment procedures on root canal surfaces can be evaluated, the condition of the presenting surfaces must be appreciated. Since root canal treatment may be carried out on teeth with or without apical periodontitis and with vital or necrotic pulp tissue, a diverse range of conditions may present, especially considering the age of the patient at presentation.

Influence of canal anatomy

The complexity of the root canal system and the patterns of prevalence of types of systems in different teeth and roots are well documented in different racial groups (2–5) and are reviewed elsewhere in this volume. These have a dominant effect on the outcomes of mechanical (6) and therefore chemical preparation (7).

Surface characteristics of the uninfected root canal surface

During elective pulpectomy on a tooth with healthy pulp tissue, a normal pulp–dentine complex would be encountered. Extirpation of the pulp tissue may leave odontoblasts either remaining in the dentinal tubules (8) or torn out. Depending upon the condition of the pulp tissue, it may fragment or be removed largely in one piece (Fig. 1). It is likely that the apical parts of the pulp, which are more fibrous, and those in accessory anatomies may remain (7, 9, 10–12), particularly in curved canals (9, 13, 14). A dying pulp, deprived of a blood supply, may shrink and pull away from the dentine surface (Fig. 2). Otherwise, an uninfected, necrotic pulp may remain behind as a dried vestige of the vital organ.

In contrast, an inflamed pulp would lose its organization and break down, leaving variable fragments of necrotic tissue over the dentine surface. If the pulp had been invaded by bacteria, the fragmentation

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Quantitative Analysis of the Effect of Irrigant Solution Sequences on Dentin Erosion

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Abstract

Objective: The purpose of the study was to examine the level of erosion on root canal wall dentin caused by immersion in different irrigant solutions in alternative sequences. **Methods:** Dentin specimens from teeth with one root canal were instrumented and randomly divided into five groups. Each group was subjected to 17% EDTA, 17% ethyleneglycoltetraacetic acid (EGTA), or 10% citric acid (CA) and 5.25% sodium hypochlorite (NaOCl) varying the time of irrigant exposure and the order of the irrigants. The specimens were examined by scanning electron microscopy (SEM), and randomized digital images of the dentin surface were taken. The area of tubule openings was measured by a semiautomatic method. **Results:** No erosion was detected when demineralizing agents were used as a final rinse after NaOCl. However, the erosion of peritubular and intertubular dentin was detected when EDTA, EGTA, or CA were used first followed by 5.25% NaOCl ($P < .05$), and an increase over 100% in the area of dentin tubule openings was measured ($P < .01$). **Conclusions:** NaOCl used as a final irrigant solution after demineralization agents causes marked erosion of root canal dentin. *(J Endod 2011;37:1437–1441)*

Key Words

Dentin, endodontic, erosion, irrigant, irrigation, scanning electron microscope

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Current methods of cleaning and shaping root canals produce a smear layer that covers the instrumented areas of the walls (1). Irrigation is considered the best method for the removal of tissue remnants and the smear layer (2, 3). Complete removal of the smear layer requires the use of a chelating agent or other demineralizing agent and a soft-tissue solvent because no single solution is capable of providing both effects (4). Although the combination of EDTA and sodium hypochlorite (NaOCl) have been advocated as an effective irrigation regimen to remove the organic and inorganic matter (5–9), there is no clear consensus regarding the ideal irrigation sequence, volume, and application time in the literature. Although NaOCl is used during instrumentation, EDTA is preferably used at the end of instrumentation to complete the removal of the smear layer (5, 10). Sufficient time and volume of NaOCl ensures a high disinfecting efficacy and enables NaOCl to penetrate into the dentin. On the other hand, a final flush of NaOCl has also been advocated because after smear layer removal NaOCl could better reach areas previously covered by the smear layer (11).

Root canal irrigation with the previously described solutions can lead to structural changes, as evidenced by the reduction of dentin strength, microhardness, and changes in surface roughness (12–14). Baumgartner and Mader (6) reported that when EDTA and NaOCl solutions were alternately applied to an uninstrumented root canal wall dentin showed an eroded appearance, and tubular orifice diameters were enlarged. Conflicting results have been obtained from some *in vitro* studies regarding the dentin surface after different irrigation protocols (7, 15, 16). Many studies have suffered from specific limitations, such as qualitative evaluation based on nonrandomized selection of the observation areas and analysis done by scores. The lack of standardization of many of the studies makes it difficult to fully understand the effect of irrigation sequences on dentin surface. Therefore, the purpose of the present study was to examine the effect on root canal wall dentin by immersion in different irrigant solutions in alternative sequences and to quantify and compare the level of erosion caused by the chemical treatments using a quantitative analysis with a semiautomatic method.

Materials and Methods

Eighty-four extracted single-rooted human teeth with one root canal without previous endodontic treatment were selected for the study. The study was approved by the university research ethics board. The teeth were stored in 0.01% NaOCl at 4°C after the root surface was cleaned with curettes. The teeth were thoroughly rinsed with distilled water before the experiments. The crowns were removed at the cementoenamel junction using high-speed bur under water cooling. At least 3 mm of coronal and apical root were removed; only the 5-mm-long middle part was used in the experiment. Residual pulp tissue was removed by fine barbed broaches. The canal wall was then instrumented by circumferential filing using #40 Hedstrom hand files (Dentsply Maillefer, Ballaigues, Switzerland) for 1 minute. After instrumentation, external grooves were made on buccolingual surfaces of the roots with a diamond disc, and the tooth blocks were split into two halves by a single edge razor blade and a hammer. The dentin blocks were randomly divided into the experimental groups and treated with 5.25% NaOCl (VWR, Mississauga, Canada), 17% EDTA (pH = 7.0), 17% ethyleneglycoltetraacetic acid (EGTA) (pH = 7.0), and 10% citric acid (CA) (Fisher Scientific, Ottawa, Canada) with designated sequence and timing as shown in Table 1. Each tooth block was put into a 15-mL capped test tube containing one of the previously described solutions, and the tube was constantly rocked for mixing. The specimen was rinsed

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What We Leave Behind In Root Canals After Endodontic Treatment: Some Issues and Concerns

Editor's Note:

This article is based on a presentation to the 13th Asian Pacific Endodontic Confederation Scientific Meeting held in Kuala Lumpur on 25 May 2005.

Abstract

The benefits of using sodium hypochlorite (NaOCl) and ethylenediaminetetraacetic acid (EDTA) as endodontic irrigants, and calcium hydroxide as an inter-appointment medicament, are well known to dentists. Many steps undertaken during endodontic treatment and retreatment are rather mechanical in nature, and less attention is committed to understanding the biological issues underlying endodontic treatment and retreatment. It should be noted that dentine is the fundamental substrate in endodontic treatment, and its properties and characteristics are the key determinant of nearly all disease and post-disease processes in the teeth. In this article the effects and counter-effects of NaOCl and EDTA on root canal dentine, and some other related issues are reviewed. This information will enable clinicians to use the beneficial effects of these chemicals, while necessary steps are considered to reduce their harmful effects on dentine substrate.

Introduction

It is now widely accepted that apical periodontitis is an inflammatory destruction of periapical tissues caused by the presence of aetiological agents from the root canal system (1). It is also widely accepted that the main cause of apical periodontitis is the presence of bacteria in the root canal system since Kakehashi *et al.* showed in 1965 that no apical periodontitis developed in germ-free rats when their molars were kept open to the oral cavity (2). Traditionally, root canal treatment is carried out to retain a tooth with apical periodontitis in a disease-free state in the oral cavity, and this objective of endodontic treatment is achieved by (i) cleaning and shaping the root canal system, and (ii) by root filling the prepared root canal lumen.

The cleaning and shaping step is intended to disinfect and remove dead tissue, bacteria and bacterial products from the root canal system. Shaping of root canals facilitates irrigation of the root canal system and subsequent root filling. The filling of the root canal system is meant to seal the periapical region from the root canal and to "bury" any remnant bacteria in the dentinal tubules. The purpose of the root filling is to deprive remnant bacteria of any nutrients and to prevent the entry of any body fluids into the root canal space. In doing so, most teeth with apical periodontitis heal (3). However, according to some investigators bacteria remaining in the dentinal tubules, though they may be buried by a root filling, would constitute an important reservoir from which reinfection may occur (4). Furthermore, the importance of a well-sealed coronal restoration has also been emphasised for a better treatment outcome (5).

Past studies have shown that instrumented cleaning of the root canal system with files will not be sufficient to remove tissues and bacteria. This is mainly because of the complex anatomy and varied configurations of root canal systems. Geometrically symmetrical instruments will not be able to reach many naturally occurring depressions, cul-de-sacs, isthmuses and other anatomical variations, which are asymmetrically disposed, within the root canal systems. In addition, the root canal diameter is usually larger than the instrument calibre used and this may further contribute to inadequate cleaning by instrumentation only (6). Consequently, bactericidal root canal irrigation and application on inter-visit medicament have become very important steps in the disinfection of root canal systems (1). The main purpose of root canal irrigation is to eliminate bacteria, and in the past, different concentrations of various chemicals were used to achieve this goal.

Studies of the microbial flora of the root canals of teeth with persistent apical lesions subsequent to root canal therapy have revealed that their bacterial flora differs markedly from that of the untreated, necrotic pulp (primary endodontic infection). While primary endodontic infection typically has a polymicrobial flora with approximately equal proportions of Gram-positive and Gram-negative bacteria, dominated by anaerobes, the microbial flora of the teeth with failing endodontic treatment (post-treatment endodontic infection) are characterised by monoinfection, predominantly Gram-positive microorganisms. These have been demonstrated to be of approximately equal proportion of facultative or obligate anaerobes (7). Further, *Enterococcus faecalis* has been found to be one of the commonest bacteria in the teeth with failed root canal therapy (8). This distinct difference in the endodontic bacterial flora is attributed to the "endodontic environmental transition (EET)".

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SCIENTIFIC ARTICLES

A New Solution for the Removal of the Smear Layer

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Various organic acids, ultrasonic instruments, and lasers have been used to remove the smear layer from the surface of instrumented root canals. The purpose of this study was to investigate the effect of a mixture of a tetracycline isomer, an acid, and a detergent (MTAD) as a final rinse on the surface of instrumented root canals. Forty-eight extracted maxillary and mandibular single-rooted human teeth were prepared by using a combination of passive step-back and rotary 0.04 taper nickel-titanium files. Sterile distilled water or 5.25% sodium hypochlorite was used as intracanal irrigant. The canals were then treated with 5 ml of one of the following solutions as a final rinse: sterile distilled water, 5.25% sodium hypochlorite, 17% EDTA, or a new solution, MTAD. The presence or absence of smear layer and the amount of erosion on the surface of the root canal walls at the coronal, middle, and apical portion of each canal were examined under a scanning electron microscope. The results show that MTAD is an effective solution for the removal of the smear layer and does not significantly change the structure of the dentinal tubules when canals are irrigated with sodium hypochlorite and followed with a final rinse of MTAD.

Microscopic examinations of root canals show that they are irregular and complex systems, with many cul-de-sacs, fins, and lateral canals. Additionally, numerous dentinal tubules open onto the root canal surface. When the dental pulp undergoes pathologic changes caused by trauma or carious invasion, the root canal system becomes susceptible to infection by several species of bacteria, with their toxins and their by-products. The microorganisms present in the root canal not only invade the anatomic irregularities of the root canal system, but they also invade the dentinal tubules and can reinfect the root canals if they remain viable after inadequate root canal treatment (1).

The main objectives of root canal therapy are cleaning and shaping and then obturating the root canal system in three dimensions to prevent reinfection. Many instrumentation techniques have been proposed to shape root canals to facilitate their complete obturation. Less attention has been directed toward the ability of these techniques to completely clean and disinfect the root canal system. Studies show that currently used methods of instrumentation, especially rotary instrumentation techniques, produce a smear layer that covers root canal walls and the openings to the dentinal tubules (2, 3). The smear layer consists of organic and inorganic substances, including fragments of odontoblastic processes, microorganisms, and necrotic materials. Presence of this smear layer prevents penetration of intracanal medication into the irregularities of the root canal system and the dentinal tubules and also prevents complete adaptation of obturation materials to the prepared root canal surfaces (4).

Various organic acids, ultrasonic instruments, and lasers have been used to remove the smear layer. Based on available evidence, it seems that these agents and methods do not provide complete disinfection of the root canal spaces in all cases when used in one-visit root canal therapy. Because of the ineffectiveness of these techniques, many practitioners rely on placement of $Ca(OH)_2$ in the root canals to assist in canal disinfection (5, 6). As a result of this recommendation, root canal therapy has to be performed in more than one appointment.

In addition to acids, ultrasonic and lasers, tetracycline has been recommended as a chelating agent during periodontal and endodontic treatment. Doxycycline has been used during periodontal treatment because of its antibacterial and chelating ability as well as its substantiveness (7). Barkhordar et al. (8) and Haznedaeroglu and Ersev (9) recommended the use of tetracycline HCl to remove the smear layer from the surfaces of instrumented canals and root-end cavity preparations. However, these investigators did not examine the antibacterial effects of tetracycline when used as an intracanal irrigant. A search of the endodontic literature showed the absence of any reports regarding the ability of an irrigant capable of removing the smear layer and disinfecting the root canal system. The purpose of this study was to investigate the effect of a new irrigation solution (MTAD), containing a mixture of a tetracycline isomer, an acid, and a detergent on the surface of instrumented root canals. (A patent application has been filed covering the technology described in this article.)

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Emergence and development of chlorhexidine resistance during sporulation of *Bacillus subtilis* 168

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Key words: Chlorhexidine; Resistance; Sporulation; *Bacillus subtilis*

1. SUMMARY

During sporulation of *Bacillus subtilis* strain 168 initiated by step-down conditions, resistance to chlorhexidine diacetate (CHA) developed at about $t_{3.5}$, before heat but after toluene resistance. Mutants blocked at stage IV of sporulation were sensitive to all three treatments. Stage V mutants were toluene resistant but moderately sensitive to heat and CHA. A stage VI mutant was resistant to all three treatments. Thus, chlorhexidine resistance is likely to be a result of spore coat, rather than of cortex, development.

2. INTRODUCTION

During bacterial sporulation, a series of events occurs resulting in many morphological and biochemical changes. The formation of the spore coat occurs in parallel with development by spores of their germination [1] and resistance [2] properties. Studies on the development of spore resistance to organic solvents have demonstrated that cells of *Bacillus subtilis* become progressively resistant to these chemicals with butanol resistance developing first, closely followed by octanol resistance and resistance to chloroform, methanol and ethanol appearing at roughly the same time and before the development of heat resistance [3–6].

Few studies have been made of the possible correlation between spore development and the onset of resistance to disinfectants [7] although it is currently believed that resistance to glutaraldehyde, hypochlorite and povidone-iodine occurs at the middle to late phase of stage V [8]. As part of a continuing study of bacterial sensitivity and resistance to chlorhexidine acetate (CHA), we have examined the development of resistance to CHA during the sporulation of *Bacillus subtilis* strain 168 and of some mutants blocked at different stages of sporulation.

3. MATERIALS AND METHODS

3.1. Organisms

B. subtilis 168 (*trp* C2) which requires tryptophan and sporulates normally was used as the wild-type strain. The other strains used (Table 1) were all Spo$^-$ and obtained from the laboratory of J. Mandelstam, Oxford.

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Effectiveness of Three Endodontic Irrigants at Various Tubular Depths in Human Dentin

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Bacteria from infected root canals can invade dentinal tubules, thus dentin disinfection is an important aspect of endodontic therapy. This study compares three endodontic irrigants for efficiency in killing bacteria established within human dentinal tubules. Root canals in extracted teeth were prepared and sterilized. Broth cultures of *Enterococcus faecalis* were allowed to grow within the canals to penetrate dentinal tubules. The infected canals were exposed individually to each of the irrigants for 1 min. Irrigants were 0.525% sodium hypochlorite, Tubulicid (0.2% EDTA), and 0.12% chlorhexidine (Peridex). Sterile water was the control. Viable bacteria were analyzed by drilling incrementally into dentin from the cementum toward the canal. Smaller diameter drills were used for each depth. Shavings were cultured at three depths, for each of three root levels: coronal, midroot, and apical. Although considerable variation occurred between roots, sodium hypochlorite seemed to be superior. Tubulicid and Peridex were better than water. More bacteria remained viable at greater distances from the pulp. These observations apparently apply to all levels in the canal.

After endodontic therapy, root canal failure from persistent infection is a possibility. Continued infection of endodontically treated teeth may occur from bacteria residing within dentinal tubules. One method of reducing the risk of failure from infection is chemical disinfection of the root canal.

In a pilot study, it was shown that commonly used root canal irrigants permeate completely through the dentinal tubules within the midsection of roots. However, the effectiveness of the irrigant largely depended upon the type of bacteria present within the tubules (1).

Research has been performed on the effectiveness of common endodontic irrigants in bovine dentin (2–4). Also, several investigators have studied pulpal disinfection in human teeth (5–8). Ringel et al. (9) postulated that reinfection of endodontically treated teeth can occur from bacteria residing within apical tubules and also from bacteria introduced into the canal during treatment.

The purpose of this study is to evaluate chemical disinfection of dentin. Sundqvist et al. (10) found that 38% of failed endodontically treated teeth were infected with *Enterococcus faecalis*. This bacterium, although not a common oral microbe, seems to be a participant in root canal failure. Because of its prevalence in chronically infected root canals, *E. faecalis* was selected as the test bacterium. This study compares bactericidal effectiveness of endodontic irrigants at three different depths within human dentinal tubules. Also, the effects of coronal, midroot, and apical canal levels on dentin permeability of both bacteria and irrigation solutions were considered.

MATERIALS AND METHODS

Twelve single-rooted, extracted teeth were obtained by extraction from patients 30 to 50 yr of age. This allowed three teeth per irrigant. Teeth were stored in tap water at 20°C until prepared for use. Crowns were removed with a diamond disk, and canals were instrumented with K-files until only clean white filings were observed. The step-back technique was used to flare the middle and coronal canals. The root canals were then sonicated with the MM-1500 instrument fitted with a #25 Rispisonic file (Medidenta, Woodside, NY) for 1 min. Root apexes were sealed with nail polish, and the roots were sterilized by autoclaving.

A turbid suspension of *E. faecalis* was obtained by growing the cells in trypticase soy broth for 12 hr at 36.5°C. Excess water was removed from the canals with sterile paper cones. The bacteria-laden suspension was placed into the canal with a sterile 27-gauge syringe and incubated at 36.5°C for 12 hr.

Excess broth was removed with sterile paper points to allow access of irrigants, simulating the clinical situation. The test irrigant was placed into the canal with a sterile 27-gauge syringe. Irrigants were sterile water (control), 0.525% sodium hypochlorite (NaOCl), Tubulicid (0.2% EDTA), and 0.12% chlorhexidine (Peridex). Three roots were used for each irrigant. Irrigants were allowed to remain in the canal for 1 min. The canal was dried with sterile paper cones to remove excess irrigant. A horizontal drill press was calibrated to ensure uniform penetration of the drill depth. With a sterile 2-mm diameter machinist twist drill, a hole 0.5 mm deep was drilled into the side of the tooth in its upper third. The shavings fell onto a trypticase soy agar plate, and the shavings

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A prospective study of the factors affecting outcomes of nonsurgical root canal treatment: part 1: periapical health

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Abstract

Ng Y-L, Mann V, Gulabivala K. A prospective study of the factors affecting outcomes of nonsurgical root canal treatment: part 1: periapical health. *International Endodontic Journal*, **44**, 583–609, 2011.

Aim To investigate the probability of and factors influencing periapical status of teeth following primary (1°RCTx) or secondary (2°RCTx) root canal treatment.

Methodology This prospective study involved annual clinical and radiographic follow-up of 1°RCTx (1170 roots, 702 teeth and 534 patients) or 2°RCTx (1314 roots, 750 teeth and 559 patients) carried out by Endodontic postgraduate students for 2–4 (50%) years. Pre-, intra- and postoperative data were collected prospectively on customized forms. The proportion of roots with complete periapical healing was estimated, and prognostic factors were investigated using multiple logistic regression models. Clustering effects within patients were adjusted in all models using robust standard error.

Results The proportion of roots with complete periapical healing after 1°RCTx (83%; 95% CI: 81%, 85%) or 2°RCTx (80%; 95% CI: 78%, 82%) were similar. Eleven prognostic factors were identified. The conditions that were found to improve periapical healing significantly were: the preoperative absence of a periapical lesion ($P = 0.003$); in presence of a periapical lesion, the smaller its size ($P \leq 0.001$), the better the treatment prognosis; the absence of a preoperative sinus tract ($P = 0.001$); achievement of patency at the canal terminus ($P = 0.001$); extension of canal cleaning as close as possible to its apical terminus ($P = 0.001$); the use of ethylene-diamine-tetra-acetic acid (EDTA) solution as a penultimate wash followed by final rinse with NaOCl solution in 2°RCTx cases ($P = 0.002$); abstaining from using 2% chlorexidine as an adjunct irrigant to NaOCl solution ($P = 0.01$); absence of tooth/root perforation ($P = 0.06$); absence of interappointment flare-up (pain or swelling) ($P = 0.002$); absence of root-filling extrusion ($P \leq 0.001$); and presence of a satisfactory coronal restoration ($P \leq 0.001$).

Conclusions Success based on periapical health associated with roots following 1°RCTx (83%) or 2°RCTx (80%) was similar, with 10 factors having a common effect on both, whilst the 11th factor 'EDTA as an additional irrigant' had different effects on the two treatments.

Keywords: outcome, periapical healing, root canal treatment, success.

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Introduction

Periapical disease is an inflammatory response around root canal termini in response to intraradicular bacterial infection. It can be prevented (in the case of pulp inflammation) or resolved (in the case of pulp infection) by root canal treatment. The principles for root canal treatment laid at the beginning of the last century (Hall 1928) remain consistent with contemporary quality guidelines approved by Endodontic societies in Europe and North America (British Endodontic Society 1983, European Society of Endodontology 1994, 2006, Canadian Academy of

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Dissolution of pulp tissue by aqueous solution of chlorhexidine digluconate and chlorhexidine digluconate gel

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Abstract

Okino LA, Siqueira EL, Santos M, Bombana AC, Figueiredo JAP. Dissolution of pulp tissue by aqueous solution of chlorhexidine digluconate and chlorhexidine digluconate gel. *International Endodontic Journal*, **37**, 38–41, 2004.

Aim To evaluate the activity of various root canal irrigants on bovine pulp tissue.

Methodology The irrigants tested were: 0.5, 1.0 and 2.5% sodium hypochlorite; 2% aqueous solution of chlorhexidine digluconate; 2% chlorhexidine digluconate gel (Natrosol^{TM}); and distilled water as control. Bovine pulp fragments were weighed and placed in contact with 20 mL of each tested substance in a centrifuge at 150 r.p.m. until total dissolution. Dissolution speed was calculated by dividing pulp weight by dissolution time. Statistical analysis was performed using the Kruskal–Wallis test.

Results Distilled water and both solutions of chlorhexidine did not dissolve the pulp tissue within 6 h. Mean dissolution speeds for 0.5, 1.0 and 2.5% sodium hypochlorite solutions were 0.31, 0.43 and 0.55 mg min^{-1}, respectively. The solvent ability of chlorhexidine solutions was similar to that of distilled water. The results for sodium hypochlorite solutions, chlorhexidine solutions and distilled water were statistically different ($P > 0.01$).

Conclusions Both chlorhexidine preparations and distilled water were not able to dissolve pulp tissue. All sodium hypochlorite solutions were efficient in dissolving pulp tissue; the dissolution speed varied with the concentration of the solution.

Keywords: chlorhexidine, irrigants, pulp.

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Introduction

The success of root canal treatment relies on thorough chemomechanical procedures (Stewart 1955). The persistence of residual pulp tissue, infected dentine or bacteria in the root canal system may be responsible for treatment failure (Callahan 1894, Grossman & Meiman 1941, Moorer & Wesselink 1982). The use of irrigating solutions facilitates debridement of the root canal space and is important for the success of root canal treatment (Cunningham & Balekjian 1980).

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Several studies have been conducted in search for an irrigant that meets four major properties: antimicrobial activity, non-toxicity to periapical tissues, water solubility and capacity to dissolve organic matter (Byströn & Sundqvist 1985, Jeansonne & White 1994, Kuruvilla & Kamath 1998).

Sodium hypochlorite has been used as a therapeutic agent since the 1930s for root canal infection (Walker 1936). It is as an excellent organic solvent and an effective antimicrobial agent (Byströn & Sundqvist 1985, Nakamura *et al.* 1985).

Chlorhexidine has been widely used in dentistry because of its broad-spectrum antimicrobial activity and substantivity. For these reasons, chlorhexidine has been recommended for root canal treatment. Chlorhexidine digluconate is formulated as an aqueous solution or gel preparation. The liquid form is most

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Ex vivo assessment of irrigant penetration and renewal during the final irrigation regimen

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Abstract

Bronnec F, Bouillaguet S, Machtou P. *Ex vivo* assessment of irrigant penetration and renewal during the final irrigation regimen. *International Endodontic Journal*, **43**, 663–672, 2010.

Aim To assess irrigant penetration in curved canals after shaping procedures *ex vivo*.

Methodology Thirty extracted mandibular molars with moderate to severe root canal curvature were included. A special aiming device was used to guarantee that each successive radiograph was taken with the same positioning. The mesiolingual canal of each tooth was instrumented with ProTaper rotary files. Apical third preparation was completed with an F1 instrument before additional step-back enlargement using F2 then F3 instruments. For each apical taper, the teeth were submitted successively to active irrigation (AI) then to passive irrigation (PI). AI consisted of a 0.5 mL flush of sodium diatrizoate (Hypaque 50%) immediately followed by manual mechanical activation with a gutta-percha point. PI consisted in flushing the canals with sodium hypochlorite passively delivered with a syringe. A digital radiograph was taken after each modality. The influence of needle tip design, needle tip insertion level, irrigant volume, root canal taper and solution activation was assessed by using digital subtraction radiography and measures of the depths of irrigant penetration. Comparisons were performed within an analysis of variance framework in a repeated-measures approach.

Results For PI, all the four explanatory variables 'apical taper', 'volume of irrigant used', 'corono-apical level of needle tip placement', 'needle tip design' had a significant ($P < 0.005$) influence on outcome of irrigation penetration.

Conclusions Only active irrigation allowed complete penetration and exchange of irrigating solution. For syringe irrigation alone, the level of needle tip placement in the canal was the most dominating factor.

Keywords: digital radiography, image processing, root canal irrigation, rotary file.

Received 23 February 2009; accepted 2 March 2010

Introduction

Thorough disinfection of the root canal system is considered a key requirement for successful root canal treatment. Traditionally it is accomplished by a combination of instrumentation and irrigation (Haapasalo *et al.* 2005), sodium hypochlorite being the most widely used solution (Whitworth *et al.* 2000, Slaus & Bottenberg 2002, Clarkson *et al.* 2003). As preparation alone cannot achieve sterilization (Byström & Sundqvist 1983, 1985a, Dalton *et al.* 1998), attention has been paid towards increasing the apical size of the root canal preparation (Baugh & Wallace 2005) to mechanically eliminate infected dentine (Card *et al.* 2002) and allow a greater volume of antiseptic irrigant to be applied (Byström *et al.* 1985b, Shuping *et al.* 2000). During root canal preparation it is impossible to distinguish the respective effects of irrigation over instrumentation when enlarging canals. Moreover, microbiological studies underestimate the cleaning function of irrigating solutions despite it being a prerequisite for optimal disinfection results (Gulabivala *et al.* 2005). SEM and histological studies tend to support the difficulty of obtaining clean root canal walls with current irrigation protocols, especially in the

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42.

Development and Validation of a Three-dimensional Computational Fluid Dynamics Model of Root Canal Irrigation

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Abstract

Introduction: Root canal irrigation plays an important role in the debridement and disinfection of the root canal system and is an integral part of root canal preparation procedures. The aim was to construct a three-dimensional computational fluid dynamics (CFD) model of root canal irrigation, with a suitable turbulence model, and validate it to provide a novel method for studying the root canal irrigation. **Methods:** A camcorder was used to record the effect of irrigation in the *in vitro* model. An exact replica of the geometry and the physical parameters of the *in vitro* irrigation model were used in CFD analysis, considering four turbulent models. The *in vitro* irrigation model was used as the reference for the evaluation of the CFD models. **Results:** The result showed that CFD analysis based on a shear stress transport (SST) k-ω turbulence model was in close agreement with the *in vitro* irrigation model. The *in vitro* and CFD analyses showed that the irrigant in the curved canal flushes only up to a limited distance beyond the tip of the needle. The results of the CFD analysis also showed that laminar flow exists in the needle lumen and transit the transitional and turbulent flow around the side-vent outlet of the needle and needle tip. **Conclusions:** The results suggested that CFD based on a SST k-ω turbulence model has the potential to serve as a platform for the study of root canal irrigation. *(J Endod 2009;35:1282–1287)*

Key Words

Computational fluid dynamics, irrigation, needle, root canal, turbulence model

An important objective of mechanical instrumentation and irrigation in endodontic therapy is the elimination of microorganisms and infected pulp tissue (1). Because of the anatomic complexity of the pulp space, some organic tissues and bacteria are often left inside root canal systems after instrumentation. Irrigation is complementary to instrumentation in facilitating the removal of bacteria, debris, and the smear layer (2, 3). The effectiveness of irrigation relies on both the mechanical flushing action and the ability of irrigants to dissolve tissue and kill bacteria (4). There have been a number of studies examining physical factors that influence the degree of irrigant penetration and its effectiveness, including canal shape and size, volume and pressure of irrigant, the type, size, and insertion depth of the irrigation needle (2, 5–7). Irrigation dynamics plays an important role (8) on the effectiveness of irrigation depending on the working mechanism(s) of the irrigant and the ability to bring the irrigant in contact with the microorganisms and dentin debris present in the root canal (9). Yet, an accurate description of the streaming pattern of irrigants in the root canal during irrigation is still not available. Direct measurements of flow patterns through the anatomic features of root canals, characterized by narrow channels, are precluded by dentin. Therefore, the exact physical mechanism(s) that contribute to the effectiveness of root canal irrigation remain uncertain.

The most commonly used methods to evaluate the effectiveness of irrigation are scanning electron microscopy, optical microscopy, root canal sectional analysis, and microbiological analysis (10–15). However, these methods only examine the final static condition rather than the process of fluid dynamics during irrigation (16). Alternatively, the effectiveness of irrigation has also been examined by flushing insoluble particles of bead-form gel from glass tubes (17) or red food dye from simulated root canals in plastic blocks (18). The primary advantage of these approaches over other methods is that they provide a real-time visual assessment of irrigation in the root canal. However, the magnitude and distribution of pressure and velocity of the fluids at different locations during irrigation remain unknown.

To overcome problems associated with the characterization of the effectiveness of endodontic irrigation, approaches based on a combination of virtual models and simulation may prove useful. Computational fluid dynamics (CFD) is a branch of fluid mechanics that solves and analyses problems involving a fluid flow by means of computer-based simulations (19). Modern CFD technology allows complex numeric simulations. These have been applied to the study of the cardiovascular system and

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43.

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A bio-molecular film *ex-vivo* model to evaluate the influence of canal dimensions and irrigation variables on the efficacy of irrigation

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Abstract

Huang T-Y, Gulabivala K, Ng Y-L. A bio-molecular film *ex-vivo* model to evaluate the influence of canal dimensions and irrigation variables on the efficacy of irrigation. *International Endodontic Journal*, **41**, 60–71, 2008.

Aims To devise an *ex vivo* model to test the efficacy of irrigation (static/dynamic) in removing a bio-molecular film from root canal walls.

Methodology Forty human teeth with single straight canals were randomly allocated to two groups for static (n = 20) or dynamic (n = 20) irrigation. The root canals were prepared to different apical sizes (20, 40) and tapers (0.04, 0.08). The teeth were split longitudinally into two, stained collagen was applied to the canal surfaces and the tooth reassembled in a silicone matrix for dynamic or static irrigation. Digital images of the canal surface were taken before and after irrigation with 9, 18, 27 and 36 mL solution. The percentage of canal surface covered with stained collagen was quantified (ipWin4®). The data were analysed using paired t-tests and linear regression models.

Results All the five explanatory variables: 'volume of irrigant used', 'mode of irrigation', 'orientation of open port of needle', 'corono-apical level of canal' and 'root canal dimension' had a significant ($P < 0.001$) influence on outcome of irrigation. The corono-apical level of canal was the most dominating factor. After irrigation, the apical third had 19.9% and 33.8% less area covered with the bio-molecular film than the middle and coronal thirds respectively.

Conclusions The stained collagen bio-molecular film could not be removed completely by either static or dynamic irrigation. Factors influencing removal, in rank order of decreasing priority, were: corono-apical level, apical size and taper of canal preparation, and dynamic/static irrigation.

Keywords: bio-molecular film, irrigation, root canal.

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Introduction

Development of a periapical lesion signifies the presence of bacteria in the root canal system (Kakehashi *et al.* 1965, Sundqvist 1976, Möller *et al.* 1981), in particular its apical portion where they can exist in a biofilm or invade dentinal tubules (Nair 1987) and pose a challenge to treatment (Nair *et al.* 2005). Organization of bacteria within biofilms confers a range of phenotypic properties that are not evident in their planktonic counterparts and amongst other characteristics make them more resistant to antimicrobial killing (Costerton *et al.* 1994, 1999, Potera 1999).

Chemo-mechanical debridement and obturation effectively reduce the bacterial load in the root canal system and allow periapical healing in about 80% of cases (Sjögren *et al.* 1990), even though the apical bacterial biofilm survives in 88% (Nair *et al.* 2005). Given that mechanical instruments only plane up to 61% of the canal surface (Mannan *et al.* 2001, Peters *et al.* 2001), the role of canal preparation has undergone a shift from one of fulfilling a prime debriding function, to one regarded more as a radicular access for the irrigant and root filling materials to the complex root canal systems (Gulabivala *et al.* 2005). An impor-

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44.

Comparison of the Cleaning Efficacy of Different Final Irrigation Techniques

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Abstract

Introduction: The aim of this study was to evaluate the removal of dentin debris from artificially made grooves in standardized root canals by 6 different final irrigation techniques. **Methods:** Conventional syringe irrigation, manual dynamic activation (MDA) with tapered or nontapered gutta-percha (GP) cones, the Safety Irrigator system, continuous ultrasonic irrigation (CUI), and apical negative pressure (ANP) irrigation were tested *ex vivo* in 20 root canals with a standardized, debris-filled groove in the apical portion of one canal wall. After each irrigation procedure, the groove was photographed, and the residual amount of dentin debris was scored. **Results:** There was no significant difference between the MDA with a nontapered GP cone, the Safety Irrigator, and the ANP irrigation. These techniques produced better cleaning efficacy than syringe irrigation ($P < .005$) but significantly worse than the MDA with a tapered cone ($P < .05$). CUI was significantly better than all the other techniques tested in this study ($P < .001$). **Conclusions:** CUI was the most effective technique in dentin debris removal from the apical irregularities, and syringe irrigation alone was the least effective. MDA technique was more effective with a tapered GP cone than with a nontapered one. *(J Endod 2012;38:838–841)*

Key Words

Apical negative pressure, continuous ultrasonic irrigation, dentin debris, manual dynamic activation

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Debridement is the aim of and also a big challenge to endodontic treatment (1), especially in the apical portion of the root canal (2). Because of the complexity of the root canal anatomy and the limitations of instrumentation (3, 4), irrigation has gained increasing attention, and one improvement in this respect is irrigant activation that resulted in the development of various irrigation techniques or systems. Removal of the dentin debris from apical uninstrumented areas seems to be a good indication of the mechanical debridement efficacy of an irrigation system, because the flow of the irrigant directly influences the debris removal (5).

Syringe irrigation is the conventional and still widely used irrigation technique. Combinations of syringe irrigation to deliver the irrigant and various ways to activate it are applied mainly as final irrigation after root canal instrumentation is completed. There are various methods to activate the irrigant, ranging from moving gutta-percha (GP) cones up and down in the root canal (manual dynamic activation [MDA]) (6–8) to instruments energized by (ultra)sonic or laser devices (9–12).

To prevent irrigant extrusion and enhance the apical irrigation, so-called apical negative pressure (ANP) systems, such as EndoVac (Discus Dental, Culver City, CA), have been introduced (13). Its microcannula can be inserted until working length (WL), and the negative pressure will create an apical circulation of the irrigant without apical extrusion. It also seems to have a better apical debridement efficacy compared with positive pressure irrigation (13–15). The Safety Irrigator (Vista Dental, Racine, WI) has been recently introduced as a simple, "negative-pressure" endodontic irrigation device. It features a large coronal evacuation tube, enabling the irrigant aspiration from the pulp chamber simultaneously with the irrigant delivery in the root canal through a flexible needle tip. The VPro tip (Vista Dental) is an ultrasonically activated, 30-gauge irrigation needle that was recently introduced to allow simultaneous continuous irrigant delivery and ultrasonic activation, recently referred to as continuous ultrasonic irrigation (CUI) (16).

The aim of this study was to compare the mechanical cleaning efficacy of conventional syringe irrigation, MDA, the Safety Irrigator system, CUI by the VPro tip, and ANP by the EndoVac system in the removal of dentin debris from simulated irregularities located at the apical area in standardized root canals.

Materials and Methods

Dentin Debris Removal Model

Straight roots from 20 extracted human maxillary canines were decoronated to obtain uniform root sections of 15 mm following the protocol described previously (5, 9). Briefly, the roots were embedded in resin and bisected longitudinally. The surfaces of the halves were then ground to leave only a little of the original root canal lumen. Four holes were drilled in the resin part, and the halves were reassembled by 4 self-tapping bolts through the holes. All the models were checked to see whether there was any leakage of liquid or gas apically or laterally before experiments. If there was any, rubber dam caulk would be applied to ensure that the root canal modeled a closed system.

New root canal spaces were prepared by Flexofiles (Dentsply Maillefer, Ballaigues, Switzerland) to #15 and rotary System GT instruments (Dentsply Maillefer) to a WL of 15 mm, an International Organization for Standardization (ISO) size of 30, and a taper of 0.06. The apical part was further enlarged by using nickel-titanium K-files #40/.02

45.

MICROSCOPY RESEARCH AND TECHNIQUE 00:00–00 (2013)

Surface Change of Root Canal Dentin after the Use of Irrigation Activation Protocols: Electron Microscopy and an Energy-Dispersive X-Ray Microanalysis

ISMAIL DAVUT CAPAR ,[1]* AND HALE ARI AYDINBELGE[2]
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KEY WORDS energy-dispersive spectrometer; irrigation agitation devices; mineral content; Self-Adjusting File

ABSTRACT This study evaluated the mineral contents of root-canal dentin after treatment with different irrigation activation protocols. One hundred and eight maxillary lateral incisor teeth were randomly divided into eight experimental groups and one control group. Root canals were prepared using ProTaper rotary files, with the exception of the Self-Adjusting File (SAF) group. Canals were irrigated with 2 mL of 5% sodium hypochlorite (NaOCl) at each instrument change, and received a final flush with 10 mL of 17% ethylenediaminetetraacetic acid (EDTA) and 10 mL of 5% NaOCl for 1 min. The control group was irrigated with distilled water. Group I (GI): Needle syringe irrigation; Group II (GII): NaviTip FX; Group III (GIII): CanalBrush; Group IV (GIV): Manual dynamic activation with gutta-percha; Group V (GV): Passive ultrasonic irrigation; Group VI (GVI): EndoActivator; Group VII (GVII): EndoVac; Group VIII (GVIII): SAF. The level of elemental composition was analyzed by a scanning electron microscopy and an energy-dispersive spectrometer (EDS) system. The results were then statistically analyzed by one-way ANOVA and Tukey tests. Ca/P ratio was changed after treatment with SAF and EndoActivator. The Ca, P, Mg, and S level changes were not statistically significant ($P > 0.05$). Final irrigation activation protocols did not alter the mineral level of root dentin surface. *Microsc. Res. Tech. 00:000–000, 2013.* © 2013 Wiley Periodicals, Inc.

INTRODUCTION

Removal of vital and necrotic remnants of pulp tissues, microorganisms, and microbial toxins from the root canal system is essential for endodontic success (Basmadjian-Charles et al., 2002; Siqueira and Rocas, 2008; Wong, 2004). Using micro-computed tomography technology (Paque et al., 2009, 2010; Peters et al., 2001), it has been shown that current NiTi rotary systems lead to untreated dentin areas. Prior to filling, clean root canals can be achieved by instrumentation supplemented with irrigants and intra-canal medicaments. Traditionally, EDTA and sodium hypochlorite (NaOCl) have been the most widely used irrigation agents. NaOCl dissolves the organic tissues, kills bacteria and yeasts. EDTA dissolves the inorganic tissues by chelation but it has no antibacterial activity in the root canal. Because of the differences between these irrigants, the classical recommendation of using NaOCl (2–6%) during instrumentation and EDTA (17%) after treatment is still valid and highly recommended (Haapasalo, 2011).

Dentin composition contains organic and inorganic components. The major inorganic components of dental hard tissue are Ca and P present in hydroxyapatite crystals. It has been reported that some chemical agents caused alterations in the chemical structure of human dentin and changed the Ca/P ratio of the dentin surface (Hennequin and Douillard, 1995; Hennequin et al., 1994; Rotstein et al., 1996). In addition to these evidences, some researchers reported that the use of chelating agents and NaOCl solutions can lead to intermittent erosions of the canal walls, characterized by surface dissolution of intertubular and peritubular dentin (Torabinejad et al., 2003). Application time, concentration, and pH of the solution are the major cause of the chelating agents demineralizing effects (Calt and Serper, 2002).

Syringes and metal needles of different sizes and tip designs have traditionally been used to deliver irrigants into the root canal space. Because of the root canal's complexity, unclean areas may still remain after irrigation (Williamson et al., 2009). Therefore, several mechanical devices have been developed to improve the penetration and effectiveness of irrigation.

The effects of chelating agents and NaOCl on dentin mineral contents have been previously evaluated (Dogan and Calt, 2001; Sen et al., 2009). However, according to our data, after use of irrigation activation protocols, remaining residual elemental composition of

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46.

The Effect of Needle-insertion Depth on the Irrigant Flow in the Root Canal: Evaluation Using an Unsteady Computational Fluid Dynamics Model

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Abstract

Introduction: The aim of this study was to evaluate the effect of needle-insertion depth on the irrigant flow inside a prepared root canal during final irrigation with a syringe and two different needle types using a Computational Fluid Dynamics (CFD) model. **Methods:** A validated CFD model was used to simulate irrigant flow from either a side-vented or an open-ended flat 30-G needle positioned inside a prepared root canal (45 .06) at 1, 2, 3, 4, or 5 mm short of the working length (WL). Velocity, pressure, and shear stress in the root canal were evaluated. **Results:** The flow pattern in the apical part of the root canal was similar among different needle positions. Major differences were observed between the two needle types. The side-vented needle achieved irrigant replacement to the WL only at the 1-mm position, whereas the open-ended flat needle was able to achieve complete replacement even when positioned at 2 mm short of the WL. The maximum shear stress decreased as needles moved away from the WL. The flat needle led to higher mean pressure at the apical foramen. Both needles showed a similar gradual decrease in apical pressure as the distance from the WL increased. **Conclusions:** Needle-insertion depth was found to affect the extent of irrigant replacement, the shear stress on the canal wall, and the pressure at the apical foramen for both needle types. *(J Endod 2010;36:1664–1668)*

Key Words

Computational Fluid Dynamics, insertion depth, irrigation, needle

Irrigation of root canals with antibacterial solutions is an integral part of chemomechanical preparation, aiming at the removal of bacteria, debris, and necrotic tissue, especially from areas of the root canal that have been left unprepared by mechanical instruments (1). Irrigants are commonly delivered using a syringe and needle (2, 3), even before passive ultrasonic activation of the solution (4). The significance of the needle position in relation to the apical terminus of the preparation, also described as needle insertion depth or penetration, has been highlighted in a series of *in vitro* (5) and *ex vivo* studies (6-9). It has been hypothesized that positioning the needle close to the working length (WL) could in fact improve the debridement and irrigant replacement (6, 10). However, previous studies have mainly focused on the removal efficiency of debris and bacteria and provided little understanding of the etiology (ie, the flow pattern developed in the root canal that leads to debridement and irrigant replacement). Limited insight in the fluid dynamics of the flow inside the root canal has been presented using thermal image analysis (9) because this approach could only provide a coarse estimation of the irrigant flow.

A Computational Fluid Dynamics (CFD) model was recently introduced as a method to study root canal irrigation (11). This model was subsequently validated by comparison with experimental high-speed imaging data (12) and used to evaluate the effect of needle tip design on the flow (13). In these previous studies, needles were positioned at 3 mm short of the WL. A similar approach has also been reported (14, 15), but the effect of needle insertion depth on the irrigant flow has not been studied in detail. The aim of this study was to evaluate the effect of needle insertion depth on the irrigant flow inside a prepared root canal during final irrigation with a syringe and two different needle types using the validated CFD model.

Materials and Methods

The root canal and apical anatomy were simulated similarly to a previous study (11), assuming a length of 19 mm, an apical diameter of 0.45 mm (ISO size 45), and 6% taper. The apical foramen was simulated as a rigid and impermeable wall, corresponding to a closed system.

Two different needle types, a side-vented and an open-ended flat needle, were modeled using commercially available 30-G needles as references, similar to a previous study (13). The external and internal diameter and the length of the needles were stan-

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47.

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Measurement of pressure and flow rates during irrigation of a root canal *ex vivo* with three endodontic needles

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Abstract

Boutsioukis C, Lambrianidis T, Kastrinakis E, Bekiaroglou P. Measurement of pressure and flow rates during irrigation of a root canal *ex vivo* with three endodontic needles. *International Endodontic Journal*, **40**, 504–513, 2007.

Aim To monitor *ex vivo* intra-canal irrigation with three endodontic needles (25, 27 and 30 gauge) and compare them in terms of irrigant flow rate, intra-barrel pressure, duration of irrigation and volume of irrigant delivered.

Methodology A testing system was constructed to allow measurement of selected variables with pressure and displacement transducers during *ex vivo* intra-canal irrigation with a syringe and three different needles (groups A, B, C) into a prepared root canal. Ten specialist endodontists performed the irrigation procedure. Each operator performed ten procedures with each needle. Data recorded by the transducers were analysed using Friedman's test, Wilcoxon Signed Rank test, Mann–Whitney *U*-test and Kendall's T_b test. The level of significance was set to 95%.

Results Significant differences were detected among the three needles for most variables. Duration of delivery and flow rates significantly decreased as the needle diameter increased, whilst pressure increased up to 400–550 kPa. Gender of the operator had a significant impact on the results. Experience of the operators (years) were negatively correlated to volume of irrigant (all groups), to the duration of delivery (groups A, B) and to the average flow rate (group A).

Conclusions Finer diameter needles require increased effort to deliver the irrigant and result in higher intra-barrel pressure. The syringe and needles used tolerated the pressure developed. Irrigant flow rate should be considered as a factor directly influencing flow beyond the needle. Wide variations of flow rate were observed among operators. Syringe irrigation appears difficult to standardize and control.

Keywords: irrigant flow rate, irrigation, needle, pressure.

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Introduction

Irrigation of the root canal with antibacterial solutions is considered an essential part of chemo-mechanical preparation (Haapasalo *et al.* 2005). Irrigation is complementary to instrumentation in facilitating removal of bacteria, debris and necrotic tissue (Lee *et al.* 2004), especially from areas of the root canal that remain unprepared by mechanical instruments (Gulabivala *et al.* 2005).

Although the effectiveness of irrigation relies on both the mechanical flushing action and the ability of irrigants to kill bacteria (Gulabivala *et al.* 2005) and dissolve tissue (Lee *et al.* 2004), it has been suggested that the flushing action may be the most important factor (Baker *et al.* 1975). Irrigation dynamics should then be considered when evaluating the effects of an irrigant on root canal contents (Gulabivala *et al.* 2005). The penetration of the irrigant and the flushing action created by irrigation are dependent not only on the anatomy of the root canal system, but also on the

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48.

Effect of Apical Preparation Size and Preparation Taper on Irrigant Volume Delivered by Using Negative Pressure Irrigation System

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Abstract

Introduction: The purpose of this investigation was to determine the effect that apical preparation size and preparation taper had on the volume of irrigant delivered to the working length of a root canal preparation in a clinically relevant amount of time. **Methods:** Forty intact human single-rooted teeth were randomly distributed into 2 separate phases. The first phase aimed to determine the smaller apical size that will allow more volume of irrigant at working length. All samples had the same taper and were sequentially instrumented to sizes of 30.06, 35.06, 40.06, and 45.06. The second phase aimed to determine the taper that will allow more volume of irrigant at working length. Teeth were sequentially instrumented to 40.02, 40.04, 40.06, and 40.08. All samples were irrigated by using the micro-cannula, and the volume of sodium hypochlorite suctioned at working length under negative pressure was measured during a period of 30 seconds by using a custom recovery device. **Results:** An increase in size from ISO #35 to ISO #40 resulted in a percentage gain of approximately 44% in mean irrigant volume, whereas an increase in size from ISO #40 to ISO #45 resulted in a percentage gain of approximately 4%. An increase in taper from 0.02 through 0.08 resulted in percentage gains of approximately 74%, 5.4%, and 2.4% increase, respectively. **Conclusions:** The data demonstrated that an increase in apical preparation size and taper resulted in a statistically significant increase in the volume of irrigant. In addition, an apical enlargement to ISO #40 with a 0.04 taper will allow for tooth structure preservation and maximum volume of irrigation at the apical third when using the apical negative pressure irrigation system. *(J Endod 2010;36:721–724)*

Key Words

Apical negative pressure irrigation, apical preparation, taper, volume

The role of microorganisms in the pathogenesis of endodontic infections has been well-established (1). These microorganisms and the by-products they produce cause inflammation and bone resorption (2), and there is a clear correlation between periradicular healing and presence of bacteria in the root canal system before filling (3–5). Mechanical instrumentation alone is ineffective at completely removing residual bacteria and necrotic debris (6). Therefore, thorough cleaning and disinfection of the root canal system are essential for the success of nonsurgical root canal therapy.

Historically, irrigation has been achieved by using a positive pressure technique whereby irrigant is expressed under positive pressure into the root canal system. However, the effectiveness and safety in delivering the irrigant have been questioned (7–9). Recently, the use of negative pressure irrigation techniques has been reported (9) to be superior to positive pressure irrigation. Negative pressure irrigation systems have been shown to deliver irrigant to the apical portions of the root canal system in a safe and effective manner (9–11). It has also been suggested that negative pressure irrigation achieves better microbial control than traditional irrigation delivery systems, regardless of the amount of preparation taper (12).

EndoVac (Discus Dental, Culver City, CA) is a commercially available negative pressure irrigation system that combines a master delivery tip that delivers irrigant to the access cavity while drawing irrigant into the canal space by using macro- and micro-cannulas to clean and disinfect the canal system.

Whereas the volume of irrigant has been shown to be directly related to effectiveness of disinfection and root canal cleanliness when using traditional irrigation techniques (13), there is little evidence demonstrating the real volume of irrigant that can be delivered when using both positive and negative pressure. Even though the irrigant expressed through a positive pressure irrigation syringe system reaches the tip of the irrigation needle, it is difficult to measure the volume of irrigant being expressed because the rate/pressure of expression varies among practitioners. Moreover, it is difficult to determine whether that irrigant is actually reaching the apical third of the prepared canal (10). Nielsen and Baumgartner (9) reported the volume of irrigant delivered by the master delivery tip of the negative pressure irrigation system, but they did not measure the volume being suctioned back by the cannula within the canal. It is clinically important to know the volume of irrigant reaching the working length and the effect that preparation size and taper have on these volumes. The purpose of this investigation was to determine the effect that apical preparation size and preparation taper have on the volume of irrigant delivered to the working length of a root canal preparation by using negative pressure irrigation technique.

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49.

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Irrigant flow in the root canal: experimental validation of an unsteady Computational Fluid Dynamics model using high-speed imaging

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Abstract

Boutsioukis C, Verhaagen B, Versluis M, Kastrinakis E, van der Sluis LWM. Irrigant flow in the root canal: experimental validation of an unsteady Computational Fluid Dynamics model using high-speed imaging. *International Endodontic Journal* **43**, 393–403, 2010.

Aim To compare the results of a Computational Fluid Dynamics (CFD) simulation of the irrigant flow within a prepared root canal, during final irrigation with a syringe and a needle, with experimental high-speed visualizations and theoretical calculations of an identical geometry and to evaluate the effect of off-centre positioning of the needle inside the root canal.

Methodology A CFD model was created to simulate irrigant flow from a side-vented needle inside a prepared root canal. Calculations were carried out for four different positions of the needle inside a prepared root canal. An identical root canal model was made from poly-dimethyl-siloxane (PDMS). High-speed imaging of the flow seeded with particles and Particle Image Velocimetry (PIV) were combined to obtain the velocity field inside the root canal experimentally. Computational, theoretical and experimental results were compared to assess the validity of the computational model.

Results Comparison between CFD computations and experiments revealed good agreement in the velocity magnitude and vortex location and size. Small lateral displacements of the needle inside the canal had a limited effect on the flow field.

Conclusions High-speed imaging experiments together with PIV of the flow inside a simulated root canal showed a good agreement with the CFD model, even though the flow was unsteady. Therefore, the CFD model is able to predict reliably the flow in similar domains.

Keywords: Computational Fluid Dynamics, high-speed imaging, irrigation, needle, Particle Image Velocimetry.

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Introduction

Irrigation of root canals with antibacterial solutions is considered an essential part of chemo-mechanical preparation (Haapasalo *et al.* 2005). Irrigation with a syringe and needle remains the most commonly used irrigation procedure (Ingle *et al.* 2002, Peters 2004). However, there is a general uncertainty about the efficiency of this procedure in the narrow, most apical part of the root canal (Senia *et al.* 1971, Vande Visse & Brilliant 1975, Ram 1977). It has been argued that the limiting factor of the irrigation procedure is the difficulty to flush the apical root canal with large volumes of fresh irrigant (Druttman & Stock 1989).

To study this problem, attempts to evaluate the irrigant flow within the root canal have been attempted, based on macroscopic observations (Kahn *et al.* 1995, Peters & Peters 2005, Zehnder 2006). However, these studies of the fluid dynamics were limited because

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Evaluation of Irrigant Flow in the Root Canal Using Different Needle Types by an Unsteady Computational Fluid Dynamics Model

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Abstract

Introduction: The aim of this study was to evaluate the effect of needle tip design on the irrigant flow inside a prepared root canal during final irrigation with a syringe using a validated Computational Fluid Dynamics (CFD) model. **Methods:** A CFD model was created to simulate the irrigant flow inside a prepared root canal. Six different types of 30-G needles, three open-ended needles and three close-ended needles, were tested. Using this CFD model, the irrigant flow in the apical root canal was calculated and visualized. As a result, the streaming velocity, the apical pressure, and the shear stress on the root canal wall were evaluated. **Results:** The open-ended needles created a jet toward the apex and maximum irrigant replacement. Within this group, the notched needle appeared less efficient in terms of irrigant replacement than the other two types. Within the close-ended group, the side-vented and double side-vented needle created a series of vortices and a less efficient irrigant replacement; the side-vented needle was slightly more efficient. The multi-vented needle created almost no flow apically to its tip, and wall shear stress was concentrated on a limited area, but the apical pressure was significantly lower than the other types. **Conclusions:** The flow pattern of the open-ended needles was different from the close-ended needles, resulting in more irrigant replacement in front of the open-ended needles but also higher apical pressure. *(J Endod 2010;36:875–879)*

Key Words

Computational Fluid Dynamics, irrigation, needle, tip

The irrigation of root canals with antibacterial solutions is considered an essential part of chemomechanical preparation (1). Irrigation with a syringe and a needle remains the most commonly used procedure (2, 3). However, there is an uncertainty about the efficiency of this procedure in the apical part of the root canal (4–6).

To increase the efficiency of syringe irrigation, different needle types have been proposed (7–13). Previous studies of the resulting flow (7, 8, 10, 12) were limited because an indirect or a macroscopic approach can only provide a coarse and incomplete estimation of the irrigant flow. Consequently, there is still no consensus on the superiority of any of these types.

Computational Fluid Dynamics (CFD) represents a powerful tool to investigate flow patterns by mathematical modeling and computer simulation (14, 15). CFD simulations can provide details of the velocity field, shear stress, and pressure in areas in which experimental measurements are difficult to perform. Recently, a CFD model was proposed for the evaluation of irrigant flow in the root canal (16) and was subsequently validated by comparison with experimental high-speed imaging data (17). The aim of this study was to evaluate the effect of needle tip design on the apical irrigant flow inside a prepared root canal during final irrigation with a syringe using this validated CFD model.

Materials and Methods

The root canal and apical anatomy were simulated similarly to a previous study (16), assuming a length of 19 mm, an apical diameter of 0.45 mm (ISO size 45), and 6% taper. The apical foramen was simulated as a rigid and impermeable wall.

Six different needle types were modeled using commercially available 30-G needles as a reference (Fig. 1). The needle types can be divided in two main groups: open-ended (Fig. 1*A-C*) and close-ended (Fig. 1*D-F*). The external and internal diameter and the length of all needles were standardized ($D_{ext} = 320\ \mu m$, $D_{int} = 196\ \mu m$, $l = 31$ mm, respectively) in order to isolate the effect of needle tip design. These values correspond closely to the real geometry of the needles, which was determined according to a previous study (18). The two outlets of the double side-vented needle were modeled identical to the outlet of the side-vented needle to exclude the possible effect of the outlet design. The needles were fixed and centered within the canal, 3 mm short of the working length (WL).

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In Vivo Debridement Efficacy of Ultrasonic Irrigation Following Hand-Rotary Instrumentation in Human Mandibular Molars

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Abstract

This study histologically compared the in vivo debridement efficacy of hand/rotary canal preparation versus a hand/rotary/ultrasound technique in mesial root canals of vital mandibular molars. Group 1 consisted of 16 teeth prepared with a hand/rotary technique whereas group 2 consisted of 15 teeth prepared in similar fashion but followed by 1 min of ultrasonic irrigation, per canal, utilizing an ultrasonic needle in a MiniEndo unit. Five uninstrumented mandibular molars served as histologic controls. After extraction and histologic preparation, 0.5 μm cross-sections, taken every 0.2 mm from the 1- to 3-mm apical levels, were evaluated for percentage of tissue removal. Nonparametric analysis revealed mean percent canal and isthmus cleanliness values to be significantly higher for group 2 at all levels evaluated, except one. In conclusion, the 1 min use of the ultrasonic needle after hand/rotary instrumentation resulted in significantly cleaner canals and isthmuses in the mesial roots of mandibular molars.

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Success in endodontic treatment depends on adequate preparation of the root canal space (1–3). Related factors in achieving this success, such as reduction in the number of organisms and obturation of the root canal system, are dependent on thorough root canal debridement (4, 5). The goal of cleaning and shaping is the removal of all vital or necrotic tissue, microorganisms, and their by-products.

The intricate nature of root canal anatomy has complicated the cleaning and shaping procedure (6–12). Small isthmuses and irregularities within the root canal system harbor tissue, microbes, and their by-products (8–10). These areas have been shown to be inaccessible to conventional hand and rotary instrumentation (13–23).

The use of ultrasonics as a primary cleaning and shaping technique has not been shown to result in better canal debridement as compared to hand instrumentation alone (24–29). These results have been attributed to constraint of the ultrasonic file within the nonflared root canal space (30).

Other researchers have studied the effectiveness of an ultrasonically activated file after hand instrumentation. The results showed greater canal and isthmus cleanliness values (13–16, 23, 31). For example, in vivo studies by Haidet et al. (16) and Archer et al. (23) histologically compared the tissue removal of step-back versus step-back/ultrasound (3 min using an ENAC piezoelectric unit) in the mesial roots of mandibular molars. Haidet et al. (16) reported that at the apical 1-mm level, canals and isthmuses were both significantly cleaner with the combination method. Archer et al. (23) found canal and isthmus cleanliness values to be significantly higher at the 1-, 2-, and 3-mm apical levels when the step-back/ultrasound method was used.

Clinicians have been slow to adopt ultrasound as an addition to endodontic cleaning and shaping. The major reasons for this are the need for three additional minutes per canal for adequate debridement, and file breakage at high levels of ultrasound activation.

We have developed an ultrasonically activated irrigating needle as an adjunctive device for canal debridement. The irrigating needle, when connected to a MiniEndo piezoelectric ultrasonic unit, can be activated at the highest power setting without needle breakage. Additionally, sodium hypochlorite can be delivered apically through the needle rather than adding the irrigating solution to the coronal access. Because more energy is produced at a higher power setting, perhaps the time of ultrasound treatment can be reduced from 3 min to 1 min. A 1-min treatment time per canal is more acceptable clinically.

Therefore, the purpose of this in vivo, prospective, randomized, single-blinded study was to histologically compare debridement efficiency of a hand/rotary cleaning and shaping technique versus a hand/rotary cleaning and shaping /ultrasound technique in the mesial roots of human mandibular molars.

Materials and Methods

Thirty-six healthy, adult volunteer subjects participated in this study. The Human Subjects Review Committee of The Ohio State University approved the study, and we obtained written informed consent from each subject.

Pulp vitality of the 36 test teeth was initially established with Green Endo-Ice refrigerant spray (Hygenic Corp., Akron, OH) and a Kerr Vitality Scanner (Kerr Dental, West Collins Orange, CA) digital electric pulp tester. Only vital teeth were included in this

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52.

Effect of EDTA, Sonic, and Ultrasonic Activation on the Penetration of Sodium Hypochlorite into Simulated Lateral Canals: An *In Vitro* Study

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Abstract

Introduction: The purpose of this study was to evaluate the penetration of 5.25% sodium hypochlorite alone or in combination with 17% EDTA in simulated lateral canals using sonic and ultrasonic activation. **Methods:** Four hundred and eighty simulated lateral canals were created in 80 single rooted cleared teeth by inserting 06 K-files at 2, 4.5 and 6 mm of working length. Samples were mounted on clear silicon to simulate the presence of surrounding periodontal tissues and its effects on fluid dynamics and then randomly assigned to four experimental groups: 1 (n = 20) 5.25% NaOCl + sonic activation; 2 (n = 20) 5.25% NaOCl + ultrasonic activation; 3 (n = 20) 5.25% NaOCl + 17% EDTA + sonic activation and 4 (n = 20) 5.25% NaOCl + 17% EDTA + ultrasonic activation. Sonic activation was delivered using the Endoactivator® inserted 2 mm short of working length and activated for 1 minute. Ultrasonic activation was performed with a stainless steel ultrasonic file inserted 2 mm short of working length and passively activated for 3 cycles of 20 seconds each. Samples were evaluated by direct observation of the images recorded under the operating microscope and by radiographic evaluation after irrigation with a contrast solution. **Results:** Sonic and ultrasonic activation resulted in a better irrigation of the lateral canals at 4.5 and 2 mm from working length compared to traditional needle irrigation alone. Traditional needle irrigation alone demonstrated significantly less penetration of irrigant into the lateral canals and was limited to the level of penetration of the needle. **Conclusion:** The addition of EDTA did not result in better penetration of irrigants into the lateral canals. *(J Endod 2009;35:891–895)*

Key Words

Passive ultrasonic irrigation, root canal irrigation, sonic irrigation

Recognizing the predominant role of microorganisms in producing pulpal and periapical pathosis, endodontic treatment is aimed at the elimination of microorganisms from the root canal system (1–4). Sjogren et al (5) showed that endodontic success was directly related to the presence of negative bacterial culture before root canal filling. Despite all efforts to achieve a root canal system free of bacteria, to date it is evident that bacteria can still survive in areas that are not accessible to current cleaning and shaping procedures. Thus, research should be oriented to improve cleaning and disinfection of root canals.

Mechanical instrumentation is the establishment of a specific cavity form that permits instruments and irrigants easy access into the canal space creating a tapered shape in order to obtain optimal final irrigation and obturation (6). Irrigation acts as a flush to remove organic and inorganic debris as well as a bactericidal agent, tissue solvent and lubricant. Byström et al established that mechanical instrumentation of the root canal followed by saline irrigation alone leaves bacteria in the canal system and the supporting actions of disinfectants such as sodium hypochlorite (NaOCl) are still necessary (7, 8).

The tissue-dissolving properties of NaOCl have been well documented; however, its ability to remove smear layer has not been showed to be effective (9). Therefore, NaOCl has been used in association with EDTA, which acts on the inorganic debris formed in instrumented root canals (10, 11). The removal of the smear layer facilitates the diffusion of the chemical substances, irrigants, and medications delivered to the root canal system, thus allowing a more predictable disinfection and seal of the canal system (12, 13).

Other factors may also play a role on the efficacy of root canal irrigation (14–17). Chow (18) showed that the efficacy of apical irrigation is directly related to the depth of insertion of the needle, which in some cases presents a challenge to the clinician. The apical third of the root canal system is particularly difficult to clean because of the complicated anatomy, apical deltas, narrow isthmus, and lateral canals (19, 20). Some studies have reported a clear correlation between lateral canals obturation and healing of periapical lesions (21, 22). However, in order to fill lateral canals, these should be thoroughly cleaned (23).

The effective delivery of irrigants to the apical third can be enhanced by using ultrasonic and sonic devices (24–31) as well as apical negative-pressure irrigation (32, 33). Activation with sonic devices generates mechanical oscillation, mainly at the tip of the file, with frequency ranging from 1 to 6 KHz. Ultrasonic activation combines acoustic waves with the chemical action of the irrigant and generates a microstreaming along the file and secondary acoustic streaming with frequency ranging from 45 and 40 KHz (34). This microstreaming moves the solution against the root canal surfaces, enhancing mechanical cleansing of the canal walls and bacterial destruction.

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53.

Review of Contemporary Irrigant Agitation Techniques and Devices

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Abstract

Introduction: Effective irrigant delivery and agitation are prerequisites for successful endodontic treatment. **Methods:** This article presents an overview of the irrigant agitation methods currently available and their debridement efficacy. **Results:**Technological advances during the last decade have brought to fruition new agitation devices that rely on various mechanisms of irrigant transfer, soft tissue debridement, and, depending on treatment philosophy, removal of smear layers. These devices might be divided into the manual and machine-assisted agitation systems. Overall, they appear to have resulted in improved canal cleanliness when compared with conventional syringe needle irrigation. Despite the plethora of *in vitro* studies, no well-controlled study is available. This raises imperative concerns on the need for studies that could more effectively evaluate specific irrigation methods by using standardized debris or biofilm models. In addition, no evidence-based study is available to date that attempts to correlate the clinical efficacy of these devices with improved treatment outcomes. Thus, the question of whether these devices are really necessary remains unresolved. There also appears to be the need to refocus from a practice management perspective on how these devices are perceived by clinicians in terms of their practicality and ease of use. **Conclusions:** Understanding these fundamental issues is crucial for clinical scientists to improve the design and user-friendliness of future generations of irrigant agitation systems and for manufacturers' contentions that these systems play a pivotal role in contemporary endodontics. *(J Endod 2009;35:791–804)*

Key Words

Agitation, debris, irrigation, machine-assisted, manual, smear layer

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Removal of vital and necrotic remnants of pulp tissues, microorganisms, and microbial toxins from the root canal system is essential for endodontic success (1–3). Although this might be achieved through chemomechanical debridement (4–6), it is impossible to shape and clean the root canal completely (7–16) because of the intricate nature of root canal anatomy (17–19). Even with the use of rotary instrumentation (20), the nickel-titanium instruments currently available only act on the central body of the canal, leaving canal fins, isthmi, and cul-de-sacs untouched after completion of the preparation (9–11, 20–24). These areas might harbor tissue debris, microbes, and their by-products (17–19), which might prevent close adaptation of the obturation material (25–27) and result in persistent periradicular inflammation (28, 29). 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 (8, 30). Ideal root canal irrigants should meet all the conditions described above for endodontic success (31). However, there is no one unique irrigant that can meet all these requirements, even with the use of methods such as lowering the pH (32–34), increasing the temperature (35–39), as well as addition of surfactants to increase the wetting efficacy of the irrigant (40, 41). Thus, in contemporary endodontic practice, dual irrigants such as sodium hypochlorite (NaOCl) with ethylenediaminetetraacetic acid (EDTA) or chlorhexidine (CHX) (42–44) are often used as initial and final rinses to complement the shortcomings that are associated with the use of a single irrigant. More importantly, these irrigants must be brought into direct contact with the entire canal wall surfaces for effective action (31, 42, 45), particularly for the apical portions of small root canals.

Throughout the history of endodontics, endeavors have continuously been made to develop more effective irrigant delivery and agitation systems for root canal irrigation. These systems might be divided into 2 broad categories, manual agitation techniques and machine-assisted agitation devices (Fig. 1). The objective of this review was to present an overview of contemporary irrigant agitation methods available in endodontics and to provide a critique of their debridement efficacy.

Manual Agitation Techniques

Syringe Irrigation with Needles/Cannulas

Conventional irrigation with syringes has been advocated as an efficient method of irrigant delivery before the advent of passive ultrasonic activation (46). This technique is still widely accepted by both general practitioners and endodontists. The technique involves dispensing of an irrigant into a canal through needles/cannulas of variable gauges, either passively or with agitation. The latter is achieved by moving the needle up and down the canal space. Some of these needles are designed to dispense an irrigant through their most distal ends, whereas others are designed to deliver an irrigant laterally through closed-ended, side-vented channels (47). The latter design has been proposed to improve the hydrodynamic activation of an irrigant and reduce the chance of apical extrusion (48). It is crucial that the needle/cannula should remain loose inside the canal during irrigation. This allows the irrigant to reflux and causes more debris to be displaced coronally, while avoiding the inadvertent expression of the irrigant into periapical tissues. One of the advantages of syringe irrigation is that it allows comparatively easy control of the depth of needle penetration within the canal and the volume of irrigant that is flushed through the canal (46).

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Formation and removal of apical vapor lock during syringe irrigation: a combined experimental and Computational Fluid Dynamics approach

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Abstract

Boutsioukis C, Kastrinakis E, Lambrianidis T, Verhaagen B, Versluis M, van der Sluis LWM. Formation and removal of apical vapor lock during syringe irrigation: a combined experimental and Computational Fluid Dynamics approach. *International Endodontic Journal*, **47**, 191–201, 2014.

Aim (i) To evaluate the effect of needle type and insertion depth, root canal size and irrigant flow rate on the entrapment of air bubbles in the apical part of a root canal (apical vapor lock) during syringe irrigation using experiments and a Computational Fluid Dynamics (CFD) model, (ii) to investigate whether the irrigant contact angle affects bubble entrapment, (iii) to examine if an established vapor lock can be removed by syringe irrigation.

Methodology Bubble entrapment during irrigation of straight artificial root canals of size 35 or 50 was evaluated by real-time visualizations. The irrigant was delivered by a closed-ended or an open-ended needle positioned at 1 or 3 mm short of working length (WL) and at a flow rate of 0.033–0.260 mL s^{-1}. Results were analysed by nonparametric tests at 0.05 significance. Selected cases were also simulated by a two-phase CFD model.

Results A vapor lock was observed in 48% of the cases investigated experimentally. Increasing the apical size, using an open-ended needle, positioning the needle closer to WL and delivering the irrigant at higher flow rate resulted in significantly smaller vapor lock. An increased contact angle resulted in the entrapment of a larger bubble when a low flow rate was used. Both brief insertion of the needle to WL whilst irrigating at a flow rate of 0.083 mL s^{-1} and delivering the irrigant at 0.260 mL s^{-1} without changing the needle position were capable of removing an established vapor lock.

Conclusions Apical vapor lock may occur under certain conditions, but appears to be easily prevented or removed by syringe irrigation.

Keywords: Apical vapor lock, bubble, Computational Fluid Dynamics, needle, root canal irrigation, syringe.

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Introduction

Irrigation of root canals with antibacterial solutions is considered an integral part of chemo-mechanical preparation (Haapasalo *et al.* 2010). Irrigant penetration

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TOPICAL REVIEW

The fluid mechanics of root canal irrigation

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Abstract
Root canal treatment is a common dental operation aimed at removing the contents of the geometrically complex canal chambers within teeth; its purpose is to remove diseased or infected tissue. The complex chamber is first enlarged and shaped by instruments to a size sufficient to deliver antibacterial fluids. These irrigants help to dissolve dying tissue, disinfect the canal walls and space and flush out debris. The effectiveness of the procedure is limited by access to the canal terminus. Endodontic research is focused on finding the instruments and clinical procedures that might improve success rates by more effectively reaching the apical anatomy. The individual factors affecting treatment outcome have not been unequivocally deciphered, partly because of the difficulty in isolating them and in making the link between simplified, general experimental models and the complex biological objects that are teeth. Explicitly considering the physical processes within the root canal can contribute to the resolution of these problems. The central problem is one of fluid motion in a confined geometry, which makes the dispersion and mixing of irrigant more difficult because of the absence of turbulence over much of the canal volume. The effects of treatments can be understood through the use of scale models, mathematical modelling and numerical computations. A particular concern in treatment is that caustic irrigant may penetrate beyond the root canal, causing chemical damage to the jawbone. In fact, a stagnation plane exists beyond the needle tip, which the irrigant cannot penetrate. The goal is therefore to shift the stagnation plane apically to be coincident with the canal terminus without extending beyond it. Needle design may solve some of the problems but the best design for irrigant penetration conflicts with that for optimal removal of the bacterial biofilm from the canal wall. Both irrigant penetration and biofilm removal may be improved through canal fluid

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Apical negative pressure irrigation versus syringe irrigation: a systematic review of cleaning and disinfection of the root canal system.

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57.

Comparison of the Volume of Root Canal Irrigant Collected by 2 Negative Pressure Needles at Different Flow Rates of Delivery

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Abstract

Introduction: A greater irrigant volume improves the effectiveness of root canal irrigation. The purpose of this study was to compare 2 negative pressure systems regarding the volume of irrigant collected from the apical area in moderately curved canals at 3 different flow rates of delivery *in vitro*. **Methods:** The mesiobuccal canals of 30 molars with a curvature between 20° and 40° were prepared to size #40.04 taper. A closed system was created. The canals were irrigated at 3, 6, and 12 mL/min for 30 seconds using EndoVac (SybronEndo, Orange, CA) and the INP needle (Mixnus Fine Engineering Co Ltd, Nagano, Japan) (both independent variables). A recovery trap was used to collect the irrigant aspirated by the negative pressure needles. Irrigant volume (dependent variable) was measured in milliliters. Data were analyzed using mixed analysis of variance. **Results:** There was a statistically significant interaction between the negative pressure system and the irrigant volume collected ($P < .0005$). The mean irrigant volume collected by the different negative pressure systems was greater for INP at 3 ($P < .001$), 6 ($P < .001$), and 12 mL/min ($P < .001$) flow rate. Both negative pressure needles showed statistically significant differences ($P < .001$) between mean irrigant volume collected at different flow rates. **Conclusions:** A greater volume was collected by increasing the flow rate of irrigant delivery for both EndoVac and INP. The INP needle could collect a greater volume of irrigant from the apical third compared with EndoVac at all 3 different flow rates. *(J Endod 2018;■:1–4)*

Key Words

Irrigant replacement, negative pressure irrigation, root canal irrigation, volume

A thorough debridement of the root canal system cannot be achieved through instrumentation alone (1). Previous studies reported residual pulp tissue ranging from 3%–20% of the apical 3 mm of mandibular molars (2) and 4%–100% of untreated canal areas of maxillary molars (3). This reinforces the notion of using chemically active irrigation solutions as a necessary adjunct to mechanical preparation. When irrigating solutions are delivered to the most apical region of the root canal system, the ability to dissolve organic tissues, kill microbes, remove microbial by-products, and remove the smear layer is better achieved (4–6). Ideally, the solutions should come into contact with the biofilm/organic tissue/canal wall (7, 8). However, when this happens, a gradual weakening or inactivation of the irrigating solution occurs (4, 8–12). Therefore, frequent replenishment and a greater volume of the irrigating solution are recommended to improve the effectiveness of the irrigating solution (9, 13, 14).

Significance

By increasing the flow rate of delivery, a greater volume of sodium hypochlorite can be collected from the apical region when using negative pressure irrigation. This would allow replenishment with fresh irrigant at the working length and potentially cleaner canals.

The ability of the irrigant solution to reach the working length by using negative pressure irrigation with EndoVac (SybronEndo, Orange, CA) and, more recently, with the INP needle (Mixnus Fine Engineering Co Ltd, Nagano, Japan) has been shown previously (15–19). The negative pressure concept is relatively simple. When the negative pressure needle is placed within the canal during aspiration, the pressure generated in the apical region of the canal is lower in comparison with the atmospheric pressure. The pressure gradient created results in a net force directed toward the lower pressure area, which affects the irrigant solution deposited in the pulp chamber directing it toward the apical region from where it is collected by the aspirating tip (16). Minimal to no extrusion can be expected (20–22) because of the negative pressures developed within the root canal (23).

The volume of irrigating solutions reaching the apical third of the canal by negative pressure systems has been previously investigated using EndoVac (24–26) and both EndoVac and the INP needle (16). Influencing factors such as apical preparation size (25, 26), taper (25), root curvature (26), and type of needle (16) were identified. However, the influence of the flow rate of delivery has not been previously investigated. Therefore, the purpose of this study was to compare 2 negative pressure systems regarding the volume of irrigant collected from the apical area in moderately curved

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Postoperative Pain after the Application of Two Different Irrigation Devices in a Prospective Randomized Clinical Trial

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Abstract

Introduction: The extrusion of irrigation solutions beyond the apical constriction may result in postoperative pain. Sodium hypochlorite can cause severe tissue irritation and necrosis outside the root canal system if extruded into the periodontal ligament (PDL) space. Different delivery techniques were discussed to reduce this potential risk. The aim of this study was to compare the postoperative level of pain after root canal therapy using either endodontic needle irrigation or a negative apical pressure device. **Material and Methods:** In a prospective randomized clinical trial, 110 asymptomatic single-rooted anterior and premolar teeth were treated endodontically with two different irrigation techniques. The teeth were randomly assigned to two groups. In the MP group (n = 55), procedures were performed using an endodontic irrigating syringe (Max-i-Probe; Dentsply Rinn, Elgin, IL). The EV group (n = 55) used an irrigation device based on negative apical pressure (EndoVac; Discus Dental, Culver City, CA). Postoperatively, the patients were prescribed ibuprofen 200 mg to take every 8 hours if required. Pain levels were assessed by an analog scale questionnaire after 4, 24, and 48 hours. The amount of ibuprofen taken was recorded at the same time intervals. **Results:** During the 0- to 4-, 4- to 24-, and 24- to 48-hour intervals after treatment, the pain experience with the negative apical pressure device was significantly lower than when using the needle irrigation ($p < 0.0001$ [4, 24, 48 hours]). Between 0 and 4 and 4 and 24 hours, the intake of analgesics was significantly lower in the group treated by the negative apical pressure device ($p < 0.0001$ [0-4 hours], $p = 0.001$ [4-24 hours]). The difference for the 24- to 48-hour period was not statistically different ($p = 0.08$). The Pearson correlation coefficient revealed a strongly positive and significant relationship for the MP group ($r = 0.851$, $p < 0.001$) and the EV group ($r = 0.596$, $p < 0.0001$) between pain intensity and the amount of analgesics. **Conclusion:** The outcome of this investigation indicates that the use of a negative apical pressure irrigation device can result in a significant reduction of postoperative pain levels in comparison to conventional needle irrigation. *(J Endod 2010;36:1295–1301)*

Key Words

EndoVac, irrigation, negative apical pressure, postoperative pain

Postoperative pain is an unwanted yet unfortunately common sensation after endodontic treatment. The incidence of postoperative pain was reported to range from 3% to 58% (1). Even severe pain may occur within 24 to 48 hours after therapy (2). After the treatment was finished, 12% of patients experienced severe pain within this time interval according to a visual analog scale (VAS) (2). The factors for postoperative pain are many-fold and can include microbial factors, the effects of chemical mediators, phenomena related to the immune system, cyclic nucleotide changes, psychological factors, and changes in the local adaptation and the periapical tissue pressure (3). Irritants to the periapical tissues that can evoke pain sensation include medications or irrigating solutions (3).

Antimicrobial debridement is a key step in root canal therapy. Bacteria play a primary role in the development of pulp necrosis, periapical pathosis, and posttreatment disease (4). Mechanical instrumentation alone is not enough to render canals free from microorganisms (5). Several studies have proven the effectiveness of sodium hypochlorite for bacterial reduction in addition to mechanical cleaning and shaping (6). Other irrigants with similar antimicrobial effects include chlorhexidine (7) and MTAD (8). Only sodium hypochlorite, however, has also proven highly effective in tissue dissolution (9) and the removal of bacterial biofilm (10). Because tissue dissolution is a prerequisite for antimicrobial action (11), sodium hypochlorite is considered the most important antimicrobial irrigant in root canal therapy (9). Sodium hypochlorite works because of its ability to hydrolyze and oxidize cell proteins, its release of free chlorine, and its pH of 11 to 12 (7).

Because of the strong cell toxicity, an associated risk with the use of sodium hypochlorite is the inadvertent injection into the periapical tissues through the apical constriction of the root canal, leading to severe, painful postoperative complications. Sodium hypochlorite accidents have been reported in the literature (12). Teeth with wide open foramina or with apical constrictions damaged by resorptive processes or by iatrogenic errors during instrumentation are at an elevated risk for the extrusion of sodium hypochlorite (13). Moreover, if excessive pressure is used during irrigation or the irrigation needle is bound within the root canal and prevents the safe coronal outflow of the solution, large quantities of sodium hypochlorite may be pushed out into the periapical tissues and subsequently lead to tissue necrosis and postoperative pain (13). This causes a dilemma because it is known that a high volume and frequency

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59.

The Self-adjusting File (SAF). Part 1: Respecting the Root Canal Anatomy—A New Concept of Endodontic Files and Its Implementation

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Abstract

Aim: To introduce a new concept, the self-adjusting file (SAF), and discuss its unique features compared with current rotary nickel-titanium file systems. **The New Concept:** The SAF file is hollow and designed as a thin cylindrical nickel-titanium lattice that adapts to the cross-section of the root canal. A single file is used throughout the procedure. It is inserted into a path initially prepared by a # 20 K-file and operated with a transline- (in-and-out) vibration. The resulting circumferential pressure allows the file's abrasive surface to gradually remove a thin uniform hard-tissue layer from the entire root canal surface, resulting in a canal with a similar cross-section but of larger dimensions. This holds also for canals with an oval or flat cross-section, which will be enlarged to a flat or oval cross-section of larger dimensions. The straightening of curved canals is also reduced because of the high pliability of the file and the absence of a rigid metal core. Thus, the original shape of the root canal is respected both longitudinally and in cross-section. The hollow SAF file is operated with a constant flow of irrigant that enters the full length of the canal and that is activated by the vibration and is replaced continuously throughout the procedure. This results in effective cleaning even at the cul de sac apical part of the canal. The SAF has high mechanical endurance; file separation does not occur; and mechanical failure, if it occurs, is limited to small tears in the latticework. **Conclusion:** The SAF represents a new step forward in endodontic file development that may overcome many of the shortcomings of current rotary nickel-titanium file systems. *(J Endod 2010;36:679–690)*

Key Words

Canal preparation, curved root canals, endodontic files, flat root canals, micro–computed tomography scan, nickel-titanium, SAF, scanning electron microscopy, self-adjusting file

The cleaning and shaping of the root canal is the key step in root canal treatment. Its aim is to remove all tissue debris from the root canal space while removing the inner layers of root canal dentin (1). For many years, it has been a common practice to enlarge the root canal to at least three ISO sizes larger than the first file to bind at the apical part of the canal (2, 3). It was assumed that such preparation will remove the inner layers of the dentin while allowing the irrigant to reach the entire length of the root canal for a thorough cleaning and disinfection of the root canal space (4, 5). This goal is easier to achieve today, even in curved root canals, because of the introduction and use of rotary nickel-titanium file systems. Because of their elasticity, these files can preserve the location of the root canal axis, thus largely preventing its transportation and ledging, which were major problems with stainless steel hand files. Rotary nickel-titanium files do this more efficiently and apparently require less operator expertise. The resulting root canal filling radiographs are impressive, yet the third dimension of the root canal is commonly ignored (6).

The goal of cleaning and shaping may be easily and reproducibly achieved with rotary files as far as relatively straight and narrow root canals with a round cross-section are concerned. In such canals, completion of the file sequence may result in a clean canal with no tissue debris and with removal of all or most of the inner layer of the heavily contaminated dentin. Nevertheless, in flat oval-shaped root canals and in curved ones, this goal is not easy attainable (7, 8).

Flat oval root canals are common in the distal roots of lower molars, upper and lower bicuspids, and lower incisors and canines. Asymmetrical, flat, tear-shaped cross-sections are another challenge. Such canals are common in most roots that contain two root canals in the same root and a potential isthmus. This includes anterior roots of lower molars, mesiobuccal roots of upper molars, first upper bicuspids, and some lower incisors. A systematic and comprehensive study by Wu et al (9) has shown that oval or flat root canal morphology is present in up to 25% of root canals, and in certain root groups it may exceed 50%. The flatness or asymmetry in these canals is usually in the buccolingual dimension; therefore, it fails to be recognized on clinical radiographs, which represent a buccolingual projection (Fig. 1).

The buccal and lingual areas of such flat root canals and the area facing the isthmus in tear-shaped ones cannot be adequately prepared by current rotary files. All current rotary files have one or another type of spiral blade and helical formation that when rotating machines the root canal into a form that has a round cross-section. Substantial untouched areas may be left on the buccal and lingual sides of a flat root

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60.

A Comparative Study of Biofilm Removal with Hand, Rotary Nickel-Titanium, and Self-Adjusting File Instrumentation Using a Novel *In Vitro* Biofilm Model

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Abstract

Introduction: This study sought to present a standardized biofilm model in extracted teeth with an artificial apical groove to quantify the efficacy of hand, rotary nickel-titanium, and self-adjusting file (SAF) instrumentation in biofilm bacteria removal. **Methods:** Thirty-six extracted single-rooted teeth with oblong canals were selected. Each tooth was split longitudinally, and a 0.2-mm-wide groove was placed in the apical 2 to 5 mm of the canal. After growing mixed bacteria biofilm inside the canal under an anaerobic condition, the split halves were reassembled in a custom block, creating an apical vapor lock. Teeth were randomly divided into 3 treatment groups (n = 10 per group) using the K-file, ProFile (Dentsply Tulsa Dental Products, Tulsa, OK), and the SAF (ReDent-Nova, Ra'anana, Israel). Irrigation consisted of 10 mL 3% NaOCl and 4 mL 17% EDTA. Six teeth received no treatment. Areas inside and outside the groove were examined using a scanning electron microscope. **Results:** The scanning electron microscope showed a consistently thick layer of biofilm grown in the canals of the control group after 4 weeks. Within the groove, a smaller area remained occupied by bacteria after the use of the SAF compared with the ProFile and the K-file (3.25%, 19.25%, and 26.98%, respectively; $P < .05$). For all groups, significantly more bacteria were removed outside the groove than inside ($P < .05$). No statistical differences were found outside the groove ($P > .05$). **Conclusions:** Although all techniques equally removed bacteria outside the groove, the SAF reduced significantly more bacteria within the apical groove. No technique was able to remove all bacteria. This biofilm model represents a potentially useful tool for the future study of root canal disinfection. *(J Endod 2013;39:658–663)*

Key Words

Biofilm, endodontic instrument, irrigation, nickel-titanium, ProFile, self-adjusting file

Colonizing microorganisms such as those found in the infected root canal space are present either as free-floating (planktonic) single cells or attached to each other or to the root canal walls to form (sessile) biofilms. Although planktonic microorganisms can be eliminated more readily by a variety of different methods, the removal of sessile biofilm bacteria from the root canal remains a major challenge (1, 2). A biofilm is a community of microorganisms embedded in a matrix of extracellular polymeric substance and attached to a solid surface. It has been accepted that within this community the biofilm bacteria express different phenotypes, often with different characteristics, than do the same bacteria in their planktonic state. Notable among these differences is the increased resistance to antimicrobial agents that can be 100- to 1000-fold greater for a species in a mature biofilm relative to that same species grown planktonically (3). Microbial invasion of the root canal system can eventually lead to pulpal necrosis and apical periodontitis. Because the bacteria in the necrotic root canal grow mostly in sessile forms, the success of endodontic treatment will depend on the effective elimination of such biofilms (1).

Currently, the eradication of a microbial infection is accomplished mainly through mechanical instrumentation and chemical irrigation. Although mechanical preparation of the infected root canal has been shown to be most effective in reducing the number of bacteria, it alone is unreliable in achieving adequate disinfection (4, 5). Irrigation allows for cleaning beyond what might be achievable through instrumentation because it enhances further bacterial elimination, facilitates necrotic tissue removal, and prevents the packing of infected debris apically (2). Nonetheless, the anatomic complexities of the root canal system present physical constraints that pose a serious challenge to adequate root canal disinfection using currently available techniques such that residual bacteria are often found in areas such as fins, isthmuses, ramifications, deltas, accessory and lateral canals, and dentinal tubules (6, 7). Recently, a new instrumentation and irrigation device, the self-adjusting file (SAF) system, was introduced by ReDent-Nova (Ra'anana, Israel) (8). Different from the traditional nickel-titanium (NiTi) rotary files, the SAF system uses a hollow reciprocating instrument that allows for simultaneous irrigation throughout the mechanical preparation. When inserted into the root canal, the manufacturer claims that the SAF is capable of adapting itself to the canal shape 3-dimensionally (9). The instrument is used in a trans-line (in-and-out) motion, and the abrasive surface of the lattice threads promotes a uniform removal of dentin (8). Siqueira et al (10) found that SAF preparation and continuous irrigation of long oval canals were more effective than rotary NiTi instrumentation and syringe/needle irrigation in reducing intracanal *Enterococcus faecalis* counts.

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The Self-adjusting File (SAF). Part 3: Removal of Debris and Smear Layer—A Scanning Electron Microscope Study

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Abstract

Aim: The aim of this study was to evaluate the cleaning ability of the Self-Adjusting File (SAF) system in terms of removal of debris and smear layer. **Methodology:** Root canal preparations were performed in 20 root canals using an SAF operated with a continuous irrigation device. The glide path was initially established using a size 20 K-file followed by the SAF file that was operated in the root canal via a vibrating motion for a total of 4 minutes. Sodium hypochlorite (3%) and EDTA (17%) were used as continuous irrigants and were alternated every minute during this initial 4-minute period. This was followed by a 30-second rinse using EDTA applied through a nonactivated SAF and a final flush with sodium hypochlorite. The roots were split longitudinally and subjected to scanning electron microscopy (SEM). The presence of debris and a smear layer in the coronal, middle, and apical thirds of the canal were evaluated through the analysis of the SEM images using five-score evaluation systems based on reference photographs. **Results:** The SAF operation with continuous irrigation, using alternating irrigants, resulted in root canal walls that were free of debris in all thirds of the canal in all (100%) of the samples. In addition, smear layer–free surfaces were observed in 100% and 80% of the coronal and middle thirds of the canal, respectively. In the apical third of the canal, smear layer–free surfaces were found in 65% of the root canals. **Conclusions:** The operation of the SAF system with continuous irrigation coupled with alternating sodium hypochlorite and EDTA treatment resulted in a clean and mostly smear layer–free dentinal surface in all parts of the root canal. *(J Endod 2010;36:697–702)*

Key Words

Apical third of root canal, cleaning debris, irrigation, irrigation protocol, SAF, self-adjusting file, smear layer

The cleaning and shaping of root canals is a key step in root canal treatment procedures. Unless all tissue remnants and debris are removed, the subsequent stage of root canal obturation may also be jeopardized, leading to the potential failure of treatment (1, 2). Any material left between the canal wall and the root canal filling may prevent intimate adaptation between the two and may provide a space for bacterial leakage and bacterial proliferation.

Accordingly, the cleaning efficacy of any endodontic file system is of major importance and has been studied intensively (3, 4). The presence of a significant amount of debris is commonly encountered when either rotary or hand files are used in root canals with flat cross-sections. The debris accumulation in the uninstrumented "fins" may not allow for proper disinfection and may prevent the root canal filling from reaching these recesses, even when warm gutta-percha compaction is applied (1, 2). Such a gross accumulation of debris may readily be visualized even when using light microscopy at a magnification of $\times 50$ (1, 2).

Furthermore, the smear layer and some amounts of debris may be present on the walls of the root canals, even with the simplest morphology. A 5-μm-thick smear layer represents a potential gap between the root canal filling and the root canal wall that may be capable of accommodating approximately five layers of bacteria. Moreover, the smear layer may block or prevent the free access of antibacterial agents to the bacteria that may have penetrated into the dentinal tubules. The evaluation of fine debris and the presence of the smear layer require higher magnification levels ($200\times$-$1{,}000\times$) that are achievable only through the use of scanning electron microscopy (SEM).

SEM has been applied by numerous investigators to study the efficacy of various rinsing protocols and file systems in the removal of debris and smear layer (5–16). Every available file system generates a smear layer and leaves debris in the root canal, and rinsing with sodium hypochlorite alone is unable to render the canal free of debris and smear layers (5–13, 15, 16). In addition, the application of chelating agents such as EDTA may dramatically improve the overall efficiency of the procedure (8-13). Finally, even when the coronal and middle thirds of the canal are relatively clean, the apical third of the root canal always presents a problem in regard to the ability to achieve the same level of cleanliness (5, 6, 9, 12). This may be of great importance because the presence of a smear layer and debris may prevent sealer adaptation to the canal walls and allow penetration of irritants into the periradicular tissues, initiating or sustaining periradicular inflammation (17, 18).

The Self-Adjusting File system (SAF; ReDent-Nova, Ra'anana, Israel) is different from any available file system in two major respects (19). First, the SAF is a hollow and flexible file that adapts itself three-dimensionally to the shape of the root canal, including the ability to adapt to its cross-section (19). The SAF vibrates when

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62.

Root Canal Preparation of Maxillary Molars With the Self-adjusting File: A Micro-computed Tomography Study

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Abstract

Introduction: The aim of this study was to describe the canal shaping properties of a novel nickel-titanium instrument, the self-adjusting file (SAF), in maxillary molars. **Methods:** Twenty maxillary molars were scanned by using micro–computed tomography at 20-μm resolution. Canals were shaped with the SAF, which was operated with continuous irrigation in a handpiece that provided an in-and-out vibrating movement. Changes in canal volumes, surface areas, and cross-sectional geometry were compared with preoperative values. Canal transportation and the fraction of unprepared canal surface area were also determined. Data were normally distributed and compared by analyses of variance. **Results:** Preoperatively, mean canal volumes were 2.88 $\pm$ 1.32, 1.50 $\pm$ 0.99, and 4.30 $\pm$ 1.89 mm^3 for mesiobuccal (MB), distobuccal (DB), and palatal (P) canals, respectively; these values were statistically similar to earlier studies with the same protocol. Volumes and surface areas increased significantly in MB, DB, and P canals; mean canal transportation scores in the apical and middle root canal thirds ranged between 31 and 89 μm. Mean unprepared surfaces were 25.8% $\pm$ 12.4%, 22.1% $\pm$12.0%, and 25.2% $\pm$ 11.3% in MB, DB, and P canals, respectively ($P > .05$) when assessed at high resolution. **Conclusions:** By using SAF instruments *in vitro*, canals in maxillary molars were homogenously and circumferentially prepared with little canal transportation. *(J Endod 2011;37:53–57)*

Key Words

Micro-computed tomography, nickel-titanium instruments, root canal preparation, self-adjusting file

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Cleaning and shaping of root canals successfully require the presence of irrigation solutions that can only be applied to the apical root canal third after enlargement with instruments (1–4). Nickel-titanium (NiTi) rotary instruments have become an important adjunct for root canal shaping, and outcomes with these instruments are fairly predictable (5). However, rotary instruments perform comparably poorly in long-oval canals such as distal canals in lower molars, specifically because they do not mechanically prepare 60% or more canal surface under these conditions (6).

Very recently a new concept, the so-called self-adjusting file (SAF), has emerged that might allow uniform dentin removal along the perimeter of oval canals. Root canal preparation with this file has been quantitatively described only in anterior teeth (7) but not in molar root canals.

The effects of root canal shaping were assessed, besides other approaches, from double-exposure radiographs (8), from cross sections by using the Bramante technique (9), and more recently by using micro–computed tomography (MCT) data (10). The latter technique allows nondestructive quantitative analyses of variables such as volume, surface areas, cross-sectional shape, taper, and the fraction of affected surface (11).

Earlier studies had indicated that differences in canal anatomy between palatal (P), mesiobuccal (MB), and distobuccal (DB) canals would play a significant role for shaping outcomes (12). More ribbon-shaped or flat canals such as the MB canal would have more unprepared canal area; moreover, on average, smaller more curved MB canals would have greater canal transportation than P canals.

On the basis of the fact that the SAF is capable of addressing non-round canal cross sections, we hypothesized that various canals in maxillary molars can be prepared to similar outcomes with respect to canal transportation and amount of prepared surface.

Studies based on MCT done in our laboratory during the last decade provided data on preparation effects for hand and rotary instruments in maxillary molars (10, 12–14). Therefore, the aim of this study was to describe the canal shaping properties of the SAF in maxillary molars.

Materials and Methods

Selection of Teeth

From teeth that had been extracted for reasons unrelated to the current study, 20 human maxillary molars were collected and stored in 0.1% thymol solution at 4°C until further use. Teeth had mature apices and were free of fractures and artificial alterations. They were mounted on scanning electron microscopy stubs and then scanned in a desktop MCT unit at an isotropic resolution of 20 μm (μCT 40; Scanco Medical, Brüttisellen, Switzerland) by using previously established methods (10, 15). Care was taken to specifically select teeth that did not have a distinct fourth canal orifice so as to include a buccolingually flat mesiobuccal canal, as judged from a preoperative MCT scan in low resolution. Teeth were then accessed by using high-speed diamond burs, and patency of the coronal canal was confirmed. Coronal flaring was accomplished with #2 Gates Glidden burs (Dentsply Maillefer, Ballaigues, Switzerland) placed to 2–3 mm below the cemento-enamel junction. Subsequently, canal lengths and patency were determined with size 10 K-files (Dentsply Maillefer) and radiographs; working lengths (WLs) were set 1 mm shorter than the radiographic apex. Each canal was then probed with #20 K-file. If it reached the WL, no further preparation was done. If the canal was narrower than that, it was prepared until #20 K-file could freely reach the WL to provide a glide path.

Ultrasonics in Endodontics: A Review of the Literature

Gianluca Plotino, DDS, Cornelis H. Pameijer, DMD, DSc, PhD,† Nicola Maria Grande, DDS,* and Francesco Somma, MD, DDS**

Abstract

During the past few decades endodontic treatment has benefited from the development of new techniques and equipment, which have improved outcome and predictability. Important attributes such as the operating microscope and ultrasonics (US) have found indispensable applications in a number of dental procedures in periodontology, to a much lesser extent in restorative dentistry, while being very prominently used in endodontics. US in endodontics has enhanced the quality of treatment and represents an important adjunct in the treatment of difficult cases. Since its introduction, US has become increasingly more useful in applications such as gaining access to canal openings, cleaning and shaping, obturation of root canals, removal of intracanal materials and obstructions, and endodontic surgery. This comprehensive review of the literature aims at presenting the numerous uses of US in clinical endodontics and emphasizes the broad applications in a modern-day endodontic practice. *(J Endod 2007;33:81–95)*

Key Words

Endodontics, innovations, ultrasonics

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The use of ultrasonics (US) or ultrasonic instrumentation was first introduced to dentistry for cavity preparations (1–3) using an abrasive slurry. Although the technique received favorable reviews (4, 5), it never became popular, because it had to compete with the much more effective and convenient high-speed handpiece (6). However, a different application was introduced in 1955, when Zinner (7) reported on the use of an ultrasonic instrument to remove deposits from the tooth surface. This was improved upon by Johnson and Wilson (8), and the ultrasonic scaler became an established tool in the removal of dental calculus and plaque. The concept of using US in endodontics was first introduced by Richman (9) in 1957. However, it was not until Martin et al. (10–12) demonstrated the ability of ultrasonically activated K-type files to cut dentin that this application found common use in the preparation of root canals before filling and obturation. The term *endosonics* was coined by Martin and Cunningham (13, 14) and was defined as the ultrasonic and synergistic system of root canal instrumentation and disinfection.

Ultrasound is sound energy with a frequency above the range of human hearing, which is 20 kHz. The range of frequencies employed in the original ultrasonic units was between 25 and 40 kHz (15). Subsequently the so-called low-frequency ultrasonic handpieces operating from 1 to 8 kHz were developed (16–21), which produce lower shear stresses (22), thus causing less alteration to the tooth surface (23).

There are two basic methods of producing ultrasound (24–26). The first is magnetostriction, which converts electromagnetic energy into mechanical energy. A stack of magnetostrictive metal strips in a handpiece is subjected to a standing and alternating magnetic field, as a result of which vibrations are produced. The second method is based on the piezoelectric principle, in which a crystal is used that changes dimension when an electrical charge is applied. Deformation of this crystal is converted into mechanical oscillation without producing heat (15).

Piezoelectric units have some advantages compared with earlier magnetostrictive units because they offer more cycles per second, 40 versus 24 kHz. The tips of these units work in a linear, back-and-forth, "piston-like" motion, which is ideal for endodontics. Lea et al. (27) demonstrated that the position of nodes and antinodes of an unconstrained and unloaded endosonic file activated by a 30-kHz piezon generator was along the file length. As a result the file vibration displacement amplitude does not increase linearly with increasing generator power. This applies in particular when "troughing" for hidden canals or when removing posts and separated instruments. In addition, this motion is ideal in surgical endodontics when creating a preparation for a retrograde filling. A magnetostrictive unit, on the other hand, creates more of a figure eight (elliptical) motion, which is not ideal for either surgical or nonsurgical endodontic use. The magnetostrictive units also have the disadvantage that the stack generates heat, thus requiring adequate cooling (15).

Applications of US in Endodontics

Although US is used in dentistry for therapeutic and diagnostic applications as well as for cleaning of instruments before sterilization (28), currently its main use is for scaling and root planing of teeth and in root canal therapy (15, 28, 29). The concept of minimally invasive dentistry (30, 31) and the desire for preparations with small dimensions has stimulated new approaches in cavity design and tooth-cutting concepts, including ultrasound for cavity preparation (32).

The following is a list of the most frequent applications of US in endodontics, which will be reviewed in detail:

1. Access refinement, finding calcified canals, and removal of attached pulp stones

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The effectiveness of syringe irrigation and ultrasonics to remove debris from simulated irregularities within prepared root canal walls

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Abstract

Lee S-J, Wu M-K, Wesselink PR. The effectiveness of syringe irrigation and ultrasonics to remove debris from simulated irregularities within prepared root canal walls. *International Endodontic Journal*, **37**, 672–678, 2004.

Aim To compare the ability of syringe irrigation and ultrasonic irrigation to remove artificially placed dentine debris from simulated canal irregularities within prepared root canals.

Methodology After canal enlargement, twelve canines were split longitudinally into two halves. On the wall of one half of each root canal a standard groove of 4 mm in length, 0.2 mm in width and 0.5 mm in depth was cut, 2–6 mm from the apex, to simulate uninstrumented canal extensions. On the wall of the other half, three standard saucer-shaped depressions of 0.3 mm in diameter and 0.5 mm in depth were cut at 2, 4 and 6 mm from the apex to simulate uninstrumented canal irregularities. Each groove and depression were filled with dentine debris mixed with 2% NaOCl to simulate a situation when dentine debris accumulates in uninstrumented canal extensions and irregularities during canal preparation. Each tooth was re-assembled by reconnecting the two halves, using wire and an impression putty material. Two per cent NaOCl was then delivered into each canal either using syringe irrigation ($n = 8$) or using ultrasonic irrigation ($n = 8$). Before and after irrigation, images of the two halves of the canal wall were taken, using a microscope and a digital camera, after which they were scanned into a PC as TIFF images. The amount of remaining dentine debris in the grooves and depressions was evaluated by using a scoring system between 0–3: the higher the score, the more the debris. The data were analysed by means of the Mann–Whitney *U*-test.

Results Both forms of irrigation reduced the debris score significantly. The debris score was statistically significantly lower after ultrasonic irrigation than after syringe irrigation ($P = 0.002$ for grooves, $P = 0.047$ for depressions).

Conclusion Ultrasonic irrigation *ex vivo* is more effective than syringe irrigation in removing artificially created dentine debris placed in simulated uninstrumented extensions and irregularities in straight, wide root canals.

Keywords: dentine debris, irrigation.

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Introduction

One of the most important procedures in root canal treatment is chemomechanical preparation of the canal system. Irrigation is complementary to instrumentation in facilitating removal of bacteria, debris and therapeutic materials such as gutta-percha, sealer and medicaments from root canals.

The effectiveness of irrigation relies on both the mechanical flushing action and the ability of irrigants to dissolve tissue. Sodium hypochlorite (NaOCl) has been used as an endodontic irrigant for at least six decades (Walker 1936). Irrigation with NaOCl has been

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The Effectiveness of Ultrasonics and Calcium Hydroxide for the Debridement of Human Mandibular Molars

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This study evaluated the ability of ultrasonics and calcium hydroxide to remove pulp tissue debris from the mesial root canals of human mandibular molars. All teeth were instrumented using a standard filing technique and irrigated with an equal volume of 2.6% sodium hypochlorite before the application of the experimental debridement methods. Debridement comparisons were made of both instrumented and uninstrumented controls at the 3-mm and 1-mm levels of the canals and isthmuses. Statistical analysis showed no differences among the experimental groups or the instrumented controls in the canals at either level or isthmuses at the 3-mm level. In the isthmuses at the 1-mm level, no differences were found among the experimental groups, but they were all significantly cleaner than the instrumented controls. These results indicate that calcium hydroxide and ultrasonics are equally effective in debriding the root canal system, and that both are significantly better than standard instrumentation alone in the isthmuses at the 1-mm level.

Debridement of the root canal system is accepted as being of vital importance to the success of endodontic treatment (1). Any tissue left within the root canal system can act as a bacterial substrate, and the protein degeneration products themselves can be very irritating to the periradicular tissues (1). In addition, tissue remaining in the canal can protect the bacteria from the bacteriocidal and flushing effects of irrigating solutions, including sodium hypochlorite (2). The complex nature of the root canal system has been demonstrated (3). Fins, isthmuses, culs-de-sac, and other irregularities act as harbors for the retention of soft tissue debris, making complete debridement with conventional instruments all but impossible (4). Senia et al. (5) speculated that incomplete debridement was due to the narrowness and irregularities of the canal in the apical areas. These anatomical problems made it very difficult for the irrigant to come into contact with the tissue in high enough concentrations and with enough volume to adequately dissolve the tissue.

In the past several years, ultrasonic instruments have been investigated as means of instrumenting and debriding root canals. Martin and Cunningham (6–8) investigated ultrasonic instrumentation of root canals and found it had advantages over conventional instrumentation and irrigation. Some of their findings were supported by Cameron (9). Other investigators, however, found that the method has shortcomings including transportation of canals (10), lack of cavitation (11, 12), and longer preparation times (13). Langeland et al. (14) and Cymerman et al. (15) found that ultrasonic instrumentation was no better in removing soft tissue debris than hand instrumentation. Weller et al. (16) found that using ultrasonics after hand instrumentation increased the amount of debris removed. This seems to agree with the finding of Walmsley (17) that significant oscillations of the ultrasonic instrument tip only occurs if it is not hitting the canal wall.

Goodman et al. (18) compared the cleanliness of canals prepared with a step-back technique to those prepared in the same manner but which, in addition, had ultrasonics applied after preparation. They demonstrated a significant improvement in cleanliness within the latter group. Stamos et al. (19) compared the cleanliness of canals and isthmuses prepared with hand, sonic, and ultrasonic instrumentation and concluded that the ultrasonic method provided better debridement than either the hand or sonic methods at the 1-mm level. Lev et al. (20) compared the debridement achieved by a hand instrumentation technique to debridement utilizing ultrasonics for 1 and 3 min following hand instrumentation. Their results indicated that both of the ultrasonic groups were cleaner than the hand-instrumented group and that 3 min was better than 1 min in removing debris.

A practical problem is that ultrasonic endodontic equipment is expensive. If a Cavi-Endo insert (Dentsply International, York, PA) would function effectively in a regular Cavitron unit (Dentsply International), perhaps more practitioners would use it for debridement of root canals. The PEC insert (Dentsply International) is now available for use in the Cavitron but only water can be used as the irrigant.

Martin and Crabb (21) suggest several uses for calcium hydroxide in endodontics. Among these are aid in bacteriological control of the canal environment, promotion of healing of periapical lesions, promotion of drying of weeping periapical lesions, and use as a temporary root canal filling material. Matsumiya and Kitamura (22) were able to demonstrate the disappearance of bacteria in canals treated with

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SCIENTIFIC ARTICLES

An In Vitro Comparison of the Step-back Technique Versus a Step-back/Ultrasonic Technique for 1 and 3 Minutes

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This study compared the debridement efficacy of the step-back preparation versus a step-back/ultrasonic preparation, for 1 and 3 min, in the mesial root canals of extracted human mandibular molars. Statistical analysis indicated no significant differences in canal cleanliness, at the 1- and 3-mm levels, between the step-back or step-back/ultrasound groups (1 or 3 min). All techniques achieved a high level of canal cleanliness. The step-back/3-min ultrasound preparation significantly cleaned isthmuses, at the 1- and 3-mm levels, more effectively than the step-back or step-back/1-min ultrasound techniques.

It is generally recognized that proper debridement of the root canal space is a critical phase of endodontic therapy (1–4). As the root canal is debrided and enlarged, the substrates essential for microbial growth are reduced. However, the complete removal of all tissue present in the canal system, although a goal for successful endodontics, is difficult. Many studies (5–10) have shown that one of the complicating factors is the complex root canal anatomy with its ramifications, fins, grooves, and other irregularities.

Recently, ultrasonic technology has provided an exciting potential for root canal debridement. Martin, Cunningham, and colleagues, in a series of studies (11–15), found that ultrasonically prepared teeth were significantly cleaner than teeth prepared with hand instruments. Weller et al. (16) demonstrated that the use of ultrasonics following hand instrumentation was the most effective method of canal debridement. Goodman et al. (17) reported that a step-back/ultrasound preparation debrided the canals at the 1-mm level and isthmuses more effectively than the step-back preparation alone. Other authors (18–20) have reported no difference between hand instrumentation and ultrasonic instrumentation.

Until recently no commercially marketed ultrasonic dental unit has been available. Since the Cavi-Endo unit has been introduced to the dental profession, research should be done to determine if this instrument can improve on present debridement techniques. Therefore, the purpose of this study was to histologically compare the debridement efficacy of a step-back preparation versus a step-back preparation followed by the use of the Cavitron Cavi-Endo dental unit, for 1 or 3 min, in the mesial root canals of extracted human mandibular first and second molars.

MATERIALS AND METHODS

Approximately 400 extracted human first and second mandibular molar teeth were collected and stored at −7°C until ready for use. The age, sex, pulpal status, or reason for extraction was not recorded. Radiographs were taken from the buccal direction and the degree of curvature of the mesial roots was determined using Schneider's method (21). In order to standardize canal curvature, only those roots demonstrating a 15 to 45 degree of curvature were used in this study. Standard root canal access openings were made using a #701 high-speed bur. After irrigation with normal saline, the pulp chamber of each tooth was visually examined and probed in order to verify the presence of pulp tissue. Only those teeth which exhibited coronal pulp tissue were used in this study. Each tooth was placed in an empty 11-dram amber vial which was labeled with a 4-digit random number code. The vials were kept at −7°C until approximately 1 h prior to instrumentation. They were then removed and allowed to thaw at room temperature. For evaluation and standardization purposes, only those mesial roots demonstrating a type III canal configuration were used in the study. This was verified during working length determination when the initial file tips were seen just protruding from two separate apical foramina. The experimental teeth were randomly divided into three groups of 20 teeth, with both mesial

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Efficacy of irrigation systems on penetration of sodium hypochlorite to working length and to simulated uninstrumented areas in oval shaped root canals

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Abstract

de Gregorio C, Paranjpe A, Garcia A, Navarrete N, Estevez R, Esplugues EO, Cohenca N. Efficacy of irrigation systems on penetration of sodium hypochlorite to working length and to simulated uninstrumented areas in oval shaped root canals. *International Endodontic Journal*, **45**, 475–481, 2012.

Aim To assess the ability of sodium hypochlorite (NaOCl) to penetrate simulated lateral canals and to reach working length (WL) when using the self-adjusting file (SAF).

Methodology Seventy single-rooted teeth with oval-shaped canals were used. Upon access, presence of a single canal was confirmed by direct visualization under a dental-operating microscope. Canal length and patency were obtained using a size 10 K-file and root length standardized to 18 mm. Pre-enlargement was restricted to the coronal one-third. The apical size of each canal was gauged at WL and samples larger than size 30 were excluded. Canals were instrumented for 5 min using the SAF system while delivering a total of 20 mL of 5.25% NaOCl and 5 mL of 17% EDTA. Then, the apical diameters were standardized to size 35 using hand files. Four hundred and twenty simulated lateral canals were then created during the clearing process and roots coated with wax to create a closed system. All samples were then cleared and randomly assigned to four experimental groups: 1 ($n = 15$) positive pressure; 2 ($n = 15$) SAF without pecking motion; 3 ($n = 15$) SAF with pecking motion; 4 ($n = 15$) apical negative pressure (ANP) irrigation and ($n = 10$) control groups. Samples were scored on the basis of the ability of the contrast solution to reach WL and permeate into the simulated lateral canals to at least 50% of the total length. The Kruskal–Wallis test was used to analyse irrigant penetration and the Tukey test to determine statistical differences between groups ($P < 0.05$).

Results All samples irrigated with ANP were associated with irrigant penetration to WL (Table 1). The differences between group 4 (ANP) and all other groups were significant in penetration to WL ($P < 0.05$). The pecking motion allowed for further penetration of the irrigant when using the SAF system but failed to irrigate at WL. None of the experimental groups demonstrated predictable irrigation of simulated lateral canals.

Conclusions In this laboratory model, ANP was the only delivery system capable of irrigating consistently to full WL. None of the systems tested produced complete irrigation in artificial lateral canals.

Keywords: irrigation, penetration, SAF.

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Introduction

Adequate instrumentation combined with effective irrigation is required to achieve sufficient disinfection during root canal treatment (Bystrom & Sundqvist

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Acoustic Hypochlorite Activation in Simulated Curved Canals

Anas Al-Jadaa, BDS, Frank Paqué, Dr. med. dent., Thomas Attin, Prof. Dr. med. dent., and Matthias Zehnder, PD, Dr. med. dent., PhD

Abstract

Introduction: It was the goal of this study to compare different NaOCl activation schemes regarding a desired and an untoward outcome. Ultrasonic tips and a currently marketed sonic system were used in conjunction with a 2.5% sodium hypochlorite solution. Necrotic pulp tissue dissolution in simulated accessory canals and transportation of the main canal were assessed. **Methods:** Epoxy resin models (10 per group) with a curved simulated main root canal and two simulated accessory canals filled with necrotic bovine pulp tissue were irrigated passively with one of three ultrasonic setups (straight stainless steel files, prebent stainless steel files, or nickel-titanium tips) or a sonic device in conjunction with a plastic tip. Activation was performed four times for 30 seconds with replenishment of the NaOCl solution in between. All the files/tips had a 2% taper and a 0.15-mm tip diameter according to the manufacturer. Data from superimposing and analyzing digital photos before and after treatment were statistically analyzed using one-way analysis of variance followed by Bonferroni's correction for multiple comparisons (alpha < 0.05). **Results:** Passive ultrasonic irrigation (PUI) in all the groups dissolved significantly more tissue than sonic activation ($p < 0.05$). No detectable canal transportation with sonic activation was observed. The difference in this outcome was not significant compared with ultrasonically activated nickel-titanium tips, whereas the straight stainless steel files caused significantly more ledging compared with these setups ($p < 0.05$). **Conclusion:** Under the current conditions, PUI with a nickel-titanium tip promoted superior tissue-dissolving effects over sonic irrigant activation while maintaining simulated canal anatomy. *(J Endod 2009;35:1408–1411)*

Key Words

Canal transportation, passive ultrasonic irrigation, pulp tissue dissolution, sodium hypochlorite, sonic, ultrasonic

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It has become evident over the past decades that complete debridement of an infected root canal system is a goal that is impossible to achieve. Mechanical preparation does obviously not suffice to clean necrotic root canals (1). Thus, it has been suggested to use acoustic irrigant activation to improve cleanliness and disinfection of root canal systems before root filling (2, 3). The synergistic effects of ultrasonic energy and sodium hypochlorite in aqueous solution appear to be especially useful in that context (2, 4, 5). Currently, passive ultrasonic irrigation (PUI) is probably the most established method to activate a sodium hypochlorite irrigant after root canal instrumentation (6–8). PUI relates to the activation of an irrigant by an ultrasonically activated file or tip that is not used for canal preparation. The term can refer to both the placement of the irrigant by a syringe with subsequent activation and delivery of the irrigant through the ultrasonic handpiece. PUI has shown promising results in the removal of debris from root canals. Previous studies, however, were mostly performed in straight simulated canals (9, 10), which are rarely encountered in teeth. One study showed no impact of canal width, taper, or curvature in disinfecting the root canal system using ultrasonic sodium hypochlorite activation after canal preparation (11). On the other hand, there is evidence that the performance of ultrasonically activated files or tips will be dramatically reduced in the case of instrument restriction (12, 13). A straight instrument placed in a curved canal will have at least three contact points with root canal walls. This might stress the need of bending the instrument to follow the canal curvature and ensure maximum efficiency and to avoid the risk of canal transportation (14). Alternative measures to avoid canal transportation and maintain instrument efficacy during acoustic irrigant activation include the use of a smooth wire in an ultrasonic device (15, 16) or a plastic tip in a sonic handpiece (17). There is, however, limited information regarding the effectiveness of these approaches. One reason for this has been the lack of model systems that allow comparative studies on desired and untoward effects of acoustic irrigant activation methods. The term acoustic activation was chosen in this communication to have a common denominator for both sonic and ultrasonic activation. With both methods, compression waves, albeit of different frequencies, are generated in the irrigant.

Using a modification of a recently introduced epoxy resin model (10), it was the goal of the current study to compare the effects of different ultrasonic tips and a currently marketed sonic system on necrotic pulp tissue dissolution in conjunction with a 2.5% sodium hypochlorite solution and transportation of the simulated main canal.

Materials and Methods

Model Fabrication

Fifty epoxy resin (Stycast; Emerson & Cuming, Westerlo, Belgium) models were fabricated with minor modifications as previously described (10). Each model was used for just one experiment. The simulated main canal was cast using a size D spreader (Dentsply Maillefer, Ballaigues, Switzerland). This instrument had a length of 25 mm, a tip diameter of 0.35 mm, and a .06 taper. The design modification was that the spreader was bent and controlled by a scale drawing on a sheet of paper representing the targeted curvature of a 20° angle between the long axis of the main canal and a line passing the apex to the start of the curvature, representing the transition point between moderately curved and severely curved canals (18). The curvature started in the last 10 mm of the total canal length, which was 25 mm. A coronal space simulating a pulp chamber was created using a rubber tube placed over the spreader coronally and sealed before model casting. The tube was 3 mm high with a 3-mm internal diameter. Two simulated accessory canals of 0.2-mm diameter opposing each other and forming a 45° angle with the simulated main canal tangent at 3 mm from the apex were created. A millimetric paper

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Influence of refreshment/activation cycles and temperature rise on the reaction rate of sodium hypochlorite with bovine dentine during ultrasonic activated irrigation

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Abstract

Macedo RG, Verhaagen B, Wesselink PR, Versluis M, van der Sluis LWM. Influence of refreshment/activation cycles and temperature rise on the reaction rate of sodium hypochlorite with bovine dentine during ultrasonic activated irrigation. *International Endodontic Journal.*

Aim To evaluate the effect of multiple refreshment/activation cycles and temperature on the reaction rate of sodium hypochlorite (NaOCl) with bovine dentine during ultrasonic activated irrigation (UAI) under *laboratory* conditions.

Methodology The root canal walls of 24 standardized root canals in bovine incisors were exposed to a standardized volume of NaOCl at different temperatures (24 °C and 38 °C) and exposure times (20, 60 and 180 s). The irrigant was refreshed and ultrasonically activated four times for 20 s followed by a 40 s rest interval, with no refreshment and no activation as the controls. The reaction rate was determined by measuring the amount of active chlorine in the NaOCl solution before and after being exposed to dentine during the specific experimental conditions. Calorimetry was used to measure the electrical-to-sonochemical conversion efficiency during ultrasonic activation.

Results Refreshment, activation and exposure time all increased the reaction rate of NaOCl ($P < 0.05$). During activation, the temperature of the irrigant increased up to 10 °C. Such temperature rise was insufficient to enhance the reaction rate of NaOCl ($P > 0.125$).

Conclusions The reaction rate of NaOCl with dentine is enhanced by refreshment, ultrasonic activation and exposure time. Temperature rise of irrigant during ultrasonic activation was not sufficient to alter the reaction rate.

Keywords: dentine, irrigation, reaction rate, sodium hypochlorite, ultrasonic activated irrigation.

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Introduction

Sodium hypochlorite (NaOCl) is the main irrigation solution used in endodontics because of its antimicrobial activity, tissue dissolving capacity and, when properly used, the absence of clinical toxicity (Zehnder 2006). Sodium hypochlorite is highly reactive by nature (Dychdala 1977). In the root canal system, NaOCl reacts with pulp tissue, microorganisms, biofilm and organic components of the root canal wall, resulting in loss of its available chlorine (Moorer & Wesselink 1982).

The reaction rate (chemical efficiency) and/or tissue dissolution capacity (chemical efficacy) of NaOCl are significantly influenced by the concentration,

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Study on the Influence of Refreshment/Activation Cycles and Irrigants on Mechanical Cleaning Efficiency During Ultrasonic Activation of the Irrigant

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Abstract

Introduction: The aims of this study were to evaluate dentin debris removal from the root canal during ultrasonic activation of sodium hypochlorite (2% and 10%), carbonated water, and distilled water and to determine the influence of 3 ultrasonic refreshment/activation cycles of the irrigant by using the intermittent flush technique. **Methods:** Root canals with a standardized groove in 1 canal wall, which was filled with dentin debris, were irrigated ultrasonically. The irrigant was refreshed and ultrasonically activated 3 times for 20 seconds. The quantity of dentin debris after irrigation was determined after each refreshment/activation cycle. **Results and Conclusions:** Ultrasonic activation of the irrigant combined with the intermittent flush method produces a cumulative effect over 3 refreshment/activation cycles. Sodium hypochlorite as an irrigant is significantly more effective than carbonated water, which is significantly more effective than distilled water, in removing dentin debris from the root canal during ultrasonic activation. *(J Endod 2010;36:737–740)*

Key Words

Cavitation, irrigation, root canal, streaming, ultrasonic

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The aim of irrigation of the root canal system is to remove pulp tissue and/or microorganisms, smear layer, and dentin debris from the root canal system, neutralize endotoxins, and lubricate canal walls and instruments (1). Irrigation of the root canal system allows the irrigant to be chemically active (chemical aspect) and permits the flushing of debris (mechanical aspect).

Passive ultrasonic irrigation (PUI) is ultrasonic activation of an irrigant in the root canal via a small, ultrasonically oscillating instrument (#15 or #20) placed in the center of the root canal after the root canal has been shaped up to the master apical file (2). PUI can induce acoustic streaming and/or cavitation of an irrigant, thereby enhancing the flushing effect (mechanical) (2, 3). Furthermore, PUI results in an increase in the temperature of the irrigant (4), which will enhance the tissue-dissolving capacity of NaOCl (chemical) (5, 6). These factors facilitate the removal of pulp tissue, bacteria, the smear layer, dentin debris, and $Ca(OH)_2$ from the root canal (2, 7, 8). However, whether this is due to the acoustic streaming, cavitation, or both is unknown.

The mechanical effect of irrigation is not similar for all irrigants activated by ultrasound. For example, distilled water is less effective than 2% NaOCl (8). However, whether a higher concentration of NaOCl or carbonated water (water with CO_2 bubbles) is more effective than distilled water or 2% NaOCl is unknown. In this study we have chosen for a 10% NaOCl solution to make the difference with the 2% more significant.

To refresh the irrigant during PUI, the intermittent flush method (IntFM) can be used. During the IntFM, a syringe is used to deliver the irrigant into the root canal; then the irrigant is activated ultrasonically (4). Depending on the irrigation time, this method is equally or more effective than refreshment with a continuous flow of irrigant in the pulp chamber (9). In previous studies, 3 refreshment/activation cycles were used (8), but it is not clear whether a cumulative effect occurs. In another study, however, that used the IntFM in removing bovine pulp tissue from lateral canals, a cumulative effect was reported with a plateau of efficiency after the third activation cycle (6).

Therefore, the purposes of this study were (1) to measure the fluidic properties of 2% and 10% NaOCl and carbonated and distilled water, (2) to evaluate the effect of these irrigants on the removal of dentin debris from the root canal during passive ultrasonic irrigation, and (3) to evaluate the effect of 3 ultrasonic refreshment/activation cycles during the IntFM.

Materials and Methods

Fluidic Properties Measurements

Density was measured on a balance (Sartorius LE324S, Elk Grove, IL). Surface tension was measured by using a tensiometer (Krüss K11, Hamburg, Germany) by submerging a plate into the fluid, slowly pulling it out, and measuring the resultant force. Viscosity was measured by using a rheometer (Haake RheoStress 600; Thermo Scientific) by measuring the stress during rotation at speeds of 10–200 s^{-1}. The experiments were done at room temperature (21°C).

Dentin Debris Removal

Twenty canines (maxillary and mandibular) were instrumented with the GT system (Dentsply Maillefer, Ballaigues, Switzerland) until size 30, taper 0.06 (master apical file

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A Comparison of the Cleaning Efficacy of Short-Term Sonic and Ultrasonic Passive Irrigation after Hand Instrumentation in Molar Root Canals

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A total of 100 maxillary molar canals were hand instrumented to a master apical file size #35 and flared to a size #60 file. The canals were randomly divided into 5 groups of 20 each. Group 1 received no further treatment. Groups 2 and 3 received passive sonic irrigation for 30 and 60 s, respectively. Groups 4 and 5 received passive ultrasonic irrigation for 30 and 60 s, respectively. The roots were split longitudinally and photographed with a digital camera. The apical portion of the root was magnified to 100×. A debris score was calculated for the apical 3 and 6 mm. The debris score was calculated as a percentage of the total area of the canal that contained debris as determined by pixels in Adobe Photoshop 5.0. Passive sonic or ultrasonic irrigation, for as little as 30 s, resulted in significantly cleaner canals than hand filing alone. Ultrasonic passive irrigation produced significantly cleaner canals than passive sonic irrigation, when sonic and ultrasonic passive irrigation were compared with only each other.

Cleansing and shaping the canals is a well-known fundamental necessity for the success of any root-canal treatment (1). Obtaining the cleanest canal possible before obturation is one of the goals of endodontic treatment. The activation of endodontic files by ultrasonic or sonic energy has been shown, in some studies, to be effective in both cleaning and shaping of root-canal systems. Richman (2) first introduced ultrasonics as a means of canal debridement. Martin et al. (3) demonstrated the ability of ultrasonically activated K-type files to cut dentin. In another study, the same authors showed that canals that were cleaned and shaped with ultrasonic instrumentation were significantly cleaner than those instrumented with conventional root-canal filing (4).

Stamos et al. (5) showed that canals were significantly cleaner at the 1-mm level, after the use of ultrasonics and 2.6% NaOCl, than those cleaned using hand instrumentation alone. Tronstad et al. (6) evaluated sonic activation of files to shape and cleanse canals. Their results showed no significant difference between sonically cleaned canals and those cleaned by hand filing with regard to cleanliness.

Acoustic streaming, as described by Ahmad et al. (7), has been shown to produce sufficient shear forces to dislodge debris in instrumented canals. When files were activated with ultrasonic energy in a passive manner, this acoustic streaming was sufficient to produce significantly cleaner canals in human maxillary teeth than those produced by hand filing alone. They deducted that to maximize acoustic streaming for debridement purposes, the best results were to have a freely vibrating file of small size subjected to a high-power setting on the ultrasonic unit. The smaller file would be less likely to contact the canal walls and reduce the acoustic-streaming effect. They found greater removal of debris and smear layer in the apical third of canals because of more intense magnitude and velocity at the apical end of the file.

Lev et al. (8) compared the cleaning ability of ultrasonics and a step-back technique. They concluded that a 3-min ultrasonic step-back technique produced a significantly cleaner isthmus between canals in the mesial roots of mandibular first molars. Their study also looked at a 1-min ultrasonic step-back technique. The 1-min technique was not significantly better than hand filing for removing debris.

Hiadet et al. (9) found that step-back preparation followed by 3 min of ultrasonic preparation provides superior cleanliness at both the apical 1-mm level and in the isthmus compared with step-back preparation alone. Archer et al. (10) found that step-back preparation followed by 3 min of ultrasonics resulted in significantly cleaner canals and isthmuses in mandibular molars compared with step-back preparation alone. The ultrasonic instrumentation was performed by placing the file 1-mm short of the working length and activating the ultrasonic unit for 3 min using a push-pull circumferential motion.

Torabinejad (11) described a passive step-back instrumentation technique where ultrasonic files were used as part of the instrumentation technique. Ultrasonic files were used 1-mm short of resistance, and used circumferentially, not allowing the tip to penetrate into dentin. The ultrasonic files were alternated with K-type files. The final step used the #15 ultrasonic file 1- to 2-mm short of the working length for 1 to 2 min before the final irrigation with NaOCl.

Cameron (12) found, under the conditions of his study, that the most effective regimen for smear layer and debris removal, at 1, 5, and 10 mm from the apical seat, was a 1-ml rinse of EDTAC after

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Wall shear stress effects of different endodontic irrigation techniques and systems

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ABSTRACT

Objectives: This study examined débridement efficacy as a result of wall shear stresses created by different irrigant delivery/agitation techniques in an inaccessible recess of a curved root canal model.

Methods: A reusable, curved canal cavity containing a simulated canal fin was milled into mirrored titanium blocks. Calcium hydroxide ($Ca(OH)_2$) paste was used as debris and loaded into the canal fin. The titanium blocks were bolted together to provide a fluid-tight seal. Sodium hypochlorite was delivered at a previously-determined flow rate of 1 mL/min that produced either negligible or no irrigant extrusion pressure into the periapex for all the techniques examined. Nine irrigation delivery/agitation techniques were examined: NaviTip passive irrigation control, Max-i-Probe® side-vented needle passive irrigation, manual dynamic agitation (MDA) using non-fitting and well-fitting gutta-percha points, EndoActivator™ sonic agitation with medium and large points, VPro™ EndoSafe™ irrigation system, VPro™ StreamClean™ continuous ultrasonic irrigation and EndoVac apical negative pressure irrigation. Débridement efficacies were analysed with Kruskal–Wallis ANOVA and Dunn's multiple comparisons tests ($\alpha = 0.05$).

Results: EndoVac was the only technique that removed more than 99% calcium hydroxide debris from the canal fin at the predefined flow rate. This group was significantly different ($p < 0.05$) from the other groups that exhibited incomplete $Ca(OH)_2$ removal.

Conclusions: The ability of the EndoVac system to significantly clean more debris from a mechanically inaccessible recess of the model curved root canal may be caused by robust bubble formation during irrigant delivery, creating higher wall shear stresses by a two-phase air–liquid flow phenomenon that is well known in other industrial débridement systems.

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Curved versus straight root canals: the benefit of activated irrigation techniques on dentin debris removal

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Objective. The aim of this study was to compare the efficacy of hydrodynamic and ultrasonic-activated irrigation to conventional syringe irrigation in removing dentin debris in straight and curved root canals.
Study design. Twelve human teeth were selected for study. The root canals of 6 single-rooted premolars with straight canals and 6 molar roots with curved canals were prepared to a size of 45 and split longitudinally. To simulate canal irregularities, 3 standardized holes were cut in 1 canal wall. The canals and holes were then covered with debris. After reassembly, 3 irrigation techniques were compared: syringe irrigation, hydrodynamic irrigation, and ultrasonic irrigation. The amount of debris that remained was evaluated microscopically and graded with a 4-score system.
Results. The hydrodynamic and ultrasonic irrigation techniques were significantly ($P < .001$) more efficient as compared with syringe irrigation in both the straight and curved root canals. Ultrasonic irrigation demonstrated a higher efficiency in the straight root canals ($P < .01$), whereas hydrodynamic irrigation was more efficient in the curved canals ($P < .01$).
Conclusions. In the straight canals, ultrasonic irrigation was the most effective, but in the curved root canals, hydrodynamic irrigation was superior. **(Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2011;111:529-534)**

Recently, the impact of root canal irrigation has been identified as an important issue. This has been reflected in the development of new irrigation methods and an increasing number of scientific studies on this topic. Most of this research has been conducted using in vitro studies on single-rooted extracted teeth[1,2] or artificial canals.[3] Unfortunately, these studies do not appropriately reflect the general clinical environment. Most root canal treatments are performed on multirooted teeth, where clinicians must treat curved canals.[4,5]

Chemo-mechanical preparation of the root canal system aims to remove microorganisms,[6] remaining pulp tissue, and dentin debris.[7] The root canal contains accessory canals, canal wall irregularities, and cavities.[8] These anatomical structures are not accessible by hand or rotary instruments in many cases.[9]

The instruments used in root canals produce dentin debris that might be pressed into existing irregularities.[10] Dentin debris is composed of dentin chips, bacteria, and necrotic pulpal tissue. Debris accumulation is a side effect of root canal instrumentation, and it may interfere with the primary objectives of root canal treatment. Complete removal of debris is essential to providing direct contact of the irrigant solution with the root canal wall and to producing adequate disinfection.[10] Furthermore, debris-filled extensions may lead to leakage of the root canal filling.[11]

Besides instrumentation, irrigation is the other important step in preparing root canals. The effectiveness of irrigation depends on both mechanical flushing and chemical action. With syringe irrigation, the ability to flush the root canal is limited and primarily depends on the depth and placement of the irrigation cannula.[12] The efficiency of irrigation can be increased by activating the solution with an ultrasonic or hydrodynamic device.[13] Passive ultrasonic irrigation, as used in the present study, is defined as the activation of rinsing solution in the root canal using an ultrasonic file without continuous flow.[14] In combination with sodium hypochlorite, this method has been shown to be more effective than conventional hand irrigation in removing dentin debris from the root canal.[1] The hydrodynamic irrigation system (RinsEndo, Dürr Dental, GmbH & Co KG, Bietigheim-Bissingen, Germany) is based on pressure-suction technology and has been shown in a few studies to be effective.[2,15] A recent review concluded that irrigant agitation plays an important role in contemporary endodontics. Recently, the efficiency of different irrigation systems, including ultrasonic, hydrodynamic, and syringe irrigation, was

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Tissue Dissolution by Sodium Hypochlorite: Effect of Concentration, Temperature, Agitation, and Surfactant

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Abstract

Aim: Sodium hypochlorite is the most commonly used endodontic irrigant because of its antimicrobial and tissue-dissolving activity. The aim of this study was to evaluate and compare the effects of concentration, temperature, and agitation on the tissue-dissolving ability of sodium hypochlorite. In addition, a hypochlorite product with added surface active agent was compared with conventional hypochlorite solutions. **Methods:** Three sodium hypochlorite solutions from two different manufacturers in concentrations of 1%, 2%, 4%, and 5.8% were tested at room temperature, 37°C, and 45°C with and without agitation by ultrasonic and sonic energy and pipetting. Distilled and sterilized tap water was used as controls. Pieces of bovine muscle tissue (68 ± 3 mg) were placed in 10 mL of each solution for five minutes. In selected samples, agitation was performed for one, two, or four 15-second periods per each minute. The tissue specimens were weighed before and after treatment, and the percentage of weight loss was calculated. The contact angle on dentin of the three solutions at concentrations of 1% and 5.8% was measured. **Results:** Weight loss (dissolution) of the tissue increased almost linearly with the concentration of sodium hypochlorite. Higher temperatures and agitation considerably enhanced the efficacy of sodium hypochlorite. The effect of agitation on tissue dissolution was greater than that of temperature; continuous agitation resulted in the fastest tissue dissolution. Hypochlorite with added surface active agent had the lowest contact angle on dentin and was most effective in tissue dissolution in all experimental situations. **Conclusions:** Optimizing the concentration, temperature, flow, and surface tension can improve the tissue-dissolving effectiveness of hypochlorite even 50-fold. *(J Endod 2010;36:1558–1562)*

Key Words

Agitation, Chlor-Xtra, sodium hypochlorite, surfactant, temperature, tissue dissolution

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Success in endodontic treatment depends to a great extent on chemomechanical debridement of the canals. Although instruments remove most of the canal contents in the main root canal area, irrigation plays an indispensable role in all areas of the root canal system, in particular those parts that are inaccessible for instrumentation (1). The most favorable features of irrigants are their flushing action, tissue-dissolving ability, antimicrobial effect, and low toxicity (2, 3). Sodium hypochlorite is the most commonly used endodontic irrigant because of its well-known antimicrobial and tissue-dissolving activity (4–6).

The dissolving capability of sodium hypochlorite relies on its concentration, volume, and contact time of the solution but also on the surface area of the exposed tissue (7). However, high concentrations are potentially toxic for periapical tissue (8–10). Also, changes in mechanical properties such as decreased microhardness and increased roughness of radicular dentin have been reported after exposure to sodium hypochlorite in concentrations of 2.5% and 5.25% (11).

Possible ways to improve the efficacy of hypochlorite preparations in tissue dissolution are increasing the pH (12) and the temperature of the solutions, ultrasonic activation, and prolonged working time (13). Although there is a general consensus that increased temperature enhances the effectiveness of hypochlorite solutions, there are only a few published articles about this (14–16). It has been suggested that preheating low-concentration solutions improves their tissue-dissolving capacity with no effect on their short-term stability. Also, systemic toxicity is lower compared with the higher-concentration solutions (at a lower temperature) with the same efficacy (15). The impact of mechanical agitation of the hypochlorite solutions on tissue dissolution was found to be very important by Moorer and Wesselink (7) who emphasized the great impact of violent fluid flow and shearing forces caused by ultrasound on the ability of hypochlorite to dissolve tissue. However, the mechanisms involved are not completely understood (13). Despite several separate reports of the various ways to improve the effectiveness of tissue dissolution by sodium hypochlorite, the relative importance of temperature, concentration, and agitation remains unclear. In the present study, all these factors were examined under controlled conditions to allow comparison of their role. Finally, a hypochlorite product with an added surface active agent was compared with conventional products in the different experimental settings.

Materials and Methods

Solutions

Sodium hypochlorite solutions in concentrations of 1%, 2%, 4%, and 5.8% were tested. Stock solution of 6 % sodium hypochlorite (Regular 1; EMD Chemicals Inc, Gibbstown, NJ) and 5.8% sodium hypochlorite (Regular 2; Inter-Med, Inc/Vista Dental Products, Racine, WI) were obtained from the manufacturers. Two different hypochlorite products with 5.8% sodium hypochlorite were included in the experiments: one conventional solution (Regular 2, Vista-Dental) and one with a surface active agent added (Chlor-Xtra, Vista-Dental). The amount of available chlorine was obtained by the manufacturers. The solutions were kept at 4°C following the recommendations of the manufacturer and brought to room temperature (RT) before use. One percent,

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Final Rinse Optimization: Influence of Different Agitation Protocols

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Abstract

Introduction: This study examined the effect of different root canal irrigant agitation protocols in the penetration of an endodontic irrigant into dentinal tubules. **Methods:** Fifty-six human single-rooted teeth were shaped with nickel-titanium instruments, and a final rinse of 5% sodium hypochlorite labeled with 0.2% alizarin red was performed. Specimens were assigned to 7 groups ($N = 8$) and submitted to the following rinse activation protocols: no agitation (control group), K-File or gutta-percha agitation, or different sonic (EndoActivator [Advanced Endodontics, Santa Barbara, CA] and Plastic Endo, Lincolnshire, IL) and ultrasonic (Satelec [Acteongroup, Merignac, France] and EMS, Nyon, Switzerland) agitations. Specimens were sectioned at 1, 3, and 5 mm from the apex in 1-mm-thick slabs, ground, and prepared for fluorescence microscopy at 100× with a wavelength of 450 milliseconds. Irrigant penetration into dentinal tubules was analyzed by using Kruskal-Wallis analysis of variance followed by post-hoc comparisons. **Results:** Groups were ranked in the following order: control = K-file = gutta-percha < EndoActivator = Plastic Endo < Satelec = EMS. At 1 mm from the apex, the highest score was found for the EMS group compared with the control, K-file, gutta-percha, EndoActivator, and Plastic Endo groups, whereas no difference was found with the Satelec group. **Conclusion:** The results support the use of an ultrasonic agitation to increase the effectiveness of the final rinse procedure in the apical third of the canal walls. *(J Endod 2010;36:282–285)*

Key Words

Cleaning, endodontic treatment, irrigation, sodium hypochlorite, ultrasound

Microorganisms and their end products are considered the main causes of pulp and periapical diseases (1), and their elimination by biomechanical procedures is crucial (2). Organic residues and bacteria located within the dentin tubules cannot be properly cleaned because of the anatomic complexities of many root canals, even after meticulous mechanical instrumentation and is a major concern for the clinical outcome (3).

Among currently used solutions, sodium hypochlorite (NaOCl) appears to satisfy most of the requirements for a root canal irrigant (4). It has the unique capacity to dissolve necrotic tissue (5) and the organic components of the smear layer (6). It also kills sessile endodontic pathogens organized in biofilms and in dentinal tubules as efficiently as chlorhexidine or iodine at a comparable concentration (7). It inactivates endotoxins (8) and also disintegrates endodontic biofilms (9, 10).

The application time of NaOCl solution is a factor that has gained little attention in endodontic studies. Even fast-acting biocides such as NaOCl require an adequate working time to reach their full potential (11). Because rotary root canal preparation techniques have expedited the shaping process, the optimal time that NaOCl at a given concentration needs to remain in the canal system is an issue yet to be resolved.

Apart from contact time, the mode of application is a matter of concern for clinicians. Moorer and Wesselink (12) opined that mechanical agitation or fluid flow was more important in the ability of NaOCl to dissolve tissue than the initial percentage of available active chlorine. The use of an irrigant in conjunction with ultrasonic vibration is directly associated with the cleaning effectiveness of the canal space (13, 14). This could reduce the time needed for the antimicrobial efficacy of the irrigating solution.

Different techniques have been proposed for the final rinsing step to reduce the time needed for an irrigant to be effective. Huang et al (15) showed that agitation of a canal irrigant using hand files or irrigation needles could significantly remove more test album medium or allow better apical irrigant replacement. In addition, manual dynamic irrigation (push-pull agitation) with a well-fitting gutta-percha point can improve the penetration and exchange of irrigant at the apical level (16). The use of a plastic file in conjunction with sonic and ultrasonic devices has also been tested. However, a recent Cochrane review (17) revealed insufficient evidence on ultrasonic instrumentation effectiveness either when it is used alone or in conjunction with hand instrumentation (18–20).

Alizarin red is a fluorescent organic compound used in biomorphologic assays for quantifying the presence of calcific depositions (21). The purpose of this study was to assess the penetration of 5% NaOCl labeled with 0.2% alizarin red into dentinal tubules

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Effectiveness of the EndoActivator System in Removing the Smear Layer after Root Canal Instrumentation

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Abstract

Introduction: Elimination of the smear layer after root canal instrumentation requires the use of irrigating solutions. This cleaning can be completed with passive ultrasonic or sonic irrigation. The aim of this study was to evaluate the effectiveness of the EndoActivator System in removing the smear layer after rotary root canal instrumentation, with and without a final flush of 17% ethylenediaminetetraacetic acid (EDTA) solution, in coronal, middle, and apical thirds. **Methods:** Forty single-canal teeth were decoronated and randomly divided into 4 groups (n = 10). The groups were instrumented by using Mtwo System. EndoActivator was used with a final rinse of 1 mL of 17% EDTA or 4% NaOCl for 1 minute. The roots were longitudinally split and were grooved in the coronal, middle, and apical thirds. Scanning electron microscopy digital photomicrographs at 400× were taken to evaluate the amount of smear layer in each third. **Results:** The NaOCl/EndoActivator group did not remove any smear layer of the root canal wall (100% in the coronal, middle, and apical thirds). In the groups that used 17% EDTA (with or without EndoActivator), the smear layer was eliminated completely (100%) in the coronal third, but the amount of removal was less in the other two thirds. The comparisons between NaOCl versus NaOCl/EndoActivator groups and EDTA/NaOCl versus EDTA/EndoActivator/NaOCl groups showed no significant differences in root canal thirds. **Conclusions:** The EndoActivator System did not enhance the removal of smear layer as compared with conventional Max-I-Probe irrigation with NaOCl and EDTA. *(J Endod 2010;36:308–311)*

Key Words

EDTA, EndoActivator System, scanning electron microscopy, smear layer, sodium hypochlorite

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Hand and rotary instrumentation techniques produce an irregular, granular, and amorphous layer covering the dentin root canal. Subsequent smear layer removal requires the use of irrigating solutions that can dissolve both organic and inorganic components to eliminate microorganisms (1) and improve the hermetic sealing of the root canal system (2).

Different studies have shown that the use of 5.25%, 2.5%, or 1% sodium hypochlorite (NaOCl) with ethylenediaminetetraacetic acid (EDTA) solutions is effective in removing the smear layer during root canal instrumentation (3–5). It has also been seen that 1 mL of 17% EDTA for 1 minute was just as effective as 3 and 10 mL of this solution in smear layer removal with a 28-gauge Max-I-Probe (Dentsply Rinn, Elgin, IL) irrigating tip after rotary instrumentation (6). Less irrigation time (15 or 30 seconds) with 1 mL of 17% EDTA significantly decreased smear layer removal when compared with a 1-minute rinse (7), whereas a longer time of 2 minutes (10 mL 17% EDTA), followed by final irrigation with 10 mL of 5% NaOCl, caused intertubular and peritubular erosion (8).

After root canal shaping, cleaning might be completed with several irrigant agitation techniques (9) such as passive ultrasonic irrigation (PUI), sonic irrigation, or a final flush by syringe irrigation. It has been established that PUI in combination with NaOCl is more effective in removing dentin debris from the root canal (10–12), particularly in areas of complex root anatomy, as compared with the routine syringe delivery of the irrigant (13), in which the needle size and the depth of insertion of the needle can influence the effectiveness of irrigants (14).

Different results have been reported when comparing the effectiveness of PUI and sonic irrigation in the cleanliness of root canals (15–17). Studies of smear layer removal are inconclusive (9) and have been shown only with PUI (15, 18, 19). However, there is a gap in our knowledge of whether sonic agitation could reproduce the smear layer removal effect found with PUI.

Recently, the EndoActivator System (Dentsply Tulsa Dental Specialties, Tulsa, OK) was introduced to improve the irrigation phase. It is a sonically-driven canal irrigation system that comprises a portable handpiece and 3 types of disposable flexible polymer tips of different sizes that do not cut root dentin. Its design allows for the safe activation of various intracanal reagents and could produce vigorous intracanal fluid agitation (20). The EndoActivator System has been shown to better irrigate the simulated lateral canals at 4.5 and 2 mm from working length as compared with traditional needle irrigation alone (21), and it reportedly removed the smear layer used with demineralizing agents like EDTA and dislodged clumps of simulated biofilm within the curved canals of molar teeth (22).

The aim of this study was to evaluate the effectiveness of the EndoActivator System in removing the smear layer after rotary instrumentation, both with and without a final flush of 17% EDTA solution, in coronal, middle, and apical thirds.

Materials and Methods

Specimen Preparation

Forty single-canal maxillary human teeth extracted for periodontal reasons were stored in a 2% thymol solution until use. The specimens were decoronated to obtain a standardized root length of 15 mm by using a diamond disk in an Accutom 50 cutting

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Effectiveness of Different Irrigant Agitation Techniques on Debris and Smear Layer Removal in Curved Root Canals: A Scanning Electron Microscopy Study

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Abstract

Introduction: The aim of this study was to evaluate the cleaning efficacy of different irrigant agitation techniques on debris and smear layer removal in curved root canals. **Methods:** Mesiobuccal root canals of 108 mandibular molars were shaped with nickel-titanium instruments, and a final rinse of NaOCl and ethylenediaminetetraacetic acid was performed. Specimens were assigned to 4 groups (n = 20) and submitted to the following irrigation agitation techniques: no agitation (control), ultrasonic, EndoActivator, and CanalBrush. Root canals were split longitudinally and subjected to scanning electron microscopy. The presence of debris and smear layer at coronal and apical levels was evaluated by using a 5-grade scoring system with 200× and 1000× magnification, respectively. **Results:** Concerning debris removal, no significant differences among groups were detected. In the coronal region, agitation of the irrigants resulted in significantly more smear layer removal than the control. EndoActivator was significantly more effective than ultrasonic agitation and CanalBrush. **Conclusions:** In curved root canals, activation of NaOCl and ethylenediaminetetraacetic acid did not enhance debris removal but resulted in significantly more effective smear layer removal at coronal levels. *(J Endod 2010;36:1983–1987)*

Key Words

Agitation, curved root canals, debris, irrigation, smear layer

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Debridement of the root canal system is essential for endodontic success (1). Nevertheless, chemomechanical preparation does not predictably remove pulp tissue, dentin debris, and smear layer because of the complex nature of root canal anatomy (2, 3). In cases of infected root canals, residual debris and smear layer harbor microorganisms and their by-products. Whereas debris removal is mandatory, removal of the smear layer remains a controversial issue (4, 5). Some authors suggest that the smear layer acts as a barrier and prevents bacterial invasion of the dentinal tubules (6, 7). However, bacteria might survive and multiply in the smear layer (5) and can also penetrate into dentinal tubules (8). In addition, the smear layer might decrease the antimicrobial effectiveness of medicaments (4) or the sealing ability of the root canal filling (9). Despite the lack of clinical data on treatment outcome, a recent review concluded that smear layer removal is recommended for more thorough disinfection of the root canal system and better adaptation of filling materials to canal walls (10).

For optimal effectiveness, irrigants must be brought into direct contact with the entire root canal wall (11), and it was stated that enhancement of the flushing action is necessary to improve root canal cleanliness (12). Different agitation techniques have been proposed to improve the efficacy of irrigation solutions, including agitation with hand files, gutta-percha cones, plastic instruments, and sonic and ultrasonic devices (13). However, conflicting results regarding the effectiveness of these agitation protocols in removing smear layer and debris have been published (14–17), and most of the studies on the effectiveness of irrigation are limited to straight root canals (15, 16). For this reason, improvement of irrigation techniques is necessary to achieve better debridement especially in the apical area of curved root canals.

Although sodium hypochlorite (NaOCl) has been recommended as the main irrigant during endodontic therapy (11), it is not able to dissolve the inorganic components of dentin debris. Therefore, NaOCl in association with a chelating agent such as ethylenediaminetetraacetc acid (EDTA) has been recommended for smear layer removal (4, 5).

The purpose of this investigation was to evaluate the efficacy of different irrigant agitation techniques in removing debris and smear layer from curved root canals.

Materials and Methods

Preparation of Specimens

One hundred eight extracted human mandibular molars with curved mesial roots obtained from no particular age group and collected from several dental offices were randomly selected and stored in tap water throughout the study. Teeth with intact apices, no previous endodontic treatment, and small restorations were included. Exclusion criteria were as follows: root length shorter than 19 mm, extensive restorations, root caries, or fractures. After preparation of the access cavity, a size 10 stainless steel file (VDW, Munich, Germany) was inserted into the mesiobuccal root canals until the tip of the instrument was just visible at the apical foramen. Radiographs were taken in buccolingual direction, and the degree of root canal curvature was determined according to the method of Schneider (18). Teeth with root canal curvatures of less than 20 degrees, calcified root canals, or root canals allowing introduction of an instrument exceeding ISO size 20 to the apical foramen were excluded. The remaining 80 teeth were

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Biofilm removal by 6% sodium hypochlorite activated by different irrigation techniques

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Running Head: Biofilm removal by different irrigation techniques

Keywords: laser activated irrigation, photoacoustic streaming, biofilms, irrigant solutions.

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Abstract

Aim To compare the removal of biofilm utilizing four irrigation techniques on a bovine root canal model.

Methodology Fifty dentine specimens (2x2 mm) were infected with biofilm. The samples were then adapted to previously created cavities in the bovine model. The root canals were irrigated twice with 2

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ORIGINAL RESEARCH

Qualitative comparison of sonic or laser energisation of 4% sodium hypochlorite on an *Enterococcus faecalis* biofilm grown *in vitro*

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Keywords
biofilm, endodontics, *Enterococcus faecalis*, laser energisation, sonic energisation.

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Abstract

The effectiveness of sonic activation, laser activation and syringe irrigation of 4% sodium hypochlorite in removing an *Enterococcus faecalis* biofilm was compared. Biofilms were grown in extracted human single rooted teeth using a flow cell apparatus. After 4 weeks' growth, teeth were subjected to each treatment using 4% sodium hypochlorite and radicular dentinal surfaces of the root canals were analysed by scanning electron microscopy. Results showed that sonic activation and syringe irrigation with sodium hypochlorite showed reduced numbers of bacterial cells on the radicular dentine but were not effective in eliminating *E. faecalis* in the dentinal tubules. Laser activation of sodium hypochlorite resulted in clean dentine walls and undetectable levels of bacteria within dentinal tubules. Qualitatively, sonic or laser activation of 4% NaOCl resulted in greater bacterial reduction compared with syringe irrigation, with laser activation producing the greatest overall reduction.

Introduction

It is well established that the causative agent of endodontic disease is the presence and growth of bacteria in either coronal dentine, the root canal space or radicular dentine (1,2). Therefore, the eradication of bacteria from all of these locations is the ideal in preventing or eliminating apical periodontitis. Studies have shown that teeth with no recoverable bacteria prior to obturation have resulted in a more favourable outcome for endodontic therapy (3), and that when endodontic treatment fails, bacteria are often isolated from the root canals of these teeth (4,5). There are many reasons for endodontic failure, but in teeth in which canals have been well treated and exhibit post-treatment disease, the presence of *Enterococcus faecalis* has been implicated as a primary reason for failure (4,5). As such, endodontic therapy is founded upon three principles: mechanical instrumentation; irrigation with antimicrobial agents; and placement of an intracanal medicament (6). The complex anatomy of the root canal system often prevents the penetration of irrigants and medicaments into recesses that cannot be accessed by mechanical instrumentation. The advent of sonic, ultrasonic and laser instruments has led to many investigations looking into their potential for the energising of irrigants (7–9). However, most of these studies have concentrated on the removal of dentinal debris and smear layer.

There has been a resurgence of interest in the energising of irrigants in endodontic treatment (10). Recently, a new sonic instrument, the EndoActivator® (Dentsply, Maillefer, Ballaigues, Switzerland), has been introduced which reportedly produces 'vigorous intracanal fluid agitation' by both 'acoustic streaming and cavitation' (11). de Gregorio *et al*. (7) compared this instrument with passive ultrasonic irrigation and found no significant differences in the ability to remove debris from simulated lateral canals of single-rooted extracted teeth. Jiang *et al*. (12) also found that the EndoActivator® was less effective than ultrasonic activation of a 2% sodium hypochorite (NaOCl) solution.

Laser-induced energising of irrigants causes cavitation and subsequent implosions which produce pressure waves accelerating fluid to a velocity of up to 20 m s^{-1} (13). Laser-energised irrigation has been shown to remove dentinal debris more effectively when compared with conventional syringe irrigation and ultrasonic energised irrigation (13,14). However, there are considerations with regard to safety as apical extrusion of the irrigant can occur (15).

Sodium hypochlorite is the most widely used endodontic irrigant in contemporary endodontic practice, and is

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Photodynamic Therapy Associated with Conventional Endodontic Treatment in Patients with Antibiotic-resistant Microflora: A Preliminary Report

Aguinaldo S. Garcez, PhD, Silvia C. Nuñez, PhD,[†] Michael R. Hamblim, PhD,[‡§||] Hideo Suzuki,* and Martha S. Ribeiro, PhD[¶]*

Abstract

Introduction: This study reports the antimicrobial effect of photodynamic therapy (PDT) combined with endodontic treatment in patients with necrotic pulp infected with microflora resistant to a previous antibiotic therapy. **Methods:** Thirty anterior teeth from 21 patients with periapical lesions that had been treated with conventional endodontic treatment and antibiotic therapy were selected. Microbiological samples were taken (1) after accessing the root canal, (2) after endodontic therapy, and (3) after PDT. **Results:** All the patients had at least 1 microorganism resistant to antibiotics. PDT used polyethylenimine chlorin(e6) as a photosensitizer and a diode laser as a light source (P = 40 mW, t = 4minutes, E = 9.6 J). Endodontic therapy alone produced a significant reduction in numbers of microbial species but only 3 teeth were free of bacteria, whereas the combination of endodontic therapy with PDT eliminated all drug-resistant species and all teeth were bacteria-free. **Conclusions:** The use of PDT added to conventional endodontic treatment leads to a further major reduction of microbial load. PDT is an efficient treatment to kill multi-drug resistant microorganisms. *(J Endod 2010;36:1463–1466)*

Key Words

Antibiotic resistant bacteria, endodontic re-treatment, laser, photodynamic therapy

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In the case of endodontic treatment failure, retreatment, surgical treatment, or extraction usually is carried out with the use of antibiotics and antiseptics as adjunctive therapies, but the long-term use of these agents can be rendered ineffective by resistance developing in the target organism (1). Currently, there is an emergence of bacteria with multiple resistances, and there is a need for alternative antimicrobial approaches (2–6).

The combination of conventional endodontic therapy and photodynamic therapy (PDT) has been shown as an effective approach in reducing bacterial load in *in vitro* and *in vivo* models (7–11).

This study investigated the combination of PDT with endodontic treatment in patients with necrotic pulp harboring microflora resistant to a previous antibiotic therapy.

Materials and Methods

Thirty teeth from 21 patients with periapical lesions who had been previously treated with endodontic treatment associated with antibiotic were selected. The patients were in good health and between the ages of 17 and 52 years. All the teeth presented sights and symptoms of periapical periodontitis and apical bone lesion detected by radiography, and some patients had pain by vertical percussion and/or local edema, all requiring root canal retreatment on teeth with closed apices. The same practitioner carried out this study in a private dental office in São Paulo, Brazil. The protocol was approved by the Institutional Review Board of the São Paulo University, and all procedures were conducted according to the principles of the Declaration of Helsinki.

Endodontic Treatment

Thirty root canals from anterior teeth were re-treated and received endodontic treatment followed by PDT. Microbiological samples were taken after accessing the root canal, after endodontic therapy, and after PDT. The first microbiological sample confirmed that all the patients had at least 1 microorganism resistant to antibiotic medication.

A periapical radiograph was taken for each case to determine the presence of apical lesion, the canal morphology, and its length.

The access to the pulp chamber was gained after installation of a rubber dam, and then the surrounding area received prophylactic asepsis and was irrigated with 5 mL of chlorhexidine solution at 2% to ensure that the crown of the tooth had minimal microbial load (8).

Once the canal was accessed, a Hedström file #15 (Maillefer Instruments SA, Ballaigues, Switzerland) was inserted inside the canal to remove the gutta-percha and root canal sealer obturation; then the root canal was irrigated with 1 mL of sterile saline solution. The canal was dried with 3 sterile paper points (Dentsply Latin America, Petropolis, Brazil) and left inside the root canal for 1 minute each. All 3 paper points were combined for microbiological analysis. This procedure was the first microbiological sampling representing the initial contamination. The paper points were deposited in a fresh sterile bottle with sterile nutrient broth.

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Enhanced Removal of *Enterococcus faecalis* Biofilms in the Root Canal Using Sodium Hypochlorite Plus Photon-Induced Photoacoustic Streaming: An *In Vitro* Study

Mohammed Al Shahrani, BDS,[1] Enrico DiVito, DDS,[2,3] Christopher V. Hughes, DMD, PhD,[4,5]
Dan Nathanson, DMD, MSD,[6] and George T.-J. Huang, DDS, MSD, DSc[1,7]

Abstract

Objective: The purpose of this study was to determine the effectiveness of laser-activated irrigation by photon-induced photoacoustic streaming (PIPS) using Er:YAG laser energy in decontaminating heavily colonized root canal systems *in vitro*. ***Materials and methods:*** Extracted single-rooted human teeth ($n=60$) were mechanically and chemically prepared, sterilized, inoculated with *Enterococcus faecalis* for 3 weeks, and randomly assigned to four groups ($n=15$): Group I (control, no decontamination), Group II (PIPS + 6% NaOCl), Group III (PIPS + saline), and Group IV (6% NaOCl). PIPS settings were all preset to 50 μsec pulse, 20 mJ, 15 Hz, for an average power of 0.3 W. After decontamination, the remaining live microbes from all specimens were collected and recovered via plate counting of the colony-forming units (CFUs). Randomized root canal surfaces were examined with scanning electron microscopy and confocal laser microscopy. Mean variance and Dunnett's *t* test (post-hoc test) comparisons were used to compare mean scores for the three groups with the control group. ***Results:*** The CFU analysis showed the following measurements (mean ± SE): Group I (control), 336.8 ± 1.8; Group II (PIPS + NaOCl), 0.27 ± 0.21; Group III (PIPS + saline), 225.0 ± 21; and Group IV (NaOCl), 46.9 ± 20.29. Group II had significantly lower CFUs than any other groups ($p<0.05$). Both imaging analyses confirmed levels of remaining bacteria on examined root surfaces. ***Conclusions:*** The use of the PIPS system along with NaOCl showed the most efficient eradication of the bacterial biofilm. It appears that laser-activated irrigation (LAI) utilizing PIPS may enhance the disinfection of the root canal system.

Introduction

Effective cleaning and shaping of the root canal system to maximally eliminate microbes is a prerequisite for successful endodontic treatment.[1–3] One important aspect of successful treatment involves the irrigant selected as well as how it is delivered and agitated.[4] Various approaches to agitate the irrigant have been tested. Sonic and ultrasonic irrigation techniques appear to be more effective than syringe irrigation alone.[4–6] Laser-activated irrigation (LAI) utilizing laser energy has been found to enhance the irrigation efficacy of NaOCl.[7,8] This is because the Er:YAG's wavelength is absorbed more effectively by the water molecules within the irrigants, resulting in more aggressive irrigant agitation.[9–11]

A new LAI system device that has been recently introduced, photon-induced photoacoustic streaming (PIPS), uses a very low power source (subablative) to rapidly pulse laser light energy, which is absorbed by the molecules within the irrigant. This transfer of energy results in a series of rapid and powerful shockwaves, capable of forcefully propelling the irrigant throughout the entire root canal system.[12,13] The specially designed Er:YAG laser-based PIPS tip utilizes a

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SHORT COMMUNICATION

Irrigant flow during photon-induced photoacoustic streaming (PIPS) using Particle Image Velocimetry (PIV)

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Abstract

Objectives This study aimed to compare fluid movements generated from photon-induced photoacoustic streaming (PIPS) and passive ultrasonic irrigation (PUI).

Materials and methods Particle Image Velocimetry (PIV) was performed using 6-μm melamine spheres in water. Measurement areas were 3-mm-long sections of the canal in the coronal, midroot and apical regions for PIPS (erbium/yttrium-aluminium garnet (Er:YAG) laser set at 15 Hz with 20 mJ), or passive ultrasonic irrigation (PUI, non-cutting insert at 30 % unit power) was performed in simulated root canals prepared to an apical size #30/0.04 taper. Fluid movement was analysed directly subjacent to the apical ends of ultrasonic insert or fiber optic tips as well as at midroot and apically.

Results During PUI, measured average velocities were around 0.03 m/s in the immediate vicinity of the sides and tip of the ultrasonic file. Speeds decayed to non-measureable values at a distance of about 2 mm from the sides and tip. During PIPS, typical average speeds were about ten times higher than those measured for PUI, and they were measured throughout the length of the canal, at distances up to 20 mm away.

Conclusions PIPS caused higher average fluid speeds when compared to PUI, both close and distant from the instrument. The findings of this study could be relevant to the debriding and disinfecting stage of endodontic therapy.

Clinical relevance Irrigation enhancement beyond needle irrigation is relevant to more effectively eradicate microorganisms from root canal systems. PIPS may be an alternative approach due to its ability to create high streaming velocities further away from the activation source compared to ultrasonic activation.

Keywords Particle image velocimetry · Photon-induced photoacoustic streaming · Ultrasonics · Endodontics · Irrigation

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Introduction

An important aim of root canal treatment is the elimination or prevention of periradicular periodontitis; it is well established that bacteria and their toxins are the cause of this disease [13] and therefore eradication, or at least reduction to a biologically acceptable number, of intracanal microorganisms is required [23]. Enlargement of root canals with current root canal instruments reduces bacterial counts even in the case of buccolingually wide root canals [24]. However, preparation does not eliminate all microorganisms from the root canal system. Therefore, antimicrobial irrigants are commonly used and it is believed that enhancement of the flushing action is effective in improving root canal cleanliness [2, 11]. Different agitation techniques have been proposed to improve the efficacy of irrigation solutions, including agitation with hand

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Enhanced Removal of *Enterococcus faecalis* Biofilms in the Root Canal Using Sodium Hypochlorite Plus Photon-Induced Photoacoustic Streaming: An *In Vitro* Study

Mohammed Al Shahrani, BDS,[1] Enrico DiVito, DDS,[2,3] Christopher V. Hughes, DMD, PhD,[4,5] Dan Nathanson, DMD, MSD,[6] and George T.-J. Huang, DDS, MSD, DSc[1,7]

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Objective: The purpose of this study was to determine the effectiveness of laser-activated irrigation by photon-induced photoacoustic streaming (PIPS) using Er:YAG laser energy in decontaminating heavily colonized root canal systems *in vitro*. ***Materials and methods:*** Extracted single-rooted human teeth ($n = 60$) were mechanically and chemically prepared, sterilized, inoculated with *Enterococcus faecalis* for 3 weeks, and randomly assigned to four groups ($n = 15$): Group I (control, no decontamination), Group II (PIPS + 6% NaOCl), Group III (PIPS + saline), and Group IV (6% NaOCl). PIPS settings were all preset to 50 μsec pulse, 20 mJ, 15 Hz, for an average power of 0.3 W. After decontamination, the remaining live microbes from all specimens were collected and recovered via plate counting of the colony-forming units (CFUs). Randomized root canal surfaces were examined with scanning electron microscopy and confocal laser microscopy. Mean variance and Dunnett's *t* test (post-hoc test) comparisons were used to compare mean scores for the three groups with the control group. ***Results:*** The CFU analysis showed the following measurements (mean ± SE): Group I (control), 336.8 ± 1.8; Group II (PIPS + NaOCl), 0.27 ± 0.21; Group III (PIPS + saline), 225.0 ± 21; and Group IV (NaOCl), 46.9 ± 20.29. Group II had significantly lower CFUs than any other groups ($p < 0.05$). Both imaging analyses confirmed levels of remaining bacteria on examined root surfaces. ***Conclusions:*** The use of the PIPS system along with NaOCl showed the most efficient eradication of the bacterial biofilm. It appears that laser-activated irrigation (LAI) utilizing PIPS may enhance the disinfection of the root canal system.

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A new LAI system device that has been recently introduced, photon-induced photoacoustic streaming (PIPS), uses a very low power source (subablative) to rapidly pulse laser light energy, which is absorbed by the molecules within the irrigant. This transfer of energy results in a series of rapid and powerful shockwaves, capable of forcefully propelling the irrigant throughout the entire root canal system.[12,13] The specially designed Er:YAG laser-based PIPS tip utilizes a

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RESEARCH

VERIFIABLE CPD PAPER

IN BRIEF

- Bacteria are responsible for the most commonly encountered dental diseases including pulpal pathology.
- The success rate of endodontics relies on the root canal system being rendered bacteria free.
- Conventional chemo-mechanical canal preparation techniques are unable to disinfect the canals predictably and consistently.
- PAD offers potential to eliminate bacteria from the root canals especially where conventional techniques have failed to do so.

Microbiological evaluation of photo-activated disinfection in endodontics (An *in vivo* study)

S. J. Bonsor,[1] R. Nichol,[2] T. M. S. Reid[3] and G. J. Pearson[4]

Objective To determine the microbiological effect of photoactivated disinfection (PAD) as an adjunct to normal root canal disinfection *in vivo*.
Design A randomised trial carried out in general dental practice.
Subjects and methods Patients presenting with symptoms of irreversible pulpitis or periradicular periodontitis requiring endodontic therapy were selected at random. A microbiological sample of the canal was taken on accessing the canal, after conventional endodontic therapy, and finally after the PAD process (photosensitiser and light) had been carried out on the prepared canal. All three samples from each canal were plated within 30 minutes of sampling and cultured anaerobically for five days. Growth of viable bacteria was recorded for each sample to determine bacterial load.
Results Thirty of the 32 canals were included in the results. Cultures from the remaining two did not reach the laboratory within the target time during which viability was sustained. Of the remaining 30, 10 canals were negative to culture. These were either one of the canals in multi rooted teeth where the others were infected or where a pre-treatment with a poly-antibiotic paste had been applied to hyperaemic vital tissue. Sixteen of the remainder were negative to culture after conventional endodontic therapy. Three of the four which had remained infected cultured negative after the PAD process. In the one canal where culturable bacteria were still present, a review of the light delivery system showed a fracture in the fibre reducing the effective light output by 90%.
Conclusions The PAD system offers a means of destroying bacteria remaining after using conventional irrigants in endodontic therapy.

INTRODUCTION

It is well established that the elimination of pathogens from root canals during endodontic treatment is difficult[1,2] and current endodontic techniques are unable to consistently disinfect the canal.[3,4] Mechanical preparation of the canal leaves a smear layer on the surface of the canal wall occluding the entrances to any patent dentinal tubules.[5] Furthermore it is a site for accumulation of bacteria within the layer itself. This together with the irregular cross section of the canal and complex internal anatomical morphology[6] result in areas where residual bacteria can accumulate and adversely affect the outcome of any endodontic therapy.[7] To assist in the cleaning and debridement of the canal a range of irrigating and disinfecting solutions have been used. The one which predominates is sodium hypochlorite used in concentrations ranging from 0.2-5%.[8] Chelating agents such as EDTA and citric acid are used as adjuncts to remove the smear layer allowing access to the tubules.[9] Additionally disinfectants such as iodine potassium iodide (IKI) are also known to penetrate into the dentine.[10]

The choice of sodium hypochlorite as an irrigating solution is in part because of its effect on any residual soft tissue, as well as destroying bacteria with the free chlorine in the solution. However since this free chlorine is used up during this process, the volume of solution required is large, the process slow[11] and there is still a substantial risk of bacterial contamination.[12]

There are only a limited number of references to the presence of bacteria leading to higher incidence of failed endodontic treatments: this is primarily because of the difficulty of carrying out microbiological culture work. However, studies have shown that in those cases where negative cultures have been obtained at time of obturation, there is a 94% success rate. When obturation is performed and the cultures are positive, the success rate is reduced to 68%[4] confirming previous studies showing that failure of healing is more likely when the canals are obturated in the presence of persistent infection.[13,14]

Recently a novel method of disinfection for use in both caries and endodontics has become available. This is photo activated disinfection – PAD™. The principle on which it operates is that photosensitiser molecules attach to the membrane of the bacteria. Irradiation with light at a specific wavelength matched to the peak absorption of the photosensitiser leads to the production of singlet oxygen, which causes the bacterial cell wall to rupture killing the bacteria.[15] Extensive laboratory studies have shown that an important aspect of this system is that the two components when used independently of one another produce no effect on bacteria or on normal tissue. It is only the combination of photosensitiser and light which produces the effect on the bacteria.[15-17]

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REVIEW

Photodynamic therapy for localized infections—State of the art

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KEYWORDS
Photodynamic therapy;
Photosensitizer;
Localized infection;
Bacteria;
Virus;
Fungus;
Skin;
Wound;
Burn

Summary Photodynamic therapy (PDT) was discovered over 100 years ago by observing the killing of microorganisms when harmless dyes and visible light were combined in vitro. Since then it has primarily been developed as a treatment for cancer, ophthalmologic disorders and in dermatology. However, in recent years interest in the antimicrobial effects of PDT has revived and it has been proposed as a therapy for a large variety of localized infections. This revival of interest has largely been driven by the inexorable increase in drug resistance among many classes of pathogen. Advantages of PDT include equal killing effectiveness regardless of antibiotic resistance, and a lack of induction of PDT resistance. Disadvantages include the cessation of the antimicrobial effect when the light is turned off, and less than perfect selectivity for microbial cells over host tissue. This review will cover the use of PDT to kill or inactivate pathogens in ex vivo tissues and in biological materials such as blood. PDT has been successfully used to kill pathogens and even to save life in several animal models of localized infections such as surface wounds, burns, oral sites, abscesses and the middle ear. A large number of clinical studies of PDT for viral papillomatosis lesions and for acne refer to its antimicrobial effect, but it is unclear how important this microbial killing is to the overall therapeutic outcome. PDT for periodontitis is a rapidly growing clinical application and other dental applications are under investigation. PDT is being clinically studied for other dermatological infections such as leishmaniasis and mycobacteria. Antimicrobial PDT will become more important in the future as antibiotic resistance is only expected to continue to increase.
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86.

Antimicrobial Photodynamic Therapy for the Treatment of Teeth with Apical Periodontitis: A Histopathological Evaluation

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Abstract

Introduction: This study evaluated the *in vivo* response of apical and periapical tissues of dogs' teeth with apical periodontitis after one-session endodontic treatment with and without antimicrobial photodynamic therapy (aPDT). **Methods:** Sixty root canals with experimentally induced apical periodontitis were instrumented and assigned to 4 groups receiving aPDT and root canal filling (RCF) or not: group aPDT+/RCF+ (n = 20): aPDT (photosensitizer phenothiazine chloride at 10 mg/mL for 3 minutes and diode laser [λ = 660 nm, 60 mW/cm^2] for 1 minute) and RCF in the same session; group aPDT+/RCF− (n = 10); group aPDT−/RCF+ (n = 20), and group aPDT−/RCF− (n = 10). Teeth were restored, and the animals were killed after 90 days. Sections from the maxillas and mandibles were stained with hematoxylin-eosin and Mallory trichrome and examined under light microscopy. Descriptive (ie, newly formed apical mineralized tissue, periapical inflammatory infiltrate, apical periodontal ligament thickness, and mineralized tissue resorption) and quantitative (ie, periapical lesion size and number of inflammatory cells) microscopic analysis was performed. Quantitative data were analyzed by the Kruskal-Wallis and Dunn tests (α = .05). **Results:** In the aPDT-treated groups, the periapical region was moderately/severely enlarged with no inflammatory cells, moderate neoangiogenesis and fibrogenesis, and the smallest periapical lesions. **Conclusions:** Although apical closure by mineralized tissue deposition was not achieved, the absence of inflammatory cells, moderate neoangiogenesis, and fibrogenesis in the periapical region in the groups treated with aPDT indicate that this can be a promising adjunct therapy to cleaning and shaping procedures in teeth with apical periodontitis undergoing one-session endodontic treatment. *(J Endod 2012;38:360–366)*

Key Words

Antimicrobial photodynamic therapy, apical periodontitis, endodontic treatment

The effective control of bacterial infection in the root canal system is critical for the post-treatment success of endodontic therapy. It has been shown that the endodontic infection in teeth with pulp necrosis and apical periodontitis is of a polymicrobial nature with a high prevalence of anaerobic microorganisms, particularly gram-negative bacteria (1), which ultimately disseminate throughout the root canal system and reach the outer root surface (apical biofilm) (2). The extraradicular infection is inaccessible to the cleaning and shaping procedures, allowing persistence and multiplication of microorganisms and leading to low success rates when no antibacterial medication is used and one-appointment endodontic therapy is performed (3).

Photodynamic therapy (PDT) has emerged as a treatment strategy for eradicating target cells, involving the use of light of a specific wavelength to activate a nontoxic light-sensitive compound (known as photosensitizer) in the presence of oxygen (4, 5). The absorption of photons from the light source by the activated photosensitizer leads it to a triple state of excitation, resulting in energy or electron transfer to available molecular oxygen with consequent formation of highly reactive oxygen species (ROS), such as singlet oxygen and free radicals. This action produces a cascade of oxidative events that ultimately kill microorganisms by causing irreversible damage to essential intracellular molecules including proteins, membrane lipids, and nucleic acids (6). Photodynamic inactivation of microorganisms by local application of photosensitizer and light limits the action of ROS and avoids systemic harmful effects on "friendly" bacterial flora (7). In addition, unlike antibiotics, which have a single target in the microbial cell, ROS generated from the photodynamic reaction has a multifunctional nature and can damage multiple cellular structures, reducing the chances of the development of PDT-resistant bacterial strains (8).

As any treatment modality, antimicrobial PDT (aPDT) should ideally have the capacity to destroy the microorganisms responsible for the disease without causing damage to the host's surrounding healthy tissues. Low toxicity and rapidity of effect are desirable qualities of aPDT (9). It has been established that photosensitizers, which have a strong cationic charge, can rapidly bind and penetrate bacterial cells, and, thus, these compounds show a high degree of selectivity for microorganisms over host cells (10). However, even though studies (11, 12) have concluded that aPDT is less damaging to the host tissues, the concentration used for cytotoxicity assessment in these studies is usually lower than that of bacterial killing. Selectivity toward bacteria

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87.

Augmenting the Antibiofilm Efficacy of Advanced Noninvasive Light Activated Disinfection with Emulsified Oxidizer and Oxygen Carrier

Saji George, PhD, and Anil Kishen, MDS, PhD

Abstract

In this study, we tested the hypothesis that the inclusion of an oxidizer and oxygen carrier in the photosensitization formulation would facilitate comprehensive disinfection of matured endodontic biofilm by light-activated disinfection (LAD). Photosensitizing formulations containing methylene blue (MB) and an oxygen carrier alone (perfluorodecahydronaphthalene) (PF1) or in combination with oxidizer (H_2O_2) (PF2) or their emulsions formed with triton-X100 (Bio-Rad Laboratories, Hercules, CA) in different proportions (PF3 and PF4) were tested for photochemical properties and damage to the biofilm structure using confocal laser scanning microscopy. Conventional chemomechanical preparation, LAD using MB in water, and LAD using MB in emulsion (PF4) were also conducted on 10-week-old *Enterococcus faecalis* biofilm within root canals. MB in emulsion (PF4) was overall the most effective photosensitizer formulation for photooxidation, generation of singlet oxygen ($p = 0.001$), and in disinfecting biofilm bacteria. Advanced noninvasive LAD using a photosensitizer formulation containing oxidizer and oxygen carrier disrupted the biofilm matrix and facilitated comprehensive inactivation of biofilm bacteria. This modified photosensitizer formulation will have potential advantages in endodontic disinfection. *(J Endod 2008;34:1119–1123)*

Key Words

Biofilm, emulsion, endodontics, oxidizer, oxygen carrier, photodynamic therapy

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Bacterial biofilm in the root canal system that evokes inflammatory response can lead to apical periodontitis (1, 2). Conventionally, disinfection of the root canal is sought by a "chemomechanical" approach that involves cleaning and shaping of the root canal system by the application of a chemical disinfectant and mechanical instrumentation (3). Nonetheless, this technique often fails to eradicate bacterial biofilms completely, mostly because of various microbiological and anatomical factors (2, 4–6). Endodontic pathogens such as *Enterococcus faecalis* have been reported to form a biofilm even on medicated root canals, which is regarded as one of the reasons for its persistence in the posttreatment endodontic environment (7). The phenotypic and genotypic variation of biofilm bacteria when compared with their "free-floating" counterparts, complemented by the structure and composition of biofilm matrix, contribute to their high antimicrobial resistance (8–10).

Recently, many *in vitro* and *in vivo* studies have highlighted the potential of light-activated disinfection (LAD) that involves the use of a photosensitizer and low-level light for treating localized bacterial infections (11–13). During LAD, the photoactivated photosensitizer molecule can either transfer an electron to the neighboring molecule (type-1 reaction) or its energy to molecular oxygen (type-2 reaction) to generate highly reactive oxygen species, mostly singlet oxygen. The killing of bacteria by LAD can be induced by either of these photoreactions; however, a type 2 reaction, which generates highly reactive singlet oxygen ($_1O^2$), is regarded as the principle bactericidal agent. Unlike antibiotics, the emergence of "LAD-resistant" bacterial strains is highly unlikely because the oxygen-based free radicals act on multiple targets in a bacterial cell (14, 15).

LAD conducted on endodontic biofilms has very often failed to achieve complete eradication, prompting many workers to combine LAD with conventional antimicrobial strategies for superior performances (16–21). Nevertheless, many workers have overlooked the necessity of designing "tissue-specific LAD conditions." This is because the physicochemical environment existing at the site of application may influence the "photodynamic effect" during light activation of a photosensitizer. For example, the "hypooxygenic" nature of bacteria-infected anatomic sites such as a root canal may adversely affect the outcome of LAD because molecular oxygen is a prerequisite for the generation of singlet oxygen (1, 22). In addition, the cumulative increase in the thickness and calcification of biofilm matrix during maturation would create a photosensitizer and oxygen-concentration gradients across the thickness of biofilm (1, 9, 10, 22).

Consequently, a combination of a photosensitizer and light may not be sufficient for the effective eradication of endodontic biofilm. We had previously reported the advantages of an advanced noninvasive light-activated disinfection (ANILAD) strategy for the eradication of endodontic biofilm (13, 23). In the first step of this dual-staged approach, sensitization was performed by using a photosensitizer dissolved in a formulation that enhanced not only the photochemical properties of photosensitizer but also allowed better diffusion of a photosensitizer into the anatomic complexities of the root canal system. In the second step, an oxygen-carrier solution was applied to enhance the oxygen availability and to facilitate light propagation during the irradiation phase. Although ANILAD performed better than conventional LAD, the bactericidal effect was significantly less in matured biofilm models (24). The increased thickness and calcification of matured biofilm matrix was thought to contribute to its resistance (9).

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Photophysical, photochemical, and photobiological characterization of methylene blue formulations for light-activated root canal disinfection

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Abstract. Tissue-specific modification of treatment strategy is proposed to increase the antimicrobial activity of light-activated therapy (LAT) for root canal disinfection. Methylene blue (MB) dissolved in different formulations: water, 70% glycerol, 70% poly ethylene glycol (PEG), and a mixture of glycerol:ethanol:water (30:20:50) (MIX), is analyzed for photophysical, photochemical, and photobiological characteristics. Aggregation of MB molecules, as evident from monomer to dimer ratio, depends on the molar concentrations of MB, which is significantly higher in water compared to other formulations. MIX-based MB formulation effectively penetrates the dentinal tubules. Although, the affinity of MB for *Enterococcus faecalis* (gram positive) and *Actinomycetes actinomycetemcomitans* (gram negative) was found to be high in the water-based formulation, followed by MIX, the MIX-based formulation significantly enhanced the model substrate photooxidation and singlet oxygen generation compared to MB dissolved in other formulations. Finally, the efficacy of LAT is evaluated on biofilms produced by both organisms under *in vitro* and *ex vivo* conditions. A dual-stage approach that applies a photosensitization medium and an irradiation medium separately is tested. The MIX-based photosensitization medium in combination with dual-stage approach demonstrates thorough disinfection of the root canal with bacterial biofilms. This method will have potential application for root canal disinfection. © *2007 Society of Photo-Optical Instrumentation Engineers.* [DOI: 10.1117/1.2745982]

Keywords: photodynamic therapy; lasers in medicine; endodontic infection; dentine; antimicrobial.

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1 Introduction

Root canal infection, also known as apical periodontitis involves inflammation and destruction of periradicular tissues adjacent to the root apex of a tooth. This is primarily caused by the presence of bacterial biofilms within the root canal system of the tooth.[1,2] Apical periodontitis is not self-healing, since microbes established in the "secluded" sanctuaries of the root canal system cannot be completely resolved by the host immune defense.[3] The principal treatment involves the elimination of microbial flora from the root canal system. Conventionally, disinfection of the root canal is achieved by combining mechanical instrumentation with caustic chemicals[4] (the chemomechanical approach). Nevertheless, complete disinfection of the root canal is not achieved, though in most cases the clinical symptoms recede.[5,6] Major factors limiting the elimination of bacteria by conventional treatment are the inability of chemical disinfectant to destroy bacteria residing in the dentinal tubules and anatomical complexities of the root canal, and the inability of the antimicrobial agents to eliminate certain species of bacteria and bacterial biofilm.[6–8] The biochemical composition of biofilm matrix and the altered physiology of biofilm bacteria may contribute toward the observed resistance to antimicrobial agents.[8–10] In fact, *Enterococcus faecalis* has shown the ability to produce biofilm on root canal wall medicated with calcium hydroxide, one of the most widely used intracanal medicament.[11] In addition to the preceding shortcomings, the indiscriminate use of caustic chemicals has been reported to adversely affect the chemical and mechanical properties of dentine.[12,13]

Recently, light-activated therapy (LAT), generally known as photodynamic therapy, is showing great potential in the treatment of localized bacterial infections.[14,15] The killing of bacteria by LAT can be induced by two photoreactions: (1) a type I reaction, where the electron transfer between the triplet state sensitizer and biomolecules results in the generation of several radical species, which can cause cell damage, and (2) a type II reaction, where the energy transfer from the triplet state sensitizer to molecular oxygen produces singlet oxygen

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Photodynamic Therapy for Endodontic Disinfection

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Abstract

The aims of this study were to investigate the effects of photodynamic therapy (PDT) on endodontic pathogens in planktonic phase as well as on *Enterococcus faecalis* biofilms in experimentally infected root canals of extracted teeth. Strains of microorganisms were sensitized with methylene blue (25 μg/ml) for 5 minutes followed by exposure to red light of 665 nm with an energy fluence of 30 J/cm^2. Methylene blue fully eliminated all bacterial species with the exception of *E. faecalis* (53% killing). The same concentration of methylene blue in combination with red light (222 J/cm^2) was able to eliminate 97% of *E. faecalis* biofilm bacteria in root canals using an optical fiber with multiple cylindrical diffusers that uniformly distributed light at 360 degrees. We conclude that PDT may be developed as an adjunctive procedure to kill residual bacteria in the root canal system after standard endodontic treatment. *(J Endod 2006;32:979–984)*

Key Words

Biofilms, endodontic bacteria, *Enterococcus faecalis*, methylene blue, photodynamic therapy, root canals

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The goal of endodontic treatment is to prevent and, when required, to cure endodontic disease, apical periodontitis (1). This principle is supported by classic studies that demonstrate significantly higher success rates, by approximately 10% in teeth that are minimally infected at the time of treatment, compared to grossly infected teeth with necrotic pulps (2). Similarly, teeth that give a negative culture for bacterial growth at the time of root canal filling have a higher success rate than teeth that are culture positive 12-26% higher) (3). Although the bulk of the infecting microorganisms are removed during endodontic instrumentation, residual bacteria are readily detectable in approximately one-half of teeth at the time of placement of a filling material, despite extensive irrigation with sodium hypochlorite (NaOCl) (4). Recently, Nair et al. (2005) detected histologically biofilm bacteria in intercanal isthmi and accessory canals of the apical 3 mm in 14 of 16 teeth, which was surgically removed on completion of the root canal treatment in a single visit (5). Scanning electron microscopic investigations have demonstrated bacterial penetration up to 1000 μm into dentinal tubules in a laboratory model (6). The presence of a smear layer after instrumentation reduces the effectiveness of irrigants and temporary dressings in disinfecting dentinal tubules (7). Additionally, the complexity of the root canal system with its isthmuses, ramifications, and dentinal tubules make complete debridement of bacteria with instrumentation and irrigation alone almost impossible (8).

Microorganisms associated with endodontic failures can be detected in the majority of failing cases using cultural methods, and can be identified in virtually all cases using PCR amplification of the microbial 16S rRNA genes (9, 10). The data indicate that the bacteria present in treatment failures are distinct from those present in infected root canals before endodontic treatment. Failing cases are associated with high proportions of gram-positive aerobic and facultative organisms, versus the predominance of strict anaerobes at presentation. This scenario has been substantiated in controlled studies that examined changes in residual root canal bacteria after treatment; facultative bacteria were more resistant to treatment than anaerobes in a monkey model (11). *Enterococcus faecalis*, which is rarely found in large proportions in untreated root canals, is highly associated with failures (12). However, some studies have failed to detect *E. faecalis* and have implicated other taxa including *Pseudomonas*, *Staphylococci*, and *Streptococci* as causative of failures (9, 13). 16S rRNA analyses have given an even more diverse picture of bacteria associated with failure, with species including *Pseudoramibacter*, *Proprionibacterium*, *Dialister*, and *Filifactor* in addition to *Enterococcus* (10). Large numbers of isolates including *Actinomyces*, *Streptococci*, *Peptostreptococcus*, and *Prevotella* in addition to *Enterococci* have also been reported (14).

Photodynamic therapy (PDT) has been used as a treatment for cancer and other nonmalignant diseases (15). PDT is based on the concept that a certain, nontoxic, photosensitizing agent known as photosensitizer (PS) can be preferentially localized in certain tissues and subsequently activated by light of the appropriate wavelength to generate singlet oxygen and free radicals that are cytotoxic to cells of the target tissue (16). Although visible light can also kill bacteria after their treatment with an appropriate PS (17), PDT has never been used to treat any specific bacterial infections in humans. Gram-negative bacteria are less susceptible to photoinactivation compared with gram-positive species (18); however, PS bearing a cationic charge can increase their killing (19, 20). A wide range of oral bacteria could be killed by red light after

RESEARCH

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IN BRIEF

- Bacteria must be eliminated from the root canal system prior to obturation for endodontic treatment to be successful.
- Sodium hypochlorite solution is the most effective endodontic irrigant in current usage, but it is not effective against all the bacteria found in the root canal system.
- Photo-Activated Disinfection (PAD) offers the potential to effectively kill endodontic bacteria with fewer toxic effects and more quickly than with sodium hypochlorite solution.

An alternative regimen for root canal disinfection

S. J. Bonsor,[1] R. Nichol,[2] T. M. S. Reid[3] and G. J. Pearson[4]

Objective To compare the effect of a combination of 20% citric acid solution and photo-activated disinfection with the use of 20% citric acid and 2.25% sodium hypochlorite solutions on bacterial load on the dentine walls in prepared canals *in vivo*.
Subjects and methods Sixty-four randomly selected cases were evaluated and allocated to one of two groups. In Group 1, after gaining access to the root canal, bacterial load on the canal walls was sampled using endodontic files. A further sample was taken after apex location and initial widening of the canal had been completed and the photo-activated disinfection process carried out. A final sample was taken after completion of the canal preparation using citric acid and sodium hypochlorite solutions. In Group 2, the initial sample was taken as described previously. A second sample was taken after conventional preparation using 20% citric acid and sodium hypochlorite solutions as co-irrigants. A final sample was then taken after a subsequent PAD treatment. All samples were cultured for facultative anaerobic bacteria.
Results Of the canals treated in Group 1 only two of the 23 canals infected showed culturable bacteria after the use of citric acid and photo-activated disinfection. Of these two canals, one was free of culturable bacteria on completion of conventional treatment but the other still contained culturable bacteria. In Group 2, four canals of the 23 infected initially, remained contaminated after conventional treatment. After subsequent photo-activated disinfection three of these four canals were free of culturable bacteria.
Conclusion Results indicate that the use of a chelating agent acting as a cleaner and disrupter of the biofilm and photo-activated disinfection to kill bacteria is an effective alternative to the use of hypochlorite as a root canal cleaning system.

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INTRODUCTION

In the preparation of a root canal both the efficient instrumentation to shape and the effective cleaning and disinfecting of the walls and lumen of the canal are essential for a successful outcome to treatment.[1] It is widely recognised that residual bacterial contamination of the canals is likely to lead to failure.[2-4] Therefore bacteria remaining within a canal after chemo-mechanical preparation must be reduced to a minimum for successful treatment.

It is generally accepted that the effective elimination of bacteria requires the initial cleaning of the canal by removal of the smear layer[5,6] and the subsequent break up of the biofilm leaving the bacteria accessible to the disinfecting agent. There are a range of materials which will remove the smear and/or disturb the biofilm structure. These include sodium hypochlorite, EDTA, citric acid and polyacrylic acid.[7-12] Of the irrigants used, sodium hypochlorite is currently preferred by most clinicians as it exhibits a proteolytic effect as well as being a disinfectant.

However, for its bactericidal effect, sodium hypochlorite relies heavily on the duration of time retained in the canal and the use of copious volumes of the solution since it is the free chlorine which acts as the disinfecting agent and this is used up rapidly. It has been shown that 20-30 minutes is required to clean and debride a canal.[13] A small volume used for a short contact time will have a limited effect. Furthermore, there is evidence that hypochlorite is not effective against all pathogenic bacteria specifically *Enterococcus faecalis* which is associated with recalcitrant canals.[14]

Further complications of conventional disinfecting agents are toxicity and microbial resistance[15-17] since most which have effective bactericidal activity are used at concentrations where normal tissue toxicity is becoming a significant factor. This can lead to adverse tissue reactions.

Despite sodium hypochlorite being regarded as the irrigant of choice, the substantial dwell time for effective elimination of bacteria and the risk of swelling and haematoma formation if extruded into the soft tissue beyond the apex are potential disadvantages which has been reported in a number of cases.[18,19] Furthermore, at the concentrations recommended, its bactericidal level and tissue damage level are relatively close together.[7,8]

Additionally, the more concentrated the solution, its surface

91.

Antimicrobial Effects of Photodynamic Therapy on Patients with Necrotic Pulps and Periapical Lesion

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Abstract

This study analyzed the antimicrobial effect of photodynamic therapy (PDT) in association with endodontic treatment. Twenty patients were selected. Microbiological samples were taken after accessing the canal, endodontic therapy, and PDT. At the end of the first session, the root canal was filled with $Ca(OH)_2$, and after 1 week, a second session of the therapies was performed. Endodontic therapy gave a mean reduction of 1.08 log. The combination with PDT significantly enhanced the reduction (1.83 log, $p = 0.00002$). The second endodontic session gave a similar diminution to the first (1.14 log), and the second PDT was significantly more effective than the first ($p = 0.002$). The second total reduction was significantly higher than the second endodontic therapy ($p = 0.0000005$). The total first + second reduction (3.19 log) was significantly different from the first combination ($p = 0.00006$). Results suggest that the use of PDT added to endodontic treatment leads to an enhanced decrease of bacterial load and may be an appropriate approach for the treatment of oral infections. *(J Endod 2008;34:138–142)*

Key Words

Endodontics, polyethylenimine and chlorin(e6) conjugate, red laser, root canal

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Elimination of the pathogenic microflora from the root canal system during endodontic therapy is one of the main goals of endodontic treatment. Microbial infection plays an important role in the development of necrosis in the dental pulp and the formation of periapical lesions (1). It is well established that the eradication of bacteria from root canals is difficult, and current endodontic techniques are unable to consistently disinfect the canal systems (2). Accepted treatment procedures to eliminate the infection include root canal debridement and mechanical shaping or smoothing (3), irrigation with disinfectant agents such as sodium hypochlorite or hydrogen peroxide, the application of an interappointment dressing containing an antimicrobial agent, and sealing of the root canal (4). In case of infection, the use of antibiotics and antiseptics is an alternative approach, but the long-term use of chemical antimicrobial agents, however, can be rendered ineffective by resistance developing in the target organisms (5–7).

Studies have shown that in cases when a negative microbiological culture has been obtained from the root canal at the time of obturation, there is a 94% success rate. On the other hand, when obturation is performed in a positive culture, the success rate is reduced to 68%. Previous studies have shown that the shoddier healing of periapical lesions is more likely in obturated root canals with positive cultures by the end of the endodontic treatment (8, 9).

Novel approaches to disinfecting root canals have been proposed recently that include the use of high-power lasers (10) as well as photodynamic therapy (PDT) (11, 12). High-power lasers function by dose-dependent heat generation, but, in addition to killing bacteria, they have the potential to cause collateral damage such as char dentine, ankylosis roots, cementum melting, and root reabsorption and periradicular necrosis if incorrect laser parameters are used (13).

PDT is a new antimicrobial strategy that involves the combination of a nontoxic photosensitizer (PS) and a light source (14). The excited photosensitizer reacts with molecular oxygen to produce highly reactive oxygen species, which induce injury and death of microorganisms (15, 16). It has been established that PS, which possess a pronounced cationic charge, can rapidly bind and penetrate bacterial cells, and, therefore, these compounds show a high degree of selectivity for killing microorganisms compared with host mammalian cells (17, 18). PDT has been studied as a promising approach to eradicate oral pathogenic bacteria (19, 20) that cause diseases such as periodontitis (21), peri-implantitis (22), and caries (23). We recently reported on the use of PDT using a polyethyleneimine (PEI) chlorin (e6 [ce6]) conjugate and fiberoptic delivered red light to combat endodontic infection caused by bioluminescent bacteria in an ex vivo model using extracted human teeth (24). When PDT followed conventional endodontic therapy, there was significantly more killing and less bacterial growth than was seen after endodontic therapy alone. Therefore, the aim of the present study was to test this combination of conventional endodontic therapy followed by antimicrobial PDT in a clinical trial in patients requiring endodontic treatment.

Materials and Methods

Photosensitizer

The PS used was a conjugate between PEI and ce6, and the synthesis and characterization has been previously described in detail (24, 25). Briefly, high–molecular-weight–branched PEI (MWt ¼10,000–25,000; Aldrich Chemical Catalog #40,872-7, Milwaukee, MI) was reacted with ce6 (Porphyrin Products, Logan, UT) in the presence of

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Photodynamic Treatment of Endodontic Polymicrobial Infection *In Vitro*

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Abstract

We investigated the photodynamic effects of methylene blue on multispecies root canal biofilms comprising *Actinomyces israelii, Fusobacterium nucleatum* subspecies *nucleatum, Porphyromonas gingivalis,* and *Prevotella intermedia* in experimentally infected root canals of extracted human teeth *in vitro*. The 4 test microorganisms were detected in root canals by using DNA probes. Scanning electron microscopy showed the presence of biofilms in root canals before therapy. Root canal systems were incubated with methylene blue (25 μg/mL) for 10 minutes followed by exposure to red light at 665 nm with an energy fluence of 30 J/cm^2. Light was delivered from a diode laser via a 250-μm diameter polymethyl methacrylate optical fiber that uniformly distributed light over 360 degrees. Photodynamic therapy (PDT) achieved up to 80% reduction of colony-forming unit counts. We concluded that PDT can be an effective adjunct to standard endodontic antimicrobial treatment when the PDT parameters are optimized. *(J Endod 2008;34:728–734)*

Key Words

Biofilms, endodontic polymicrobial infection, methylene blue, photodynamic therapy, root canals

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The purpose and ultimate goal of endodontic treatment are to eliminate the bacterial infection in the root canal system and allow healing of apical periodontitis. Primary root canal therapy is a highly predictable procedure; however, inability to sufficiently disinfect the root canal system might lead to failure or persistent apical pathosis (1). Although mechanical debridement combined with chemical irrigation removes the bulk of infecting microorganisms, residual bacteria are readily detectable in approximately one half of teeth just before obturation (2). Certain operative problems such as inadequate instrumentation, a missed canal, or an inadequate restoration might lead to post-treatment endodontic disease (3). In addition, the anatomic complexity of the root canal system makes complete debridement of bacteria almost impossible, even if conventional methods of chemomechanical debridement are performed to the highest technical standards (4). Because there is a marked decrease in the prognosis of endodontic retreatment, we sought adjuncts to standard endodontic antimicrobial procedures that might increase the effectiveness of orthograde endodontic treatment/retreatment (1).

The bacterial microflora of primary endodontic infection differs from that of post-treatment endodontic disease. Both cultural methods and polymerase chain reaction–based methods have demonstrated that primary endodontic infections are associated with polymicrobial and strictly anaerobic microorganisms (4–6). Endodontic treatment failures, however, are frequently associated with gram-positive aerobic and facultative microorganisms (6). The presence of *Enterococcus faecalis* in failed endodontic treatment is extensively covered in the literature (3, 7) and is rarely detected in primary infected and untreated cases. Yet, one cannot discount the presence or significance of other microorganisms belonging to the genera *Actinomyces, Propionibacterium, Porphyromonas,* and *Prevotella,* which have been frequently detected in endodontic treatment failures (3, 7, 8).

Photodynamic therapy (PDT) was developed as a therapy for cancer and is based on the concept that a nontoxic photosensitizing agent, known as photosensitizer, can be preferentially localized in premalignant and malignant tissues and subsequently activated by light of the appropriate wavelength to generate singlet oxygen and free radicals that are cytotoxic to cells of the target tissue (9). Several studies have shown that oral bacteria are susceptible to PDT (10, 11). In recent years, PDT has been used to target microorganisms in root canals *in vitro* (12–20) and *in vivo* (21–23). These studies suggested the potential of PDT as an adjunct to standard endodontic antimicrobial treatment. Methylene blue (MB), a well-established photosensitizer, has been used in PDT for targeting endodontic bacteria (12, 15, 18, 19). The hydrophilicity of MB (24), along with its low molecular weight and positive charge, allows passage across the porin-protein channels in the outer membrane of gram-negative bacteria (25). MB predominantly interacts with the anionic macromolecule lipopolysaccharide, resulting in the generation of MB dimers (25), which participate in the photosensitization process (25).

The present *in vitro* study evaluated the response of multispecies root canal biofilms of single-rooted extracted human teeth to PDT after sensitization with MB and exposure to red light at 665 nm. For the development of root canal biofilms, 4 bacterial species were used: the gram-positive rod *Actinomyces israelii*, and the gram-negative rods *Fusobacterium nucleatum* subspecies *nucleatum*, *Porphyromonas gingivalis,*

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Effect of Cell-Photosensitizer Binding and Cell Density on Microbial Photoinactivation

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Photodynamic therapy involves the use of nontoxic dyes called photosensitizers and visible light to produce reactive oxygen species and cell killing. It is being studied as an alternative method of killing pathogens in localized infections due to the increasing problem of multiantibiotic resistance. Although much has been learned about the mechanisms of microbial killing, there is still uncertainty about whether dyes must bind to and penetrate various classes of microbe in order to produce effective killing after illumination. In this report, we compare the interactions of three antimicrobial photosensitizers: rose bengal (RB), toluidine blue O (TBO), and a poly-L-lysine chlorin(e6) conjugate (pL-ce6) with representative members of three classes of pathogens; *Escherichia coli* (gram-negative bacteria), *Staphylococcus aureus* (gram-positive bacteria), *Candida albicans* (yeast). We compared fluence-dependent cell survival after illumination with the appropriate wavelengths of light before and after extracellular dye had been washed out and used three 10-fold dilutions of cell concentration. pL-ce6 was overall the most powerful photosensitizer, was equally effective with and without washing, and showed a strong dependence on cell concentration. TBO was less effective in all cases after washing, and the dependence on cell concentration was less pronounced. RB was ineffective after washing (except for *S. aureus*) but still showed a dependence on cell concentration. The overall order of susceptibility was *S. aureus* > *E. coli* > *C. albicans*, but *C. albicans* cells were 10 to 50 times bigger than the bacteria. We conclude that the number and mass of the cells compete both for available dye binding and for extracellularly generated reactive oxygen species.

Considerable progress has been made in treatment of infections; however, the increasing worldwide occurrence of antibiotic-resistant bacteria is a considerable concern. Therefore, there is a significant need for new antimicrobial techniques. Photodynamic therapy (PDT) uses light-activatable dyes termed photosensitizers (PS) and visible light that, when combined in the presence of oxygen, produce cytotoxic species and tissue destruction (6, 8). It has been approved for treatment of age-related macular degeneration and certain types of cancer and premalignant lesions (7). Antimicrobial therapy is one of the possible future applications of this technique. PDT is known to be effective against viruses, bacteria, and fungi and therefore has been proposed to be used as a therapy for localized infections (10). The development of microbial resistance to PDT is not known and is thought unlikely to be developed (15). Although antimicrobial PDT has been known for about a century (22), the underlying mechanisms of its action are not completely understood. Nonetheless, some parameters important for bacterial inactivation are established.

It is known that gram-positive bacteria are generally more susceptible to PDT as compared to gram-negative species (17, 24). This difference is explained by the structural differences in the cell walls. Gram-negative cells have a complex outer barrier structure including two lipid bilayers, while gram-positive cells have only one lipid bilayer and a relatively permeable outer coat. The yeasts such as *Candida albicans* are even more resistant to photodynamic inactivation (PDI) due to the presence of a nuclear membrane that may present an additional barrier for PS penetration (29); therefore, higher doses of PS and light have to be used. It was shown previously (12, 26) that a positive charge on the PS molecule (such as a poly-L-lysine–PS conjugate or a cationic substitution-containing porphyrin) allows it to bind to, and in some cases penetrate, the microbial permeability barrier. Therefore, positively charged PS are generally more efficient and can act at lower concentrations than neutral and anionic PS molecules. Negatively charged PS are not able to penetrate this gram-negative barrier but may still be effective (although at higher concentrations); in this case, singlet oxygen generated during the irradiation at the outer surface or in solution in close proximity to the cell is thought to diffuse into bacteria and produce fatal damage to lipids and proteins in the inner membrane (4, 5).

We formed the hypothesis that there are three groups of antimicrobial PS: those that are tightly bound and penetrate into microorganisms, those that are only loosely bound, and those that do not demonstrate binding. In order to confirm this hypothesis, we employed three PS thought to be representative of these PS classes—a poly-L-lysine chlorin(e6) conjugate (pL-ce6), toluidine blue O (TBO), and rose bengal (RB)—with representative species from different microbial groups: gram-negative bacterium *Escherichia coli*, gram-positive bacterium *Staphylococcus aureus*, and yeast *Candida albicans*. Fluence-dependent cell survival after illumination with the appropriate wavelength of light before and after extracellular PS had been washed out from the cell suspension was compared. Using the

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Root Canal Anatomy: An Online Study Guide

Abstract

The Editorial Board of the *Journal of Endodontics* has developed a literature-based study guide of topical areas related to endodontics. This study guide is intended to give the reader a focused review of the essential endodontic literature and does not cite all possible articles related to each topic. Although citing all articles would be comprehensive, it would defeat the idea of a study guide. This section will review articles related to root canal anatomy including classification systems, individual teeth reviews, furcation canals, apical anatomy, dental anomalies, and demographic/geographic analysis. *(J Endod 2008;34:e7–e16)*

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Introduction

The delivery of high-quality clinical care requires a thorough understanding of the endodontic literature. The Editorial Board of the *Journal of Endodontics* (JOE) has developed this online study guide for endodontists and fellow clinicians interested in endodontics.

There are several potential applications for an online study guide. First, an online study guide permits clinicians to focus in on particular areas of endodontics where they can quickly review key papers devoted to one particular topic. For example, this particular study guide provides a summary of key papers in the area of present articles related to root canal anatomy including classification systems, individual teeth reviews, furcation canals, apical anatomy, dental anomalies, and demographic/geographic analysis.

Second, a study guide permits speakers to efficiently review background material in preparation for future courses, lectures, or continuing educational events. Third, an online study guide permits students to review key papers in preparation for future examinations or for development of residency seminars. And, fourth, an online study guide permits readers to quickly and efficiently access either the abstract or the entire paper cited in the tables (see Discussion for details).

Methods

One potential problem in developing an online study guide was to provide a summary of major papers that contributed to a given topic area. The inclusion of all possible papers on a given topic would lead to an unwieldy collection that failed to clearly identify key papers in the area. Of course, the exclusion of key papers is also problematic. To address this issue, the JOE Editorial Board developed the overall list of topics to be covered and then for each topic generated an initial tabulation of key historical and contemporary papers on that topic. This list was then sent to two outside reviewers who were both experienced educators and Diplomates of the American Board of Endodontics. These reviewers then recommended additions and deletions of papers to the proposed topic list.

In order to maintain currency, the JOE Editorial Board proposes to periodically update each topical study guide using the same peer-reviewed process as described above.

Results

The results of the study guide (1–109) pertain to articles related to root canal anatomy including classification systems, individual teeth reviews, furcation canals, apical anatomy, dental anomalies, and demographic/geographic analysis is given in Tables 1 through 6.

Discussion

The journey to clinical excellence requires not only outstanding clinical skills but also that special knowledge that accrues from a study of the endodontic literature. The purpose of the JOE online study guide is to serve as one source for efficiently reviewing key papers that are organized by topic area and presented with the advantages of online Internet technology.

Although JOE readers are undoubtedly familiar with many aspects of the Internet, there are special features available at JOE online that provide particular advantages in their application for a study guide. For example, if this particular

In Remembrance of Franklin S. Weine

Canal Configuration in the Mesiobuccal Root of the Maxillary First Molar and Its Endodontic Significance

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This article is in memory of Franklin S. Weine.

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The ultimate objective of endodontic therapy has been stated to be the obliteration of the prepared root canal space with an inert material in order to restore the integrity and state of good health of the treated tooth in the dental arch (1). According to Ingle (2), the most common cause of endodontic failure is apical percolation, with the largest percentage of cases failing due to incomplete canal obliteration. Other reasons for failure in this category include leaving a canal completely unfilled and inadvertently removing a silver point. Quite often a canal is left unfilled because the operator has failed to recognize its presence. Rankine-Wilson and Henry (3) and others (4, 5) have described the not uncommon finding of a bifurcated canal in mandibular incisors, cuspids, and premolars. Green (6) gave an exhaustive description of the presence of auxiliary and secondary canals among all the teeth in the dental arch. Therefore, it is the obligation of those interested in endodontics to be thoroughly familiar with root canal anatomy, in both normal and abnormal situations, in order to keep this cause of endodontic failure to a minimum.

In Ingle's (2) chart listing the frequency of treatment of teeth, compiled from 1957 to 1962, the maxillary first molar represented 5.45 per cent of endodontic cases. In Weine's (7) study, however, that tooth represented 31.6 per cent of pulpal exposures. With an increased desire of the patient for tooth retention as well as the availability of improved instruments and techniques, it can be assumed that maxillary first molars will be treated more and more (8–10). Also contributing to this frequency is the increasing endodontic-periodontic therapy collaboration, since the maxillary molar is one of the most frequent candidates for root amputation (11, 12).

We were impressed by the fact that maxillary first molars that did not respond properly to routine surgical and/or nonsurgical treatment were brought to successful conclusions by the discovery and treatment of a second mesiobuccal canal. (See case histories.) Therefore, we decided to section the mesiobuccal roots of extracted maxillary first molars to determine canal configuration and the incidence of an additional canal.

Method

The mesiobuccal roots of 208 extracted maxillary first molars were sectioned from a mesial approach in a buccolingual direction, using a coarse sandpaper disk. The root canal or canals were exposed, when possible, from the roof of the pulp chamber to the apex, and the typical configurations were classified and tabulated.

Results

The canal configurations fell into three general categories:

Type I. A single canal from the pulp chamber to the apex.

Type II. A larger buccal canal and a smaller canal located lingual to the former which merged from 1 to 4 mm. from the apex.

Type III. Two distinct canals and two distinct apical foramina, with the buccal canal being larger and usually longer from the roof of the chamber to its apical foramen.

Of the 208 teeth sectioned, 101 (48.5 per cent) exhibited the Type I (single canal) configuration (Fig. 1), seventy-eight (37.5 per cent) showed the Type II (bifurcated canal but common apical foramen) appearance (Fig. 2), and twenty-nine (14.0 per cent) were classified as Type III (two separate canals) (Fig. 3).

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endodontics

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Root canal anatomy of the human permanent teeth

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Two thousand four hundred human permanent teeth were decalcified, injected with dye, and cleared in order to determine the number of root canals and their different types, the ramifications of the main root canals, the location of apical foramina and transverse anastomoses, and the frequency of apical deltas.
(ORAL SURG. 58:589-599, 1984)

The main objective of endodontic therapy is the thorough mechanical and chemical cleansing of the entire pulp cavity and its complete obturation with an inert filling material. According to Seltzer and Bender,[1] failures in treatment occur despite rigid adherence to this basic principle. Ingle[2] lists the most frequent cause of endodontic failure as apical percolation and subsequent diffusion stasis into the canal. The main reasons for this failure are incomplete canal obturation, an untreated canal and inadvertent removal of a silver cone. A canal is often left untreated because the dentist fails to recognize its presence. The dentist must have a thorough knowledge of root canal morphology before he can successfully treat a tooth endodontically.

In the literature, there is divergence of opinion as to the anatomy of the pulp cavities of the human permanent teeth.[3-32] The incidence of two or more root canals in the mandibular first premolar, for example, has been reported to be as low as 2.7% and as high as 62.5%, whereas the incidence of two or more root canals in the mandibular second premolar has been reported to vary between 0% and 34.3%.[3-11] The incidence of two canals at the apex of the maxillary second premolar has been reported to be as low as 4% and as high as 50%.[6-13]

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These discrepancies are, in part, the result of the marked variations in anatomy that are present and, in part, the result of the very real difficulties that are always encountered when root canal morphology is studied. Because of the many dissimilarities in selection of material and classification of canal configurations, the results of most reports cannot be compared directly with one another.

Because the literature is inconclusive, I decided to conduct a detailed investigation of the anatomy of the root canals of extracted human teeth. A standardized technique that involved examination of transparent specimens was used.

METHODS AND MATERIALS

For this investigation, 2,400 permanent teeth were obtained from various oral surgery practices. All teeth were obtained from adults. The age, sex, and race of the patients and the reasons for extraction were not recorded. Immediately after extraction, the teeth were fixed in 10% formalin and decalcified in 5% hydrochloric acid. On completion of this process, the teeth were washed in tap water and placed in a 5% solution of potassium hydroxide for 24 hours. The teeth were washed in tap water for 2 hours, and hematoxylin dye was injected into the pulp cavities with the use of a 25-gauge needle on a Luer-Lok plastic disposable syringe. Hematoxylin was used because of its ability to stain fresh pulp tissue, even

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The antimicrobial efficacy of the erbium, chromium:yttrium-scandium-gallium-garnet laser with radial emitting tips on root canal dentin walls infected with *Enterococcus faecalis*

Wanda Gordon, DMD; Vahid A. Atabakhsh, DDS; Fernando Meza, DMD; Aaron Doms, DDS; Roni Nissan, DMD; Ioana Rizoiu, MS; Roy H. Stevens, DDS, MS

ABSTRACT

Background. The authors used an in vitro model to investigate the ability of an erbium, chromium:yttrium-scandium-gallium-garnet (Er,Cr:YSGG) laser with radial emitting tips to disinfect *Enterococcus faecalis*–infected dentin.

Materials and Methods. The in vitro infected-dentin model system consisted of a dentin cylinder, prepared from a human anterior tooth root, cemented into a sealable two-chamber device fabricated from a syringe needle cap. The model's lower chamber contained a buffer solution, and the dentin cylinder was placed between the upper and lower chambers. After sterilization, the authors inoculated the root canal of each dentin cylinder with *E. faecalis*. They used an Er,Cr:YSGG laser with radial emitting tips to irradiate the root canal of each infected dentin cylinder (varying laser power and exposure time). After laser treatment, the authors machined the root canal dentin walls and collected the resulting dentin filings in the buffer-reservoir. They quantified the *E. faecalis* titer of each buffer-reservoir by using selective agar plates.

Results. The authors found that bacterial recovery decreased when laser irradiation duration or power increased. A greater degree of disinfection was achieved with a 120-second application of laser than with sodium hypochlorite treatment. Finally, they found that a 99.7 percent reduction in bacterial counts could be obtained using the laser.

Conclusion. The results of this study suggest that the Er,Cr:YSGG laser with a radial emitting tip has a significant antimicrobial effect on dentinal tubules infected with *E. faecalis*.

Clinical Implications. Er,Cr:YSGG laser treatment could be a valuable tool for root canal disinfection during endodontic treatment.

Keywords. Bacteria; disinfection; endodontic therapy; lasers; root canal.
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Bacteria are the primary causative agents in pulpal and periapical pathosis.[1,2] The challenge of nonsurgical endodontic treatment is to achieve total disinfection and elimination of bacteria from the root canal system. Clinical endodontic procedures rely on mechanical instrumentation and intracanal irrigants and medicaments to disinfect the root canal system. Although current instrumentation techniques involving hand and/or rotary instruments as well as ultrasonic and sonic devices can greatly reduce the bacterial load in the infected canal, they fall short of the goal of total disinfection of the root canal system.[3-5] Irrigants such as

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Laser Induced Explosive Vapor and Cavitation Resulting in Effective Irrigation of the Root Canal. Part 1: A Visualization Study

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Background and Objectives: Limited information exists regarding the induction of explosive vapor and cavitation bubbles in an endodontic rinsing solution. It is also not clear whether a fiber has to be moved in the irrigation solution or can be kept stationary. No information is available on safe power settings for the use of cavitation in the root canal. This study investigates the fluid movements and the mechanism of action caused by an Er,Cr:YSGG laser in a transparent root model.
Material and Methods: Glass models with an artificial root canal (15 mm long, with a 0.06 taper and apical diameter of 400 µm) were used for visualization and registration with a high-speed imaging technique (resolution in the microsecond range) of the creation of explosive vapor bubbles with an Er,Cr:YSGG laser at pulse energies of 75, 125, and 250 mJ at 20 Hz using a 200 µm fiber (Z2 Endolase). Fluid movement was investigated by means of dyes and visualization of the explosive vapor bubbles, and as a function of pulse energy and distance of the fiber tip to the apex.
Results: The recordings in the glass model show the creation of expanding and imploding vapor bubbles with secondary cavitation effects. Dye is flushed out of the canal and replaced by surrounding fluid. It seems not necessary to move the fiber close to the apex.
Conclusion: Imaging suggests that the working mechanism of an Er,Cr:YSGG laser in root canal treatment in an irrigation solution can be attributed to cavitation effects inducing high-speed fluid motion into and out the canal. Lasers Surg. Med. 41:514–519, 2009.
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Key words: absorption; endodontics; Er,Cr:YSGG; fiber optics; laser dentistry; root canal; smear layer

INTRODUCTION

A wide spectrum of possible strategies exists for attaining the goal of removing the canal contents and eliminating infection. They all have in common that there is a chemo-mechanical preparation for each strategy: at the basis root canal instruments are used for shaping and cleaning, in addition irrigants are needed for cleaning and disinfecting and especially in these areas that cannot be reached by instruments or are insufficiently cleaned. So irrigation is a very important part of root canal treatment procedures. Hand irrigation, however, is not so effective in the apical part of the root canal, nor in oval extensions, isthmuses, and anastomoses [1–7]. In order to enhance the spreading of the irrigant and to activate irrigants sonic and ultrasonic activation have been investigated and promoted [8–11].

Lasers have been proposed as or an alternative for the conventional approach in cleaning, disinfecting and even shaping of the root canal or as an adjuvant to conventional chemo-mechanical preparation in order to enhance debridement and disinfection [12–15].

Several wavelengths are associated with bactericidal effects [16–19]. Some are used to remove or to modify the smear layer after root canal preparation [20–24]. All these studies have in common that the desired effects are the result of photo-thermal effects since the laser devices were used without air and/or water cooling and depending on the laser-tissue/target interaction also more or less on absorption. Because of the rather high intensities required for disinfection and smear layer removal, potential concerns exist regarding heating of dentin. Various coolants and irrigants can be used during intra-canal laser treatment to reduce thermal stress to the radicular dentin and to the periodontium [25].

Another manner to remove smear layer and to disrupt the biofilm is the use of ultrasound: with a small file or

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Effectiveness of different laser systems to kill *Enterococcus faecalis* in aqueous suspension and in an infected tooth model

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Abstract

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Aim To assess the antibacterial action of laser irradiation (Nd:YAG, KTP), photo activated disinfection (PAD) and 2.5% sodium hypochlorite (NaOCl) on *Enterococcus faecalis*, in an aqueous suspension and in an infected tooth model.

Methodology Root canals of 60 human teeth with single straight canals were prepared to apical size 50, autoclaved, inoculated with an *E. faecalis* suspension and incubated for 48 h. They were randomly allocated to four treatment and one control groups. After treatment, the root canals were sampled by flushing with physiological saline, and the number of surviving bacteria in each canal was determined by plate count and solid phase cytometry. The same experimental or control treatments were completed on aqueous suspensions of *E. faecalis*, and the number of surviving bacteria was determined in the same way.

Results In aqueous suspension, PAD and NaOCl resulted in a significant reduction in the number of *E. faecalis* cells ($P < 0.001$), whilst Nd:YAG or KTP had no effect. In the infected tooth model, only the PAD and NaOCl treated teeth yielded significantly different results relative to the untreated controls ($P < 0.001$).

Conclusions The laser systems as well as PAD were less effective than NaOCl in reducing *E. faecalis*, both in aqueous suspension and in the infected tooth model.

Keywords: disinfection, laser, photodynamic therapy, root canal.

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Introduction

The role of micro-organisms and their by-products in the pathogenesis of apical periodontitis has clearly been established (Kakehashi *et al.* 1965, Sundqvist *et al.* 1998). Likewise, disinfection of the root canal system has been recognized as an essential aspect of root canal treatment. Traditionally, this is accomplished by chemo-mechanical cleaning, a combination of (i) mechanical instrumentation; (ii) use of disinfecting solutions for irrigation of the root canal space; and (iii) placement of intracanal medication between appointments (Byström & Sundqvist 1981, 1983, 1985, Sjögren *et al.* 1991). However, despite meticulous chemo-mechanical cleaning, eradication of all micro-organisms from the root canal system is difficult (Sjögren *et al.* 1997, Nair *et al.* 2005). Micro-organisms have been shown to persist in the anatomical complexities of the root canal system and to be the cause of treatment failure (Lin *et al.* 1991, Sundqvist *et al.* 1998). Therefore, various laser systems have been examined as adjuncts to currently used disinfection methods in root canal treatment. The laser light is thought to be able to reach areas that are inaccessible

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ORIGINAL ARTICLE

Radiographic examination of apical extrusion of root canal irrigants during cavitation induced by Er,Cr:YSGG laser irradiation: an in vivo study

Harry Huiz Peeters · Latief Mooduto

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Abstract
Objectives The purpose of the present study was to test the hypothesis that apical extrusion of the irrigant occurs during laser-driven irrigation in vivo.
Materials and methods Three hundred human root canals, in 181 patients, were divided into two groups: the no lesion group (n=140) and the lesion group (n=160). All the root canals were enlarged using a crown down technique up to size 30–80 K-files, depending on the original condition of the root canal. For the final irrigation, the teeth were irrigated with a mixture of radiopaque contrast medium and NaOCl in solution. The solution was activated for 60 s in teeth with one canal or two canals and for 120 s in teeth with three or four canals.
Results Radiopaque contrast medium was absent from the periapical tissues of all samples.
Conclusions No contrast medium was observed radiographically in the periapical tissues. The hypothesis that apical extrusion of root canal irrigants occur during laser cavitation was rejected.
Clinical relevance It appears that the power of the laser used at 1 W for 1–2 min can drive the irrigation solution to the tip of the canal without harming the apical tissues.

Keywords Apical extrusion · Cavitation · Contrast · Laser-driven irrigation

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Introduction

Large areas of the root canal wall, particularly in the apical third but also areas in ribbon-shaped and oval canals, cannot be cleaned mechanically. It has been shown that 35 % or more of the root canal system (RCS) is untouched by endodontic instruments, which means that microorganisms could survive in these untouched areas [1].

Although shaping of the root canal has been improved with advances in metal technology, cleaning of the canal still relies heavily on the adjunctive use of chemical rinsing and soaking solutions because of the anatomical complexity and irregularity of teeth [2]. This highlights the importance of root canal irrigation in the debridement and disinfection of the RCS [1]. Endodontic irrigants are used to remove pulp tissue, microorganisms, microbial by-products and debris from the RCS [3, 4].

For optimal effectiveness of irrigation, the preparation of the root canal should facilitate the insertion of the irrigation needle and agitation devices to 1–2 mm short of the working length (WL). In addition, the irrigation solution should make direct contact with all parts of the canal wall [5]; a flushing action is necessary for optimal cleaning of the root canal [6]. The problem with these techniques is that the depth of needle penetration depends on the size and morphology of the individual canal. Predictable delivery of irrigants to the WL with needle irrigation is rarely possible [7]. If too little positive pressure is used, the irrigants may not reach the WL. If too much positive pressure is used, the irrigants may be forced beyond the apical constriction, which can produce tissue damage, pain and swelling; this is commonly described as a sodium hypochlorite (NaOCl) accident [8–12]. To enhance the dispersal of the irrigant and to activate it, different agitation techniques have been investigated and developed. These include the use of hand files, gutta-percha cones, plastic instruments and sonic and ultrasonic techniques [13].

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Nd:YAG Laser Irradiation Effect on Apical Intracanal Dentin - A Microleakage and SEM Evaluation

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The purpose of this *in vitro* study was to evaluate the effect of neodymium:yttrium-aluminum-garnet (Nd:YAG) laser irradiation on intracanal dentin surface by SEM analysis and its interference in the apical seal of filled canals. After endodontic treatment procedures, 34 maxillary human incisors were randomly assigned to 2 groups. In the negative control group (n=17), no additional treatment was performed and teeth were filled with vertically condensed gutta-percha; in the laser-treated group (n=17), the root canals were irradiated with Nd:YAG laser (1.5 W, 100 mJ, 15 Hz) before filling as described for the control group. Two specimens of each group were prepared for SEM analysis to evaluate the presence and extent of morphological changes and removal of debris; the other specimens were immersed in 0.5% methylene blue dye (pH 7.2) for 24 h for evaluation of the linear dye leakage at the apical third. SEM analysis of the laser-treated group showed dentin fusion and resolidification without smear layer or debris. The Student's *t*-test showed that the laser-treated group had significantly less leakage in apical third than the control group. Within the limitations of this study, it may be concluded that the morphological changes on the apical intraradicular dentin surface caused by Nd:YAG laser resulted in less linear dye apical leakage.

Key Words: Endodontics, laser, apical leakage, intracanal irradiation.

INTRODUCTION

The fundamental part in endodontic therapy is the removal of inorganic and organic debris followed by the appropriate filling of the canal space in order to seal it off from the surrounding oral tissues. The main purpose of this last step is to achieve a complete seal that prevents bacterial leakage and a further recontamination of root canal dentin in the entire root canal system, particularly in the apical third. Apical leakage has been proven an important reason for root canal treatment failure and its occurrence is generally associated with deficient smear layer removal (1-3).

A number of studies have demonstrated that the traditional method for root canal preparation produces a significant amount of smear layer that can adhere on the dentinal walls, obliterating the dentinal tubules. It thus reduces dentinal permeability and hinders penetration of intracanal drugs into dentin, even when chemical irrigation is used combined with mechanical instrumentation. It has been claimed that the incidence of leakage is significantly reduced in the absence of smear layer and that smear layer removal is capable of enhancing seal ability and hence increasing resistance to bacterial penetration (4).

New techniques that may result in higher success rates have recently been developed and the use of lasers in Endodontics has appeared as an interesting adjunct to

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103.

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ORIGINAL ARTICLE

Er:YAG 2,940-nm laser fiber in endodontic treatment: a help in removing smear layer

Rebecca Guidotti · Elisabetta Merigo · Carlo Fornaini · Jean-Paul Rocca · Etienne Medioni · Paolo Vescovi

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Abstract Cleaning and disinfection of the root canal system are some of the most important goals in endodontic therapy. The aim of this preliminary study is to assess the effectiveness of Er:YAG laser fiber in removing the smear layer produced during root canal walls instrumentation. Forty-eight single-rooted teeth were prepared with manual and rotary Ni-Ti instruments, in addition to 2.5 % NaOCl irrigation. Samples were randomly subdivided into groups and treated with: three irradiations of 5 s each, with 300-μm Er:YAG endodontic fiber, 1 W and 2.5 % NaOCl solution (A Group); two laser irradiations with 17 % EDTA solution and 2.5 % NaOCl solution (B Group); laser irradiation plus 17 % EDTA solution and 2.5 % NaOCl (C Group); only in the final wash of 17 % EDTA (control group D). During laser treatment, temperature variations were analyzed by using thermocouple and thermal camera devices in order to test both deep and superficial temperatures. Each sample was finally observed by scanning electron microscope (SEM) at the coronal, medium, and apical thirds at ×500 magnification and blindly scored depending on the amount of smear layer. Statistical analysis of the results was conducted using the Kruskal–Wallis and Mann–Whitney test to determine the eventual significant differences between the quantity of smear layer in each group and between the groups at coronal, medium, and apical third: a p value <0.05 was considered significant. The thermal analysis realized by thermocouple with the used parameters demonstrated that laser endodontic fiber produces an average deep temperature increase of 3.5±0.4 °C; analysis performed with a thermal camera showed an average superficial temperature increase of 1.3±0.2 °C produced by laser endodontic fiber use. Deep and superficial temperatures fall immediately after irradiation possibly without causing structural damage or anatomical alteration inside the root canal and neither on periodontal tissues. SEM analysis showed that specimens of group B had the highest level of cleaning in every third, with a significant difference with groups D and A; group C samples showed a good percentage of cleaned tubules in apical and middle thirds, while group D teeth showed open dentinal tubules in coronal third, with a statistical difference with group A samples which were the worst cleaned. The Er:YAG fiber double irradiation with EDTA 17 % and NaOCl 2.5 % has been demonstrated to be effective in removing smear layer, even in the apical third which is described as the hardest area to clean during endodontic treatment.

Keywords Cleaning · Endodontic treatment · Er:YAG laser · Root canal system · Smear layer

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Introduction

The etiology of pulp diseases is often due to the presence of bacteria and their by-products within the root canal system and periradicular area, causing chronic and acute dental infections [1, 2]. McComb and Smith in 1975 showed that in instrumented root canals, there always remains a residual of smear layer composed by tooth structure, inorganic components, and organic contaminants such as coagulated proteins, blood cells, saliva, and microorganisms [3, 4].

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BRIEF REPORT

Comparison of dentin root canal permeability and morphology after irradiation with Nd:YAG, Er:YAG, and diode lasers

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Abstract The aim of this study was to compare the effects of Nd:YAG, Er:YAG, and diode lasers on the morphology and permeability of root canal walls. The three laser wavelengths mentioned interact differently with dentin and therefore it is possible that the permeability changes caused will determine different indications during endodontic treatment. Twenty-eight human single-rooted teeth were instrumented up to ISO 40 and divided into four groups: group C, control (GC), non-laser irradiated; group N (GN), irradiated with Nd:YAG laser; group E (GE), with Er:YAG laser and group D (GD) with diode laser. After that, the roots were filled with a 2% methylene blue dye, divided into two halves and then photographed. The images were analyzed using Image J software and the percentage of dye penetration in the cervical, middle, and apical root thirds were calculated. Additional scanning electron microscopy (SEM) analyses were also performed. The analysis of variance (ANOVA) showed significant permeability differences between all groups in the middle and cervical thirds ($p<0.05$). The Tukey test showed that in the cervical third, GN presented means of dye penetration statistically significantly lower than all of the other groups. In the middle third, GE and GD showed statistically higher dye penetration means than GC and GN. SEM analysis showed melted surfaces for GN, clean wall surfaces with open dentinal tubules for GE, and mostly obliterated dentinal tubules for GD. Er:YAG (2,094 nm) laser and diode laser (808 nm) root canal irradiation increase dentinal permeability and Nd:YAG (1,064 nm) laser decreases dentin permeability, within the studied parameters.

Keywords Endodontics · Root canal dentin · Laser dentistry · Morphology · Ultrastructure

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Introduction

The adequate cleaning of the root canal is based on the removal of organic and inorganic debris, followed by proper filling in order to seal it off from the surrounding oral tissues. A number of studies have demonstrated that the conventional technique of root canal preparation produces a considerable amount of smear layer and remaining pulp tissue that can be deposited on the dentinal walls and obliterate the dentinal tubules [1]. It thus reduces dentinal permeability and hinders penetration of intracanal medicaments into dentin, even when chemical irrigation is used in conjunction with mechanical instrumentation [2].

Over the last few years, many researchers have investigated the potential application of different types of lasers in endodontic therapy. Laser irradiation in the root canal is capable of vaporizing soft tissue, fusing, or glazing hard