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Strategies to optimize the removal of smear layer from the root canal system

Charysson Vinicius Benetti,[1] Natalia Panho,[1] Giovana Domitila Rafagnin[1]

[1]Department of Endodontics, School of Dentistry, University of Paranaense (UNIPAR), Francisco Beltrão, PR, Brazil

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Abstract

Objective: to evaluate the different methods for agitation of the irrigation solution based on the existing literature data, comparing the use of EndoActivator, EndoVac, Easy Clean system, Xp-Endo Finisher, Photon Induced Photoacoustic Streaming (PIPS) and Passive Ultrasonic Irrigation (PUI) associated with chemical agents in the removal of the RCS smear layer**. Material and Methods:** 28 journals articles, 2 books, 2 monographs and 6 dissertations were selected regarding the different alternatives for the removal of smear layer from the RCS in the PUBMED databases - US National Library of Medicine National Institutes of Health; SCIELO - Scientific Electronic Library Online and MEDLINE - Medlars Online. **Results:** as an alternative of removal of smear layer to improve sanitizing of the RCS and to increase the success rate of the endodontic treatment, different irrigation techniques have been proposed, including agitation of irrigation solution in mechanical, sonic or ultrasonic way, Ni-Ti instruments, plastic and laser energy. **Conclusion:** many studies prove the efficacy of the different methods for agitation of the irrigating solution in the removal of smear layer, contributing for the sanitizing process of the root canal system.

Keywords: Smear layer; Irrigation solution; Endodontic treatment.

Introduction

The chemical and mechanical root canal preparation is the main method for the reduction and control of the microorganisms of the root canal system (RCS). However, the friction of the instruments used to model the conduits induces the formation of a layer of organic materials (microorganisms, pulp cells, nerve fibers, vessels, collagen and tissue fluid) and inorganic materials (dentin scrap) that are adhered to the root canal walls, this layer is called a smear layer.[1] This presence acts as a physical barrier, preventing the penetration of irrigating solutions, medicaments and sealant cement inside the dentinal tubules, making it difficult to cement adhesion to the dentinal surface,[2] and also serves as a source of nutrients for bacteria present in the RCS.[3]

According to Lopes and Siqueira,[4] if the smear layer is not adequately removed, it may favour the occurrence of microleakage in the root canals even after the final filling.

The irrigating solution such as sodium hypochlorite (NaOCl) plays a key role in its removal, since it is able to access areas of the RCS where the instruments cannot reach, especially areas of isthmus, lateral and accessories canals, apical deltas and extension canal where in these cases only 40% of the canal walls are touched by mechanical instruments.[5,6] In addition, it has antimicrobial and dissolution capacity of the remaining pulp tissue.[7]

In order to make its action even more effective, the literature proposes the association of chemical solutions (EDTA and NaOCl) and agitation techniques of the solution, including mechanical agitation with manual files, gutta-percha cones and Easy Clean, laser energy, sonic and ultrasonic devices.[8,4]

The objective of this work is to evaluate irrigation methods based on the literature data, comparing the use of EndoActivator, EndoVac, Easy Clean system, Xp-Endo Finisher, Photon Induced Photoacoustic Streaming (PIPS) and Passive Ultrasonic Irrigation (PUI) associated with a chelating agent (EDTA) in the removal of the smear layer.

Material and Methods

We selected 28 articles, 2 books, 2 monographs and 6 dissertations referring only to the different alternatives for the removal of smear layer from the RCS in the PUBMED databases - US National Library of Medicine National Institutes of Health; SCIELO - Scientific Eletronic Library Online and MEDLINE - Medlars Online, published from February 2002 to July 2018. Data were collected from March 2018 to August 2018.

Results

The objective of the biomechanical preparation is modelling and sanitizing the root canal system to allow adequate filling. However, the instruments used to model the ducts form a dense agglomerate deposited mainly in the apical region due to the friction of these instruments against the dentinal walls.[4]

According to Lopes & Siqueira,[4] after an observation with scanning electron microscopy, the presence of tiny dentinal remnants and an amorphous substance adhered to the walls of the conduit, called smear layer, were observed. This layer adhered to the root canal walls has the capacity to reduce dentin permeability by approximately 30 to 40%, limiting the penetration of the irrigating solution used during the procedure, as well as the intracanal medication and the sealant cement inside the dentinal tubules.[4]

Herein, it is believed that its effective removal can contribute to the success of endodontic therapy.[7] It is also known that a large part of the canal wall surface is not touched during instrumentation, regardless of the technique performed, allowing the permanence of contaminated areas.[9]

Haapasalo *et al.*[10] affirm that the irrigating solution plays a fundamental role before, during and after the instrumentation of root canals, because it facilitates the removal of microorganisms, remnant tissues and smear layer, reaching areas inaccessible by the instruments, preventing the permanence of hard and soft tissue in the interior of the root canal and the extrusion of debris beyond the apex.[10,5]

According to Van Der Sluis,[6] the effectiveness of irrigation depends on the irrigating solution's properties, but also on the ability to carry it in areas of difficult access and contact with debris that must be removed.[6]

Thus, different irrigation techniques are being proposed to contribute to the removal of the smear layer and to the sanitizing process as a whole.[8,11] After the bibliographic search, the systems that presented the best results for smear layer removal were: ultrasonic agitation through Passive Ultrasonic Irrigation (PUI), sonic agitation by the Endoactivator, mechanical by the Easy Clean system and Xp-Endo Finisher, by the Photon Induced Photoacoustic Streaming (PIPS) and by negative pressure through the EndoVac system. Each system has a specific clinical protocol, described in Table 1.

Table 1. Activation protocols of irrigation solution according to each system[29, 43, 16, 42, 32, 19, 23]

System	Mechanism of action	Protocol
PUI	Ultrasonic	1. Activate EDTA 17% for 15 seconds, 2mm from the radiographic apex; 2. Activate NaOCl for 15 seconds, 2mm from the radiographic apex; 3. Repeat steps 1 and 2; 4. Conventional final irrigation (syringe + needle).
XP-Endo Finisher	Mechanic	1. Fill the canal with irrigating solution; 2. Insert XP-F into the whole canal and activate it performing slow and smooth longitudinal movements with amplitude of 7-8 mm for 1 minute; 3. Remove the instrument from the canal still rotating; 4. Conventional irrigation (syringe + needle) with canal aspiration to remove suspended debris.
Endoactivator	Sonic	1. Fill the pulp chamber with the irrigating solution of choice; 2. Select the tip that best fits manually in the conduit 2 mm from the working length apex; 3. Perform back and forth movements with amplitude of 2 to 3mm for 30 to 60 seconds; 4. Aspiration e drying; 5. Repeat the above steps for each irrigating solution used.
Easy Clean	Mechanic	1. Fill the root canals with the irrigating solution of choice; 2. Insert the Easy Clean 2 mm from the working length apex; 3. 3 cycles of 20 seconds with sodium hypochlorite (NaOCl); 4. 3 cycles of 20 seconds with 17% EDTA; 5. Repeat again 3 cycles of 20 seconds with NaOCl; 5. Conventional final irrigation (syringe + needle).
PIPS	Photoacoustic	1. Use a 14 mm long tip of tapered shape; 2. Insert into the pulp chamber already filled with irrigating solution; 3. The laser must be performed at a 0,3W, 15Hz and 20mJ per pulse for 1 minute; 4. After the activating time, the canal must be dried.
EndoVac	Negative pressure	1. This system uses 4 cycles of irrigation: 1º with NaOCl, 2º with EDTA 17%, 3º with NaOCl and 4º with saline; 2. Irrigation of the pulp chamber with the syringe, and the master tip adapted in the dental aspirator, during the preparation of the root canals and each instrument; 3. After finishing the instrumentation, use the macrocannula + syringe to eliminate gross residues; 4. Use the microcannula, inserted up to the working length, keeping it in the root canal for 6 seconds. Remove 2mm and hold for another 6 seconds. 5. Repeat the same procedure. 6. Keep the canal flooded with the irrigation solution until the new cycle.

Endoactivator

The Endoactivator (Dentsply Maillefer, Ballaigues, Switzerland) consists of a system capable of producing sound vibrations (sonic agitation of 1 - 10 KHz) with greater range of motion, creating an acoustic flow of the irrigating agent allowing it to penetrate as waves in the deep and inaccessible root canal systems for endodontic files.[2,13,14] It is a system that presents itself as a portable handpiece where three types of disposable tips of different sizes are attached to the base of flexible polymer and do not cut the dentin of the root canal, being a small activator (yellow) with tip #15/02, medium activator (red) with tip #25/04 and large activator (red) with tip #35/04.[14-16] This device can exert three speeds 10,000, 6,000 and 2,000 cycles per minute.[12]

Haapasalo *et al.*[10] emphasize that the endoactivator does not insert new irrigating solution in the canal but facilitates its penetration and mechanical cleaning inside the root canal, with no increase in the risk of extrusion of the irrigating agent beyond the apex.[10]

Bharti *et al.*[13] and Duarte *et al.*[2] affirm that the tips of this system can only be used after the correct instrumentation of root canals, obtaining a minimum apical size of 0.35 mm for adequate disinfection.

EndoVac

The EndoVac system (Discus Dental, Culver City, CA, USA) was created to minimize the effects of positive pressure from conventional irrigation, in order to reduce the periapical extrusion of the irrigating agent. Therefore, this system consists of an irrigation device based on negative pressure.[13] EndoVac is intended to provide adequate and safe cleaning of the root canal, especially in the apical region, through a suction system placed on the working length.

The system consists of three components, which are responsible for carrying the irrigating solutions to the access cavity, a microcannula and a macrocannula used to clean and disinfect the canal system.[2,17] The macrocannula is responsible for the removal of residues of the middle third being of plastic with open end of caliber 55mm (ISO) and a conicity of 2 mm, while the master tip provides irrigation of the agent constantly into the pulp chamber. Bharti *et al.*,[13] emphasize that the negative pressure keeps the debris and the irrigation solution always in the coronal direction, avoiding that the irrigating agent goes beyond the apex.

The microcannula has a diameter of 0.32 mm and is destined for the apical region, in this way it is necessary that the canal has been prepared by a minimum tip file #35. It is characterized by a closed tip with twelve open holes (four rows of three), arranged radially on its sides in the last 0.7mm in length, being responsible for the removal of debris in this area and for maintaining a constant flow and abundant suction of the irrigation solution throughout the root canal, allowing cleaning and disinfection of the canal without extrusion.[17-20]

The apical suction pulls the solution from the crown-apex towards the sides of the root canal, generating a turbulent cascade effect, forcing irrigators to pass between the canal walls and on the outer surfaces of the microcannula, promoting vigorous turbulence.[21-23]

Easy Clean

The Easy Clean (Dental Equipment, Belo Horizonte, MG, Brazil) is a system that aims to clean the root canals through the mechanical agitation of irrigation solutions throughout its length, with no risk of deforming the canal structure because, unlike the ultrasonic tips, this instrument is made of a plastic material called acrylonitrile butadiene styrene (ABS), with tip # 25/04 and cross section in the form of “wing of airplane”, which can be inserted until the apical region.[24] It can act in reciprocating motion, that is, a turn of 180° clockwise followed by a turn of 90° counterclockwise,[24,25] or in a rotational movement, where it presents more satisfactory results in cleaning the conduit and the areas of isthmus.[26]

Ultrasound - Passive Ultrasonic Irrigation (PUI)

Ultrasound has the ability to transform electrical energy into propagation waves (acoustic energy) or vice versa, and is thus called piezoelectric energy.[7,27] This energy transmission is performed by the oscillatory movement of a smooth metallic tip, by ultrasonic waves, promoting the acoustic flux and cavitation effect of the solution.[6]

Van der Sluis *et al.*[6] describe the acoustic flow as circular and rapid movements of the fluids around the ultrasonic tip, and cavitation as the creation or expansion of gases (bubbles) present in a chemical solution, formed by the tensile forces and induced by fluxes in high speed. These bubbles expand and subsequently collapse with the dentinal walls of the canal, promoting the removal of remaining pulp tissue, microorganisms and smear layer.

The term passive vibration with ultrasound refers to the intracanal ultrasonic activation in oscillations between 25 and 30 KHZ with low amplitude of movement to agitate the irrigator solution through thin and smooth inserts without touching the dentinal walls of the root canal.[7,27] Van der Sluis *et al.*[6] emphasize that, besides acting in chemical disinfection, this technique is beneficial because it allows an adequate cleaning with removal of smear layer of the RCS, presenting reduced risks in creating deformities in the canal structure. For Ferrari and Bombana,[28] PUI generates an increase in solution temperature and also promotes an improvement in efficiency for tissue dissolution of hypochlorite.

Currently there are several brands of ultrasonic inserts, an example is the Irrisonic E1 (Helse Dental Technology; São Paulo, Brazil). This is characterized by having an active tip of 2 mm in diameter and 0,01 of taper, equivalent to a manual file #20 (ISO).[29]

Xp-Endo Finisher

The Xp-Endo Finisher (FKG Dentaire, La Chaux-de-Fonds, Switzerland) is a non-cutting Ni-Ti file with its active tip and a #25 diameter. Thanks to this type of special alloy, the instrument has a linear form in the martensitic phase, which is obtained at a temperature below 30°C, but when inserted inside the root canal, at body temperature (35-37°C), it induces its change to the austenitic phase, in which the instrument takes the form of a spoon in the last 10 mm of its length, with a depth of 1,5mm. When in rotation the instrument reaches a diameter of 3mm in the last 10mm of its length, gaining a format similar to a lamp. According to its manufacturer, when the tip of the instrument is squeezed, the lamp expands and increases its diameter to 6 mm. Thus, when the instrument is moved up and down (between 7 and 8mm) inside the conduit the natural constrictions and expansions of the canal will alternately dilate and contract the lamp and the tip of the instrument. This phenomenon causes the instrument to scrape the canal walls causing the turbulence of the irrigation solution.[11,30]

Photon-Induced Photoacoustic Streaming (PIPS)

PIPS is a recently proposed technique that uses light phenomena to aid in irrigation. It differs from other techniques because only the laser tip is placed in the pulp chamber, avoiding contact with the root canal walls.[31,32] In this technique, an Yttrium-Aluminum-Garnet Erbium (Er/YAG) laser is used as a ferrule and energy source equivalent to 0.3W and short pulse rates (50 microseconds). It has been shown to be effective in reducing the smear layer by activating the irrigator solution in the pulp chamber.[3,32] When the laser is activated together with the irrigation solution, the high absorption of the laser combined with its energy peak, 3W) causes a photomechanical phenomenon. A strong photoacoustic shock wave promotes a three-dimensional movement of the irrigation solution.[31]

According to Peeters and Mooduto,[33] the laser tip in the pulp chamber can lead to the irrigating solution to the apex, without damaging the periapical tissues. For this reason, Guneser *et al.*[31] affirm that PIPS is more effective in the debridement of the SCR compared to the conventional irrigation technique.

Discussion

In recent years, different studies have been carried out aiming to analyse the capacity and effectiveness of the various methods of agitation of irrigation solutions in the removal of the smear layer.

Kato *et al.*[25] carried out a study comparing PUI and Easy Clean, verifying that the agitation of the irrigating solution with Easy Clean promotes cleaner walls, removing debris from the apical portion, even in curved canals. Duque et al.[26] in a similar study concluded that the Easy Clean system used in continuous rotation and low speed provides a better cleaning of the canal and isthmus region, compared to the action of different systems for agitation of the irrigating solution (Easy Clean in rotation continuous and oscillatory, Ultrasound, EndoActivator and conventional irrigation).

This is due to the fact that Easy Clean promotes mechanical agitation along the entire length of the instrument without barriers due to its contact with the walls of the root canal. In addition, since the instrument is made of plastic (ABS) and has a cross-section in the shape of an “airplane wing” with lower cutting power, there is less wear on the dentin wall.[24,25]

However, according to the authors Kato *et al.*[25] and Rodrigues *et al.*,[24] PUI promotes a more efficient cleaning of intermediate portions of straight and conical canals, since in these regions the diameter of the conduit is greater than in the apical millimetres, allowing the ultrasonic insert to work freely without contact with the dentin walls. However, due to the large anatomical variations of the roots, such as in curved and atresic canals, the ultrasonic tip can touch the walls of the canal, limiting its movement and generating a negative result in the conduction of the ultrasonic energy, besides being able to cause accidents, as uncontrolled removal of dentin, deviation of the original canal pathway, apical obstruction and even root perforation.[24]

In the studies of the authors Castagnola *et al.*[34] and Goode *et al.*,[35] the efficacy of the removal of smear layer from root canals using different systems for agitation of irrigation solution was evaluated, which included EndoActivator, EndoVac and conventional irrigation (NaviTip). In both studies the EndoActivator system obtained a better removal of smear layer and organic debris in all thirds of the root canal, especially in the middle and apical third. Nevertheless, the EndoVac system achieved a 99% reduction of debris in mechanically inaccessible areas in curved canals.

Mancini *et al.*[15] corroborate this result after a similar study, comparing the efficacy of smear layer removal using EndoActivator, EndoVac and Passive Ultrasonic Irrigation (PUI) all combined with 5.25% NaOCl. In conclusion, the EndoActivator system was considerably more efficient than the PUI in the removal of smear layer present in 3, 5 and 8 mm from the vertex. On the other hand, the EndoVac system removed significantly more smear layer in those same regions. This can be explained by the formation of bubbles at the time of application of the solution, since EndoVac aspirates sodium hypochlorite faster than it applies, generating a negative pressure system.

Another advantage of EndoVac according to Azim *et al.*[36] is to have a very low index of irrigating solution extrusion, resulting from the negative pressure generated in the canal, which differentiates it from other agitation systems that exert positive pressure during irrigation.

When the PUI and the EndoActivator are isolated compared in isolation, as demonstrated by Gonçalves *et al.*[14] after performing a quantitative analysis in the removal of the smear layer from the apical third of curved roots, it is concluded that the sonic and ultrasonic activation methods did not present differences among themselves in the removal of the smear layer. Though, there is a significant difference between irrigation solution activated and non-activated when they are compared.

Ordinola-Zapata *et al.*[37] compared the efficiency of smear layer removal using conventional irrigation, EndoActivator, PUI and laser PIPS. The results indicated that the best systems were the PIPS and PUI laser, while conventional irrigation and EndoActivator System presented no relevant differences in biofilm removal. The authors suggest that the oscillation frequency of the sonic system was not able to disrupt the biofilm structure present in the walls of the root canal. In a similar study by Arslan *et al.*[32] using these same systems, the authors concluded that PIPS was significantly more effective than sonic and ultrasonic irrigation techniques for removing dentin debris.

The result can be explained by the large amounts of energy transferred to the irrigating solution with the laser activation, since this technique uses low energy levels in short pulsations to generate energy peaks, causing the photoacoustic shock wave to induce three-dimensional movement of the irrigation solutions. In addition, the tip of the PIPS does not need to reach the apical portion of the conduit, it is placed only in the pulp chamber, constituting as a minimally invasive technique in which wear of the dentinal walls of the root is avoided.[32] Another advantage of this system is that it uses low energy levels and pulses of microseconds (20mJ at 15Hz and a mean power of 0.3W), so its thermal effect is minimal, avoiding the carbonization and formation of cracks in the walls of the root canal by increasing the temperature.[38,39] When the light energy is activated against the irrigating solution, a photomechanical effect occurs, instead of a thermal effect, which differentiates it from other lasers available in the market.[3]

Quinto *et al.*[40] conducted a study to analyse the efficacy of XP Endo Finisher in the removal of the SCR smear layer from 36 extracted teeth using 5mL NaOCl 1.5%, followed by activation with the Xp-Endo Finisher file for 1 minute at 800 rpm + 3mL of 1.5% NaOCl + 3mL of 0.9% saline solution. The authors concluded that there was a greater susceptibility to smear layer removal and a lower risk of microleakage when XP Endo Finisher was used compared to conventional irrigation with NaOCl and EDTA.

This result can be attributed to the fact that the XP Endo Finisher has the capacity to change its martensitic phase, at room temperature, to the austenitic phase, at body temperature, acquiring a spoon shape due to its high flexibility and shape-memory. Herein, when in rotation, the austenitic phase allows the instrument to contract and expand according to the anatomy of the root canal when being moved up and down, with no wear of the dentine, agitating the irrigating solution and promoting cleaning when accessing areas that are impossible to achieve with a conventional instrument.[30,41] Its easy use and effectiveness appear as a great alternative for sanitizing RCS after mechanical preparation.[40]

Thus, many studies show the efficacy of agitation of the irrigating solution for smear layer removal, showing superiority compared to conventional irrigation. However, it is still not possible to state which technique or association of techniques present the best results, requiring further studies in this field.

Conclusion

The different techniques for agitation of the irrigating solution presented in this review have particularities, with advantages and disadvantages, application protocols and different results, according to the literature. Although it is not possible to state clearly which one would be the best technique, since there is no work that encompasses and compares all systems, it is possible to admit that the methods cited in this work are beneficial and superior to conventional irrigation, promoting better results regarding the removal of smear layer.

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Mini Curriculum and Author's Contribution

1. Charysson Vinicius Benetti - Undergraduate student of Dentistry. Contribution: bibliographic research, acquisition and interpretation of data, preparation of the manuscript. ORCID: 0000-0002-5297-2886
2. Natalia Panho - Undergraduate student of Dentistry. Contribution: bibliographic research, acquisition and interpretation of data, preparation of the manuscript. ORCID: 0000-0003-3010-5279
3. Giovana Domitila Rafagnin - DDS. Contribution: preparation of the manuscript, critical review and final corrections. ORCID: 0000-0002-5401-2301

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Corresponding Author

Charysson Vinicius Benetti

E-mail: charysson.benetti@edu.unipar.br