Int. J. Odontostomat.,
19(3):291-303, 2025.

Comparative Study of the Extent of Penetration of the Irrigant in the Dentinal Tubules and Removal of Smear Layer Using Ultrasonic Activation and XP-Endo Finisher® File. An *ex vivo* Study

Estudio Comparativo del Alcance de Penetración del Irrigante en los Túbulos Dentinarios y Remoción de Lodillo Dentinario Utilizando Activación Ultrasónica y XP-Endo Finisher®. Estudio *ex vivo*

Vania Alejandra Enseñat[1]; Susana Lizette Bertheau Solis[2]; Esther Vaillard Jiménez[2]; Alejandro Gerardo Martínez Guerrero[2] & Eric Reyes Cervantes[3]

ENSEÑAT, V. A.; BERTHEAU SOLIS, S. L.; VAILLARD JIMÉNEZ, E.; MARTÍNEZ GUERRERO, A. G. & REYES CERVANTES, E. Comparative study of the extent of penetration of the irrigant in the dentinal tubules and removal of smear layer using ultrasonic activation and XP-Endo Finisher® File. An *ex vivo* study. *Int. J. Odontostomat., 19(3)*:291-303, 2025.

ABSTRACT. It is now proven that ultrasonic irrigation effectively removes tissue debris, bacteria and smear layer in root canals. An anatomical finishing file, XP-endo Finisher® (FKG Dentaire, La Chaux-de Fonds, Switzerland), was recently introduced with the intention of improving the root canal disinfection process. The results of this study will allow us to know the capabilities and shortcomings of two current techniques for activating irrigation solutions. Therefore, in this study, these two activation systems (ultrasonic and XP-endo Finisher®) were compared in terms of the extent of tubular penetration of the irrigant and the removal of smear layer. 42 newly extracted, single-canal permanent dental organs were instrumented and irrigated with 5.25 % sodium hypochlorite and divided into three groups of 14 dental organs each: G1 (control group) with conventional manual irrigation, G2 (Xp-endo Finisher®) and G3 (ultrasonic irrigation). From each group, 7 dental organs were analyzed with confocal microscopy to observe fluorescence in the penetration of the irrigant and 7 dental organs were prepared for observation under a scanning electron microscope to observe the presence of smear layer in the apical third. The images were analyzed by 2 independent examiners in cecum (endodontic specialists). Statistical analysis was performed with the SPSS statistical package version 22.0 and Statgraphics Centurion. To determine whether there are differences between the experimental groups and the control group, the ANOVA statistical test with its respective statistical significance ($p \leq 05$) and the post hoc multiple range test. Group 2 (Xp-endo Finisher®) obtained the greatest extent of penetration of the irrigant in the dentinal tubules and the highest smear layer removal, followed by ultrasonic irrigation and conventional irrigation, with statistically significant differences between them. By showing the greater volume of penetration of the irrigant in the dentinal tubules and a greater removal of smear layer in the canals activated with the XP-endo Finisher® system, it is proposed as a tool that will favor the prognosis of endodontic treatment.

KEY WORDS: Irrigation, ultrasonic activation, smear layer, dentinal tubules.

INTRODUCTION

By means of computed tomography, it has been shown that after mechanical instrumentation regardless of the technique employed, 35 % or more of the walls of the root canal (including the branches, fins, isthmuses and lateral canals) remain intact to the instrumentation, therefore, it is not able to fully prepare the root canal system, and disinfection is the key to optimizing the filling process and the success of endodontic treatment (Peters *et al*., 2001). Also, during instrumentation all endodontic instruments form a 1 to 2 μm thick layer on the canal walls called the smear layer, which contains organic and inorganic substances with microorganisms that can penetrate to a depth of 40 μm into the dentin tubules (Violich & Chandler,

[1] Av. Lázaro Cárdenas number 3, office 8, Lomas de las Flores c.p. 24060, Campeche, México. vaniaensenat@hotmail.com.
[2] Universidad Autónoma de Puebla, Endodontics Department, 31 Poniente 1304, Los Volcanes, C.P. 72410 Puebla, Puebla, México. susana.bertheau@correo.buap.mx
[3] Centro Universitario de Vinculación y Transferencia de Tecnología BUAP, Prolongación de la 24 Sur y Avenida San Claudio, Ciudad Universitaria, Jardines de San Manuel, C.P. 72000 Puebla, Puebla, México.

Received: 2025-04-09 Accepted: 2025-04-30

2010). Therefore, it is necessary to eliminate it because it prevents the penetration of irrigation agents and intraduct medication, which can affect the quality of the filling. To this end, several techniques and devices have been proposed as adjuvants to conventional chemo-mechanical protocols of endodontic treatment to improve debridement and disinfection, including irrigation with sonic or ultrasonic devices, the negative pressure irrigation system, and irrigation activated by different types of lasers.

As an endodontic irrigant, sodium hypochlorite (NaOCl) is used in concentrations ranging from 0.5 % to 6 %. In high concentrations it has a better ability to dissolve tissues, but even in low concentrations when used in large volumes, it can be equally effective (Basrani & Haapasalo, 2013). Temperature, time, and concentration of the irrigant all play an important role in the depth of penetration into the dentinal tubules. In 2010, Zou *et al*. reported that the penetration depth of sodium hypochlorite ranged from 77 µm to 300 µm (Zou *et al*., 2010).

Disinfection studies have shown that conventional manual irrigation leaves a lot of debris clogged in the irregularities of the root canal system and does not allow the correct administration of the irrigation solution in the apical third of the canal (Shin *et al*., 2010; Muñoz & Camacho-Cuadra, 2012). Also, have shown that the irrigation solution does not travel more than 1-1.5 mm deeper in the duct than the tip of the needle (Boutsioukis *et al*., 2010). In addition, many root canals present with apical curvatures, which makes it almost impossible to place the irrigation needle within 1 mm of the working length (Park *et al*., 2013; Psimma *et al*., 2013).

Recent studies have demonstrated the effectiveness of ultrasonic activation after completion of rotary instrumentation, resulting in improved smear layer and detritus removal from small anatomical irregularities, and synergistic behavior with irrigants to kill biofilm bacteria (van der Sluis, *et al*. 2007; Park, 2013; Layton, 2015; Neelakantan *et al*.,2015). Ultrasound is a form of sonic energy that is transmitted in the form of a pattern of elastic waves that have the property of propagating through different solid, liquid or gaseous media. In 1976, Martin and Cunningham developed an ultrasonic device which they marketed under the name Caviendo®. The tips were designed to oscillate at frequencies of 25-30 kHz, which are beyond the limit of human auditory perception (>20 kHz). It operates in a transverse vibration, with a characteristic pattern of nodes and antinodes along its length (Park, 2013). After the root canal has been formed (regardless of the instrumentation technique used), a small-bore file is inserted into the center of the root canal, down to the apical portion. Subsequently, the root canal is filled with an irrigation solution and the oscillating instrument activates the irrigant by means of ultrasonic waves. The latter induces acoustic currents and cavitation (van der Sluis *et al*., 2010). Acoustic transmission is the rapid movement of fluid in a circular or vortex/swirl-like motion around a vibrating instrument (van der Sluis *et al*., 2007). This so-called "acoustic microcurrent" produces shear stresses along the root canal wall, which removes detritus, smear layer and bacteria from the root canal system (Layton *et al*., 2015). Cavitation refers to the oscillatory motions of gas-filled bubbles in an acoustic field, bubbles that are fed by energy from the ultrasonic field (Macedo *et al*., 2014). This transient type of cavitation activity has been shown to occur around ultrasound tips (van der Sluis *et al*., 2010). The intensity is directly related to the transmission speed. When the instrument cannot vibrate freely in the root canal, it will be less intense, but it will not stop completely (van der Sluis *et al*., 2007). This ultrasonic activation is known as passive ultrasonic irrigation (PUI), first described by Weller *et al*. in 1980. The term "passive" does not adequately describe the process, as it is in fact active; However, when it was first introduced, the term "passive" referred to the non-shear action of the ultrasound-activated instrument. During PUI, energy is transmitted from an oscillating tip to the irrigant present in the root canal using ultrasonic waves. As a result, the authors have recommended modifying the term passive ultrasonic irrigation to ultrasonically activated irrigation (van der Sluis *et al*., 2010).

Recently, a new type of file with an anatomical finish, XP-endo Finisher® was introduced, which consists of a file with a small diameter of ISO 25 and zero taper (25/.00), which gives it greater flexibility and shows greater resistance to cyclic fatigue (Zand *et al*., 2017). It is produced using an alloy exclusive to the commercial house FKG, the NiTi MaxWire (Austensitic-Martensitic Electropolishing-FleX). This material reacts at different temperature levels and is highly flexible (Bao *et al*., 2017; Zupanc *et al*., 2018). At room temperature, in its martensitic phase (M phase), the instrument is straight, however, when subjected to body temperature inside the root canal, it enters its austenitic phase (phase A) and assumes a semicircular shape with a diameter of 1.5 mm that allows it to adapt to any shape of canal, reaching irregularities and areas of resorption (Keskin *et al*., 2017; Silva *et al*., 2018). One of the main advantages of XP-endo Finisher® is that it can extend its reach by 6mm in diameter or 100 times that of a file of equivalent size. According to the manufacturer, when the instrument is placed inside the duct in rotation mode, the shape of its phase A allows the instrument to access and clean areas that other instruments could not reach, without damaging the dentin or altering the original shape of the canal (Valente *et al*., 2017; Uygun *et al*., 2017). The XP-endo Finisher® instrument should be used after the shaping of the root canal system up to at least a 25 gauge. It should be worked along the entire length of the duct for approximately 1 minute at a speed of 800 rpm (800-1000 rpm) and 1 Ncm of torque. Ducts should always contain irrigant but filling the access cavity prior to file insertion should be avoided (Elnaghy *et al*., 2017; Vaz-Garcia *et al*., 2018). The effectiveness of this system has been mentioned in various studies.

Keskin *et al*. evaluated the elimination of intracanal medication with the XP-endo Finisher® system, ultrasonic irrigation and Endo-activator®, and they found that both, ultrasonic irrigation and XP-endo Finisher®, were the most efficient techniques (Keskin *et al*., 2017). Leoni *et al*. (2017) evaluated the efficiency of four irrigation protocols; XP-endo Finisher® and ultrasonic activation had the best results in canal cleanliness compared with the conventional irrigation and SAF system, but they found no statistically significant differences between these two techniques.

At this moment, no studies have been recorded comparing the action of conventional irrigation with XP-endo Finisher® activated irrigation and ultrasonic irrigation, in terms of its ability to penetrate the irrigant into the dentinal tubules and dentin sludge removal. Therefore, the aim of this research is to evaluate the removal of smear layer and the penetration of irrigation solutions into dentinal tubules by comparing XP-endo Finisher® system, ultrasonic irrigation and conventional irrigation, and analyze whether there are significant differences.

MATERIAL AND METHOD

This study was approved by the Research Committee of the Faculty of Stomatology (CIFE) at the Benemérita Universidad Autónoma de Puebla, and in accordance with the ethical principles of the Council of International Organizations of Medical Sciences CIOMS/ OMS (2002) and the World Medical Association (WMA).

This is a clinical study, *ex vivo* quasi experimental and comparative, where a probabilistic, non-random sample calculated at 95 % confidence was analyzed, accordingly for analysis with a 0.05 and 80 % statistical power. N=42 Samples distributed for each group to be compared, were selected according to the following inclusion criteria: permanent single-canal, caries-free and restoration-free dental organs, extracted for orthodontic or periodontal reasons from patients treated at the Faculty of Stomatology (FEBUAP), in an age range of 15 to 30 years and with curvatures of less than 30º (Schneider technique). The 42 teeth were selected and stored in 0.5 % sodium hypochlorite solution for 24 hours for decontamination and kept in distilled water until use. Periapical radiographs confirmed the presence of a single root canal. The dental crowns were sectioned using a diamond blade and abundant irrigation with water, at a standardized length of 15 mm.

The working length was determined by inserting a type K #10 file (Dentsply Maillefer, Ballaigues, Switzerland) until the tip was visible through the apical foramen under 16X magnification, the final working length was obtained by subtracting 1 mm from this measurement. The root surface was covered with 2 coats of nail varnish and the apex was closed with soft modeling wax to prevent extrusion of the irrigant during irrigation procedures. Root canals were formed with hand-held instruments up to the K-type file #15, followed by NiTi Protaper Next rotary instruments (Dentsply, Maillefer) up to the X3 instrument (30/.07). Instrumentation was carried out following the manufacturer's instructions with Elements Sybron® Endo rotary motor, maintaining apical permeability with a #10 hand instrument between each instrument. The samples were irrigated with 2 ml of 5.25 % NaOCl manually deposited between each instrument with a hypodermic syringe and a 27-gauge side-exit needle.

A final irrigation protocol was performed using 5 ml of NaOCl at its maximum concentration (5.25 %) for 1 min and 5ml of 17% EDTA for 1 min. After the procedure, the root canal was washed with 5ml of distilled water and then dried using paper tips (Dentsply Maillefer®).

The samples were divided into three groups (n=14 each): G1 (control group), G2 (XP-endo Finisher®) and G3 (Passive Ultrasonic Irrigation), where the final irrigation was carried out as follows:

- Group 1 (conventional irrigation): The root canal was irrigated for 60 seconds using a 27-gauge side-exit needle, with inlet and outlet movements.

- Group 2 (XP Endo Finisher®): The XP-endo Finisher® file was introduced into the root canal at 1 mm from the working length, activating it at a speed of 800 rpm with a smooth inlet and outlet movement along the entire working length for 3 cycles of 20 seconds each.

- Group 3 (Ultrasonic Irrigation): The activating tip (25/.02) for the Satelec® P5 Booster ultrasonic equipment (25/.02) was placed in the root canal at 1 mm from the working length and activated for 3 cycles of 20 seconds each.

To evaluate the penetration into the dentinal tubules with fluorescence under confocal microscopy (n=7 from each group, in total n=21), the final irrigation was performed as follows: 5ml of 5% NaOCl (2 activation cycles of 20 seconds) and then 2.5 ml of 5% NaOCl labeled with 2.5ml of fluorescent Rhodamine B for each duct (1 activation cycle of 20 seconds). The solution of fluorescent Rhodamine B (Sigma-Aldrich®) at a concentration of 0.1% was prepared with an analytical balance (Adventure pro®) and the magnetic bullet stirring grid to obtain a homogeneous solution of the fluorophore, in the Physiology laboratory of the FEBUAP (Fig. 1).

After the irrigation procedures for each study group, the root canals were dried with paper tips from the Protaper Next® system and the coronal accesses were sealed with Cavit® temporary restorative material. Samples were stored in plastic vials with distilled water until were embedded in the model with stone plaster horizontally and vertically in preparation for mounting on the trimmer. The samples were sectioned with a Buehler IsoMed® low-speed trimmer and a 0.3mm caliber cutting disc at the FEBUAP dental biomaterials laboratory (Fig. 2). The samples were bathed with sterile saline solution for 1 minute to remove organic and inorganic debris that was produced after the cuts.

Fig. 2. Low speed Buehler IsoMed® trimmer.

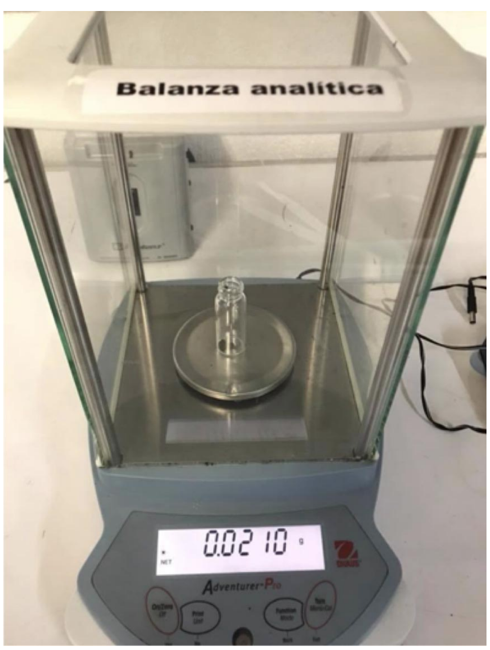

Fig. 1. Weight of the exact amount of Rhodamine B on the analytical balance (Adventure pro®).

Samples were prepared in the Scanning Microscopy laboratory of the University Center for Linkage and Technology Transfer (CUVyTT) BUAP. For the scanning electron microscope (SEM) analysis, the samples were covered with an external gold coating with the Denton Vacuum Desk V® (Fig. 3). Once ready, the samples were mounted on the inner platform of the MEB's vacuum chamber as the figure 4 shows. Microphotographs were obtained at 500x, 1000x and 3000x magnification.

The images were analyzed by 2 independent examiners in cecum (endodontic specialists) to assess the degree of dentin sludge removal. The examiners had no information to determine the technique or material used in each of the samples. The images were evaluated using the scale reported by some authors, which has served as the basis for multiple investigations (Caron *et al*., 2010; Peeters & Suardita, 2011; Wang *et al*., 2013) regarding the removal of the smear layer where: 1) There is no smear layer, and the dentinal tubules are open; 2) Small scattered amounts of mud and open dentinal tubules; 3) Thin layers of mud and partially open dentinal tubules; 4) Partially covered by a thick layer of dentin mud; 5) Completely covered by a thick layer of dentin mud.

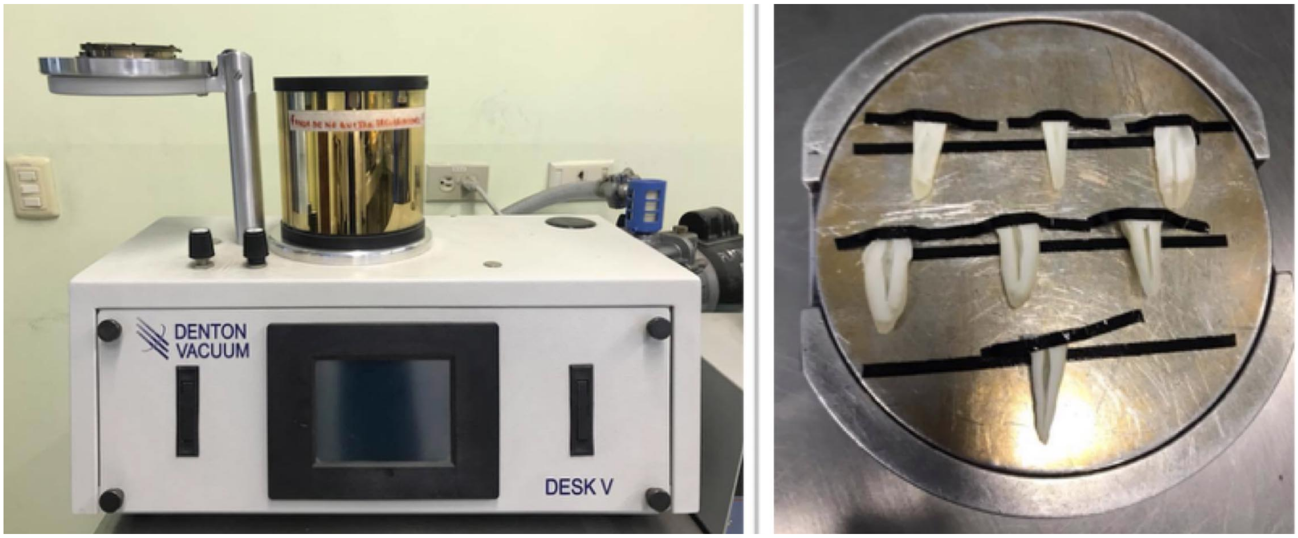

Fig. 3. Denton Vacuum Desk V® equipment for external gold coating.

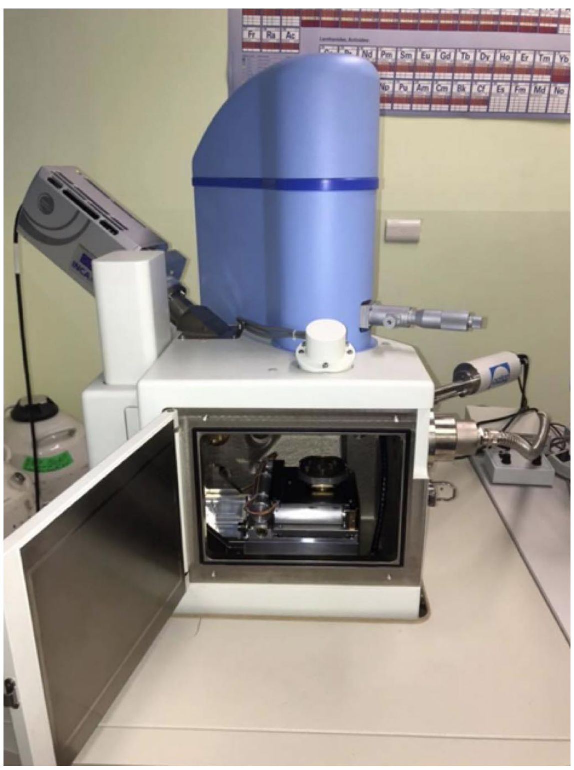

Fig. 4. Vacuum chamber of the Scanning Electron Microscope (SEM).

With the analysis of the samples under the scanning electron microscope, 63 microphotographs of the irrigated root canals were obtained, seen at a magnification of 500x, 1000x and 3000x. The samples (n=21) for the Confocal Microscopy were analyzed in the Institute of Physiology BUAP. To evaluate the penetration of the irrigant into the dentin tubules, 1 mm thick cross-sections were made using a Buehler IsoMed® low-speed trimmer and 0.3 mm gauge cutting disc at 4 mm from the root apex. The sections were then polished with silicon carbide abrasive paper. The samples were then mounted on glass slides and examined with an inverted confocal microscope (Nikon C2 Plus®) at 10x with a wavelength of 543 µm (Fig. 5).

The deepest penetration point was measured from the duct wall to the point of maximum dye penetration in mm (green line), using the confocal microscope software (Nikon C2 Plus®) as show Fig. 6. The digital images were imported into the ImageJ program (ImageJ software, NIH) to measure the total penetration area of the dentinal tubules (Fig. 7). The penetration area of the dentinal tubules was measured in micrometers (µm) and converted to square millimeters (mm^2) for statistical analysis. The results were recorded in the Excel database to obtain a true idea of the dimension and volume of penetration of the irrigant into the dentinal tubules, brightfield images and fluorescence images were taken from each sample, which were superimposed using the confocal microscope program (Fig. 8) and compared (Fig. 9).

Statistical analysis was performed with the SPSS statistical package version 22.0 and Statgraphics Centurion. For categorical variables, percentages and corresponding graphs were used. For numerical variables, measures of central tendency and dispersion were used. To determine whether there are differences between the experimental groups and the control group, the ANOVA statistical test with its respective statistical significance ($p \leq 05$) and the post hoc multiple range test were used. Cohen's Kappa test was used to measure intra- and inter-observer agreement.

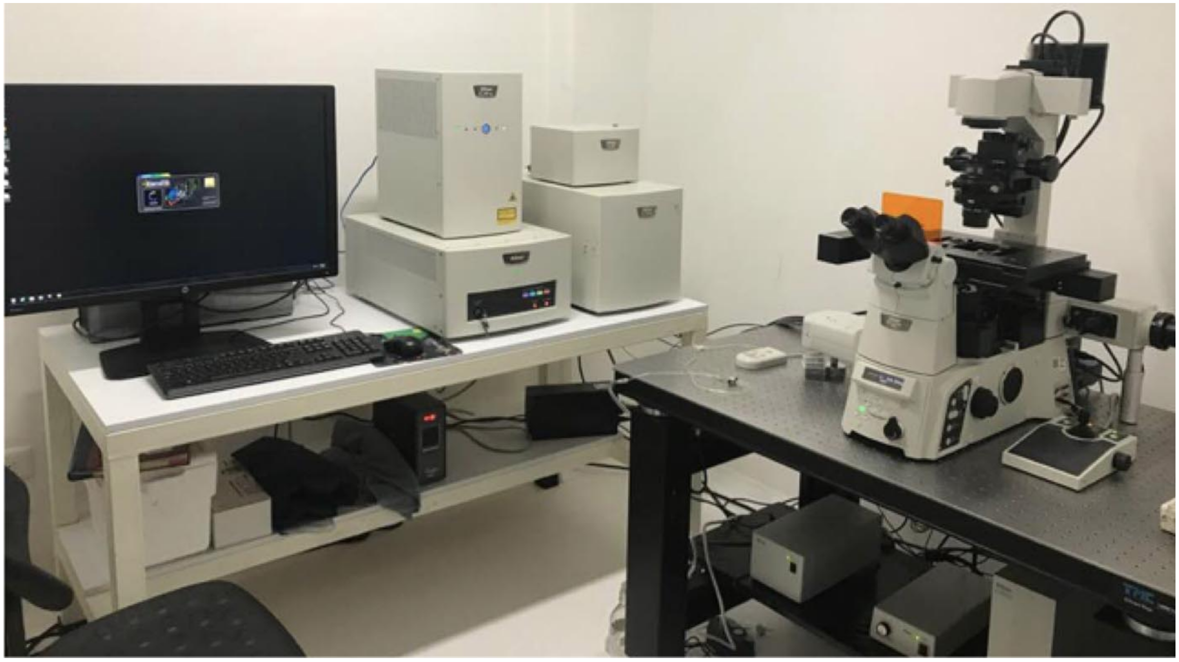

Fig. 5. Inverted confocal microscope (Nikon C2 Plus®).

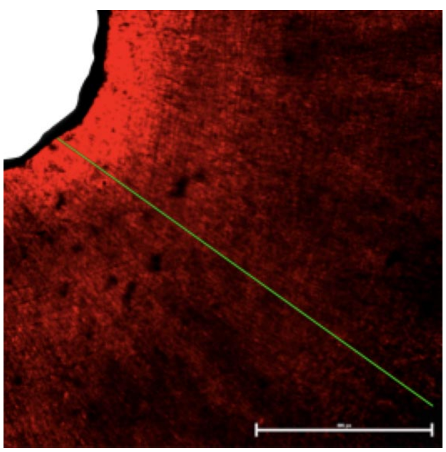

Fig. 6. Measurement of the maximum depth of penetration of the irrigant in microns, obtained using the confocal microscope software (green line).

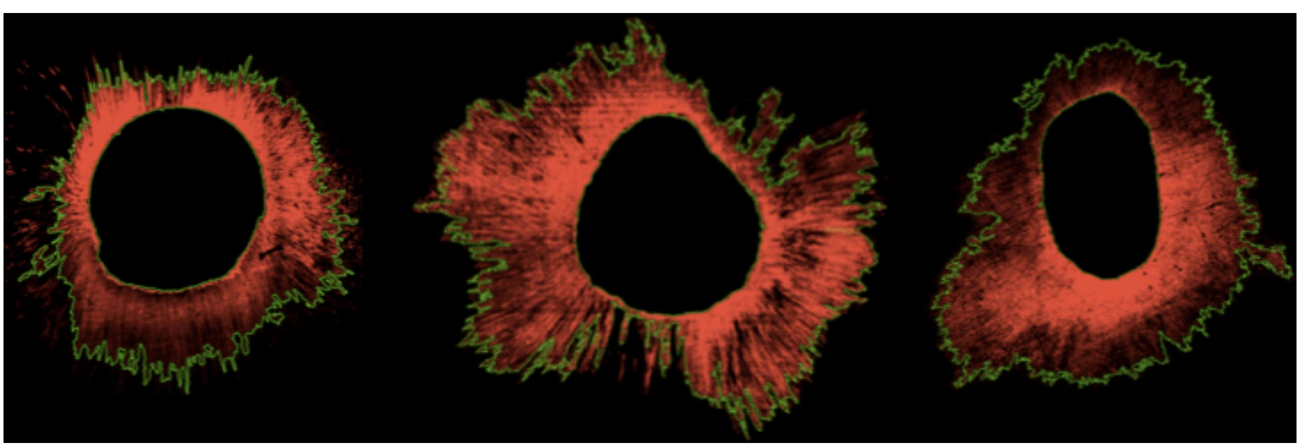

Fig. 7. Representative images of the samples of each group where the delimitation and measurement of the irrigant penetration area was carried out using the Image J program software.

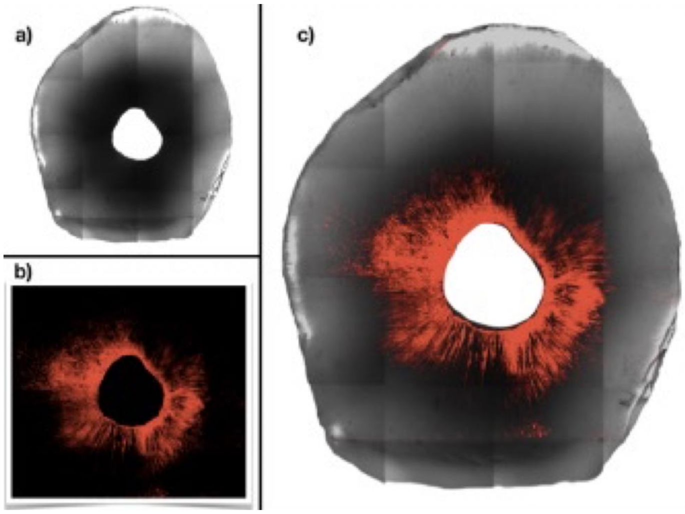

Fig. 8. Box a) shows the image obtained with brightfield microscopy of a cross-section of the sample belonging to Group 2: XP-endo Finisher®. b) the penetration of the irrigant in dentinal tubules of the same section is observed with fluorescence microscopy, and c) the montage of both images using the microscope software.

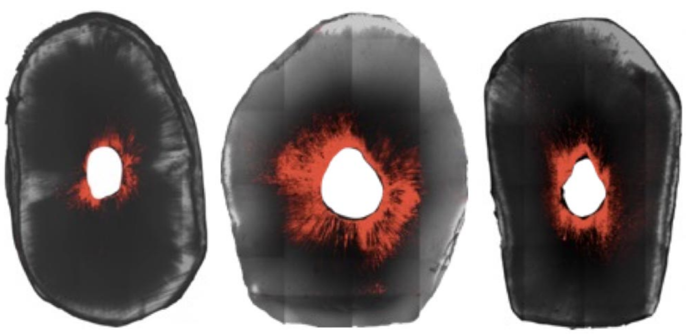

Fig. 9. Representative figures from left to right: Control group, XP-endo Finisher® group and Ultrasonic irrigation group.

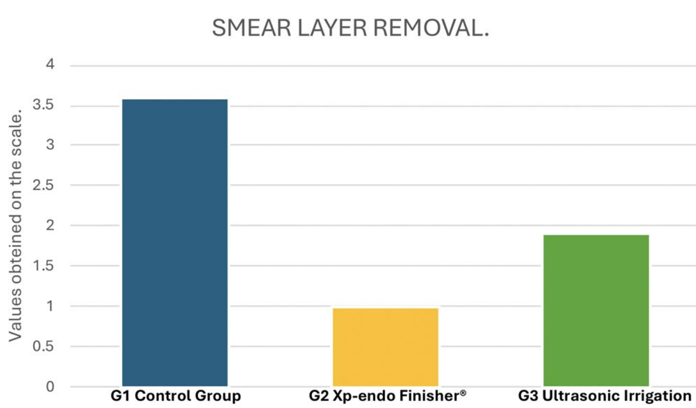

Fig. 10. Representation of the difference in means between groups in terms of smear layer remotion studied under Scanning Electron Microscopy (SEM). Group 2 (XP-endo Finisher®) obtained the best results in terms of smear layer removal at the level of the apical third of the root canal, followed by Group 3 (Ultrasonic irrigation) and finally Group 1 (Conventional irrigation), which presented the least smear layer removal.

RESULTS

The statistical analysis of the samples studied under Scanning Electron Microscopy (SEM) indicates that there are differences in the removal of dentinal sludge depending on the final irrigation technique used. Group 2 (XP-endo Finisher®) obtained the best results in terms of smear layer removal at the level of the apical third of the root canal, followed by Group 3 (Ultrasonic irrigation) and finally Group 1 (Conventional irrigation), which presented the least smear layer removal (Fig. 10). An intra and inter observer kappa concordance index of 0.986 was obtained. This suggests that there was excellent reliability and reproducibility among the observers (Table I).

In G1 obtained an average on the scale of 4 which is equivalent to the presence of tubules partially covered by a thick layer of dentin mud. Below are images obtained with the MEB at 500x, 1000x and 3000x shown in Fig. 11. In XP-endo Finisher® System (group G2), obtained the best results, all observers gave it a value of 1, which on the scale corresponds to samples in which smear layer is not observed and the dentinal tubules are open (Fig. 12). Finally, Ultrasonic irrigation technique (group G3), obtained an average on the scale of 2 that corresponds to small, scattered amounts of mud and open dentinal tubules (Fig. 13).

Regarding the penetration of the irrigant into the dentin tubules, the following table shows the total values of the penetration area obtained (Table II). Since the P-value of the test is less than 0.05, there is a statistically significant difference between the study groups with a significance value of 95.0 % confidence (Table III). With the post hoc test of multiple ranks, it was shown that there are significant differences between the three groups (Table IV).

In the intergroup analysis, the maximum depth of penetration in the XP-endo Finisher® group was statistically superior compared to the ultrasonic irrigation group and the control group with conventional irrigation, as show in Table V.

Table I. Concordance and reliability of observations.

Group 1 n=14	Group 2 n=14	Group 3 n=14
Conventional irrigation (Control Group)	XP-endo Finisher	Ultrasonic irrigation
k= 0.98	k= 1.00	k= 0.98

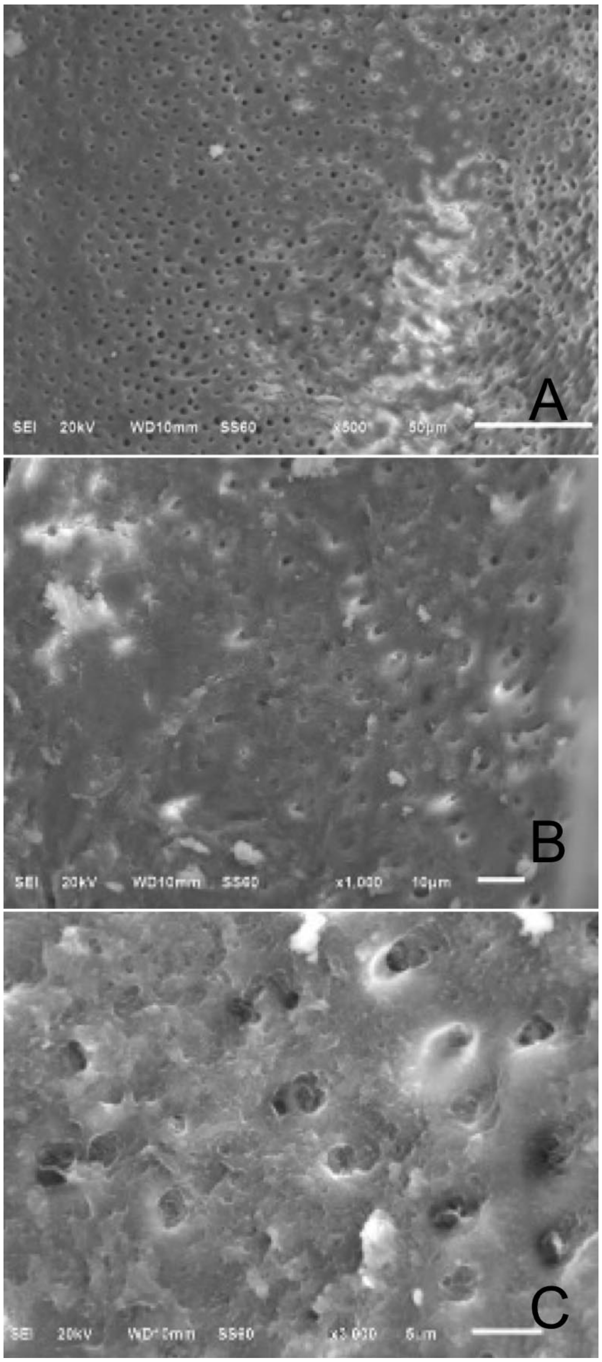

Fig. 11. Control Group 1 (Conventional irrigation) obtained an average on the measurement scale 4, which is equivalent to the presence of tubules partially covered by a thick layer of dentin mud at apical third. A) microphotography at 500x, B) microphotography at 1000x, and C) microphotography at 3000x.

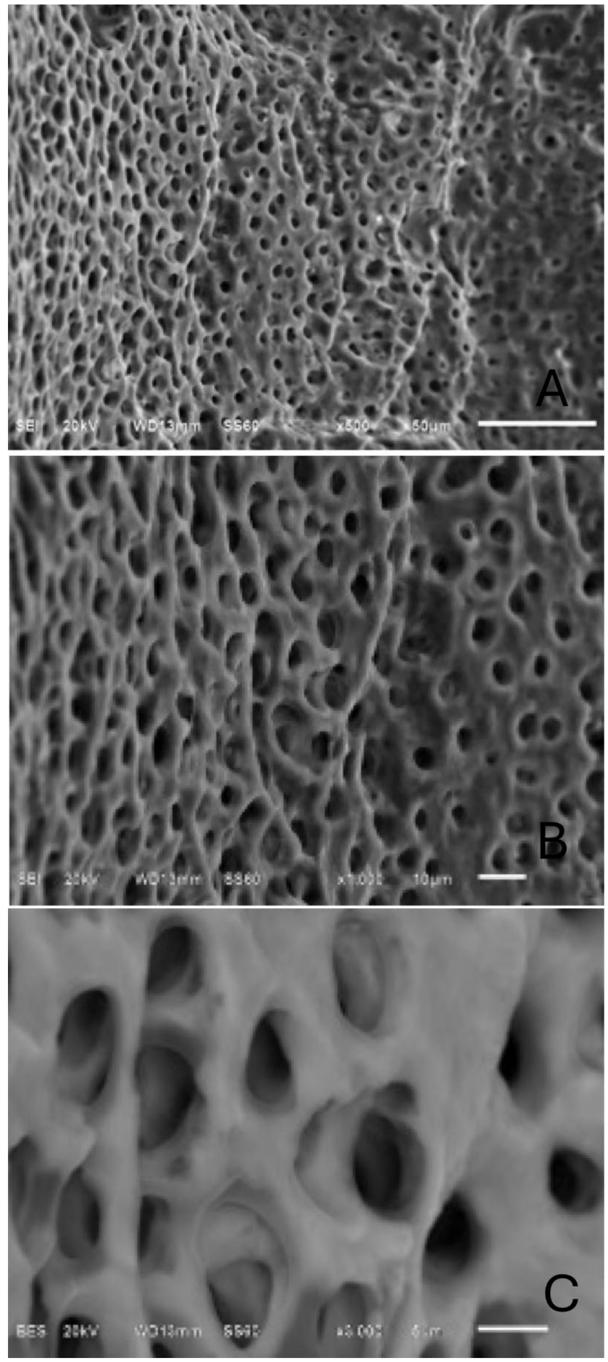

Fig. 12. Group 2 XP-endo Finisher® System achieved the best results. All observers gave it a value of 1, which on the scale corresponds to samples in which smear layer is not observed and the dentinal tubules are open at apical third. A) microphotography at 500x, B) microphotography at 1000x, and C) microphotography at 3000x.

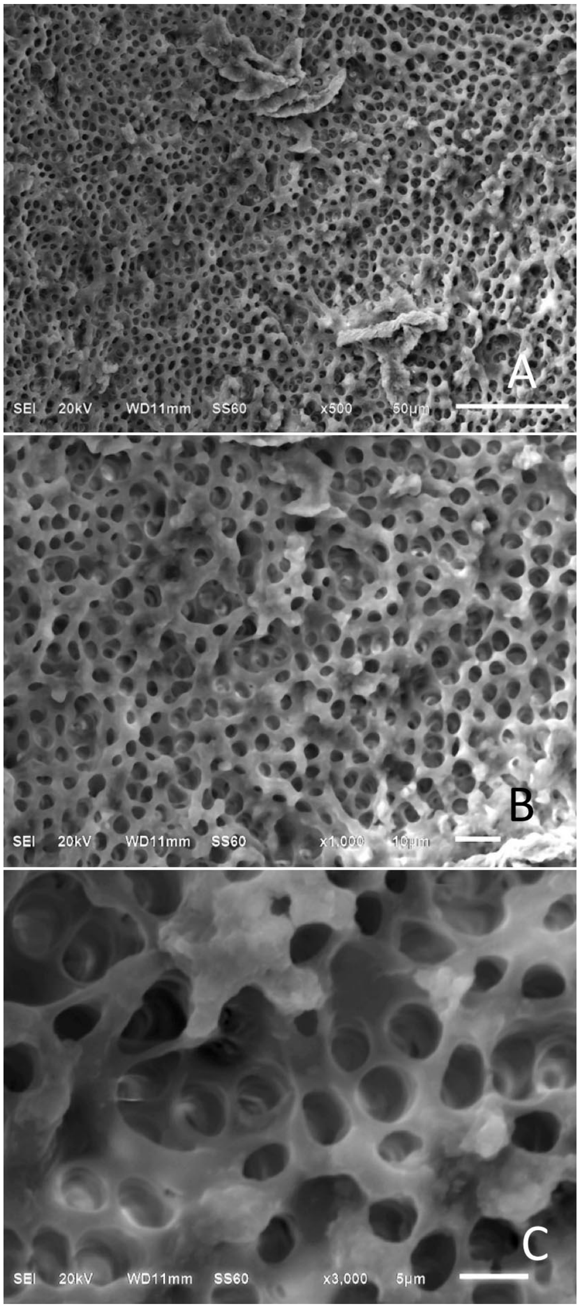

Fig. 13. Group 3 Passive ultrasonic irrigation obtained an average on the scale of 2 which corresponds to small, scattered amounts of mud and open dentinal tubules at apical third. A) microphotography at 500x, B) microphotography at 1000x, and C) microphotography at 3000x.

DISCUSSION

From the results obtained in this study and statistically analyzed, it is evident that the XP-endo Finisher® system had the best performance in terms of smear layer removal and the greatest penetration of the irrigant in the dentinal tubules. The smear layer prevents the penetration of irrigation solutions, compromises the effect of intraductal medication and affects the quality of the filling, increasing the risk of bacterial microfiltration and reinfection of the root canal system during endodontic treatment (Orstavik & Haapasalo, 1990; Mancini *et al*., 2013; Haapasalo *et al*., 2013). The results of the present study show that both the XP-endo Finisher® system and Ultrasonic irrigation removed a greater amount of dentin sludge compared to conventional manual irrigation at the level of the apical third of the root canal.

These results are consistent with the study by Sanabria-Liviac *et al*. (2017) who demonstrated that the use of the XP-Endo Finisher® system is an effective method for the removal of the smear layer after root canal instrumentation and is more effective than ultrasonic irrigation with and without EDTA in the middle and apical thirds of the canal. A correlation has been found between the removal of the dentinal sludge layer and the repair of periapical lesions (Peters & Barbakow, 2000; Wang *et al*., 2017). Therefore, its complete removal plays an important role during endodontic treatment. Because the smear layer contains both inorganic and organic material, the sequential use of sodium hypochlorite and a chelating agent or acid that dissolves the inorganic tissue is required (Arslan *et al*., 2016).

The recommended combination is to perform the final irrigation with 17 % EDTA solution followed by 6 % NaOCl (Haapasalo *et al*., 2013; Peters & Barbakow, 2000). However, there is no consensus regarding the optimal volume, application time, temperature, or activation method for use with irrigation solutions. Currently, no studies have been reported between the XP-Endo Finisher® system and Ultrasonic irrigation for the evaluation of smear layer removal using similar experimental protocols. Even though sodium hypochlorite is a general-purpose root canal irrigant, data on depth of penetration into dentinal tubules are lacking. The highest penetration of NaOCl in the dentinal tubules

Table II. Statistical summary of irrigant penetration in dentin tubules.

	Recount	Average	Standard Deviation	Coefficient of variation
G1: Control Group	7	4406.5	2087.46	47.3724 %
G2: XP Endo Finisher®	7	14687.5	1222.4	8.32272 %
G3: Ultrasonic Irrigation	7	12808.6	1028.03	8.02612 %
Total	21	10634-2	4801.27	45.1493 %

Table III. ANOVA Statistical Test.

	Sum of squares	Gl	Medium squares	Reason-F	Value-P
Between groups	4.19593E8	2	2.09796E8	91.10	0.0000
Intra groups	4.14518E7	18	2.30288E6		
Total	4.61044E8	20			

Table IV. Post hoc multi-rank testing.

Contrast	*Sig.*	*Difference*	*+/- Limits*
Control Group - XP Endo Group	*	-10281.0	1704.17
Control Group – Ultrasound Group	*	-8402.11	1704.17
XP Endo Group – Ultrasound Group	*	1878.92	1704.17

Table V. Recording the maximum depth of penetration of the irrigant into tubules.

G 1 Control Group Conventional Irrigation	**G 2** XP-endo Finisher®	**G 3** Ultrasonic irrigation
338 μm	894 μm	721 μm

that has been reported with a conventional irrigation technique is 100 to 300 mm with a 6 % solution for 20 minutes at 45 ºC (Neelakantan *et al*., 2015; Giardino *et al*., 2017). Increasing the concentration of NaOCl from 1% to 6 % improves the depth of penetration of its antibacterial action, but it is not able to achieve complete eradication of bacteria from the dentinal tubules, especially beyond the first 300 μm of the dentin-pulp junction (Zou *et al*., 2010). These reports are consistent with the data obtained in the present study, where the maximum levels of sodium hypochlorite penetration depth were 894 μm, 721 μm and 338 μm for the XP-endo Finisher®, ultrasonic irrigation and conventional irrigation groups, respectively. However, the depth of penetration cannot be directly compared with other studies due to differences in the methodology adopted.

When comparing the total volume of penetration of the irrigant in the dentinal tubules between the groups of the present study, it was found that the highest volume of penetration of the irrigant corresponds to the XP-endo Finisher® group, which presented statistically significant differences when compared to Ultrasonic irrigation and the control group. Further research needs to be done to verify whether longer irrigation times and different temperatures correspond to deeper penetration and reveal a difference between the techniques employed.

Bao *et al*. (2017) found similar results to our research, they studied the capacity of 3 techniques for the removal of bacterial biofilm and demonstrated that final irrigation with the XP-endo Finisher® system resulted in greater bacterial reduction than the conventional irrigation technique and Ultrasonic irrigation (Bao *et al*., 2017). The XP-endo Finisher's® greater effectiveness in this study is due to its flexibility that allows it to expand its reach to 6 mm in diameter or 100 times more than a file of equivalent size, allowing it to reach irregular areas of the duct (Trope & Debelian, 2015; Hamdan *et al*., 2017). This can be explained due to the highly flexible MaxWire (Austensitic-Martensitic Electropolish - FleX) alloy combined with the small core size and zero taper of the instrument (25/.00) (Alves *et al*., 2016). This unique property promoted agitation of the irrigation solution within the duct, resulting in the disruption and removal of the smear layer and greater penetration of the irrigant into the tubules (Zivkovic *et al*., 2015).

This evaluation of the results under the Scanning Electron Microscope (SEM), it is semi quantitative and may be subject to possible biases when selecting the field for a high-power magnification and variations in the interpretation of the results by the observer (Kara Tuncer, 2015). It also requires sectioning the root to open the duct so that it can be observed. This step is quite difficult to perform reproducibly when dealing with thin and/or curved roots (Bolles *et al*., 2013). SEM examination provides detailed observations of dentinal tubules and surface integrity and appearance with high-resolution imaging and a large depth of field, but it would be difficult to study the general trend of bacterial invasion and irrigant penetration into dentinal tubules with this method, as only confined regions could be examined (Guimarães *et al*., 2014).

Confocal microscopy has been used in endodontics to evaluate the adaptation of filling materials and the penetration of endodontic cement into dentinal tubules, as well as to visualize intratubular bacteria (Mamootil & Messer, 2007). Therefore, in this study it was decided to use this method to show the penetration of the irrigant into the dentinal tubules. Due to the tortuous trajectory of dentinal tubules, they are difficult to observe in their entirety through a single cut. With the confocal microscope, the sample can be observed not only on the surface but also in depth, making multiple slices and obtaining a three-dimensional image. Therefore, it provides a more accurate and informative structural correlation than two-dimensional analysis (Diaspro & Robello, 2000; Chandra *et al*., 2012). The analysis under MEB and confocal microscopy of the present study was carried out only in the apical third of all samples, because this area presents the highest number of anatomical irregularities and is more difficult to access with different irrigation techniques (Park *et al*., 2012; 2013). Previous studies have shown that the apical third region of the root canal behaves completely differently from the middle and coronal thirds. The coronal third is the most permeable to the action of irrigants, followed by the middle third and finally the apical third (Azim *et al*., 2016). The reduction in penetration is related to the number of dentinal tubules decreasing from 40,000 mm^2 in the coronal region to 14,400 mm^2 in the apical region. On the other hand, dentinal tubules have a reduction in tubule diameter due to advanced dentin sclerosis. Dental sclerosis reduces the space available for the penetration of irrigation solutions and bacteria (Thaler *et al*., 2008). Therefore, dental organs from patients in an age range of 15 to 30 years were used in this study because dentin sclerosis is known to begin after this age in the apical third of teeth. Coming studies could include older age range of teeth, wider radicular curvatures, longer periods of irrigation time and controlled irrigant temperature, to discover the differences between these irrigant activation protocols.

CONCLUSION

Under the limitations of this study, it can be concluded that the penetration of the irrigant into the dentinal tubules is deeper when the XP endo Finisher® system is used and the smear layer removal is superior to ultrasonic irrigation and conventional irrigation. There were statistically significant differences between the 3 study groups: The samples irrigated with XP-endo Finisher® system showed a maximum penetration of the irrigant at 894mm in the dentin, and the dentinal tubules were observed permeable and without the presence of smear layer, which improves the disinfection effect of the root canal system and may have a positive impact on the prognosis of endodontic treatment.

ACKNOWLEDGEMENTS. We express our gratitude to MSc. Eric Reyes Cervantes and his crew at the University Center for Linkage and Technology Transfer BUAP, also to MChemSc. Alberto Vinizio Jerezano Domínguez for their support to conduct this study.

ENSEÑAT, V. A.; BERTHEAU SOLIS, S. L.; VAILLARD JIMÉNEZ, E.; MARTÍNEZ GUERRERO, A. G. & REYES CERVANTES, E. Estudio comparativo del alcance de penetración del irrigante en los túbulos dentinarios y remoción de lodillo dentinario utilizando activación ultrasónica y XP-Endo Finisher®. Estudio *ex vivo. Int. J. Odontostomat., 19(3)*:291-303, 2025

RESUMEN: En la actualidad está comprobado que la irrigación ultrasónica logra remover eficazmente restos de tejido, bacterias y lodillo dentinario en los conductos radiculares. Sin embargo, recientemente se introdujo una lima de acabado anatómico, XP-endo Finisher® (FKG Dentaire, La Chaux-de Fonds, Suiza), con la intención de mejorar el proceso de desinfección radicular. Por lo que el objetivo de este estudio es comparar estos dos sistemas de activación en cuanto al alcance de penetración tubular del irrigante y la remoción de lodillo dentinario. 42 órganos dentarios permanentes unirradiculares recién extraídos, de un solo conducto, fueron instrumentados e irrigados con hipoclorito de sodio al 5.25% y se dividieron en tres grupos de 14 órganos dentarios cada uno: G1 (grupo control) irrigado de manera manual convencional, G2 (Xp-endo Finisher®) y G3 (Irrigación ultrasónica). De cada grupo 7 órganos dentarios fueron analizados con microscopía confocal para observar la fluorescencia en la penetración del irrigante y 7 órganos dentarios fueron preparados para su observación en microscopio electrónico de barrido para observar la presencia de lodillo dentinario, en el tercio apical. El grupo 2 (Xp-endo Finisher®) obtuvo el mayor alcance de penetración del irrigante en los túbulos dentinarios y de igual modo, la mayor remoción de lodillo dentinario seguido del grupo 3 (irrigación ultrasónica) y el grupo 1 (irrigación convencional), con diferencias estadísticamente significativas entre ellos. Al mostrar el mayor volumen de penetración del irrigante en los túbulos dentinarios y una mayor remoción de lodillo dentinario en los conductos activados con el sistema XP-endo Finisher®, éste se propone como una herramienta que favorecerá el pronóstico del tratamiento endodóntico.

PALABRAS CLAVE: Irrigación, activación ultrasónica, lodillo dentinario, túbulos dentinarios.

REFERENCES

Alves, F. R. F.; Marceliano-Alves, M. F.; Sousa, J. C. N.; Silveira, S. B.; Provenzano, J. C. & Siqueira, J. F. Removal of root canal fillings in curved canals using either reciprocating single or rotary multi-instrument systems and a supplementary step with the XP-Endo Finisher. *J. Endod., 42(7)*:1114-9, 2016.

Arslan, D.; Guneser, M. B.; Dincer, A. N.; Kustarci, A.; Er, K.; Siso, S. H. Comparison of smear layer removal ability of QMix with different activation techniques. *J. Endod., 42(8)*:1279-85, 2016.

Azim, A. A.; Aksel, H.; Zhuang, T.; Mashtare, T.; Babu, J. P. & Huang, G. T. Efficacy of 4 irrigation protocols in killing bacteria colonized in dentinal tubules examined by a novel confocal laser scanning microscope analysis. *J. Endod., 42(6)*:928-34, 2016.

Bao, P.; Shen, Y.; Lin, J. & Haapasalo, M. *In vitro* efficacy of XP-endo Finisher with 2 different protocols on biofilm removal from apical root canals. *J. Endod., 43(2)*:321-5, 2017.

Basrani, B. & Haapasalo, M. Update on endodontic irrigating solutions. *Endod. Top., 27*:74-102, 2013.

Bolles, J. A.; He, J.; Svoboda, K. K.; Schneiderman, E. & Glickman, G. N. Comparison of Vibringe, EndoActivator, and needle irrigation on sealer penetration in extracted human teeth. *J. Endod., 39(5)*:708-11, 2013.

Boutsioukis, C.; Lambrianidis, T.; Verhaagen, B.; Versluis, M.; Kastrinakis, E.; Wesselink, P. R. & van der Sluis, L. W. M. The effect of needle-insertion depth on the irrigant flow in the root canal: Evaluation using an unsteady computational fluid dynamics model. *J. Endod., 36(10)*:1664-8, 2010.

Caron, G.; Nham, K.; Bronnec, F. & Machtou, P. Effectiveness of different final irrigant activation protocols on smear layer removal in curved canals. *J. Endod., 36(8)*:1361-6, 2010.

Chandra, S. S.; Shankar, P. & Indira, R. Depth of penetration of four resin sealers into radicular dentinal tubules: a confocal microscopic study. *J. Endod., 38(10)*:1412-6, 2012.

Diaspro, A. & Robello, M. Two-photon excitation of fluorescence for three-dimensional optical imaging of biological structures. *J. Photochem. Photobiol. B., 55(1)*:1-8, 2000.

Elnaghy, A. M.; Mandorah, A. & Elsaka, S. E. Effectiveness of XP-Endo Finisher, EndoActivator, and file agitation on debris and smear layer removal in curved root canals: A comparative study. *Odontology, 105(2)*:178-83, 2017.

Giardino, L.; Cavani, F. & Generali, L. Sodium hypochlorite solution penetration into human dentine: a histochemical evaluation. *Int. Endod. J., 50(5)*:492-8, 2017.

Guimarães, B. M.; Amoroso-Silva, P. A.; Alcalde, M. P.; Marciano, M. A.; de Andrade, F. B. & Duarte, M. A. H. Influence of ultrasonic activation of 4 root canal sealers on the filling quality. *J. Endod., 40(7)*:964-8, 2014.

Haapasalo, M.; Qian, W. & Shen, Y. Irrigation: beyond the smear layer. *Endod. Top., 27(1)*:35-53, 2013.

Hamdan, R.; Michetti, J.; Pinchon, D.; Diemer, F. & Georgelin-Gurgel, M. The XP-Endo Finisher for the removal of calcium hydroxide paste from root canals and from the apical third. *J. Clin. Exp. Dent., 9(7)*:855-60, 2017.

Kara Tuncer, A. Effect of QMix 2 in 1 on sealer penetration into the dentinal tubules. *J. Endod., 41(2)*:257-60, 2015.

Keskin, C.; Sariyilmaz, E. & Sariyilmaz, Ö. Efficacy of XP-endo Finisher file in removing calcium hydroxide from simulated internal resorption cavity. *J. Endod., 43(1)*:126-30, 2017.

Layton, G.; Wu, W. I.; Selvaganapathy, P. R.; Friedman, S. & Kishen, A. Fluid dynamics and biofilm removal generated by syringe-delivered and 2 ultrasonic-assisted irrigation methods: A novel experimental approach. *J. Endod., 41(6)*:884-9, 2015.

Leoni, G. B.; Versiani, M. A.; Silva-Sousa, Y. T.; Bruniera, J. F. B.; Pécora, J. D. & Sousa-Neto, M. D. *Ex vivo* evaluation of four final irrigation protocols on the removal of hard-tissue debris from the mesial root canal system of mandibular first molars. *Int. Endod. J., 50(4)*:398-406, 2017.

Macedo, R.; Verhaagen, B.; Rivas, D. F.; Versluis, M.; Wesselink, P. & van der Sluis, L. W. M. Cavitation measurement during sonic and ultrasonic activated irrigation. *J. Endod., 40(4)*:580-3, 2014.

Mamootil, K.& Messer, H. H. Penetration of dentinal tubules by endodontic sealer cements in extracted teeth and in vivo. *Int. Endod. J., 40(11)*:873-81, 2007.

Mancini, M.; Cerroni, L.; Iorio, L.; Armellin, E.; Conte, G. & Cianconi, L. Smear layer removal and canal cleanliness using different irrigation systems (EndoActivator, EndoVac, and passive ultrasonic irrigation): Field emission scanning electron microscopic evaluation in an *in vitro* study. *J. Endod., 39(11)*:1456-60, 2013.

Muñoz, H. R. & Camacho-Cuadra, K. *In vivo* efficacy of three different endodontic irrigation systems for irrigant delivery to working length of mesial canals of mandibular molars. *J. Endod., 38(4)*:445-8, 2012.

Neelakantan, P.; Cheng, C. Q.; Mohanraj, R.; Sriraman, P.; Subbarao, C. & Sharma, S. Antibiofilm activity of three irrigation protocols activated by ultrasonic, diode laser or Er:YAG laser *in vitro*. *Int. Endod. J., 48(6)*:602-10, 2015.

Orstavik, D. & Haapasalo, M. Disinfection by endodontic irrigants and dressing of experimentally infected dentinal tubules. *Endod. Dent. Traumatol., 6(4)*:142-9, 1990.

Park, E.; Shen, Y. & Haapasalo, M. Irrigation of the apical root canal. *Endod. Top., 27(1)*:54-73, 2012.

Park, E. Ultrasonics in endodontics. *Endod. Top., 29*:125-59, 2013.

Park, E.; Shen, Y.; Khakpour, M. & Haapasalo, M. Apical pressure and extent of irrigant flow beyond the needle tip during positive-pressure irrigation in an *in vitro* root canal model. *J. Endod., 39(4)*:511-5, 2013.

Peters, O. A.; Schönenberger, K. & Laib, A. Effects of four Ni–Ti preparation techniques on root canal geometry assessed by micro computed tomography. *J. Endod., 34 (3)*:221-30,2001.

Peters, O. A. & Barbakow, F. Effect of irrigation on debris and smear layer on canal walls prepared by two rotary techniques: a scanning electron microscopic study. *J. Endod., 26(1)*:6-10, 2000.

Peeters, H. H. & Suardita, K. Efficacy of smear layer removal at the root tip by using ethylenediaminetetraacetic acid and erbium, chromium: Yttrium, scandium, gallium garnet laser. *J. Endod., 37(11)*:1585-9, 2011.

Psimma, Z.; Boutsioukis, C.; Kastrinakis, E. & Vasiliadis, L. Effect of needle insertion depth and root canal curvature on irrigant extrusion *ex vivo*. *J. Endod., 39(4)*:521-4, 2013.

Sanabria-Liviac, D.; Moldauer, B. I.; Garcia-Godoy, F.; Antonio-Campos, A.; Casaretto, M.; Torres-Navarro, J. & Scalercio, J. M. Comparison of the XP-Endo Finisher file system and passive ultrasonic irrigation (PUI) on smear layer removal after root canal instrumentation: Effectiveness of two irrigation methods on smear layer removal. *J. Dent. Oral Heal., 4(101)*:1-7, 2017.

Shin, S. J.; Kim, H. K.; Jung, I. Y.; Lee, C. Y. & Kim, E. Comparison of the cleaning efficacy of a new apical negative pressure irrigating system with conventional irrigation needles in the root canals. *Oral Surg. Oral Med. Oral Pathol., 109(3)*:479-84, 2010.

Silva, E. J. N. L.; Belladonna, F. G.; Zuolo, A. S.; Rodrigues, E.; Ehrhardt, I. C.; Souza, E. M. & De-Deus, G. Effectiveness of XP-endo Finisher and XP-endo Finisher R in removing root filling remnants: a micro-CT study. *Int. Endod. J., 51(1)*:86-91, 2018.

Thaler, A.; Ebert, J.; Petschelt, A. & Pelka, M. Influence of tooth age and root section on root dentine dye penetration. *Int. Endod, J., 41(12)*:1115-22, 2008.

Trope, M.; Debelian, G. XP-3D Finisher TM file - the next step in restorative endodontics. *Endod. Pr., 8*:22-4, 2015. Available in: https://endopracticeus.com/xp-3d-finisher-file-the-next-step-in-restorative-endodontics/

Uygun, A. D.; Gündogdu, E. C.; Arslan, H. & Ersoy, I. Efficacy of XP-endo Finisher and TRUShape 3D conforming file compared to conventional and ultrasonic irrigation in removing calcium hydroxide. *Aust. Endod. J., 43(2)*:91-95, 2017.

Valente, N. F.; Paredes de Oliveira, J. Z.; Moura de Carvalho Valoura, A. V.; Hecksher, F.; Lima Moreira, H. J. & Nogueira Leal da Silva, E. J. A new instrument for root canal system finishing after chemomechanical preparation: XP-Endo Finisher. *Rev. Bras. Odontol., 74(4)*:305-8, 2017.

van der Sluis, L. W. M.; Versluis, M.; Wu, M. K. & Wesselink, P. R. Passive ultrasonic irrigation of the root canal: a review of the literature. *Int. Endod. J., 40(6)*:415-26, 2007.

van der Sluis, L. W. M.; Vogels, M. P.; Verhaagen, B.; Macedo, R. & Wesselink, P. R. Study on the influence of refreshment/activation cycles and irrigants on mechanical cleaning efficiency during ultrasonic activation of the irrigant. *J. Endod., 36(4)*:737-40, 2010.

Vaz-Garcia, E. S.; Vieira, V. T. L.; Petitet, N. P. D. S. F.; Moreira, E. J. L.; Lopes, H. P.; Elias, C. N.; Silva, E. J. N. L. & Antunes, H. D. S. Mechanical properties of anatomic finishing files: XP-Endo Finisher and XP-Clean. *Braz. Dent. J., 29(2)*:208-13, 2018.

Violich, D. R. & Chandler, N. P. The smear layer in endodontics - A review. *Int. Endod. J., 43(1)*:2-15, 2010.

Wang, X.; Cheng, X.; Liu, B.; Liu, X.; Yu, Q. & He, W. Effect of laser-activated irrigations on smear layer removal from the root canal wall. Photomed. Laser Surg., 35(12):668-94, 2017.

Wang, Z.; Shen, Y. & Haapasalo, M. Effect of smear layer against disinfection protocols on Enterococcus faecalis-infected dentin. *J. Endod., 39(11)*:1395-400, 2013.

Wolters, W. J.; Duncan, H. F.; Tomson, P. L.; Karim, I. E.; McKenna, G.; Dorri, M.; Stangvaltaite, L. & van der Sluis, L. W. M. Minimally invasive endodontics: a new diagnostic system for assessing pulpitis and subsequent treatment needs. *Int. Endod. J.* 2017 Sep;50(9):825-829. doi: 10.1111/iej.12793. PMID: 28776717.

Zand, V.; Mokhtari, H.; Reyhani, M. F.; Nahavandizadeh, N. & Azimi, S. Smear layer removal evaluation of different protocol of BioRace file and XP endo Finisher file in corporation with EDTA 17% and NaOCl. *J. Clin. Exp. Dent., 9(11)*:1310-4, 2017.

Zivkovic, S.; Neskovic, J.; Jovanovic-Medojevic, M.; Popovic-Bajic, M. & Zivkovic-Sandic, M. XP-endo Finisher: A new solution for smear layer removal. *Serb. Dent. J., 62(3)*:122-9, 2015.

Zou, L.; Shen, Y. & Li, W. H. M. Penetration of sodium hypochlorite into dentin. *J. Endod., 36(5)*:793-6, 2010.

Zupanc, J.; Vahdat-Pajouh, N. & Schäfer, E. New thermomechanically treated NiTi alloys - a review. *Int. Endod. J., 51(10)*:1088-103, 2018.

Corresponding author:
Bertheau Solis Susana Lizette
49 poniente 4901-8
Prados Agua Azul
Puebla
MÉXICO

E-mail: susana.bertheau@correo.buap.mx