[BAU Journal - Health and Wellbeing](https://digitalcommons.bau.edu.lb/hwbjournal)

Volume 3 | Issue 2
ISSN: 2789-8288

Article 10

April 2021

COMPARATIVE STUDY OF THE EFFECT OF THREE DIFFERENT IRRIGATING TECHNIQUES ON DEBRIS AND SMEAR LAYER DISTRIBUTION IN ROOT CANALS (AN IN VITRO STUDY)

Maysoun Mohamad Ahmad
Specialist in Endodontics, Faculty of Dentistry, Beirut Arab University, Beirut, Lebanon, maysoun1986@hotmail.com

Mohamed Atef Ibrahim
Professor of Operative and Esthetic Dentistry, Faculty of Dentistry, Beirut Arab University, Beirut, Lebanon, mohatef16@gmail.com

Amr Abdallah
Professor of Conservative department, Faculty of Dentistry, Alexandria University, Alexandria, Egypt, dr_amr_abdallah@hotmail.com

Recommended Citation

Ahmad, Maysoun Mohamad; Ibrahim, Mohamed Atef; and Abdallah, Amr (2021) "COMPARATIVE STUDY OF THE EFFECT OF THREE DIFFERENT IRRIGATING TECHNIQUES ON DEBRIS AND SMEAR LAYER DISTRIBUTION IN ROOT CANALS (AN IN VITRO STUDY)," *BAU Journal - Health and Wellbeing*: Vol. 3: Iss. 2, Article 10.
DOI: https://doi.org/10.54729/2789-8288.1143

COMPARATIVE STUDY OF THE EFFECT OF THREE DIFFERENT IRRIGATING TECHNIQUES ON DEBRIS AND SMEAR LAYER DISTRIBUTION IN ROOT CANALS (AN IN VITRO STUDY)

Abstract

The aim of this study was to compare, in vitro, the cleaning efficacy of three different irrigation techniques: syringe irrigation (Navitip) using NaOCl, sonic irrigation system (EndoActivator), and passive ultrasonic irrigation system (PUI) on debris and smear layer distribution in the root canal at three different levels. Materials and Methods: Sixty freshly extracted single-rooted human mandibular premolars were decoronated to a standardized length of twenty millimeters. Specimens were shaped to IRace 25 size and irrigated with 3 mL 2.5% NaOCl between instrumentation. Teeth were divided randomly into three equal groups: Group I (n=20): Irrigation manually with a syringe (Navitip) (n=20), irrigation was done with 3 mL 2.5% NaOCl for one minute using 30 gauge needle. Group II (n=20): Final rinse with 3 ml 2.5% NaOCl activated for one minute with passive sonic irrigation system (endoactivator). Group III (n=20): Final rinse with 3 ml 2.5% NaOCl activated for one minute with PUI system. Root canals were then split longitudinally and field emission scanning electron microscopy was used to eval¬uate endodontic smear layer and debris removal from the instrumented root canals. This was done using a scale from 0-5 as described by Hulsmann et al. Results of this study showed that Both (PUI) and (EndoActivator®; Dentsply) have resulted in superior removal of smear layer and debris when compared to needle-and-syringe irrigation. Conclusion: None of the techniques completely removed all the smear layer and debris from root canal walls at the apical part of the canal. However, PUI system showed significantly better cleaning than needle and sonic systems in the entire length of the root canal.

Keywords

Passive Ultrasonic Irrigation, Endoactivator, Debris, Smear layer, Scanning Electron Microscopy

1. INTRODUCTION

The success of root canal treatment depends on cleaning and disinfection of the entire root canal system, which requires elimination of microorganisms and microbial components and prevention of its re-infection during and after treatment. This goal is pursued by chemo-mechanical debridement, where the mechanical systems are associated with the irrigating solutions.

During the cleaning and shaping process, organic pulpal remnants and inorganic dentinal debris accumulate and adhere onto the radicular canal wall producing an amorphous irregular smear layer (Torabinejad, Handysides, Khademi, & Bakland, 2002). The use of both hand and rotary instruments create smear layer of different thickness on the canal walls as a consequence of the denting cutting action.

Viable microorganisms in the dentinal tubules may use the smear layer as a reservoir for sustained growth and replication. The presence of a smear layer may also inhibit the action and effectiveness of root canal irrigants and inter-appointment medicaments (Orstavik & Haapasalo, 1990). Removing the smear layer will allow better adaptation of obturation materials to the canal wall (Oksan, Aktener, Sen, & Tezel, 1993). Hence, optimal removal of debris and smear layer should be intended for during root canal treatment (Moldauer, 2017).

Numerous instrumentation protocols and irrigants have been used in attempt to clean and decontaminate the endodontic system.

Sodium hypochlorite (NaOCl) is considered the main root canal irrigant because of its tissue dissolution and antimicrobial properties.

During conventional needle irrigation, replenishment, and fluid exchange do not extend much beyond the tip of the irrigating needle. Vapor lock that results in trapped air in the apical third of root canals might also hinder the exchange of irrigants and affect the debridement efficacy of irrigants. That is why different techniques and irrigant delivery devices have been proposed to increase the flow and distribution of irrigating solutions within the root canal system.

Different devices for irrigation delivery have been proposed to increase the flow and distribution of irrigating solutions within the root canal system. Passive ultrasonic irrigation (PUI) first described by Weller et al (Weller, Brady, & Bernier, 1980), used a stainless-steel file to activate the irrigant in the canal. PUI is able to alter and eventually disrupt the endodontic biofilm, facilitating better penetration of irrigants throughout the endodontic dentinal walls.

On the other hand, EndoActivator (Dentsply, Tulsa Dental) uses sonic activation of the irrigants comprising a portable handpiece and three types of disposable flexible polymer tips of different sizes have tapers and terminal diameters that closely match the dimensions of the final root canal preparation that do not cut root dentin. Cavitation and acoustic streaming significantly improves the debridement and disruption of the smear layer and biofilm.

It is hypothesized that there is no difference between ultrasonic irrigation (PUI) and sonic irrigation (PSI) (Endoactovator) and syringe irrigation using NaOCl on the removal of debris in root canals. This study has been undertaken to compare, in vitro, the cleaning efficacy of these three aforementioned different irrigation techniques.

2. MATERIALS AND METHODS

Sixty extracted single-rooted human mandibular premolars were collected for this study. Those teeth were extracted for orthodontic or periodontal purposes. The teeth were selected based on radiographic and visual similarity in shape, size, flatness, and straightness of the root.

Teeth selected were free of cracks, caries, fractures, calcifications, attrition, external resorption and previous root canal treatment with completely formed roots and fully formed mature apices, having almost the same length of (20-22 mm) from occlusal surface to apical foramen were selected.Teeth were radiographed buccolingually and mesiodistally to confirm straight single canals. Teeth with Calcified canals, severe canal curvature, or previously root canal treated teeth, or internally or externally resorbed teeth were excluded .Tissues and debris were removed from the surfaces using hand curettes (Hu Friedy. Chicago, USA). With tap water, all teeth were washed and subsequently stored in saline solution until use.

After access cavity preparation was done the crowns of all teeth were reduced using a tapered round diamond bur (Micro-Mega, Besancon, France) to a standardized length of twenty millimeters. Working length was determined by placing a #10 file (FKG Dentaire, La-Chaux-de Fonds, Switzerland) into the root canal until it was visible at the apical foramen and then 1mm was deducted from that length. To simulate clinical conditions, apices were sealed with varnish. The root canals were prepared with crown-down technique to reach apical size number twenty five by using iRaCe files (15/0.06, 25/0.04) (FKG Dentaire, La-Chaux-de Fonds, Switzerland) which were used according to the manufacturer's instructions with gentle in and out strokes. Optimum speed and torque were 600 rpm and 1.5 N/cm, respectively. Irrigation was performed using 3 mL 2.5% NaOCl after every change of instrument (Chematek SpA, Rome, Italy). Irrigating solutions were delivered by means of a 30-G Navitip needle inserted deeply at 1 mm from the working length. The specimens were then assigned randomly to each of three groups for final irrigation.

The teeth were divided randomly into three equal groups (test groups), twenty each, according to the irrigation technique used.

Group I: Irrigation manually with Navitip (n=20)
Irrigation was done with 3 mL 2.5% NaOCl for 1 minute using 30 gauge Navitip 1mm short of the working length.

Group II: Final rinse with 3 ml 2.5% NaOCl activated for 1 minute with sonic irrigation system (endoactivator) using Medium(25/04) tip inserted 1mm short of the working length (n=20).

Group III: Final rinse with 3 ml 2.5% NaOCl activated for 1 minute with PUI system using Satelec Endo File K15/21 (Acteon) on power 6 Newtron units and inserted 1mm short of the working length (n=20).

2. 1. Specimen Preparation

Field emission scanning electron microscopy was used to evaluate endodontic smear layer and debris removal from the instrumented root canals. To facilitate fracture into halves, all roots were grooved longitudinally on the external surface with a diamond disc without penetration into the root canals. The roots were then split into halves with a chisel (Brassler, USA) and mallet (Dentalis, USA) with a Race large gutta-percha cone (FKG Dentaire, La-Chaux-de Fonds, Switzerland) in the root canal to limit tooth fragments covering endodontic canal walls. For each root, the half containing the most visible part of the endodontic wall was conserved and coded. The coded specimens were secured on metal stubs, desiccated, and viewed with field emission scanning electron microscopy.

Micro-photographs were taken and captured on the computer screen for scoring. Dentinal wall of each tooth was observed in the region of coronal, middle, and apical segments.

The scanning electron microscopes images were evaluated for debris particles on canals walls and the number of open and closed dentinal tubules of the selected areas.

This was done using a scale from 0-5 as described by Hulsmann et al (Hulsmann, Rummelin, & Schafers, 1997)

2.2. Score of the Debris

The remaining debris was scored according to the scale used by Hulsmann, et al (1997).

- Score 1: Clean root canal wall with only few small debris particles.
- Score 2: Few small agglomerations of debris.
- Score 3: Many agglomerations of debris covering less than 50% of the root canal wall.
- Score 4: More than 50% of the root canal wall covered by debris.
- Score 5: Complete or nearly complete root canal wall covered by debris.

2.3. Score of the Smear Layer

The smear layer was scored as follows according to the scale used by Hulsmann, et al (1997).

- Score 1: No smear layer with open dentinal tubules.
- Score 2: Small amount of smear layer, some dentinal tubules open.
- Score 3: Homogenous smear layer covering the root canal wall, only few dentinal tubules open.

DOI: 10.54729/2789-8288.1143

- Score 4: Complete root canal wall covered by a homogenous smear layer, no open dentinal tubules.
- Score 5: Heavy, non-homogenous smear layer covering the complete root canal wall.

The photomicrographs were analyzed, and these scoring systems were applied to the coronal, middle, and apical segments of the canal. Then the results were tabulated and submitted to statistical analysis. The percentage of debris and the smear layer distribution around the dentinal tubules was measured by "image J software" (National Institutes of health, Bethesda, MD). This software gives the results in the form of percentages that are converted to the scoring system explained by Hulsmann et al.

2.4. Statistical Analysis of the Data

Data were fed to the computer using IBM *SPSS software package version 20.0.*

Quantitative data were described using mean and standard deviation for normally distributed data. Kolmogorov–Smirnov test was used for checking the normality of distribution.

For normally distributed data, comparison more than two population were analyzed F-test (ANOVA) to be used. followed by Post Hoc test "by Tukey method" to detect the level of significant between each two groups.

3. RESULTS

Results of our study showed that there was a significant higher score of SL in group I (navitip) more than groups II (EA) and III (PUI), on the other hand group III(PUI) was significantly lower than group II (EA) ($p < 0.05$)(as shown as Fig.1). And a significantly higher percentage of debris in group I (navitip) more than that in groups II (EA) and III (PUI), where there was no significant difference between groups II (EA) and III (PUI) ($P > 0.05$)(as shown as Fig.2). Which means both ultrasonically activated irrigation (PUI) and sonically activated irrigation (EndoActivator®; Dentsply) have resulted in superior removal of smear layer and debris in straight root canals when compared to needle-and-syringe irrigation. Examples of smear layer and debris removal in the coronal, middle, and apical thirds for all groups (as shown as Fig.3).

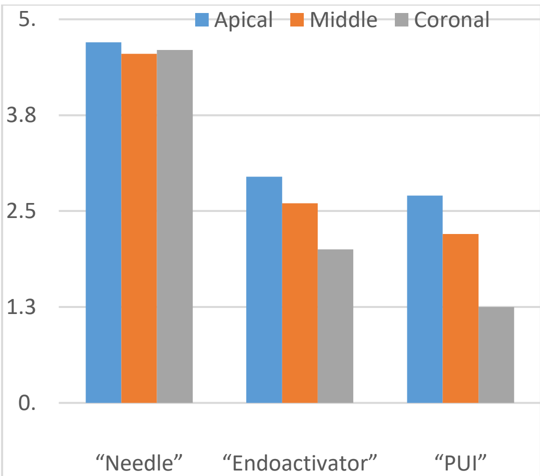

Fig.1: Comparison between different thirds regarding smear layer distribution according to Hulsmann score

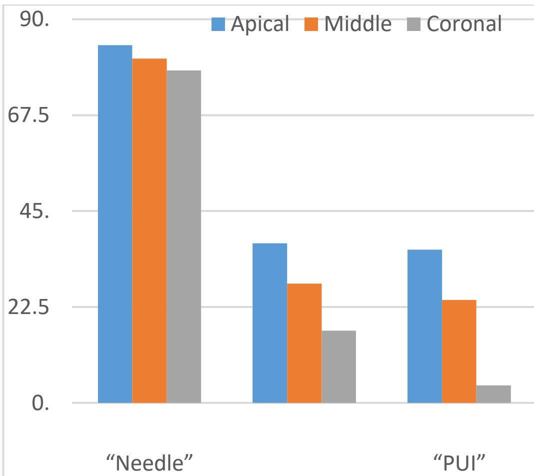

Fig.2: Comparison between different thirds regarding percent of debris change

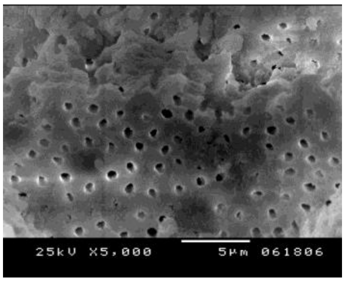

Fig.3a

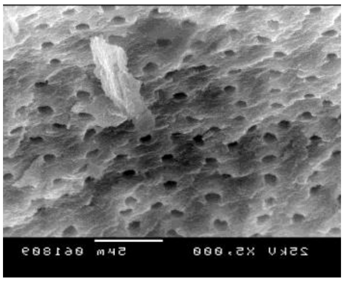

Fig.3b

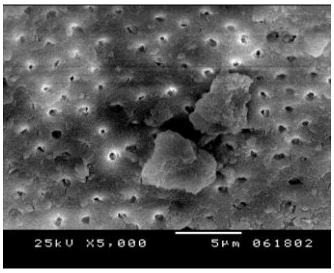

Fig.3c

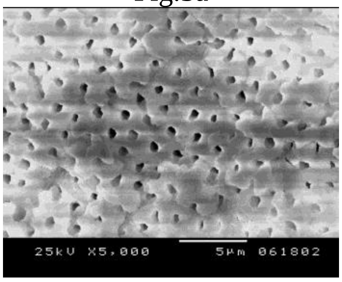

Fig.3d

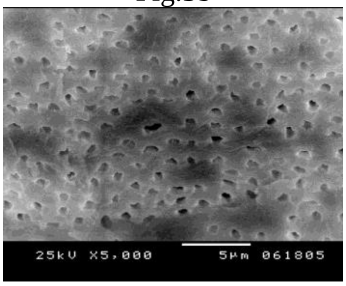

Fig.3e

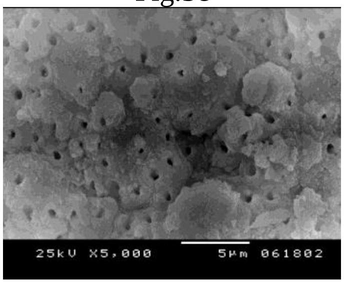

Fig.3f

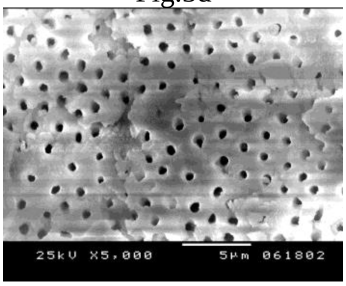

Fig.3g

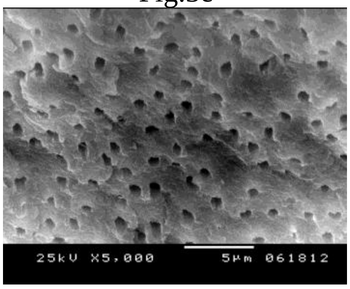

Fig.3h

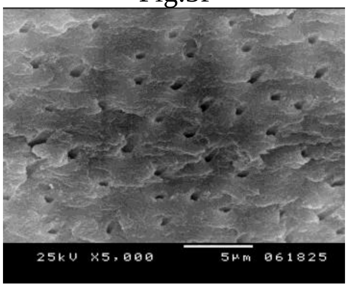

Fig.3i

Fig.3: a, b, c Amount of smear layer removal and open dentinal tubules after needle irrigation in the coronal, middle and apical levels (left to right)

Fig.3: d,,e,,f Amount of smear layer removal and open dentinal tubules after sonic irrigation in the coronal, middle and apical levels (left to right)

Fig.3: g,h,i Amount of smear layer removal and open dentinal tubules after ultrasonic irrigation in the coronal, middle and apical levels (left to right)

4. DISCUSSION

Disinfecting the root canal system during and after the instrumentation process is the main purpose of the irrigant solutions in endodontics. Root canal instrumentation produces a layer of hard tissue debris on the root canal wall (i.e. smear layer), preventing the penetration of irrigants and intracanal medicaments into the dentinal tubule and it may also reduce the adaptation of root filling materials to the root canal wall (Neelakantan, Ounsi, Devaraj, Cheung, & Grandini, 2018). Rotary instrumentation with NiTi files is especially prone to the creation of a smear layer, hence its use in the present study (Heard & Walton, 1997).

Previous studies have shown that the conventionally used needle irrigation technique is not very effective in the removal of smear layer and debris (Mancini, et al., 2013) (Rödig, Döllmann, Konietschke, Drebenstedt, & Hülsmann, 2010) (Gu, et al., 2009), since the irrigant solution only penetrates up to 1.1mm beyond the needle's tip (Munoz & Camacho-Cuandra, 2012). For better cleaning efficacy, the irrigant should be in contact with the root canal wall in its full extent (Zehnder, 2006), with activation systems playing a significant part in this goal (Çapar & Aydinbelge, 2014).

DOI: 10.54729/2789-8288.1143

The aim of this study was to compare the effectiveness in smear layer and debris removal between the conventional irrigation technique and two agitation methods, sonic irrigation system (EA) and passive ultrasonic irrigation, when using 3% NaOCl as the only irrigant solution.

Root canal shaping was performed on extracted single-rooted human mandibular premolars to limit the variations in the canals sizes and anatomy (Bao, Shen, Lin, & Haapasalo, 2017). However, extreme care was shown during the selection of the experimental teeth to reduce the number of anatomical variations (De Souza, Cai, Simionato, & Lage-Marques, 2008). Inclusion and exclusion criteria were verified under a 20X magnification laboratory microscope.

Instrumentation was done using IRace system from FKG Dentaire, using iRaCe files (15/0.06, 25/0.04) (FKG Dentaire, La-Chaux-de Fonds, Switzerland) which were used according to the manufacturer's instructions with gentle in and out strokes. The final file used in this study was R2 (25/0.04) to reach apical size number 25.

The irrigating solution used was 3mL 2.5% NaOCl during instrumentation. The choice to use this solution alone in this study, not in conjunction with EDTA, was motivated by the desire to evaluate the system's absolute power of SL and debris removal without resorting to the above-mentioned chelating agent as justified in detail in several previous studies (Schäfer, Erler, & Dammaschke, 2006) (Bürklein, Hinschitza, Dammaschke, & Schäfer, 2012).

Riddling of endodontic irrigants into the complicated root canal system is very important for successful endodontic treatment. It depends on the diameter of the prepared canal, coronal enlargement, the type and volume of irrigant, and irrigant delivery system (Gadaalay, et al., 2017).

Size 30 G Navitip needles were selected for this study, allowing penetration within 1 mm of the tooth apices without any interference or binding from the root canal walls and without activation.

The use of various sonic, and PUI devices, and techniques have been reported to improve tissue removal, more vigorous irrigation of lateral canals, and additional removal of canal bacteria (Klyn, Kirkpatrick, & Rutledge, 2010).

Passive ultrasonic irrigation (PUI) seems to be the prime irrigation method used among endodontists (Dutner, Mines, & Anderson, 2012). To date, most of the literature says that ultrasonic devices are more powerful than sonic ones (Plotino, Grande, & Mercade, 2019). Ultrasonic irrigation exhibits better canal debridement efficacy over the use of needle irrigation alone (Plotino, Pameijer, Grande, & Somma, 2007).

PUI has some advantages, namely the acoustic streaming effect that increases wall shear stress and enhances the rupturing of intra-radicular biofilm. However, ultrasonic irrigation presents some drawbacks; when the oscillating tip touches the root canal wall, for example, it dampens the energy and constrains the file movement, and file-to-wall contact occurs approximately 20% of the time. Moreover, ultrasonic files are made of metal alloy, therefore, when they touch the root canal wall, this may cause uncontrolled removal of dentin, deforming the root canal morphology (Lea & Walmsley, 2009)(Plotino, Grande, & Mercade, 2019).

On the other hand, among sonic devices, Endoactivator is the most studied, but it operates only at approximately at 0.166–0.3 kHz and most of the studies showed better results for ultrasonic irrigation, probably because of the higher power (approximately 40 kHz). Sonic devices present some advantages over ultrasonic ones: the oscillating points are made of a plastic-like material, it does not stop when in contact with the root canal wall, and it is not able to deform the root canal, so it can be used safely in curved root canals (Plotino, Grande, & Mercade, 2019).

Scanning electron microscopy (SEM) has been widely applied for structural and histological analysis of dentine (Kessler, Peters, & Lorton, 1983) (Stamos, Sadeghi, Haasch, & Gerstein, 1987) (Bolanos, Sinai, Gonsky, & Srinivasan, 1988) (Loushine, Weller, & Hartwell, 1989) (Hulsmann, Rummelin, & Schafers, 1997) (Teixeira, Felippe, & Felippe, 2005).
In this study, both ultrasonically activated irrigation (PUI) and sonically activated irrigation (EndoActivator®; Dentsply) have resulted in superior removal of smear layer and debris in straight root canals when compared to needle-and-syringe irrigation. Conventional needle-and-syringe irrigation was unable to remove the smear layer from the middle and apical third of root canals. Ultrasonic irrigation was more effective than sonic activation in removing the smear layer. The percentage of open dentinal tubules followed the same order as removal of the smear layer.

These results coincide with a study by Urban et al who assessed the efficacy of different final irrigation activation methods in removing debris and smear layer in the apical, middle, and coronal portion of straight root canals, and the results of the study showed that PUI has been shown to be more effective than syringe needle irrigation in removing pulpal tissue remnants and dentin debris, bacterial reduction, and smear layer removal (Urban, Donnermeyer, Schäfer, & Bürklein, 2017).

Also Neelakantan et al evaluated the removal of the smear layer by some commonly used (needle-and-syringe irrigation, sonic activation, ultrasonically activated irrigation) and new root canal irrigation strategies (negative pressure irrigation and polymer rotary file) using a novel approach by comparing pre- and post-experimental images, where they concluded that Ultrasonic irrigation was more effective than sonic activation in removing the smear layer (Neelakantan, Ounsi, Devaraj, Cheung, & Grandini, 2018).

Mobaraki and Yeter concluded that PUI showed higher efficacy in smear layer removal compared with conventional syringe irrigation (Mobaraki & Yeter, 2020).

The results of another study by Priyatam et al who evaluated intracanal smear layer removal using syringe and needle irrigation (ie, conventional irrigation [CI]) with and without adjunctive activation using EndoActivator or EndoUltra also agreed with our study that the use of both the EndoActivator and EndoUltra resulted in significantly cleaner smear layer scores at all canal thirds compared to conventional irrigation ($P < .001$) (Karade, Johnson, Baeten, Chopade, & Hoshing, 2018).

The fact that the reduced performance of sonic activation compared to ultrasonic activation stated in previous studies is explained by the following, Ultrasonic devices typically operate at a frequency of about 30 kHZ and an amplitude of 75 lm, EA works at lower frequency of 167 Hz, but with higher displacement amplitude (1 mm), which might exceed the diameter of the root canals. Consequently, frequent wall contact occurs resulting in a reduced effectiveness (Ahmad, Pitt Ford, Crum, & Walton, 1988).

Our results stated that none of the techniques completely removed all the smear layer and debris from root canal walls at the apical part of the canal. It is reasonable to assume that the decreased cleaning efficiency in the apical third of the canals was related to the reduced canal diameter. The canal diameter has an impact on the effectiveness of debris removal and on the volume and exchange of irrigant at the working length (Urban, Donnermeyer, Schäfer, & Bürklein, 2017).

The issue of apical preparation size is still a matter of debate. Several studies confirmed that a larger file could have been used to facilitate the hydrodynamic flow of the irrigant solution to the apical third of the canal and enhances the effectiveness of irrigation (Albrecht, Baumgartner, & Marshall, 2004). On the other hand, especially in curved root canals, larger apical preparation might increase the risk of instrument separation, root fracture, or perforation (Albrecht, Baumgartner, & Marshall, 2004).

5. CONCLUSION

Within the limitations of the present in vitro study, it can be concluded that none of the techniques completely removed all the smear layer and debris from root canal walls at the apical part of the canal. However, passive ultrasonic irrigation system showed significantly better cleaning than syringe and needle and sonic systems in the entire length of the root canal. And therefore, the null hypothesis was rejected as all activation methods were superior compared to manual irrigation concerning both debris and smear layer removal.

REFERENCES

- Ahmad, M., Pitt Ford, T., Crum, L., & Walton, A. (1988). Ultrasonic debridement of root canals: acoustic cavitation and its relevance. *J Endod, 14,* 486– 93.
- Albrecht, L., Baumgartner, J., & Marshall, J. (2004). Evaluation of apical debris removal using various sizes and tapers of ProFile GT files. *Journal of Endodontics, 30*, 425-428.
- Bao, P., Shen, Y., Lin, J., & Haapasalo, M. (2017). In Vitro Efficacy of XP-endo Finisher with 2 Different Protocols on Biofilm Removal from Apical Root Canals. *Journal of Endodontics, 43*(2), 321-325.
- Baumgartner, J., & Mader, C. (1987). A scanning electron microscopic evaluation of four root canal irrigation regimens. *J Endod, 13*, 147-57.

- Bolanos, O., Sinai, I., Gonsky, M., & Srinivasan, R. (1988). A comparison of engine and air-driven instrumentation methods with hand instrumentation. *Journal of Endodontics, 14*, :392-396.
- Bürklein, S., Hinschitza, K., Dammaschke, T., & Schäfer, E. (2012). Shaping ability and cleaning effectiveness of two single-file systems in severely curved root canals of extracted teeth: Reciproc and WaveOne versus Mtwo and ProTaper. *Int Endod J*, 449–461.
- Çapar, I., & Aydinbelge, H. (2014). Effectiveness of various irrigation activation protocols and the selfadjusting file system on smear layer and debris removal. Scanning. *36*(6), 640–7.
- De Souza, E., Cai, S., Simionato, M., & Lage-Marques, J. (2008). High-power diode laser in the disinfection in depth of the root canal dentin. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology, 106*(1), e68-e72.
- Dutner, J., Mines, P., & Anderson, A. (2012). A Irrigation trends among American Association of Endodontists members: a web-based survey. *J Endod., 38*(1), 37-40.
- Gadaalay, S., Hariramani, S., Dhore, P., Kale, A., Agrawal, M., & Doshi, S. (2017). Comparative evaluation of efficacy of three different irrigation activation systems in debridement of root canal isthmus: An in vitro study. *endodontology, 29*(1), 39-42.
- Giansiracusa Rubini, A., Plotino, G., Al-Sudani, D., Grande, N., Sonnino, G., Putorti, E., . . . Gambarini, G. (2014). A new device to test cutting efficiency of mechanical endodontic instruments. *Med Sci Monit, 20*, 374-8.
- Gu, L., Kim, J., Ling, J., Choi, K., Pashley, D., & Tay, F. (2009). Review of contemporary irrigant agitation techniques and devices. *J Endod, 35*, 791-804.
- Haapasalo, M., Wang, Z., Shen, Y., Curtis, A., Patel, P., & Khakpour, M. (2014). Tissue dissolution by a novel multisonic ultracleaning system and sodium hypochlorite. *J Endod., 40*(8), 1178-81.
- Haupt, F., Meinel, M., Gunawardana, A., & Hülsmann, M. (2019). Effectiveness of different activated irrigation techniques on debris and smear layer removal from curved root canals: a SEM evaluation. *Australian Endodontic Journal*.
- Heard, F., & Walton, R. (1997). Scanning electron microscope study comparing four root canal preparation techniques in small curved canals. *Int Endod J, 30*(3), 23–31.
- Hulsmann, M., Rummelin, C., & Schafers, F. (1997). Root canal cleanliness after preparation with different endodontic handpieces and hand instruments: a comparative SEM investigation. *J Endod, 23*(5), 301-6.
- Kanumuru, P., Sooraparaju, S., Konda, K., Nujella, S. R., & Penigalapati, S. (2015). Comparison of Penetration of Irrigant Activated by Traditional Methods with A Novel Technique. *J Clin Diagn Res, 9*(11), ZC44–7.
- Karade, P., Johnson, A., Baeten, J., Chopade, R., & Hoshing, U. (2018). Smear Layer Removal Efficacy Using EndoActivator and EndoUltra Activation Systems: An Ex Vivo SEM Analysis. *Compendium of continuing education in dentistry, 39*(4), e9–e12.
- Kessler, J., Peters, D., & Lorton, L. C. (1983). Comparison of the relative risk of molar root perforations using various endodontic instrumentation techniques. *Journal of Endodontics, 9*, 439-447.
- Klyn, S., Kirkpatrick, T., & Rutledge, R. (2010). In vitro comparisons of debris removal of the EndoActivator system, the F file, ultrasonic irrigation, and NaOCl irrigation alone after hand-rotary instrumentation in human mandibular molars. *J Endod, 36*(8), 1367-71.

- Lea, S., & Walmsley, A. (2009). Mechano-physical and biophysical properties of power-driven scalers: driving the future of powered instrument design and evaluation. *Periodontol 2000, 51*, 63-78.

- Loushine, R., Weller, R., & Hartwell, G. (1989). Stereomicroscopic evaluation of canal shape following hand, sonic, and ultrasonic instrumentation. *Journal of Endodontics, 15*, 417-421.

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

- Macias, D., Bravo, V., & Echeverria, D. (2017). Effect of sonic versus ultrasonic activation on aqueous solution penetration in root canal dentin. *Journal of Oral Research, 7*(1), 24-29.

- Mancini, M., Cerroni, L., Iorio, L., Armellin, E., Conte, G., & Cianconi, L. (2013). *J Endod, 39*, 1456-60.

- Mobaraki, B., & Yeter, k. (2020). Quantitative analysis of SmearOFF and different irrigation activation techniques on removal of smear layer: A scanning electron microscope study. *Microscopy Reserach and Technique, 83*(12), 1480-1486.

- Moldauer, B. (2017). 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. *JDOH, 4*(1), 1-7.

- Munoz, H., & Camacho-Cuandra, K. (2012). In vivo efficacy of three different endodontic irrigation systems for irrigant delivery to working length of mesial canals of mandibular molars. *J Endod, 38*, 445–448.

- Nakamura, V., Pinheiro, E., Prado, L., Silveira, A., Carvalho, A., Mayer, M., & Gavini. (2017). Effect of ultrasonic activation on the reduction of bacteria and endotoxins in root canals: a randomized clinical trial. *Int Endod J., 1*, e12-e22.

- Neelakantan, P., Ounsi, H., Devaraj, S., Cheung, G., & Grandini, S. (2018). Effectiveness of irrigation strategies on the removal of the smear layer from root canal dentin. *Odontology, 107*(2), 142-149.

- Oksan, T., Aktener, B., Sen, B., & Tezel, H. (1993). The penetration of root canal sealers into dentinai tubules. A scanning electron microscopic study. *International Endodontic Journal, 26*(5), 301-305.

- OKŞAN, T., AKTENER, B., ŞEN, B., & TEZEL, H. (1993). The penetration of root canal sealers into dentinai tubules. A scanning electron microscopic study. *International Endodontic Journal, 26*(5), 301-305.

- Orstavik, D., & Haapasalo, M. (1990). Disinfection by endodontic irrigants and dressings of experimentally infected dentinal tubules. *Dental Traumatology, 6*(4), 142-149.

- Pérez, V., Rodríguez, P., & Echeverri, D. (2014). Activación Sónica Versus Ultrasónica de EDTA al 10% para Remoción de Barrillo Dentinario en el Tercio Apical del Canal Radicular. *Int J Odontostomat, 8*(1), 153–9.

- Plotino, G., Pameijer, C., Grande, N., & Somma, F. (2007). Ultrasonics in endodontics: a review of the literature. *J Endod., 33*, 81-95.

- Rödig, T., Döllmann, S., Konietschke, F., Drebenstedt, S., & Hülsmann, M. (2010). Effectiveness of different irrigant agitation techniques on debris and smear layer removal in curved root canals: a scanning electron microscopy study. *J Endod, 36*(12), 1983-7.

- Schäfer, E., Erler, M., & Dammaschke, T. (2006). Comparative study on the shaping ability and cleaning efficiency of rotary Mtwo instruments. Part 2. Cleaning effectiveness and shaping ability in severely curved root canals of extracted teeth. *Int Endod J, 39*(3), 203-12.

- ŞEN, B., WESSELINK, P., & TÜRKÜN, M. (1995). The smear layer: a phenomenon in root canal therapy. *International Endodontic Journal, 28*(3), 141-148.
- Sen, B., wesselink, P., & Turukun, M. (1995). The smear layer: a phenomenon in root canal therapy. *International Endodontic Journal, 28*(3), 141-148.
- Stamos, D., Sadeghi, E., Haasch, G., & Gerstein, H. (1987). An in vitro comparison study to quantitate the debridement ability of hand, sonic, and ultrasonic instrumentation. *Journal of Endodontics, 13*, 434-440.
- Teixeira, C., Felippe, M., & Felippe, W. (2005). The effect of application time of EDTA and NaOCl on intracanal smear layer removal: an SEM analysis. *International Endodontic Journal, 38*, :285-290.
- Torabinejad, M., Handysides, R., Khademi, A., & Bakland, L. (2002). Clinical implications of the smear layer in endodontics: a review. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology, 94*, 658-666.
- Urban, K., Donnermeyer, D., Schäfer, E., & Bürklein, S. (2017). Canal cleanliness using different irrigation activation systems: a SEM evaluation. *Clinical Oral Investigations, 21*(9), 2681-2687.
- Virdee, S., Seymour, D., Farnell, D., Bhamra, G., & Bhakta, S. (2018). Efficacy of irrigant activation techniques in removing intracanal smear layer and debris from mature permanent teeth: a systematic review and meta-analysis. *Int Endod J, 51*, 605-21.
- Weller, R., Brady, J., & Bernier, W. (1980). Efficacy of ultrasonic cleaning. *J Endod, 6*(9), 740-3.
- Yang, G., Wu, H., Zheng, Y., Zhang, H., Li, H., & Zhou, X. (2008). Scanning electron microscopic evaluation of debris and smear layer remaining following use of ProTaper and Hero Shaper instruments in combination with NaOCl and EDTA irrigation. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* , 63-71.
- Zehnder, M. (2006). Root canal irrigants. *J Endod, 32*, 389-398.