BAU Journal - Creative Sustainable Development

Volume 3 | Issue 2
ISSN: 2664-9446

Article 5

May 2022

DIFFERENT IRRIGANT ACTIVATION TECHNIQUES IN REMOVING DENTIN DEBRIS: AN IN-VITRO STUDY

Maya T. Eter
Master Student in Endodontology, Faculty of Dentistry, Beirut Arab University, Beirut, Lebanon, mte347@student.bau.edu.lb

Roula S. Abiad
Professor of Endodontology, Faculty of Dentistry, Beirut Arab University, Beirut, Lebanon, r.abiad@bau.edu.lb

Dentine debris, needle irrigation, ultrasonic activation, sonic activation, dentinal groove.

DIFFERENT IRRIGANT ACTIVATION TECHNIQUES IN REMOVING DENTIN DEBRIS: AN IN-VITRO STUDY

Abstract

During endodontic treatment, the efficiency of irrigation depends on two criteria: the antimicrobial and dissolving properties of the irrigation solution and the delivery system used that dictates the flushing action of the irrigant and consequently enable it to reach complex areas. The purpose of this in-vitro study was to compare the cleaning efficiency of EDDY sonic activation with needle irrigation and passive ultrasonic activation regarding elimination of dentin debris. Forty single rooted extracted teeth were instrumented and then were split in bucco-lingual direction. A longitudinal groove was performed in the inner surface of one root half of each tooth. Grooves were filled with dentine debris mixed with 5.25 % NaOCl in order to simulate an uninstrumented canal extension. Root halves were reassembled and were randomly divided into three groups: G1 needle irrigation, G2 passive ultrasonic activation (Acteon Satelec, Merignac, France) and G3 sonic activation using EDDY system (VDW, Munich, Germany). Ten roots served as control. After irrigation protocols, root halves were disassembled and digital images of grooves were taken using a stereomicroscope (Olympus, Japan). Evaluation of the amount of the remaining dentin debris was performed using a scoring system. No statistically significant difference existed between negative control and passive ultrasonic activation and EDDY activation respectively. Both activation techniques performed equally in removing dentine debris and significantly better than needle irrigation. No significant difference was found between needle irrigation and positive control.

Keywords

Dentine debris, needle irrigation, ultrasonic activation, sonic activation, dentinal groove.

1. INTRODUCTION:

During endodontic treatment, both mechanical instrumentation and chemical irrigation are necessary for adequate disinfection of the root canal system from microorganisms and their byproducts, vital tissues, necrotic pulpal remnants and dentin debris (Eneide et al., 2019). However, complete removal of these components is commonly not achievable in complex anatomical areas of the root canal (Justo et al., 2014). For instance, Peters et al. reported in their study that at least 35% of root canal walls remain untouched regardless of the instrumentation technique used (Peters, Schönenberger, & Laib, 2001). In fact, dentin debris accumulate into canal irregularities and prevent the flow of irrigants. These trapped debris contain microorganisms which in conjunction with root canal biofilm contribute to persistent canal infection and thus the failure of endodontic treatment (Cesario et al., 2018).

Irrigation techniques affect greatly the outcome of endodontic treatment as irrigant needs to access and disinfect all canal irregularities and extension that are inaccessible by instrumentation, flush out dentin debris, kill microorganisms, destroy endotoxins, dissolve pulpal tissues and remove the smear layer (Duque et al., 2017). The most commonly used irrigant is sodium hypochlorite due to its antimicrobial activity and its ability to dissolve organic tissues (Eneide et al., 2019). However, dentin debris are composed mainly of inorganic components, which cannot be dissolved by sodium hypochlorite (Van Der Sluis, Versluis, Wu, & Wesselink, 2007). Therefore, the efficiency of irrigation depends on two criteria: the antimicrobial and dissolving properties of the irrigation solution, and the delivery system used that dictates the flushing action of the irrigant and consequently enables it to reach complex areas and to remove both organic and inorganic debris (Justo et al., 2014).

Conventional needle irrigation was frequently reported to be ineffective in delivering irrigation solution to the whole root canal system especially in the presence of complex anatomy. Its insufficient flushing action does not allow the irrigant to adequately clean the apical third of the canal and to reach canal irregularities such as isthmuses, accessory and secondary canals (Virdee, Seymour, Farnell, Bhamra, & Bhakta, 2018).

Several studies have shown that the flushing action of irrigants could be promoted by activation (Castagnola et al., 2014; Lee, Wu, & Wesselink, 2004b). In fact, different activation methods and devices have been introduced in order to promote root canal debridement such as ultrasonic and sonic activation (Eneide et al., 2019).

Using ultrasonic energy in root canal debridement was firstly introduced by Richman in 1957. When a file is activated with passive ultrasonic energy, it produces acoustic microstreaming that creates enough shear forces to dislodge debris from instrumented root canals (Richman, 1957). This results in significantly cleaner canals when compared to canals cleaned by conventional needle irrigation (Plotino et al., 2019; Sabins, Johnson, & Hellstein, 2003). However, when the ultrasonic file touches the canal wall, the energy drops down leading to restriction of the file movement, also the repeated file-to-wall contact causes uncontrolled dentin removal and thus induces deformation in the canal morphology (Plotino et al., 2019).

Passive activation of ultrasonic file in the root canal was advocated in 1999 by Jensen et al., who suggested the activation of an ultrasonic file after the completion of hand instrumentation with ultrasonic energy irrespective of the preparation technique employed and without any attempt to contact or instrument the canal walls (Jensen, Walker, Hutter, & Nicoll, 1999). In these instances, the file will vibrate freely in the root canal which increases the acoustic micro-streaming and hydrodynamic cavitation (Sabins et al., 2003).

Sonic energy was also used for irrigant activation during root canal treatment. In contrast to ultrasonic devices, which make the file vibrates along multiple nodes and antinodes, sonic devices operate at only one negative and positive node (Agarwal et al., 2017). Endoactivator was the most studied sonic device when comparing sonic and ultrasonic irrigant activation (Plotino et al., 2019). Nevertheless, this device employs low frequency (166–300 Hz) when compared to ultrasonic device (40 000 Hz). This most likely explains why studies tend to favor the use of ultrasonic activation over sonic activation for canal debridement (Plotino et al., 2019). Another sonic powered system has been introduced, the EDDY system (EDDY; VDW, Munich, Germany), that operates on a vibrating air scaler handpiece at a high power of 6000 Hz. According to the manufacturer, the vibration at high frequency is transferred to the non-cutting polyamide tip which in turn will oscillate at high amplitude due to the high-quality tip material. The movements of the tip will trigger acoustic streaming and cavitation effects similar to those produced by passive ultrasonic activation but without iatrogenic cutting of dentinal walls ("Innovative Sonic Powered Irrigation," 2021; Plotino et al., 2019).

The purpose of this in vitro study was to compare the cleaning efficiency of EDDY sonic activation with conventional needle irrigation and passive ultrasonic activation regarding elimination of dentin debris from an artificial groove created into the apical third of prepared root canals. The null hypothesis tested was that there would be no differences in dentin debris removal by different irrigant activation techniques.

2. MATERIALS AND METHODS:

The present research was conducted after the approval of the Institutional Review Board of Beirut Arab University (IRB approval code: 2021-H-0092-D-R-0451).

Forty single rooted extracted human teeth with minimal curvature were selected and decoronated with a diamond disk (Kirar, Jain, & Patni, 2017) at the level of the cemento-enamel junction to obtain a standardized root length of 14 mm. These teeth were stored in thymol solution until use (Justo et al., 2014). The presence of a single canal was confirmed by placing a K-file #10 (Mani, Japan) and by taking mesiodistal and buccolingual radiographs. Working length was determined visually using a dental operating microscope (Leica Microsystems, Wetzlar, Germany) by subtracting 1 mm from the measurement when the file passes the major foramen (Urban, Donnermeyer, Schäfer, & Bürklein, 2017). Root canals were then cleaned and shaped using Reciproc Blue rotary files (VDW, Munich, Germany), 5 ml of 5.25% sodium hypochlorite and 5 ml of 17% EDTA solution. Irrigation was performed using 30-gauge side vented needles (Endo-top, Poland) inserted 1 mm from the working length (Kirar et al., 2017).

After instrumentation, teeth were fixed in Eppendorf vials with an impression silicone material (3M ESPE^{TM}, Seefeld, Germany) (Arslan et al., 2015). After complete setting, teeth were removed from the silicone material, and two longitudinal grooves were created on the buccal and lingual external root surfaces of each tooth with a diamond disk under copious water-cooling, in order to facilitate later separation of the root in bucco-lingual direction. Grooves were created with caution in order to conserve the inner dentinal layer that surrounds the canal. Then, a razor blade was placed in the buccal or lingual groove and gentle tapping was performed on the blade in order to separate the root into two longitudinal halves. After root splitting, a longitudinal groove was performed in the inner surface of one root half of each tooth by a scaler. The groove was of approximately 1 mm wide, 0.5 mm deep and 3 mm long and it was located 2 to 5 mm away from the apex. The root halves were then cleaned from debris using a tooth brush and irrigated with 5ml of 17% EDTA and 5ml of 5.25 % sodium hypochlorite. Grooves were then filled with dentin debris mixed with 5.25% NaOCl to simulate a situation where dentin debris accumulates in uninstrumented canal extensions. Root halves were reassembled using sticky wax and the apical foramen of each root was sealed with wax to assure a close system, then roots were remounted in Eppendorf vials (Arslan et al., 2015). Samples were randomly divided into three groups according to the irrigation technique (table 1):

Group 1 (G1): Needle irrigation
Group 2 (G2): Passive Ultrasonic Irrigation (PUI) (Acteon Satelec, Merignac, France)
Group 3 (G3): Sonic Powered Irrigation using EDDY (EDDY; VDW, Munich, Germany).

Also, 10 roots were equally divided into negative and positive control groups.

In group 1, teeth were irrigated with 5ml of 5.25% sodium hypochlorite; a 30-gauge side vented needle was used during the procedure and was placed 1 mm from the working length for 1 minute. The irrigant was then left in the canal for 1 minute. Thereafter, the canal was rinsed with normal saline for 1 minute and was irrigated with 5ml of 17% EDTA for 1 minute. The solution was left in the canal for another 1 minute. The canal was again rinsed with normal saline. Another cycle was performed by irrigating the canal with 5 ml of 5.25% sodium hypochlorite for 1 minute and by leaving it in the canal for another 1 minute (Kirar et al., 2017).

In group 2, irrigants in the root canal were activated using ultrasonic device (Acteon Satelec, Merignac, France). The canal was irrigated with 5ml of 5.25% sodium hypochlorite and an ultrasonic tip (IrriSafe taper 20/02; Satelec Acteon, Merignac, France) was used for activation 1 mm shorter than the working length for 1 minute and without touching the canal walls. Hereafter, the irrigant was left in the canal for 1 minute, then normal saline was used for rinsing followed by irrigation with 5 ml of 17 % EDTA. EDTA solution was ultrasonically activated with the same file for 1 minute, then the solution was left undisturbed in the canal space for another 1 minute. The canal was rinsed with normal saline. A final irrigation was performed with 5ml of 5.25% sodium hypochlorite which was ultrasonically activated for 1 minute and then left untouched in the canal for another 1 minute (Kirar et al., 2017).

In group 3, EDDY sonic powered system (EDDY; VDW, Munich, Germany) was used, this system employs sonic energy to activate irrigating solution and to produce acoustic streaming with cavitation effects. According to the manufacturer, EDDY flexible polyamide tips enhance tissue dissolving ability of irrigants and are able to reach beyond curvature, maintaining the original anatomy of the canal. Each canal was irrigated with 5ml of 5.25% sodium hypochlorite and EDDY irrigation tip was used for activation, 1 mm shorter than the working length for 1 minute. Hereafter, the irrigant was left in the canal for 1 minute, then normal saline was used for rinsing followed by irrigation with 5 ml of 17 % EDTA. EDTA solution was activated with EDDY sonic powered system using EDDY irrigation tip for 1 minute, the solution was then left in the canal space for another 1 minute. The canal was rinsed with normal saline. A final irrigation was performed with 5ml of 5.25% sodium hypochlorite which was sonically activated for 1 minute and then left untouched in the canal for 1 minute (Kirar et al., 2017).

Five roots served as negative control group where teeth were prepared and split with the grooves left empty. Another 5 roots served as positive control group where teeth were prepared, split and the grooves were filled with dentin debris but without subsequent removal of these debris (Pabel & Hülsmann, 2017).

After each irrigation protocol, root canals were rinsed with 5ml distilled water and dried with paper points. Thereafter, roots were separated and digital images of root halves containing the groove were taken using a stereomicroscope (Olympus, Japan) attached to a digital camera at 2.5x magnification.

Evaluation of the amount of the remaining dentin debris was performed using the following scoring system (Aksel, Küçükkaya Eren, & Serper, 2017; Van Der Sluis et al., 2007; van der Sluis, Vogels, Verhaagen, Macedo, & Wesselink, 2010) (Fig.1):

Score 1: less than 25% of the groove surface is filled with debris
Score 2: 25 to 50% of the groove surface is filled with debris
Score 3: 50 to 75% of the groove surface is filled with debris
Score 4: more than 75% of the groove surface is filled with debris.

The differences in dentine debris scores between different groups were assessed by means of Kruskal Wallis test using the SPSS software (SPSS, Inc, Chicago, USA). The level of significance was set at P= 0.05. Multiple comparisons were adjusted using a Bonferroni correction.

Table 1: Samples distribution in G1, G2, G3, negative control and positive control groups.

Groups	Number of teeth
G1: Needle irrigation	n=10
G2: Passive ultrasonic irrigation	n=10
G3: EDDY sonic activation	n=10
Negative control	n=5
Positive control	n=5
Total	N= 40

Reference: Eter, M. & Abiad, R.

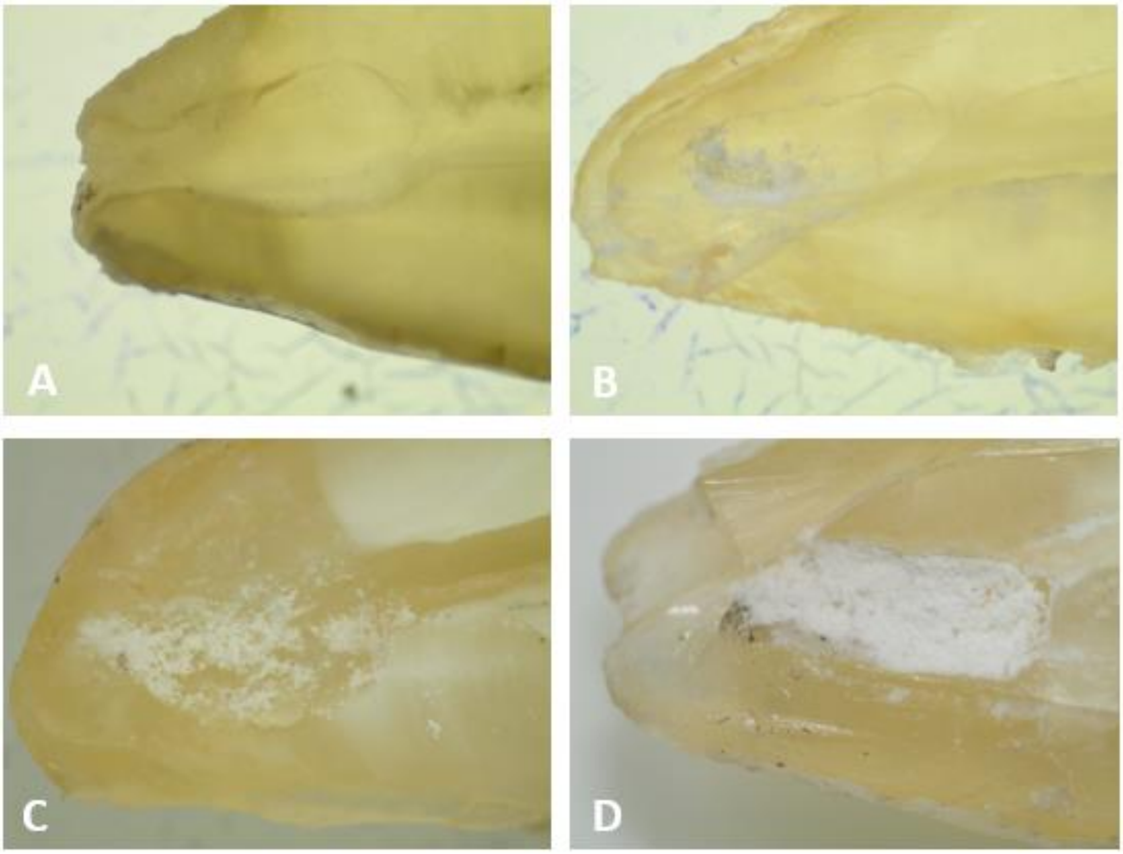

Fig.1: Dentine debris scores. (A) Score 1: less than 25% of the groove surface is filled with debris; (B) Score 2: 25 to 50% of the groove surface is filled with debris; (C) Score 3: 50 to 75% of the groove surface is filled with debris; (D) Score 4: more than 75% of the groove surface is filled with debris. Magnification: 2.5x.
Reference: Eter, M. & Abiad, R.S.

3. RESULTS:

The results of this study are reported in Table 2. All positive control samples showed a completely filled groove (score 4), whereas all negative control samples showed a completely empty groove (score 1). All samples in different groups showed remaining debris regardless of the activation technique used. None of the 10 samples in the needle irrigation group whereas 6 of the 10 samples in the passive ultrasonic activation group and 5 of the 10 samples in the EDDY activation group showed 1 debris scores (table 2 and Fig.2). The passive ultrasonic activation and the EDDY activation groups exhibited the best scores.

Statistical analysis revealed a statistically significant difference between all groups including positive and negative controls ($P<0.01$). Pairwise comparison demonstrated that no statistically significant difference existed between negative control and passive ultrasonic activation ($P=1$) and EDDY activation ($P=1$) respectively. Both activation techniques performed equally in removing dentine debris ($P=1$) and significantly better than needle irrigation ($P=0.024$ for passive ultrasonic activation and $P=0.029$ for EDDY activation). Interestingly, no significant difference was found between needle irrigation and positive control ($P=1$). The distribution of samples among different scores is represented in Fig.3 and the results of pairwise comparisons of groups are represented in table 3.

Table 2: Distribution of dentine debris scores in different groups

Groups \ Scores	1 Less than 25% of debris	2 25-50% of debris	3 50-75% of debris	4 More than 75% of debris
G1	0	2	2	6
G2	6	2	1	1
G3	5	4	1	0
Negative control	5	0	0	0
Positive control	0	0	0	5
Sum	16	8	4	12

Reference: Eter, M. & Abiad, R.

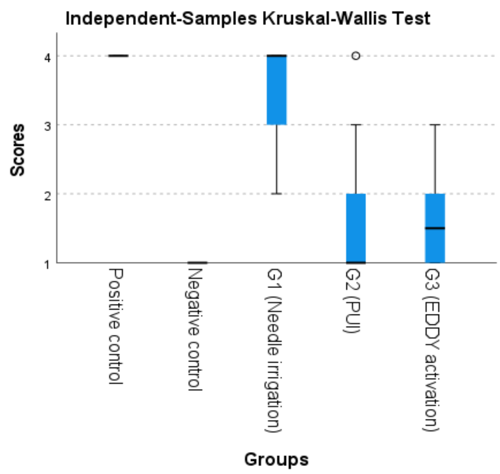

Fig.2: Distribution of dentine debris scores in different groups
Reference: Eter, M. & Abiad, R.

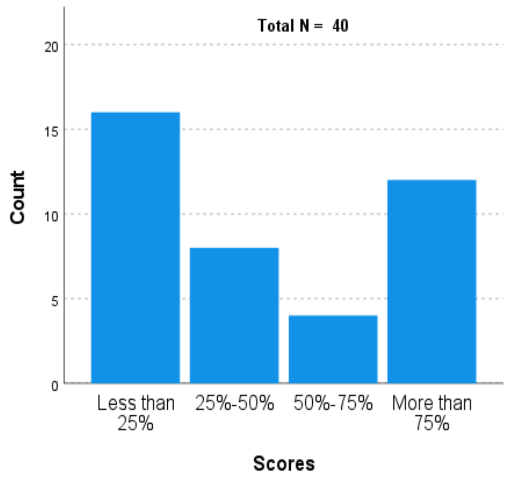

Fig.3: Distribution of samples among different scores
Reference: Eter, M. & Abiad, R.

Table 3: Results of Pairwise comparisons of groups.
The significance level is 0.05. (a)Significance values have been adjusted by the bonferroni correction for multiple tests.

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
Negative control-Positive control	26.000	7.016	3.706	.000	.002
Negative control-G1 (Needle irrigation)	-21.600	6.076	-3.555	.000	.004
Negative control-G2 (PUI)	-6.800	6.076	-1.119	.263	1.000
Negative control-G3 (EDDY activation)	-6.600	6.076	-1.086	.277	1.000
G3 (EDDY activation)-Positive control	19.400	6.076	3.193	.001	.014
G3 (EDDY activation)-G1 (Needle irrigation)	15.000	4.961	3.023	.002	.025
G3 (EDDY activation)-G2 (PUI)	.200	4.961	.040	.968	1.000
G2 (PUI)-Positive control	19.200	6.076	3.160	.002	.016
G2 (PUI)-G1 (Needle irrigation)	14.800	4.961	2.983	.003	.029
G1 (Needle irrigation)-Positive control	4.400	6.076	.724	.469	1.000

Reference: Eter, M. & Abiad, R.

4. DISCUSSION

The removal of debris, smear layer, and thus most microorganisms from infected root canals remains the most important objective of endodontic treatment (Hulsmann, Peters, & Dummer, 2005). Despite the release and the implementation of new endodontic instruments and devices, more than 50% of root canal walls remain untouched by mechanical preparation due to the complex anatomy of the root canal system including isthmuses, extensions, lateral and accessory canals (Paqué, Ganahl, & Peters, 2009). In addition, investigators had proven that both reciprocating and rotating instruments contributed to the accumulation of debris into canal irregularities during canal preparation (Paqué, Al-Jadaa, & Kfir, 2012). Irrigation and mostly activation of irrigation solution are primordial for canal debridement, improvement of disinfection and cleanliness of the entire root canal system (Urban et al., 2017). Thus, the objective of this study was to compare the effectiveness of sonic activation using EDDY, passive ultrasonic activation and conventional needle irrigation in the removal of dentin debris from simulated canal extension created in the apical third of extracted human teeth.

In this study, the removal of debris has been used as a standard for the evaluation of the cleaning efficiency of different irrigant activation techniques, because debris includes dentin chips, residual necrotic and vital pulp tissues attached to the canal wall which are considered in many cases to be infected (Hülsmann, Rümmelin, & Schäfers, 1997). This debris may impede the penetration of antimicrobial agents of irrigants and intracanal medications into dentinal tubules and canal irregularities. Hence, infection and biofilm may persist in the canal wall zones covered with debris compromising the prognosis after root canal treatment (Carr, Schwartz, Schaudinn, Gorur, & Costerton, 2009).

Many studies confirmed that debridement of the apical third of the canal is more difficult than the coronal two thirds regardless of the irrigation technique used (Al-Ali, Sathorn, & Parashos, 2012; Schmidt et al., 2015; Urban et al., 2017). This is probably due to the fact that canal diameter decreases significantly in the apical third, and that canal diameter influences the volume, exchange of irrigants and effectiveness of debris elimination at the working length (De Gregorio et al., 2013; van der Sluis, Wu, & Wesselink, 2005). For these reasons, the artificial groove in this study, was performed in the apical third of the canal.

It was already demonstrated that the level of root canal disinfection greatly depends on the size of the preparation (Chow, 1983). Irrigant activation methods were reported to be efficient in root canals with greater preparation size (Usman, Baumgartner, & Marshall, 2004; van der Sluis et al., 2005). Comparable studies have experienced the effectiveness of irrigant activation methods in root canals prepared to a final size of 40 (Bhuva et al., 2010; Neuhaus, Liebi, Stauffacher, Eick, & Lussi, 2016), while, in this study the samples were instrumented to a final preparation size of 25 taper 8%, to test the effectiveness of these methods in narrower root canal.

The most commonly used activation technique among endodontists seems to be passive ultrasonic irrigation (Dutner, Mines, & Anderson, 2012), so that this activation technique is considered as a gold standard (Mohmmed et al., 2018, 2017). This is probably due to the fact that most studies have demonstrated the superiority of passive ultrasonic activation over sonic activation in canal debridement (Jensen et al., 1999; Plotino, Pameijer, Maria Grande, & Somma, 2007; Van Der Sluis et al., 2007)(Ahmad, Ford, Crum, & Wilson, 1990). Cavitation effect is the creation and the subsequent breakdown of millions of tiny bubbles in a fluid, whereas acoustic streaming is defined as a rapid movement of the fluid in a vortex or circular direction around the vibrating tip (Van Der Sluis et al., 2007). Passive ultrasonic irrigation was repeatedly reported as superior to needle irrigation in eliminating tissue residues and dentin debris, removing smear layer and reducing bacterial loads (Lee, Wu, & Wesselink, 2004a; Van Der Sluis et al., 2007). These findings are in accordance with the result of this study. On the other hand, passive ultrasonic irrigation has its limitation: firstly, the contact of the ultrasonic insert with the canal walls causes the energy of the oscillating file to drop and limits the file movement (Walmsley & Williams, 1989). This is especially important in curved canal where the free oscillation of the ultrasonic file is significantly restrained. In addition, ultrasonic files, despite having a non-active tip, are fabricated from steel, which is harder than dentin. Accordingly, ultrasonic files may create irregularities in the root canal, and thus should only be used for final irrigation (Boutsioukis, Verhaagen, Walmsley, Versluis, & van der Sluis, 2013).

Until recently, sonic devices used for irrigant activation demonstrated lower efficiency than ultrasonic devices, mostly due to their inferior power. Typically, sonic devices operate at 1 to 8000

Hz whereas ultrasonic devices operate at 25 000- 40 000 Hz (Sabins et al., 2003; Walmsley & Williams, 1989). However, sonic activation has some advantages over ultrasonic activation: the sonic tips are made from plastic-like material, so the movements of the tip are not restrained when it comes in contact with the root canal walls. Hence, no irregularities are created by the sonic tip in the canal walls. In addition, the flexible tip of sonic devices may be more beneficial in severely curved canals in comparison to rigid metal ultrasonic tips, because they may easily access the apical area of the canal in curved canals and can vibrate despite contact with the canal walls. This probably makes sonic activation safer and more convenient in curved canal than ultrasonic activation (Neuhaus et al., 2016). The EDDY system is a sonic activation device, which according to the manufacturer operates at a significantly higher power than other more popular sonic devices ("Innovative Sonic Powered Irrigation," 2021).

The results of this study showed that no statistically significant difference existed between sonic and passive ultrasonic activation in debris removal from the artificial groove and that both activation techniques performed significantly better than conventional needle irrigation. This result is consistent with that of a previous article which demonstrated that sonic activation with EDDY system might be similar to passive ultrasonic activation in decreasing the amount of debris in curved and straight root canals (Neuhaus et al., 2016). Also, Haupt et al., found that sonic activation with EDDY was significantly more efficient in removing debris and smear layer from curved root canals than needle irrigation (Haupt, Meinel, Gunawardana, & Hülsmann, 2020). Similarly, two recent researches confirmed the results of this study which demonstrated that EDDY activation and passive ultrasonic activation were equally effective in removing debris and smear layer from the root canal (Alsubait et al., 2021; Plotino et al., 2021). Furthermore, Eneide et al. found that sonic activation with EDDY showed the greater reduction of E. Faecalis and eight other bacterial types when compared to passive ultrasonic activation and needle irrigation especially in narrow canals. They concluded that sonic activation with EDDY is efficient in eliminating bacterial layers from the root canal walls (Eneide et al., 2019). Similarly, two other articles showed that irrigant activation whether with passive ultrasonic activation, Endoactivator or EDDY system promotes the tissue dissolving ability of irrigant from simulated grooves in the root canals of extracted human teeth (Conde et al., 2017; Urban et al., 2017).

In this study, the assessment of the remaining dentin debris was only based on the analysis of two-dimensional pictures of the simulated standard groove; hence, the measurement of the thickness of residues in the created canal extension was not possible. Moreover, despite that this in-vitro technique may be beneficial for standardizing the amount of dentin debris, size and position of the groove, and the volume of irrigant used (Plotino et al., 2019; Rödig, Bozkurt, Konietschke, & Hülsmann, 2010), this study design has its limitation because the artificial groove does not represent the complexity of the root canal system, so the removal of dentin debris from the groove might be easier than from oval canal irregularities and isthmuses in vivo (Rödig et al., 2010). This may lead to an overestimation of the cleaning efficiency of different irrigant activation methods. Accordingly, more laboratory and clinical studies must be performed to accurately determine the cleaning efficacy of EDDY sonic system especially in complex root canal systems such as severely or doubly curved root canals.

5. CONCLUSION:

Under the condition of this study, the removal of dentin debris from artificial apical groove was best achieved by sonic activation using EDDY as well as by passive ultrasonic activation. Both activation techniques were more effective than conventional needle irrigation. However, additional studies are needed to verify these results and to notably determine an irrigation technique, which minimizes the spread of microorganisms beyond the apex in order to avoid subsequent local and systemic pathological reactions.

REFERENCES:

- Agarwal, A., Nanda, Z., Deore, R. B., Rudagi, K., Baig, M. O., & Fareez, M. A. (2017). Evaluation of Apical Vapor Lock Formation and comparative Evaluation of its Elimination using Three different Techniques: An in vitro Study. *The Journal of Contemporary Dental Practice*, *18*(9), 790–794. https://doi.org/10.5005/jp-journals-10024-2128
- Ahmad, M., Ford, T. R. P., Crum, L. A., & Wilson, R. F. (1990). Effectiveness of ultrasonic files in the disruption of root canal bacteria. *Oral Surgery, Oral Medicine, Oral Pathology*, *70*(3), 328–332. https://doi.org/10.1016/0030-4220(90)90150-Q
- Aksel, H., Küçükkaya Eren, S., & Serper, A. (2017). Comparison of triple antibiotic paste removal by different irrigation techniques. *Dental Materials Journal*, *36*(3), 303–308. https://doi.org/10.4012/dmj.2016-105
- Al-Ali, M., Sathorn, C., & Parashos, P. (2012). Root canal debridement efficacy of different final irrigation protocols. *International Endodontic Journal*, *45*(10), 898–906. https://doi.org/10.1111/j.1365-2591.2012.02046.x
- Alsubait, S., Alshaibani, Y., Alshehri, N., Alnuwaiser, N., Alajimi, T., Almaflehi, N., & Alkahtany, M. (2021). Efficacy of Different Endodontic Irrigant Activation Techniques on Debris Removal from the Mesial Root Canal System of Mandibular Molars. *J Contemp Dent Pract*, *22*(3), 231–236. Retrieved from https://pubmed.ncbi.nlm.nih.gov/34210920/
- Arslan, H., Akcay, M., Capar, I. D., Saygili, G., Gok, T., & Ertas, H. (2015). An in vitro comparison of irrigation using photon-initiated photoacoustic streaming, ultrasonic, sonic and needle techniques in removing calcium hydroxide. *International Endodontic Journal*, *48*(3), 246–251. https://doi.org/10.1111/IEJ.12306
- Bhuva, B., Patel, S., Wilson, R., Niazi, S., Beighton, D., & Mannocci, F. (2010). The effectiveness of passive ultrasonic irrigation on intraradicular *Enterococcus faecalis* biofilms in extracted single-rooted human teeth. *International Endodontic Journal*, *43*(3), 241–250. https://doi.org/10.1111/j.1365-2591.2009.01672.x
- Boutsioukis, C., Verhaagen, B., Walmsley, A. D., Versluis, M., & van der Sluis, L. W. M. (2013). Measurement and visualization of file-to-wall contact during ultrasonically activated irrigation in simulated canals. *International Endodontic Journal*, *46*(11), 1046–1055. https://doi.org/10.1111/iej.12097
- Carr, G. B., Schwartz, R. S., Schaudinn, C., Gorur, A., & Costerton, J. W. (2009). Ultrastructural Examination of Failed Molar Retreatment with Secondary Apical Periodontitis: An Examination of Endodontic Biofilms in an Endodontic Retreatment Failure. *Journal of Endodontics*, *35*(9), 1303–1309. https://doi.org/10.1016/j.joen.2009.05.035
- Castagnola, R., Lajolo, C., Minciacchi, I., Cretella, G., Foti, R., Marigo, L., Gambarini, G., Angerame, D., Somma, F. (2014). Efficacy of three different irrigation techniques in the removal of smear layer and organic debris from root canal wall: A scanning electron microscope study. *Giornale Italiano Di Endodonzia*, *28*(2), 79–86. https://doi.org/10.1016/j.gien.2014.09.001
- Cesario, F., Duarte, M. A. H., Duque, J. A., Alcalde, M. P., De Andrade, F. B., So, M. V. R., De Vasconcelos, B.C., Vivan, R. R. (2018). Comparisons by microcomputed tomography of the efficiency of different irrigation techniques for removing dentinal debris from artificial grooves. *Journal of Conservative Dentistry*, *21*(4), 383–387. https://doi.org/10.4103/JCD.JCD_286_16
- Chow, T. W. (1983). Mechanical effectiveness of root canal irrigation. *Journal of Endodontics*, *9*(11), 475–479. https://doi.org/10.1016/S0099-2399(83)80162-9
- Conde, A. J., Estevez, R., Loroño, G., Valencia de Pablo, Ó., Rossi-Fedele, G., & Cisneros, R. (2017). Effect of sonic and ultrasonic activation on organic tissue dissolution from simulated grooves in root canals using sodium hypochlorite and EDTA. *International Endodontic Journal*, *50*(10), 976–982. https://doi.org/10.1111/iej.12717
- De Gregorio, C., Arias, A., Navarrete, N., Del Rio, V., Oltra, E., & Cohenca, N. (2013). Effect of apical size and taper on volume of irrigant delivered at working length with apical negative pressure at different root curvatures. *Journal of Endodontics*, *39*(1), 119–124. https://doi.org/10.1016/j.joen.2012.10.008
- Duque, J. A., Duarte, M. A. H., Canali, L. C. F., Zancan, R. F., Vivan, R. R., Bernardes, R. A., & Bramante, C. M. (2017). Comparative Effectiveness of New Mechanical Irrigant Agitating Devices for Debris Removal from the Canal and Isthmus of Mesial Roots of Mandibular Molars. *Journal of Endodontics*, *43*(2), 326–331. https://doi.org/10.1016/j.joen.2016.10.009

- Dutner, J., Mines, P., & Anderson, A. (2012). Irrigation trends among american association of endodontists members: A web-based survey. *Journal of Endodontics*, *38*(1), 37–40. https://doi.org/10.1016/j.joen.2011.08.013
- Eneide, C., Castagnola, R., Martini, C., Grande, N. M., Bugli, F., Patini, R., Cordaro, M., Sanguinetti, M., Olivi, G., Isola, G., Marigo, L. (2019). Antibiofilm activity of three different irrigation techniques: An in vitro study. *Antibiotics*, *8*(3), 1–8. https://doi.org/10.3390/antibiotics8030112
- Haupt, F., Meinel, M., Gunawardana, A., & Hülsmann, M. (2020). Effectiveness of different activated irrigation techniques on debris and smear layer removal from curved root canals: a SEM evaluation. *Australian Endodontic Journal : The Journal of the Australian Society of Endodontology Inc*, *46*(1), 40–46. https://doi.org/10.1111/AEJ.12342
- Hulsmann, M., Peters, O. A., & Dummer, P. M. H. (2005). Mechanical preparation of root canals: shaping goals, techniques and means. *Endodontic Topics*, *10*(1), 30–76. https://doi.org/10.1111/j.1601-1546.2005.00152.x
- Hülsmann, M., Rümmelin, C., & Schäfers, F. (1997). Root canal cleanliness after preparation with different endodontic handpieces and hand instruments: A comparative SEM investigation. *Journal of Endodontics*, *23*(5), 301–306. https://doi.org/10.1016/S0099-2399(97)80410-4
- Innovative Sonic Powered Irrigation. (2021). Retrieved October 29, 2021, from https://www.vdw-dental.com/en/products/detail/eddy/
- Jensen, S. A., Walker, T. L., Hutter, J. W., & Nicoll, B. K. (1999). Comparison of the cleaning efficacy of passive sonic activation and passive ultrasonic activation after hand instrumentation in molar root canals. *Journal of Endodontics*, *25*(11), 735–738. https://doi.org/10.1016/S0099-2399(99)80120-4
- Justo, A. M., Da Rosa, R. A., Santini, M. F., Ferreira, M. B. C., Pereira, J. R., Duarte, M. A. H., & Só, M. V. R. (2014). Effectiveness of final irrigant protocols for debris removal from simulated canal irregularities. *Journal of Endodontics*, *40*(12), 2009–2014. https://doi.org/10.1016/j.joen.2014.08.006
- Kirar, D. S., Jain, P., & Patni, P. (2017). Comparison of different irrigation and agitation methods for the removal of two types of calcium hydroxide medicaments from the root canal wall: An in-vitro study. *Clujul Medical*, *90*(3), 327–332. https://doi.org/10.15386/cjmed-737
- Lee, S. J., Wu, M. K., & Wesselink, P. R. (2004a). The effectiveness of syringe irrigation and ultrasonics to remove debris from simulated irregularities within prepared root canal walls. *International Endodontic Journal*, *37*(10), 672–678. https://doi.org/10.1111/j.1365-2591.2004.00848.x
- Lee, S. J., Wu, M. K., & Wesselink, P. R. (2004b). The efficacy of ultrasonic irrigation to remove artificially placed dentine debris from different-sized simulated plastic root canals. *International Endodontic Journal*, *37*(9), 607–612. https://doi.org/10.1111/j.1365-2591.2004.00857.x
- Mohmmed, S. A., Vianna, M. E., Penny, M. R., Hilton, S. T., Mordan, N. J., & Knowles, J. C. (2018). Investigations into *in situ Enterococcus faecalis* biofilm removal by passive and active sodium hypochlorite irrigation delivered into the lateral canal of a simulated root canal model. *International Endodontic Journal*, *51*(6), 649–662. https://doi.org/10.1111/iej.12880
- Mohmmed, S. A., Vianna, M. E., Penny, M. R., Hilton, S. T., Mordan, N., & Knowles, J. C. (2017). Confocal laser scanning, scanning electron, and transmission electron microscopy investigation of Enterococcus faecalis biofilm degradation using passive and active sodium hypochlorite irrigation within a simulated root canal model. *MicrobiologyOpen*, *6*(4), e00455. https://doi.org/10.1002/mbo3.455
- Neuhaus, K. W., Liebi, M., Stauffacher, S., Eick, S., & Lussi, A. (2016). Antibacterial Efficacy of a New Sonic Irrigation Device for Root Canal Disinfection. *Journal of Endodontics*, *42*(12), 1799–1803. https://doi.org/10.1016/j.joen.2016.08.024
- Pabel, A. K., & Hülsmann, M. (2017). Comparison of different techniques for removal of calcium hydroxide from straight root canals: an in vitro study. *Odontology*, *105*(4), 453–459. https://doi.org/10.1007/s10266-017-0293-6
- Paqué, F., Al-Jadaa, A., & Kfir, A. (2012). Hard-tissue debris accumulation created by conventional rotary versus self-adjusting file instrumentation in mesial root canal systems of mandibular molars. *International Endodontic Journal*, *45*(5), 413–418. https://doi.org/10.1111/j.1365-2591.2011.01991.x

- Paqué, F., Ganahl, D., & Peters, O. A. (2009). Effects of Root Canal Preparation on Apical Geometry Assessed by Micro-Computed Tomography. *Journal of Endodontics*, *35*(7), 1056–1059. https://doi.org/10.1016/j.joen.2009.04.020
- Peters, O. A., Schönenberger, K., & Laib, A. (2001). Effects of four Ni-Ti preparation techniques on root canal geometry assessed by micro computed tomography. *International Endodontic Journal*, *34*(3), 221–230. https://doi.org/10.1046/j.1365-2591.2001.00373.x
- Plotino, G., Colangeli, M., Özyürek, T., DeDeus, G., Panzetta, C., Castagnola, R., Grande, N. M., Marigo, L. (2021). Evaluation of smear layer and debris removal by stepwise intraoperative activation (SIA) of sodium hypochlorite. *Clinical Oral Investigations*, *25*(1). https://doi.org/10.1007/S00784-020-03358-6
- Plotino, G., Grande, N. M., Mercade, M., Cortese, T., Staffoli, S., Gambarini, G., & Testarelli, L. (2019). Efficacy of sonic and ultrasonic irrigation devices in the removal of debris from canal irregularities in artificial root canals. *Journal of Applied Oral Science*, *27*, 1–6. https://doi.org/10.1590/1678-7757-2018-0045
- Plotino, G., Pameijer, C. H., Maria Grande, N., & Somma, F. (2007). Ultrasonics in Endodontics: A Review of the Literature. *Journal of Endodontics*, *33*(2), 81–95. https://doi.org/10.1016/j.joen.2006.10.008
- Richman, M. (1957). The use of ultrasonics in root canal therapy and root resection. *J Dent Med*, *12*, 12–18. Retrieved from https://ci.nii.ac.jp/naid/10027432450
- Rödig, T., Bozkurt, M., Konietschke, F., & Hülsmann, M. (2010). Comparison of the vibringe system with syringe and passive ultrasonic irrigation in removing debris from simulated root canal irregularities. *Journal of Endodontics*, *36*(8), 1410–1413. https://doi.org/10.1016/j.joen.2010.04.023
- Sabins, R. A., Johnson, J. D., & Hellstein, J. W. (2003). A comparison of the cleaning efficacy of short-term sonic and ultrasonic passive irrigation after hand instrumentation in molar root canals. *Journal of Endodontics*, *29*(10), 674–678. https://doi.org/10.1097/00004770-200310000-00016
- Schmidt, T. F., Teixeira, C. S., Felippe, M. C. S., Felippe, W. T., Pashley, D. H., & Bortoluzzi, E. A. (2015). Effect of Ultrasonic Activation of Irrigants on Smear Layer Removal. *Journal of Endodontics*, *41*(8), 1359–1363. https://doi.org/10.1016/j.joen.2015.03.023
- 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. https://doi.org/10.1007/s00784-017-2070-x
- Usman, N., Baumgartner, J. C., & Marshall, J. G. (2004). Influence of instrument size on root canal debridement. *Journal of Endodontics*, *30*(2), 110–112. https://doi.org/10.1097/00004770-200402000-00012
- Van Der Sluis, L. W. M., Versluis, M., Wu, M. K., & Wesselink, P. R. (2007). Passive ultrasonic irrigation of the root canal: A review of the literature. *International Endodontic Journal*, Vol. 40, pp. 415–426. https://doi.org/10.1111/j.1365-2591.2007.01243.x
- van der Sluis, L. W. M., Vogels, M. P. J. M., Verhaagen, B., Macedo, R., & Wesselink, P. R. (2010). Study on the Influence of Refreshment/Activation Cycles and Irrigants on Mechanical Cleaning Efficiency During Ultrasonic Activation of the Irrigant. *Journal of Endodontics*, *36*(4), 737–740. https://doi.org/10.1016/j.joen.2009.12.004
- van der Sluis, L. W. M., Wu, M.-K., & Wesselink, P. R. (2005). The efficacy of ultrasonic irrigation to remove artificially placed dentine debris from human root canals prepared using instruments of varying taper. *International Endodontic Journal*, *38*(10), 764–768. https://doi.org/10.1111/j.1365-2591.2005.01018.x
- Virdee, S. S., Seymour, D. W., 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. *International Endodontic Journal*, *51*(6), 605–621. https://doi.org/10.1111/iej.12877
- Walmsley, A. D., & Williams, A. R. (1989). Effects of constraint on the oscillatory pattern of endosonic files. *Journal of Endodontics*, *15*(5), 189–194. https://doi.org/10.1016/S0099-2399(89)80233-X