Efficacy of Different Endodontic Irrigant Activation Techniques on Debris Removal from the Mesial Root Canal System of Mandibular Molars

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ABSTRACT

Aim and objective: This study was conducted to compare debris removal from the mesial canal system with four different irrigation techniques: sonic activation with EDDY, passive ultrasonic irrigation (PUI), mechanical activation with the XP-endo Finisher (XPF), and manual dynamic irrigation (MDI) with gutta-percha.

Materials and methods: Fifty-six extracted mandibular molars with isthmus in the apical 5 mm in mesial roots were sectioned horizontally at 3 mm and 5 mm from the apex. The sections were reassembled, and the mesial canals were prepared chemomechanically. Specimens were allocated randomly into four groups according to the final irrigation technique. Standardized images of the coronal aspect of cross sections were obtained using a digital stereomicroscope before and after final irrigation protocols to calculate the percentage of debris elimination from the canal system after final irrigation.

Results: The use of EDDY, PUI, and XPF exhibited significant reductions in debris compared with MDI at 5 mm ($p < 0.00$) and at 3 mm ($p < 0.00$). Furthermore, no significant difference was noted among EDDY, PUI, and XPF. For intragroup analysis, no statistically significant difference in the percentage of debris elimination was noted between 3 mm and 5 mm in all four groups.

Conclusion: All groups showed a reduction in debris after the final irrigation protocol. However, the use of EDDY, PUI, and XPF after cleaning and shaping yielded a significant reduction in debris compared with MDI.

Clinical significance: The use of PUI, XPF, and EDDY as an adjunctive irrigation step presented similar results in improving canal cleanliness, which is hypothesized to affect the treatment outcome.

Keywords: Debris removal, Isthmus, Root canal irrigation, Sonically activated irrigation, Ultrasonically activated irrigation, XP-endo Finisher.

The Journal of Contemporary Dental Practice (2021): 10.5005/jp-journals-10024-3054

INTRODUCTION

Complete debridement of the root canal system is a challenge due to the presence of a complex canal anatomy.¹ Most of the available systems for canal mechanical preparation result in 16–56% of the walls untouched.^{2,3} Uninstrumented areas may harbor pulp tissue, bacteria and their byproducts, and dentinal debris that might lead to treatment failure.⁴ Therefore, irrigation with the disinfecting solution is mandatory to improve disinfection during canal preparation.⁵

Manual irrigation with a syringe remains the most commonly used irrigation method.⁶ However, it has been shown that syringe irrigation is unable to remove debris from apical irregularities.⁷ Therefore, different techniques and devices were developed to activate the irrigant mainly after the completion of root canal preparation to enhance the canal debridement. A simple method for irrigant activation is moving a well-fitted gutta-percha cone in short, gentle strokes to agitate the irrigant in a technique known as manual dynamic irrigation (MDI). This technique is effective in debris removal.⁸ Passive ultrasonic irrigation (PUI) is an ultrasonic activation of the irrigant with a small, oscillating instrument placed in the root canal.⁹ PUI can induce acoustic streaming and cavitation.^{9,10} Previous studies showed that PUI promoted better cleaning of the canal compared with conventional irrigation.^{11,12} XPF (FKG Dentaire, La Chaux-de-Fonds, Switzerland) is a size 25 nontapered instrument that was introduced to improve endodontic disinfection. When rotated and moved up and down in the canal,

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How to cite this article: Alsubait S, Al-Shibani Y, Al-Shehri N, *et al.* Efficacy of Different Endodontic Irrigant Activation Techniques on Debris Removal from the Mesial Root Canal System of Mandibular Molars. *J Contemp Dent Pract* 2021;22(3):231–236.

Source of support: Nil

Conflict of interest: None

XPF might be able to clean the untouched areas. Previous studies reported that both PUI and XPF have similar effectiveness in the removal of hard tissue debris.^{11,13}

Recently, EDDY (EDDY, VDW, Munich, Germany), a new sonic device, was launched. EDDY is a flexible, smooth polyamide tip with a size of 25 and 0.04 taper. Typically, sonic devices operate at 1–8 kHz.¹⁴ EDDY is employed with sonic activation at a frequency of 6000 Hz using a conventional air scaler. The manufacturer claims that the high-frequency vibration induces acoustic streaming and

cavitation, and these two effects are generated by PUI and are attributed to its enhancement in cleaning efficiency.

Several earlier studies have evaluated the effectiveness of EDDY on the removal of debris from the root canal system.^{15–19} However, the evaluation of its efficacy on teeth with complex canal anatomy has been reported in few studies with conflicting results,^{15,16,19} which highlights the need for further research. Thus, the aim of the present study was to compare the efficacy of four different irrigation techniques *in vitro*: sonic activation with EDDY, PUI, mechanical activation with the XPF, and MDI with gutta-percha on debris removal from a mesial canal system. The null hypothesis tested was that there is no difference among the four irrigation activation techniques on debris removal from the mesial root canals of mandibular molars.

MATERIALS AND METHODS

Ethical Approval

The study methodology was approved by the Institutional Review Board (E-20-4663) and the College of Dentistry Research Center of King Saud University (FR 0549), Riyadh, Kingdom of Saudi Arabia.

Sample Size Estimation and Teeth Selection

The sample size was calculated using G*Power 3.1.9.4 software at an alpha error probability of 0.05 with an effect size of 0.45 and power of 82%. Power analysis showed that the required sample size per group was 14 teeth.

Human mandibular molars that had been extracted for reasons unrelated to the current study were selected. The inclusion criteria were teeth with fully formed apices, moderately curved canals (10°–25°),²⁰ teeth without cracks, teeth without calcifications, and teeth with no previous endodontic treatment as confirmed by digital radiographs. Selected teeth were scanned in a microcomputed tomography (μ -CT) device (1173 Micro-CT, Bruker SkyScan, Kontich, Belgium) at 85 kV, 90 μ A, 16.98 μ m pixel size, 0.25 brass filter, and 360° rotation around the vertical axis with a rotation step of 0.4° to confirm the presence of an isthmus in the apical 5 mm in mesial roots. Teeth that met the criteria were randomly distributed into four groups using a computer algorithm (www.random.org) according to the final irrigation protocol. The Kolmogorov–Smirnov test showed a normal distribution of the data, and Levene's test confirmed the intergroup homogeneity regarding the volume of the canals and isthmus areas in the apical 5 mm in mesial roots ($p > 0.05$). Each tooth was coded and stored in saline solution.

Specimen Preparation

The pulp chambers were accessed conventionally. The occlusal cusps were flattened to obtain a stable reference point during chemomechanical preparation. The coronal one-third of the mesial canals was flared using a ProTaper Gold Sx file (Dentsply Maillefer, Ballaigues, Switzerland). Working length (WL) was recorded at a distance 0.5 mm shorter from the length at which a size 10 K-file (Dentsply Maillefer, Ballaigues, Switzerland) was visible at the mesiobuccal and mesiolingual canal terminus. Afterward, flowable composite resin (SDI wave, Bayswater, Australia) was used to seal the apices of the mesial roots and distal canal orifice. Canals were irrigated with saline followed by the placement of cotton pellets and temporary filling material (Coltosol F, Coltène, Altstätten, Switzerland) to seal the access opening.

The experimental model described by Passalidou et al.¹² was used in the present study. Before mounting, the apical 3 mm of the

roots were immersed in methylene blue for the identification of the apex during sectioning. Each tooth specimen was embedded vertically in a rubber mold (with 30 mm edges) containing acrylic resin (Vertex Orthoplast; Vertex-Dental, Zeist, The Netherlands) 2 mm apical to the occlusal surface. After the resin had hardened, four holes were drilled at the corners of the blocks, and then each block was sectioned axially at 3 and 5 mm from the apex (Isomet, Buehler Ltd., Lake Blu, New York, United States). Standardized images of the coronal aspect of each section were obtained using a stereomicroscope digital microscope (KH-7700, Hirox, Japan) at 50 $\times$ magnification. These images comprised the prepreparation images. The specimens were reassembled and firmly tightened with the help of guide pins and metal bolts in the predrilled shafts.

Canal Preparation

After the removal of the temporary filling and cotton pellet, a size 10 K-file was placed inside the mesiobuccal and mesiolingual canals to verify WL and proper assembly. ProTaper Gold instruments were used according to the manufacturer's instructions up to size 30 with a 0.09 taper (F3). Each instrument was discarded after instrumenting two teeth or if an unwinding occurred. After each instrument, 2 mL of 2.5% sodium hypochlorite (NaOCl) was applied using a 30-gauge tip needle (Ultradent Inc., South Jordan, Utah, United States) inserted as deep as possible without binding, respecting the maximum distance of 1 mm from the WL. After completion of instrumentation, each canal was irrigated with 2 mL of NaOCl with the needle placed 1 mm short of the WL and dried with paper points (Dentsply Maillefer). The access opening was sealed. The specimen was disassembled, and images of the coronal surface of each section were obtained as previously described (postpreparation images).

Final Irrigation Protocol

The specimen sections were reassembled, and all metal bolts were firmly tightened. A size 10 K-file was placed inside the mesial canals to verify proper assembly. Two milliliters of NaOCl was applied to the root canals and pulp chamber with a syringe. Afterward, the irrigant was activated according to the assigned supplementary irrigation protocols as follows:

- Sonic activation with EDDY (EDDY): The irrigant was activated with an EDDY tip placed 1 mm short of the WL and operated by an air scaler handpiece (SonicFlex, KaVo, Biberach, Germany) at a frequency of 6000 Hz. The EDDY tip was moved vertically (2–4 mm) inside the canal. Each EDDY tip was used in two teeth and then discarded.
- Passive ultrasonic irrigation (PUI): A noncutting, 20/0.00, ultrasonic stainless steel tip (Irrisafe; Satelec Acteon Group, Merignac, France) mounted on an ultrasonic device (P5 Newtron; Satelec) at a power setting of 8 was placed 1 mm short of the WL and moved up and down (2–4 mm) in vertical motions. Each ultrasonic stainless steel tip was used in two teeth and then discarded.
- XP-endo Finisher (XPF): The XPF instrument was inserted inside the canal and then activated at 800 rpm using slow and gentle 7 to 8 mm vertical movements up to the WL inside a cabinet with a temperature kept at 37°C (Gourmia; Brooklyn, New York, United States).²¹ Each XPF instrument was used in two teeth and then discarded.
- Manual dynamic irrigation (MDI): A ProTaper F3 gutta-percha cone (Dentsply Maillefer) was inserted into the WL. In and out movements were performed manually.

Irrigant in all groups was activated for 30 seconds, and then the canal was irrigated with an additional 2 mL NaOCl followed by activation of the irrigant for an additional 30 seconds. All groups received a final irrigation with 2 mL NaOCl in each canal using a 30-gauge needle placed 1 mm short of WL, and canals were then dried with paper points. Afterward, each specimen was disassembled, and images of each section were obtained as described above. These images comprised the postirrigant activation images. A single operator performed all procedures.

Method of Evaluation

The full color images were viewed, and the area of debris was marked and quantified by one blinded operator who was not involved in canal preparation using ImageJ software (National Institutes of Health, Bethesda, Maryland, United States). Debris was defined as any material present on the canal walls, in the canal lumen, or in the isthmus. For each section, the following formula was used to calculate the amount of debris removed after the use of the final irrigation protocol: $[(D_{BIA} - D_{AIA})/D_{BIA}] \times 100$, where D_{BIA} is the amount of debris before irrigant activation, and D_{AIA} is the amount of debris after irrigant activation.

Statistical Analysis

The normality of the data was confirmed by the Shapiro–Wilk test. Analysis of variance was performed and complemented by Tukey's test for pairwise comparisons to compare the means of the percentage of removed debris between groups. The *t*-test was used for intragroup analysis to compare the percentage reduction in debris at 3 and 5 mm. The significance level was set at $p < 0.05$. Data were statistically analyzed using SPSS software (version 21.0, SPSS IBM, Armonk, New York, United States).

RESULTS

Figures 1 and 2 show representative images of the canal system after sectioning, cleaning, and shaping, and after final irrigation at 5 mm and 3 mm from the WL, respectively. The mean and standard deviation of the percentage of eliminated debris for all groups are shown in Table 1.

All groups showed a reduction in debris after the final irrigation protocol. However, the use of EDDY, PUI, and XPF after cleaning and shaping yielded a significant reduction in debris compared with MDI at 5 mm ($p < 0.00$) and at 3 mm ($p < 0.00$). Furthermore, no significant difference was noted among EDDY, PUI, and XPF at

Figs 1A to C: Representative images of root cross sections at 5 mm (A) before canal preparation, (B) after canal preparation, and (C) after supplementary irrigant activation with a (1) EDDY, (2) passive ultrasonic, (3) XPF, or (4) manual dynamic activation with gutta-percha cone

Figs 2A to C: Representative images of root cross sections at 3 mm (A) before canal preparation, (B) after canal preparation, and (C) after supplementary irrigant activation with a (1) EDDY, (2) passive ultrasonic, (3) XPF, or (4) manual dynamic activation with gutta-percha cone

Table 1: Means and standard deviations for the percentage of debris reduction after the use of different final irrigation protocols at 3 mm and 5 mm from WL

	Final irrigation protocols				"p" value
	EDDY	PUI	XPF	MDI	
3 mm	86.42 ± 2.75 ^a	87.33 ± 3.99 ^a	87.32 ± 3.84 ^a	45.82 ± 3.97 ^b	0.00
5 mm	88.88 ± 4.43 ^a	88.39 ± 4.3 ^a	87.85 ± 5.98 ^a	49.12 ± 4.65 ^b	0.00
"p" value	0.09	0.51	0.78	0.06	

Different superscripted lowercase letters indicate statistically significant differences in the percentage of debris reduction between EDDY, PUI, XPF, and MDI within each section level ($p < 0.05$); PUI, passive ultrasonic irrigation; XPF, XP-endo Finisher; MDI, manual dynamic irrigation

5 mm (EDDY vs PUI: $p = 0.91$, EDDY vs XPF: $p = 0.92$, and PUI vs XPF: $p = 1$) or at 3 mm (EDDY vs PUI: $p = 0.99$, EDDY vs XPF: $p = 0.94$, and PUI vs XPF: $p = 0.99$). For intragroup analysis, no statistically significant difference in the percentage of debris elimination was noted between 3 and 5 mm in all four groups (Table 1).

DISCUSSION

Complete disinfection of mandibular molars is difficult due to the complex canal anatomy. One of the major complexities in molars is the presence of isthmuses. The isthmus is defined as a narrow connection between two or more canals in the same root.²² It

has been reported that isthmuses are found in 87 and 66% of the mandibular first and second molars, respectively.²³ The highest incidence of isthmuses was observed at 3 to 6 mm from the apex.²⁴ In clinical practice, the isthmus area is difficult to access and debride using mechanical instrumentation. Therefore, isthmus-containing mesial roots of mandibular molars were selected for this study. To reduce the potential anatomical biases between the groups, teeth were scanned before canal preparation, and the volume of the canals and isthmus areas in the apical 5 mm were statistically analyzed. The irrigant penetration into the apical one-third of the canal is related to the apical preparation size. Size 30 is the minimum instrumentation size that is needed to achieve proper irrigant

penetration into the apical third.²⁵ Therefore, in the present study, preparation of the F3 file was performed.

Different methods have been used to assess the cleanliness of root canals after the use of different irrigant activation techniques. Micro-CT has been used in previous studies.^{11,13,16} However, the major limitation of this technology when used for calculating the amount of debris is that the organic debris present in the root canal system cannot be viewed on radiographic images.²⁶ The use of root sectioning and microscopic evaluation methodology was used in other studies to overcome this limitation.^{12,27,28} Thus, this methodology was selected for the present study. The K-Kube model that was described by Passalidou et al.¹² was used in this study. In addition to the ability to evaluate soft and hard tissue debris, it allows each tooth to serve as its own control by evaluating the same section at each treatment procedure. Furthermore, the K-Kube model provides a closed system that more accurately simulates *in vivo* conditions.

In the present study, none of the tested supplementary irrigant activation techniques was able to remove debris completely from the root canals. The finding is consistent with previous studies.^{12,15,16} However, the use of EDDY, PUI, and XPF resulted in significantly higher percentages of debris reductions compared with MDI. Hence, the null hypothesis was rejected. MDI has the advantage of being a simple and low-cost technique. However, MDI was the least effective in debris removal from the canal system, which might be explained by the repeated friction of the debris against the canal walls with a well-fitted gutta-percha that produces more particular agglomeration on canal walls.²⁹ This observation was consistent with previous studies regarding debris and smear layer removal.^{12,30}

PUI has been reported to reduce debris in the root canal after canal preparation,^{11,12} which is consistent with the results of the present study. The efficacy of PUI is related to the high-frequency vibration that induces acoustic streaming and cavitation. In the current study, XPF presented similar effectiveness to PUI in the reduction of hard and soft debris. Leoni et al.¹¹ and De-Deus et al.¹³ evaluated the removal of hard tissue debris using micro-CT technology and reported similar findings. XPF is an instrument that is made of a highly flexible proprietary alloy. XPF has a small core size and a zero taper. Most likely, when activated inside the canal, the helical movement of the file may touch and displace the debris inside the canal system.¹¹

Conflicting results have been reported in the literature regarding the efficacy of sonic activation techniques in removing debris from the root canal system.^{14,31} Compared with ultrasonic activation, sonic irrigation devices operate at lower frequencies. EDDY is a newly introduced ultrasonic activation device that operates at high frequency (6000 Hz). In the present study, the cleaning ability of EDDY is similar to that of PUI. This finding is consistent with those reported by Haupt et al.¹⁵ This finding might be explained by the high frequencies in EDDY compared with other sonic irrigation devices, which is expected to improve the irrigant flow to displace the debris. However, this finding is in disagreement with Linden et al.,¹⁶ where PUI resulted in a significantly higher percentage of reduction compared to EDDY. Hard tissue debris removal was evaluated in the Linden et al.¹⁶ study, whereas hard and soft tissue debris were considered in the present study. To the best of our knowledge, this is the first study that evaluated canal cleanliness after the use of EDDY and XPF supplementary techniques. Both activation techniques showed similar effectiveness in the removal of root canal debris. In the current investigation, no differences in debris reduction were noted between 3 and 5 mm in all groups.

This finding might be attributed to the final canal preparation size (30.09), which allowed the activation instrument to oscillate freely, followed by the agitation of the irrigant and disruption of the debris.

A major limitation of this *in vitro* study is that it cannot duplicate the *in vivo* conditions. However, this study can provide information that can help clinicians select supplementary irrigant activation techniques. From a clinical point of view, the results of the present study can be translated into the fact that the use of PUI, XPF, and EDDY as an adjunctive irrigation step had similar results in improving canal cleanliness, which is hypothesized to affect the treatment outcome. However, the EDDY tip may have an advantage compared to PUI and XPF. The soft polymer tips in EDDY sonic devices would reduce the risk of unintentional dentin removal from the prepared canal system, which can be caused by the use of PUI³² and XPF.³³ Further studies are required to assess dentin removal after using sonic activation at high frequency.

CONCLUSION

In conclusion, sonic activation with EDDY, PUI, mechanical activation with XPF, and MDI with gutta-percha showed a reduction in debris after the final irrigation protocol. However, the use of EDDY, PUI, and XPF after cleaning and shaping yielded significant reductions in debris compared with MDI.

ACKNOWLEDGMENT

The authors would like to thank the College of Dentistry Research Center at King Saud University for its support in the present project.

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