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Apical Debris Extrusion of Rotary and Reciprocating Files Combined with Two Supplementary Irrigation Techniques

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Abstract

Objectives: To quantify the amount of debris extrusion after root canal instrumentation with rotary (Zenflex; ZF) and reciprocating (EdgeOne Fire; EOF) file systems combined with either Manual Dynamic Activation (MDA) or Passive Ultrasonic Irrigation (PUI).

Methods: Ninety mandibular molars with complete root formation and 10°-20° curvature were selected, disinfected, and stored. Teeth with immature apex, resorption, caries, or calcified canals were excluded. High-speed diamond burs accessed the teeth and mesial roots were used for investigation. Specimen were randomly divided into 6 groups (n=15) based on file (ZF and EOF) and irrigation systems(MDA and PUI). The apical size of prepared root canal was 25. The Myers and Montgomery method was used to collect apical debris. Debris extrusion was measured by weighing tubes pre- and post-experiment after incubating for 5 days. The mean weight differences of debris extrusion among file and irrigation system groups were compared using Two-way ANOVA with Tukey's test.

Results: The statistics showed a significant effect of irrigation technique on debris extrusion (p=0.002), while file system (p=0.698) and interaction (p=0.406) were not significant. PUI as an adjunctive irrigation with ZF and EOF (mean=0.19±0.17 and 0.19±0.14 µg respectively) significantly reduced debris extrusion compared to reciprocating EOF systems without adjunctive irrigation technique (mean=0.37±0.13 µg) (p=0.020 and p=0.017, respectively).

Conclusions: Irrigation technique significantly influenced debris extrusion, while file system had no effect. The use of PUI with both file systems reduced debris extrusion compared to EOF without adjunctive irrigation.

Keywords: apical debris extrusion, mechanical instrumentation, root canal preparation, rotary NiTi file

Introduction

Complete root canal debridement, achieved through chemical irrigants and mechanical instrumentation, is a critical step in non-surgical root canal treatment.[1,2] Chemomechanical debridement can lead to apical extrusion of debris, pulp tissue fragments, necrotic tissue, microorganism and irrigants which is one of the main causes of periapical inflammation and postoperative flare-ups.[3] Flare-ups, characterized by pain, swelling, or both, may occur within hours or days following root canal treatment and often result in unexpected interappointment emergency visits. The incidence of flare-ups during root canal treatment ranges from 1.4% to 16%.[1-3]

Despite efforts to maintain the working length short of the apical terminus across various preparation techniques and instruments, debris extrusion continues to occur in varying amounts.[2,3] Studies showed mechanical instrumentation using hand files produced more apical debris extrusion than engine-driven rotary preparation.[1,3] Moreover, push-pull filing motions generate more apical debris than rotational motions.[2]

Recently, advances in Nickel-Titanium (NiTi) rotary file technology have facilitated more effective cleaning and shaping of the root canal system. These improvements in metallurgy allow for greater preservation of tooth structure while maintaining canal anatomy. However, the literature remains inconclusive regarding the differences in apical debris extrusion between various rotary file systems. Earlier studies indicated that reciprocating file system produces more debris extrusion than continuous rotation file system[2,3], while study of Ujariya *et al.,*[4] reported inconsistent result. Recently, Kerr Corporation launched a new NiTi rotary system used in continuous motion called ZenFlex™ (Kerr Corporation, Pomona, CA, USA) which characterized by 1 mm maximum instrument diameter with the purpose to maintain more tooth structure after root canal preparation. Moreover, the manufacturer claimed of ensuring an increased cyclic fatigue and torsional resistance in comparison to other comparable instrument brands due to the proper heat treatment and the innovative design of ZenFlex™.[5]

EdgeOne Fire™ (EdgeEndo, Albuquerque, NM, USA), a recently introduced reciprocating file system, undergoes proprietary heat treatment (FireWire™) to enhance flexibility and a negligible restoring force.[6] A comparative study on the shaping ability of three reciprocating NiTi single file systems; Reciproc® blue, WaveOne® Gold and EdgeOne Fire™, in curved root canals reported that there were no statistically significant differences in the degree of canal transportation distances and preparation times among these 3 groups. The EdgeOne Fire system recorded more statistically significant percent change of canal curvature than the WaveOne® Gold system. Despite this, there are no data in literature regarding apical debris extrusion of those instruments.

The most commonly used method of smear layer removal has been the alternating irrigation with a combination of ethylenediaminetetraacetic acid (EDTA) and sodium hypochlorite (NaOCl). This combination can remove smear layer completely in the coronal and middle thirds but less effective in the apical third owing to the inability of the irrigating solutions to reach the apical third of the root canals.[7,8] For optimal effectiveness, the irrigants must contact the entire root canal surface. However, complex canal anatomy and the vapor lock effect in the apical third hinder conventional syringe irrigation from wetting the entire surface.[9]

Conventional syringe irrigation typically reaches only 1.5-2.0 mm beyond the needle tip, limiting its effectiveness to the coronal and middle thirds.[10] Therefore, intracanal agitation or activation of the irrigants is a necessary adjunction to mechanical instrumentation to remove debris and bacteria from the root canals.[11,12] Several systems for intracanal agitation of the irrigants have been proposed, which might be categorized as manual agitation devices, including the use of hand files, gutta-percha points and canal brushes, and machine-assisted agitation devices, like sonic or ultrasonic devices, rotary brushes and pressure alternation devices. Studies have shown that manual dynamic activation (MDA) using well-fitting gutta-percha master cone with gentle up and down movement in short 2- to 3-mm strokes in an instrumented canal can produce an effective hydrodynamic effect and significantly improve the displacement and exchange of any given reagent. This will result in better contact of the irrigating solution with the root canal walls, and thus enhance debridement.[13]

Studies indicated that irrigation is one of the procedures that can cause extrusion of intracanal debris into periapical[14,15] area and type of irrigation system can affect the frequency and amount of apical debris extrusion.[16] It has been known that passive ultrasonic irrigation (PUI) is more effective than conventional irrigation (CI), using syringe and needle, in eliminating pulp tissue and dentin debris.(16) PUI can remove debris and bacteria adhered on the root surface by action of acoustic streaming which produces shear stresses along the root canal wall.

To date, the effect of PUI on the apical extrusion of debris when used in conjunction with single-file systems has not been studied much. Studies evaluating the effect of MDA and PUI on the apical extrusion of debris are lacking, and therefore, this study aims to quantify the amount of debris extrusion after root canal instrumentation with rotary and reciprocating file systems combined with either MDA or PUI. The null hypothesis (H_0) is that there is no significant difference in the amount of debris extrusion among different combinations of ZF and EOF file systems with either MDA or PUI.

Materials and Methods

This study was approved by the Human Experimentation Committee, Faculty of Dentistry, Chiang Mai University, Thailand (NO.18/2023).

2.1 Sample size

Sample size was calculated by adopting an alpha (α) level of 0.05, beta (β) level of 0.20 i.e., power = 80%, effect size (f) = 0.4. The calculation based on results of Gummadi *et al.,*(16) using G*power version 3.1.9.7 (Heinrich Heine University, Düsseldorf, Germany) revealed the total sample size is 90 samples.

2.2 Sample selection

Ninety mandibular molars (except mandibular third molar) were collected and stored in normal saline. The included teeth had complete root formation with root curvature approximately 10º-20º measured by Schneider method.(17) Calculus and debris were removed with ultrasonic scaling and disinfected with 5.25% NaOCl for 10 minutes then stored in normal saline until used. Periapical radiographs in mesiodistal and buccolingual views had been taken to verify apical foramen and root canal configuration. Only teeth which mesial root had type II or IV Vertucci's configuration were included in this study. Teeth with immature apex, root resorption, root caries, and calcified canal were excluded.

2.3 Experimental model design

The mesiobuccal canal of mesial root was used in our study. Each specimen was created by the following procedure. High-speed diamond burs were used to access the teeth and to separate the distal and mesial roots. In the mesial roots, the canals were checked for apical patency with K-file no.10 (Densply Sirona, Ballaigues, Switzerland). The length of each canal was established by inserting no.10 K-file into canal space until the tip of file was visible at apical foramen, then subtract 1 mm. The final working length of mesiobuccal canal was 16 mm and adjusted by flattening the cusp tip, then confirmed with a radiograph. A K-file no.15 inserted until the working length was reached and teeth which had a passive fit at the working length were selected. Teeth were divided randomly into 6 groups based on the file system and the irrigation system (n=15).

2.4 Specimen preparation and debris collection model

The model and process for collecting apical debris extrusion was adopted from Myers and Montgomery method (Figure 1).(18) Double layer of cyanoacrylate used to cover the external surface of all roots except for 1 mm from root apex. Each empty Eppendorf tubes were numbered and weighed without the lids by 5-digit analytical balance (Shimadzu, Kyoto, Japan). Pre-experimental weight of tube (W1) was the mean value of weighting each empty tube for 3 times.

Micromotor used to make a hole on the lid of the tube then mesial roots were inserted into the hole and fixed with cyanoacrylate. To keep the balance of air pressure inside and outside of the tubes, a 27-guage needle was inserted in to the lid. The lid was attached back to the tube and the whole apparatus was concealed in a glass bottle with putty, the glass bottle was then covered with black tape to prevent the operator from seeing through while doing the instrumentation process.

The samples were allocated using a random group allocation online software (http://www.randomizer.org) into six groups of fifteen teeth according to the file system (Zenflex and EdgeOne Fire) and the irrigation systems (PUI and MDA) (n=15) used.

2.5 Root canal preparation and irrigation

The mechanical Instrumentation procedures were performed using X-smart Plus motor (Densply Maillefer, Ballaigues, Switzerland). The instrument flutes were cleaned with sterile gauze after 3 passes. The canal was irrigated with 2 ml of distilled water using using a 30G

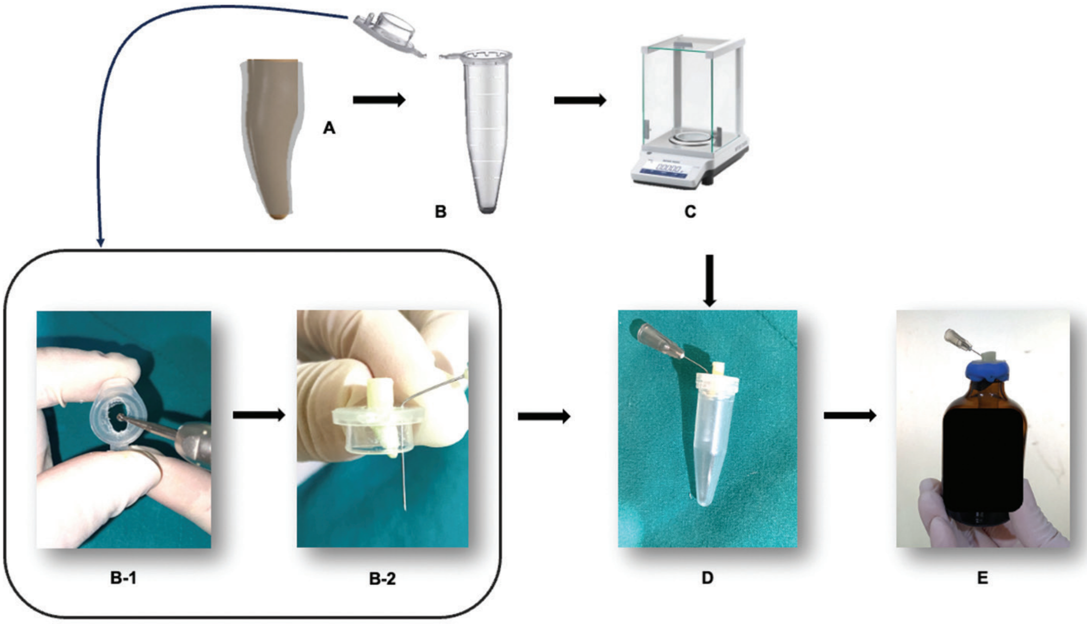

Figure 1: Schematic illustration of the debris collection model modified from Myers and Montgomery (1991).[18] (A), Cyanoacrylate (nail polish) was applied 1 mm above the root apex to seal the apical foramen: (B), The lid of an Eppendorf tube was removed: (B-1), A hole was drilled in the lid to fit each sample, and the sample was sealed in place with cyanoacrylate: (B-2), The sample was inserted up to the mid-root level, and a needle was inserted through the lid to equalize pressure: (C), The Eppendorf tube was weighed without the lid: (D), The prepared lid was securely placed back onto the tube: (E), The tube was fixed to a glass bottle using putty, and the bottle was covered with tape to prevent contamination.

needle with a syringe and size 10 K-file was used to maintain apical patency. These procedures were repeated until the file reached the WL. Total volume of irrigant was limited to 8 ml per tooth.

Group 1: ZF – without adjunctive irrigation

Zenflex™ rotary file size 20 taper 06 to 25 taper 06 were used according to the manufacturer's instruction with a rotational speed of 500 rpm and torque of 2 Ncm. The conventional irrigation using a 30G needle with a syringe with normal saline solution was performed.

Group 2: EOF – without adjunctive irrigation

EdgeOne Fire™ file size 25 taper 07 was used according to the manufacturer's instruction with a 350 rpm speed in 170° CCW and 50° CW direction and completes 360° in 3 cycles.[19] The canal was irrigated in the same manner as in Group 1.

Group 3: ZF + MDA

Zenflex™ rotary file size 20 taper 06 to 25 taper 06 were used, followed by irrigating with MDA technique. With a gentle up and down movement of a gutta percha master cone size 25 taper 04 with the WL-1mm in short 2- to 3-mm strokes with the frequency approximately 100 times per minute (~1.6 Hz) was done.

Group 4: EOF + MDA

EdgeOne Fire™ file size 25 taper 07 was used, followed by irrigating with MDA technique in the same protocol as in Group 3.

Group 5: ZF + PUI

Zenflex™ rotary file size 20 taper 06 to 25 taper 06 were used, followed by PUI technique. An irrisafe with tip size 20 (Satelec Acteon, Merignac, France) was activated at 2 mm short of working length for 1 minute after preparation of canal via Newtron P5® ultrasonic device (Satelec Acteon, Merignac, France) with level 6 of power setting folowing the manufacturer's instruction.

Group 6: EOF + PUI

EdgeOne Fire™ file size 25 taper 07 was used, followed by PUI technique as described in Group 5.

Each rotary file was used for a maximum of four canals and cleaned between uses with sterile gauze, ultrasonic bath (1 min), and microscopic inspection to ensure no debris remained. Instrumentation and irrigation were performed by one operator, while an independent examiner (blinded to the groups) assessed debris extrusion.

2.6 Debris collection and measurement

Following instrumentation, the root was removed from the lid, and any residual debris was rinsed into the Eppendorf tube using 1 mL of distilled water. The tubes were then incubated at 70°C for 5 days to evaporate moisture before weighing the extruded debris. The post-experimental weight (W2) was recorded as the average of three measurements. Debris extrusion was calculated as: (W2-W1).

2.7 Statistical analysis

All the graphs, calculations, and statistical analyzes were performed using GraphPad Prism software version 10.4.1 for MacOS (GraphPad Software, San Diego, CA, USA). The difference of mean weight of extruded debris among all groups were examined using two-way analysis of variance (ANOVA) with Tukey's post hoc test in order to investigate the main effect of each factor (file system and irrigation technique) and interaction effect of both factors on apical debris extrusion. The level of significance was set at $p<0.05$.

Results

The mean ± standard deviation (SD) of apical debris extrusion for each experimental group, along with the results of the two-way ANOVA analysis were demonstrated in Table 1. The analysis revealed a significant main effect of irrigation technique ($F(2,84)=6.965$, $p=0.002$), indicating that the irrigation method significantly influenced the amount of debris extrusion. However, the main effect of file system was not significant ($F(1,84)=0.152$, $p=0.698$), suggesting that the type of file system did not independently affect debris extrusion. Additionally, the interaction effect between file system and irrigation technique was not statistically significant ($F(2,84)=0.911$, $p=0.406$), indicating that the influence of irrigation technique on debris extrusion remained consistent regardless of the file system used.

As illustrated in Figure 2, post hoc multiple comparisons using Tukey's test showed that debris extrusion was significantly lower in groups of both files which PUI was added as an adjunctive irrigation method (Group 5 and 6; mean=0.19±0.17 and 0.19±0.14 µg respectively) ($p=0.020$ and $p=0.017$, respectively) than using EOF file only (Group 2; mean = 0.37±0.13 µg). The combination of PUI regardless of file system (Group 5 and 6) tended to produce less debris extrusion than those groups using MDA technique (Group 3 and 4; 0.28±0.15 and 0.24±0.15 µg respectively) although the statistical significance could not be observed. Furthermore, ZF without supplemental irrigation (Group 1; mean=0.30±0.12 µg) did not exhibit a statistically significant difference in debris extrusion compared to other groups.

Discussion

Apical debris extrusion produced by root canal treatment during mechanical instrumentation and irrigation could caused postoperative flare-ups, inflammation, and delayed periapical healing.[20,21] Previous studies have demonstrated that increased debris extrusion is associated with greater inflammatory mediator release, such as prostaglandins and substance P, which contribute to postoperative discomfort.[22,23] Additionally, residual extruded debris may harbor bacterial biofilms, increasing the risk of persistent apical periodontitis.[24]

In this study, the mesiobuccal canals of mandibular

Table 1: Mean ± SD of debris extrusion (µg) for different file systems and irrigation techniques. Two-way ANOVA results are reported, showing the effects of file system (rotary vs. reciprocating), irrigation technique (w/o irrigation, MDA, PUI), and their interaction. $p<0.05$ is considered statistically significant (**). Abbreviations: w/o = without irrigation, MDA = Manual Dynamic Agitation, PUI = Passive Ultrasonic Irrigation.

File system	Irrigation technique	Mean ± SD	Two-way ANOVA (*p*-value)
ZF	w/o adjunctive	0.30±0.12	File system: 0.698
	MDA	0.28±0.17	Irrigation technique: 0.002 **
	PUI	0.19±0.17	Interaction: 0.406
EOF	w/o adjunctive	0.37±0.13	
	MDA	0.25±0.15	
	PUI	0.19±0.16	

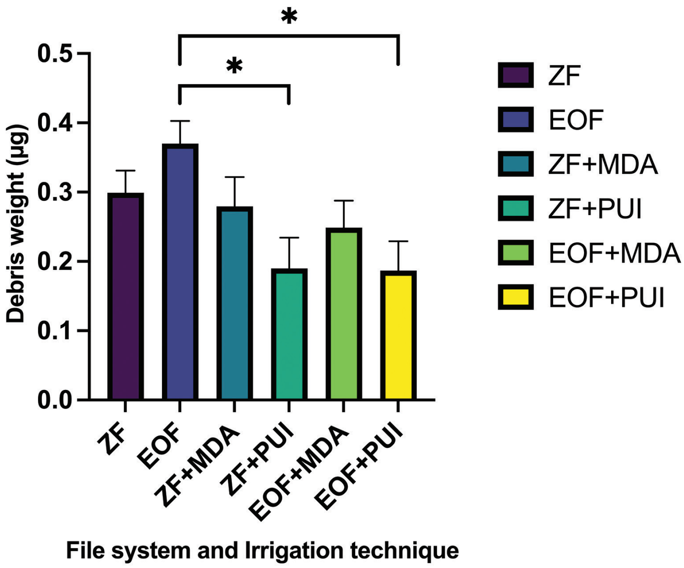

Figure 2: Mean debris extrusion (µg) for different file systems and irrigation techniques. ZF = Zenflex; EOF = EdgeOne Fire; MDA = Manual Dynamic Agitation; PUI = Passive Ultrasonic Irrigation. Error bars represent standard of error (SE). Asterisks (*) indicate statistically significant differences ($p<0.05$, Tukey's post hoc test).

molars were selected due to their relevance in clinical scenarios where curved canals are commonly found in multirooted posterior teeth. Moreover, curved and complex canals were one of the factors that affected the treatment outcome and the amount of apical debris extrusion.[25] The materials and methods of this study was modified from the study of Myers and Montgomery[18], which was the mainly method used to study the amount of apical debris extrusion after mechanical instrumentation and irrigation. Distilled water was used as the irrigant instead of NaOCl to prevent crystallization and contamination of the debris with sodium crystals.[16,21,26]

The present study evaluated the effects of different file systems (rotary vs. reciprocating) and irrigation techniques (without adjuctive irrigation, MDA, and PUI) on debris extrusion. Two-way ANOVA revealed that irrigation technique had a significant effect on debris extrusion (p=0.002), whereas file system (p=0.698) and the interaction between the two factors (p=0.406) were not significant. These findings suggest that irrigation strategy plays a more critical role in debris extrusion than the choice of file system.

The significant effect of irrigation technique aligns with previous studies demonstrating that PUI significantly reduces apical debris extrusion compared to conventional irrigation methods.[27] The enhanced debris removal with PUI is attributed to its ability to induce acoustic streaming and cavitation, effectively dislodging debris and minimizing its apical extrusion.[28] Additionally, the oscillating motion of the ultrasonic file promotes lateral flow of irrigant along the root canal walls, preventing debris accumulation at the apex.[29] Our post hoc analysis demonstrated that both rotary (ZF) and reciprocating (EOF) file groups using PUI (Group 5 and 6) extruded significantly less debris compared to the EOF without adjuctive irrigation method (Group 2). These findings support the combining PUI as an adjunctive root canal irrigation to optimize debris removal[16] and minimize the risk of postoperative complications associated with extruded debris.[30,31]

In contrast, although no significant differences were observed, the MDA technique tended to produce relatively more debris than PUI when combined with the same file system (Group 3 vs. Group 5 and Group 4 vs. Group 6). This may be attributed to the up-and-down movement of the gutta-percha cone in MDA, which may generate unstable hydraulic forces and push debris beyond the apex. Furthermore, variability in the pumping force applied manually by the examiner may contribute to inconsistent debris extrusion.

Interestingly, the type of file system did not significantly influence debris extrusion. Our results showed that ZF without adjunctive irrigation (Group 1) did not exhibit a significant difference in debris extrusion compared to any other groups. Although mean debris extrusion in Group 1 was lower than that in EOF without adjunctive irrigation (Group 2), this difference did not reach statistical significance (Figure 2). These findings suggest that, while different file kinematics may influence debris extrusion, the effect may not be as substantial as the irrigation technique, which demonstrated a significant impact. The absence of a significant difference between Group 1 and the MDA or PUI groups further reinforces the dominant role of irrigation dynamics over file motion in controlling debris extrusion. This contradicts previous reports suggesting that reciprocating systems generate more extruded debris due to their cutting dynamics and lack of continuous withdrawal motion.(2,3,16) The discrepancies between studies may occur from differences in tooth type, working length, apical diameter, and file size.

The absence of a significant interaction effect between file system and irrigation technique suggests that the beneficial effect of PUI is independent of the instrumentation technique used. This reinforces the idea that irrigation technique exerts a stronger influence on debris extrusion than file kinematics, supporting the prioritization of effective irrigation strategies in clinical practice.

In clinical situation, although there is no study at the present that demonstrate the certain amount of extruded debris that can cause the postoperative complications. While the observed reduction in apical debris extrusion of approximately 0.1 micrograms may seem minor, its clinical significance should not be underestimated. A literature review emphasized that any irritation to periapical tissues, including minimal debris extrusion, may result in flare-ups and impede healing.(22) Therefore, even a small reduction in debris extrusion could potentially decrease the risk of postoperative complications, thereby enhancing patient comfort and treatment success.

A limitation of this study is that the experimental model does not fully replicate the clinical periapical structure, as it lacks the apical resistance typically provided by bone or periapical tissue.(22) Additionally, there were different microhardness of dentin between samples which could affect the difficulty of the instruments while cutting dentin.(32) Future studies could improve upon these limitations by developing more realistic models, such as using gel to mimic an apical barrier or employing micro-CT to collect debris.(26) Further research could also focus on clinical outcomes, such as the incidence of postoperative pain following the use of ZenFlex and EdgeOne Fire combined with MDA and PUI.

Conclusions

With the limitations of the study, our data found that irrigation technique significantly influenced apical debris extrusion, while file system motions had no effect. PUI significantly reduced debris extrusion compared to reciprocating EOF systems without adjunctive irrigation technique. The absence of an interaction effect suggests that irrigation plays a more critical role than instrumentation motion.

Acknowledgments

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Conflicts of Interest

The authors declare no conflict of interest.

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