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Evaluation of Irrigation Techniques in the Removal of Root Canal Filling Material: Micro-CT and SEM Study

SUMMARY

Background/Aim: *This study aimed to compare the different irrigation activation methods in retreatment of oval-shaped root canals.* ***Material and Methods:*** *Forty distal canals from mandibular molars were filled. After the removal of filling material, specimens were assigned to four groups as follows; control, passive ultrasonic irrigation (PUI), self-adjusting file (SAF), and XP-endo Finisher (XPF). The amount of residual filling material was assessed by micro-computed tomography (micro-CT) and root canal walls were examined by using scanning electrom microscopy (SEM). Data were analyzed using the Kruskal-Wallis and Dunn test.* ***Results:*** *None of the activation techniques removed root canal remnants completely. The amount of filling material significantly decreased in all activation techniques compared to the control group ($p<0.05$). There was no significant difference between the PUI, SAF, and XPF groups in the micro-CT analysis ($p>0.05$). SEM evaluation showed higher scores in the apical region in all groups ($p<0.05$).* ***Conclusions:*** *The use of activation methods reduces the amount of residual filling material.*

Keywords: Passive Ultrasonic İrrigation, Retreatment, Self-Adjusting File, XP-Endo Finisher

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Introduction

Successful endodontic treatment depends on effective cleaning, shaping, and hermetically obturation of root canal system[1,2]. Periapical disease may continue or occur in some cases after initial root canal treatment despite the high success rate of the root canal treatment[3]. In general, unsuccessful root canal treatment has been associated with intraradicular infection by various microscopic, culture, and molecular studies[4-5]. Bacteria that cause resistant radicular infection are usually found in hard-to-reach areas where the instrumentation and irrigation are ineffective during the treatment. These unreachable areas are anatomical structures such as dentin tubules, lateral canals, isthmus, oval or curvature shaped root canals[6]. The remaining smear, debris, or pulp tissue in such areas may cause endodontic failure due to the existing microorganisms or reduced the adaptation of the root canal filling to the root canal walls[2].

When initial root canal treatment fails, root canal filling must be removed and the root canal system should be disinfected. This may be achieved with stainless steel hand files, heated instruments, lasers, ultrasonics, and nickel-titanium (NiTi) systems. Numerous studies indicated that none of the techniques completely remove of the root canal filling material[7]. Failure in complete removal of the material may limit the efficacy of irrigation solutions and thereby successful disinfection. Therefore, additional procedures have been suggested to enhance the removal of filling material such as irrigation activation[8].

XP-endo Finisher (XPF) (FKG Dentaire, La Chaux-de-Fonds, Switzerland) is an irrigation activation file used after root canal preparation, which aims to increase the cleanliness of the root canal system without cutting the dentin. XPF is a size #25 non-tapered instrument fabricated with a special NiTi alloy called MaxWire (Martensite-Austenite, Elektropolish-Flex). The special alloy provides the file change into the martensitic phase

and straightening when instrument cooled below 30 ºC. However, under the body temperature, the file changes into the austenite phase and converts to a spoon-like shape. This provides the file high flexibility and the spoon-like shape can expand up to 6mm diameter. The rotational and up and down movements in the canal for 7 or 8 mm provide more contact of the file to the canal walls and creates fluctuations in the irrigation solution[9]. The XPF file was initially developed to remove debris and smear, moreover, the manufacturer suggested the use of the file for the removal of the root canal filling material and medicaments.

The aim of this study was to investigate the efficacy of Passive Ultrasonic Irrigation, Self Adjusting File, and XPF activation methods on residual root canal filling after retreatment in oval-shaped root canals by micro-CT and SEM analysis. The null hypothesis of the present study was that additional activation techniques increased the removal of filling material.

Material and Methods

Tooth Selection

This study was performed under the regulations of the ethics committee (protocol no:2016-35-10/02). Forty human mandibular molars that were extracted for periodontal reasons were selected. Each tooth exhibited the following features: mature apices, one straight root with oval-shaped distal canal anatomy, and absence of resorptions or calcifications. The 3D images of teeth were taken with cone-beam computerized tomography (J Morita Mfg. Corp., Kyoto, Japan) to determine the oval-shaped anatomy of the distal root canal. The root canals were classified as oval-shaped when the buccolingual diameter was two times larger than the mesiodistal diameter at the coronal part of the distal canal[10]. The soft tissue remnants and calculus on the teeth were cleaned and stored in distilled water at +4 °C until use. The distal roots were separated from mesial roots and decoronated with a diamond burr at the cementoenamel junction using a high-speed handpiece.

Root canal preparation

A 10# K file (VDW Antaeos, Munich, Germany) inserted into the distal canal until the tip was visible at the apical foramen and initial length was recorded. The working length (WL) was determined by subtracting 1 mm from the initial length. All roots were prepared with the step-back technique to a size of master apical file #35 using hand files. At each instrument change, the root canal was irrigated with 1 ml of 2.5% sodium hypochlorite (NaOCl) (Imicryl, Konya, Turkey). After the preparation, the final irrigation was performed with 5 ml 17% EDTA for 1 min followed by 2 ml 2.5% NaOCl. Then the root canal was flushed with 10 ml of distilled water and dried with paper points (DiaDent Group International Inc., Cheungju, Korea).

Root canal filling

Root canal filling was performed by cold lateral condensation using AH Plus sealer (Dentsply DeTrey, Konstanz, Germany) and gutta-percha cones (DiaDent, DiaDent Group, Burnaby, Canada). The access cavities were sealed with resin-modified glass ionomer cement. Then, the samples were stored in 100% humidity at 37°C for 30 days to allow for the complete set of the sealer.

Initial micro-CT Imaging

The specimens were scanned in 100 mA SkyScan 1172® (SkyScan 1172®; Kontich, Belgium) micro-CT scanner with a 100-kV and 21 μm isotropic resolution. Pixels of the scans were adjusted to 10 μm, and scans were performed with a 0.4 rotation step and a 360° vertical rotation. The filter used was made of copper and aluminum. The average scan duration was 150 min. At the end of the scanning, 400 raw images were obtained for each sample and recorded in TIFF format.

Retreatment

The retreatment procedures were performed by removing the filling material from each root canal using ProTaper Universal Retreatment files (Dentsply; Tulsa Dental, Switzerland) as recommended by the manufacturer. No solvent was used during instrumentation procedures. After the removal of bulk filling material, the canals were irrigated with 2 ml of 2.5% NaOCl, followed by circumferential instrumentation with the #40 H file for 60 seconds. All specimens were irrigated with 2 ml of 2.5% NaOCl and 2 ml of 17% EDTA and dried. This retreatment procedure was applied to all samples. Then, the samples were randomly divided into 1 control and 3 experimental groups (n = 10) according to irrigation activation methods.

Control group (Group 1): No additional activation procedure was performed. Passive Ultrasonic Irrigation group (Group 2): Specimens were irrigated with 2 ml of 2.5 % NaOCl followed by activation of the irrigant for 30 sec with a #20/.00 ultrasonic tip (IRRs Smooth wire VDW GmbH, Munich, Germany) coupled with an ultrasound device marked at power 20 (VDW GmbH, Munich, Germany). The ultrasonic tip was manipulated by using in-and-out movements to 1 mm shorter than WL where the tip vibrated freely. This procedure was repeated 3 more times. In the final irrigation, specimens were irrigated with 17% EDTA for 60 sec, then flushed with 2 ml of distilled water, and were dried with paper points. Self Adjusting File group (Group 3): The 2.0 mm diameter Self Adjusting File (SAF, Re-Dent Nova, Ra'anana, Israel) was used with an endodontic motor (X-Smart,

Dentsply, Maillefer, Ballaigues, Switzerland) and the RDT3-NX head (ReDent Nova, Ra'anana, Israel), which generated 5,000 in-and-out vibrations per min and has an amplitude of 0.4 mm. The canals were irrigated with 2.5% NaOCl for 2 min using the VATEA system (ReDent Nova, Ra'anana, Israel) at a flow rate of 4 ml/min. For the final irrigation, specimens were irrigated with 17% EDTA for 60 sec and 2 ml of distilled water, respectively, and were dried. XP-endo Finisher group (Group 4): Before the insertion into the root canal, the XPF file was placed in a special transparent tube and cooled with a spray to obtain a straight form. The XPF file was operated in the canal for 30 sec at 800 rpm and 1 Ncm with 2 ml 2.5% NaOCl warmed at 37ºC. The file was used in-and-out motion with 1 mm shorter than the WL. This procedure was applied for a total of 4 cycles. In the final irrigation, specimens were irrigated with 17% EDTA for 60 sec, then flushed with 2 ml of distilled water, and were dried.

Final micro-CT Imaging

After using the activation procedures, all samples were rescanned in the micro-CT device using the previous parameters.

Evaluation of remaining root canal filling

Micro-CT evaluation

The initial and final images were reconstructed using the InstaRecon® (SkyScan 1172®; Kontich, Belgium) software and recorded in BMP format. Volume (mm^3) of the residual filling material was quantified with this software. The percentage volume of the reduction before and after retreatment were calculated.

SEM evaluation

All specimens were grooved on the buccal and lingual surfaces with a diamond disc and split longitudinally. Two halves of the roots were examined using SEM (FEI Quanta FEG 450, Czech Republic) at 15-20 kV and 1000× magnification.

Two halves of the roots were examined of the root canal walls as coronal, middle, and apical thirds. The SEM images were scored based on the report by Pirani *et al.*[11]

0 – more than 75% of the tubules were visibly exposed;
1 – smear layer present and <75% of tubules were visibly exposed;
2 – smear layer present in a limited area and <50% of tubules were visibly exposed;
3 – smear layer present in the dentine and no tubules were visible.

Statistical Analysis

Statistical analysis was performed with SPSS 19.0 software (SPSSInc., Chicago, IL, USA). Variables were expressed as mean ± standard deviation, minimum and maximum. Data were analyzed using the Kruskal-Wallis test and a pairwise comparison of the subgroups was performed by the Dunn test. The statistical significance level was set at $p<0.05$.

Results

The mean percentages of residual filling material after the retreatment procedures are shown in Table 1. None of the techniques completely removed the root canal filling material from the canals (Figure 1). In micro-CT analysis, significantly less residual filling materials were recorded in PUI, SAF and, XPF groups compared to the control group ($p<0.05$). There was no significant difference among the PUI, SAF and XPF groups ($p>0.05$).

Table 1. The mean percentage (%) of the residual filling material volume in groups after retreatment and irrigation activation in micro-CT evaluation

Group	Mean	N	Standard deviation	Minimum	Maximum
Control[a]	39.24180	10	15.809074	8.616	49.584
PUI[b]	13.54070	10	8.807677	0.301	30.723
SAF[b]	16.47430	10	11.267889	3.798	37.392
XPF[b]	17.56270	10	13.768927	1.729	43.32

Different superscript letters indicate a statistically significant difference between groups ($P<0.05$).

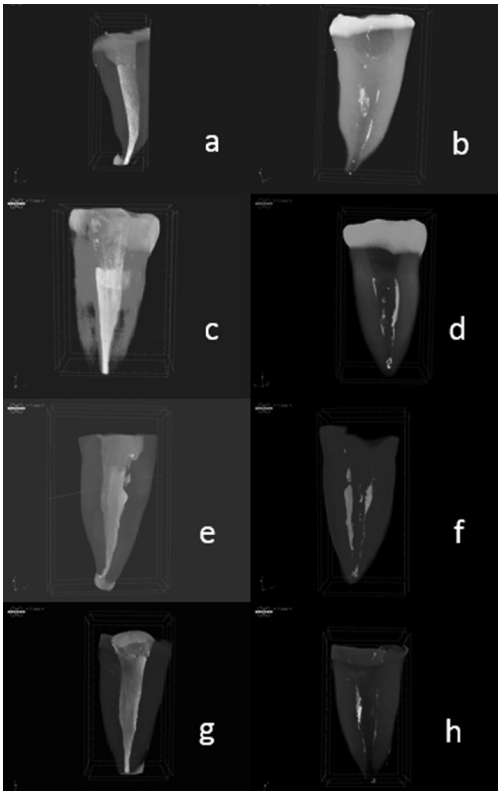

Figure 1. Representative micro-CT images of groups before and after retreatment process. (a-b:control, c-d: PUI, e-f: SAF, g-h: XP-endo Finisher)

Representative SEM images were shown in Figure 2. The mean scores and standard deviations of all thirds of the groups were presented in Table 2. The highest scores were observed in the apical thirds among the regions in all groups. No significant differences were found between middle and, coronal thirds in any activation method ($p>0.05$). In the coronal third, no significant difference was found between the control and the SAF groups ($p>0.05$). However, significantly lower scores were obtained in PUI and XPF groups compared to the control group ($p<0.05$). There was no significant difference between PUI, SAF and, XPF groups in the coronal third ($p>0.05$).

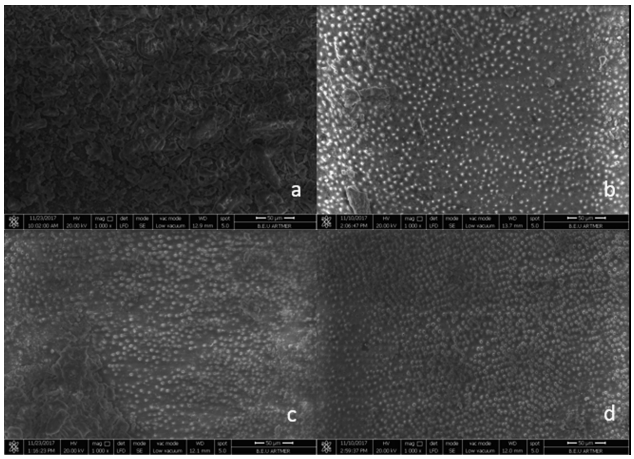

Figure 2. Representative SEM images from middle thirds of each group. (a: control, b: PUI, c:SAF, d: XP-endo Finisher)

Table 2. Mean score values of groups of SEM evaluation

Groups	Canal third	Mean	Standard deviation	Median	Min.	Max.
Control	Coronal	1.75	1.070	2.00	0	3
	Middle	1.85	1.089	2.00	0	3
	Apical	2.70	0.733	3.00	0	3
PUI	Coronal	0.80	0.768	1.00	0	2
	Middle	1.55	0.945	2.00	0	3
	Apical	2.40	0.821	3.00	0	3
SAF	Coronal	0.85	0.875	1.00	0	2
	Middle	1.50	1.192	2.00	0	3
	Apical	2.20	1.056	3.00	0	3
XPF	Coronal	0.45	0.759	0.00	0	2
	Middle	0.45	0.686	0.00	0	2
	Apical	1.45	1.050	1.00	0	3

No significant differences were found among the control, PUI, and SAF groups in the middle and apical thirds ($p>0.05$). Lower scores were observed in the XPF group than the other groups in the middle third ($p<0.05$). In the XPF group, significantly lower scores were observed than the control and PUI groups in the apical third ($p<0.05$). However, no significant difference was recorded between the XPF and SAF groups in the apical third.

Discussion

Some additional cleaning processes are required to achieve success in endodontic retreatment due to the complex anatomical structure of the root canal and the presence of the compound and resistant pathogens[12]. The instruments fail to provide complete cleaning of the inner layer of dentin because of their round cross-section, especially in oval-shaped canals[11-14]. It was indicated that the root canal structure affects the cleaning of the root canal system more than the blade design of the instruments[14]. Therefore, the endodontic procedures may be adversely affected due to the difficulty in cleaning the oval-shaped root canals during both initial root canal treatment and retreatment[15]. Increasing the diameter of the file during the preparation of the round root canals could be useful to decrease the amount of remaining root canal fillings[6]. However, in oval-shaped root canals more additional preparation can cause weakening of the root structure[17]. Thus, oval-shaped distal root canals of the mandibular first molar teeth were used in the current study.

Previous studies have reported the limitation of complete removal of the filling material from the root canal even after reinstrumentation[18-21]. This situation shows that the irrigation activation techniques are necessary following the instrumentation during retreatment. In the current study, the efficacy of various irrigation activation methods on the removal of residual root canal filling materials was compared by two analysis methods including micro-CT and SEM. Micro-CT was used to obtain the amount of the filling material with volumetric data and SEM was used to investigate the root canal surface and open dentin tubules after the retreatment procedures under high magnifications[8,19].

To the best of our knowledge, no study compared the efficacy of PUI, SAF and, XPF activation techniques in removal of root canal filling material. Previously, Kfır *et al*.[22], used the same activation techniques in removal of calcium hydroxide and no significant difference was found among the techniques. In accordance with the previous studies, using additional activation techniques decreased the amount of residual filling material according to the micro-CT analysis[23,24]. Moreover, no significant difference was found among the experimental groups in the present study. Therefore, the null hypothesis of the presented study was accepted.

Aksel *et al*.[25] reported that additional use of XPF instrument enhanced the removal of root canal filling material. In another study, Alves *et al*.[20] stated that using XPF instrument significantly improved filling material. The XPF results of the present study were supported by these previous studies. De Deus *et al*.[23] compared the efficacy of the XP-endo Finisher R and PUI during the removal of filling material from oval-shaped root canals. The XP-endo Finisher R instrument removed significantly more root

filling material than PUI[23]. In the present study, micro-CT evaluation showed that XPF and PUI groups presented similar results. The discordance may be associated to the using the different version of the XPF instrument. The XP-endo Finisher R instrument is size #30, however XPF is a size #25 instrument. Furthermore, the activation time period of the PUI was longer than the De Deus e*t al.*[23] used (2 min. and 1,5 min. respectively). In another previous study, Da Rosa *et al.*[18] reported that passive ultrasonic irrigation activation is not effective in removing root canal filling in both curve and oval-shaped root canals. The apical diameter was increased 3-fold by instrumentation at oval-shaped root canals and the activation time period of the PUI was 1 minute in this previous study. Also, circumferential instrumentation for 60 sec with the #40 H file in the present study may cause different results. Longer activation time of the PUI may be required to remove the adhesive root canal sealer and shows similar performance in comparison with SAF and XP-endo Finisher techniques which have a working principle including contact with root canal filling during preparation.

SEM was used to evaluate the cleaning of the root canal wall surfaces after supplementary retreatment processes and the same samples were examined. Keles *et al*.[8] reported that additional SAF activation after retreatment increased the number of the open dentin tubules in the coronal and middle part of the root canal, but was not effective in the apical region. In contrast to this result, the results of the present study revealed that SAF did not increase the root canal wall cleaning in any region at SEM evaluation. In the present study, different results may be obtained due to additional circumferential preparation by hand file after removal of root canal filling. Keles *et al*.[26], compared the debris removal efficacy of SAF and PUI after retreatment in oval root canals. They reported that similar amounts of debris were removed in the SAF and PUI groups in all three regions. Consistent with the previous study, in the present study, no significant difference was found between the control, SAF and, PUI groups in all three regions.

PUI depends on the transmission of acoustic energy from an oscillating file to an irrigation solution. This energy is transmitted by means of ultrasonic waves and turn in to acoustic streaming and cavitation of the irrigant. It has been reported that cavitation caused by vibration around the ultrasonic file does not play an effective role in root canal debridement[27]. In addition, ultrasonic activation in the apical region due to vapor lock effect acoustic streaming and cavitation effect has been reported to be reduced[28,29]. Similarly, PUI showed less efficacy in the apical region at SEM evaluation in the present study. There is no consensus on the efficacy and protocol of PUI activation in nonsurgical retreatment. Results were usually inconsistent possibly because of differences in root canal morphology and irrigation activation procedures. In some of the studies, continuous irrigation activation was performed with PUI, in some of them activation was performed by cycles and the solution was refreshed between cycles. It was found that activation with cycles increased the efficacy but 1 min PUI activation was insufficient in retreatment[18,28,30]. With this in mind, in the present study, the solution was refreshed between cycles to increase the effectiveness of passive ultrasonic irrigation and to equalize the activation time of the experimental groups, activation was performed 4 times for 30 sec.

When PUI and XPF activation methods were applied, more open dentin tubules were obtained in the coronal region but there was no statistically significant difference between SAF and the control group. Furthermore, the SEM evaluation demonstrated that XPF file was associated with cleaner root canal walls at middle third of root canal when compared to PUI and SAF activation methods. The current findings at middle third of root canal might be explained by expansion of XPF instruments at body temperature. During the activation, the elliptical part of the instrument is compressed by the resistance imposed by canal anatomy, therefore forcing the tip of the instrument against the root canal walls. This mechanical movement may allow the instrument to come into contact and remove the root filling remnants from the canal walls. This mechanical action may allow the instrument's contact and dislodge root filling material from the canal walls even in some hard-to-reach areas. SAF has been reported to be less effective when the diameter of the root canal space is greater than the diameter of SAF[8]. In this study, since the SAF is smaller than the inner area of the coronal and middle third of the root canal, it may not have touched all parts of the root canal walls. PUI activation is performed without contacting the file with the root canal wall. Thus, the current results demonstrated that the mechanical feature of XPF irrigation activation instruments touching the canal walls is more effective in removal of residual root filling material.

In apical region, significantly cleaner root canal walls were obtained in XPF than PUI and control groups. It has been claimed that gas bubbles eliminate the acoustic streaming and cavitation effects of PUI as it progresses towards the apical[8].

Conclusions

According to both micro-CT and SEM analyses, root canal filling was not completely removed in any group[25,31,32]. In the limitations of the present study, retreatment of oval-shaped canals requires additional activation techniques after the removal of bulk root canal filling. The passive ultrasonic irrigation, self adjusting file and XP-endo Finisher activation techniques reduced the amount of the residual filling material.

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