Passive ultrasonic irrigation, EndoActivator system and XP-endo Finisher R as additional cleaning techniques to remove residual filling materials from flattened root canals

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Abstract

Background: The effectiveness of endodontic retreatment essentially depends on the cleaning and/or disinfection processes. In this context, the removal of root canal filling materials plays a crucial role.

Aims: To assess the efficacy of passive ultrasonic irrigation (PUI), EndoActivator system (EAS), and XP-endo Finisher R (XPEFR) as additional cleaning techniques to remove the remaining root canal filling materials from flattened root canals.

Subjects and Methods: Thirty-six similar flattened distal root canals of extracted human first lower molars were selected by micro-computed tomography (micro-CT) and then instrumented and filled. After the initial retreatment procedures, the residual volume of root canal filling materials was assessed by micro-CT (V1). Then, the specimens were divided into three groups (n.12), according to the additional cleaning technique and submitted to another micro-CT scan (V2).

Statistical Analysis Used: Analysis of variance and Games-Howell tests (P < 0.05).

Results: The percentage reduction in the residual volume of root canal filling materials reached by PUI, EAS, and XPEFR was 28.38%, 28.12%, and 43.52%, respectively, considering the total space of the root canal (P > 0.05). In the apical third, these values were 20.05%, 21.54%, and 48.82% (P < 0.05).

Conclusions: Additional cleaning techniques enabled removing a greater amount of root canal filling material from flattened distal root canals of extracted human first lower molars. Considering the total space of the root canal, there were no statistically relevant differences among the groups. In the apical third, XPEFR performed better.

Keywords: EndoActivator; endodontic retreatment; passive ultrasonic irrigation; XP-endo Finisher R

INTRODUCTION

The main objective of endodontic therapy is to keep or restore the health of periradicular tissues. From a biological standpoint, this intervention in vital teeth is a relatively simple procedure. The pulp is excised, and the...
root canal system is sealed to avoid its contamination. On the other hand, the same procedure in infected teeth is considerably more critical. Even when a periapical lesion is not seen radiographically, it may be present; however, it is necessary to control the endodontic infection and seal the pulp cavity to provide conditions for the patient’s immune system to play its role – recovery of periradicular tissue health. Nevertheless, failure may occur even when all the clinical stages have been performed correctly, and the main reason is the permanency of the intraradicular infection. In such cases, nonsurgical endodontic retreatment is usually recommended.[3]

Endodontic reintervention consists of performing a new treatment, because the first one has failed, or simply because the professional wishes to provide a more predictable treatment for the patient, especially in cases of teeth that are to undergo prosthetic rehabilitation. The success of endodontic retreatment essentially depends on the effectiveness of the cleaning and/or disinfection processes. To this end, the removal of root canal filling materials plays a crucial role. Several alternatives have been proposed to render root canals completely free from filling materials, including instruments with different designs, alloys, kinematics, lasers, and sonic and ultrasonic equipment. However, the key purpose remains a major challenge.[5]

Passive ultrasonic irrigation (PUI) was firstly proposed by Weller et al.[3] The technique is based on the passive insertion of a metal tip/file coupled to an ultrasonic device oscillating at a frequency of 30 kHz into a root canal filled with an irrigating or chelating solution. When the instrument is activated, it is surrounded by acoustic streaming to magnify the performance of the solution agitation and to enhance the removal of debris, smear layer, and root canal filling materials.

The EndoActivator system (EAS) (Dentsply Tulsa Dental Specialties, Tulsa, OK) is a sonically driven irrigant activation tool which was developed to produce vigorous fluid agitation within the root canal. The system has been shown to raise the efficacy of the irrigation better than traditional needle irrigation. It is composed of a portable handpiece and three kinds of disposable flexible polymer tips of distinct sizes (15.02, 25.04, and 35.04), which do not cause wear to the intracanal dentin.[14]

The XP-Endo Finisher R (XPEFR) (FKG Dentaire SA, La Chaux-de-Fonds, Switzerland) is an ISO #30, 30-mm nontapered instrument, manufactured with a special NiTi alloy called MaxWire (Martensite-Austenite Electropolish-Flex, FKG Dentaire). According to the manufacturer, the file is straight in its martensitic phase (room temperature and when cooled) and changes into an austenitic phase when exposed to body temperature, at which time it takes on a unique spoon shape 1.5 mm deep and 10 mm long to its tip, fashioned by its molecular memory. Its recommended operating speed for the use with irrigating solutions is 800 rpm after chemomechanical preparation, up to an ISO #30 file or larger.[3]

Regardless of the technique used, the difficulties in performing endodontic retreatment seem to be proportional to the anatomical complexity of the root canal. Endodontic files are relatively effective for removing filling materials from straight and narrow root canals with round cross-sections. On the other hand, several studies have addressed the inability of these instruments to touch the polar areas of flattened root canals, and their propensity to accumulate residual material in the root canal, thus compromising the prognosis of the endodontic retreatment.[6]

To the best of our knowledge, just one study was performed to assess the efficacy of PUI, EAS, and XPEFR as additional techniques for removing residual root canal filling materials by micro-computed tomography (micro-CT). However, it was conducted in flattened root canals of extracted human mandibular premolars.[6] Therefore, the present study is the first scientific investigation planned to perform the same analysis in flattened distal root canals of extracted human first lower molars. The null hypotheses tested were that: (I) there are no advantages when using additional cleaning techniques for the removal of root canal filling materials and (II) there are no differences in root canal filling materials removed by PUI, EAS, or XPEFR, despite the area assessed (total space vs. apical third of the root canal).

**SUBJECTS AND METHODS**

This study was approved by the research ethics committee of the University (n. 2.599.986). The sample size determination was conducted using the analysis of variance (ANOVA) test and considered an effect size of 0.5 (acquired from a pilot study with three specimens), a significance level of 5% and a test power of 80%. The calculation was done with a G’Power v. 3.1.9.4 software (Heinrich-Heine Universität Düsseldorf, Dusseldorf, Germany) and pointed out that a minimum of 36 specimens (n. 12 per group) would be needed.

**Sample selection**

Initially, 144 human first lower molars extracted for reasons unrelated to this research were acquired from the institutional tooth bank as a preselection. Then, the teeth were radiographed in the mesiodistal (MD) and buccolingual (BL) views to ascertain the presence of a single canal in the distal root. The tooth crown of 72 teeth was initially sectioned up to 2 mm from the cementoenamel junction (buccal side as the reference)
using a double-sided diamond disc, aiming to make a plateau for performing the initial micro-CT scan (SkyScan 1174; Bruker micro-CT, Kontich, Belgium) to analyze the anatomical characteristics of the teeth at 800 μA, with a 50 kV X-ray source. The parameters used for the scanning procedure included a rotation step of 0.7° and 360° around the vertical axis, 16.82 μm pixel size, and a 0.5-mm thick aluminum filter. Micro-CT scanning process lasted about 55 min per specimen. Micro-CT scanning process was designed to analyze the data obtained, in order to select 36 specimens with very similar flattened distal root canals, based on the following features: complete formed root apex, with a curvature of up to 20° in the BL and MD directions, without previous endodontic treatment or root resorption, and with specific numerical parameters: volume (mm³) – 7.23–7.73; area (mm²) – 37.52–42.83; structure model index (SMI) – 1.98–2.03; and diameter ratio – 3.80–3.90.[7,8]

**Root canal preparation**

Initially, the opening cavity was refined using high-speed Endo Z burs (KG Sorensen, Barueri, São Paulo, Brazil) under continuous irrigation with water. Then, the distal canal orifice was identified, and it was explored with a #15 K-file (Dentsply-Maillefer, Ballaigues, Switzerland), until its tip was observed at the apical foramen under magnification (×10), using an operating microscope (Alliance Microscopia, São Carlos, São Paulo, Brazil). This procedure was performed to check the apical patency and establish the working length (WL) at 1 mm of the apical foramen.

Each root was sheeted with two layers of nail polish and embedded in condensation silicone (Zhermack, Badia Polesine, Rovigo, Italy) to pretend the periodontal ligament, taking care to warn extrusion of the irrigating solution and debris. The root canal was instrumented using the ProTaper Next system (Dentsply-Maillefer) driven by an electric endodontic motor (X-Smart Plus, Dentsply Maillefer), following the manufacturer’s instructions, up to the X4 file. Irrigation was conducted at each file change or use, using 2.5 ml of 2.5% sodium hypochlorite (NaOCl) (Fórmula and Aço, São Paulo, São Paulo, Brazil), and a NaviTip 31G double sideport needle (Ultradent, Indaiatuba, São Paulo, Brazil), calibrated at 2 mm of the WL, while apical patency was maintained with a #15 K-file (Dentsply-Maillefer). A total of 20 ml of irrigating solution was used during the chemomechanical preparation. Afterward, the canal was flooded with 2 ml of 17% ethylenediaminetetraacetic acid (EDTA) (Biodinâmica, Ibirapuera, Paraná, Brazil) for 3 min, and with 2 ml of 2.5% NaOCl. Final irrigation was achieved with 2 ml of distilled water, and the canal was dried with X4 absorbent paper points (Dentsply-Maillefer).

**Root canal filling**

Initially, a X4 gutta-percha cone (Dentsply-Maillefer) was placed into the canal up to the WL, until the tug-back sensation was felt. Then, the root canal was filled using the Tagger hybrid technique and AH Plus sealer (Dentsply De Trey, Konstanz, Germany). The endodontic opening was sealed with a temporary restoration material (Coltosol, Coltene/Whaledent AG, Altstatten, Switzerland), and the specimens were kept at 37°C and in 100% humidity for 45 days.

**Root canal retreatment**

Each specimen was positioned in the condensation silicone again, and the root canal filling materials were removed with the ProTaper Universal Retreatment system (PTURS) (Dentsply-Maillefer). Then, the canal was reinstrumented using the X5 file coupled to the same aforementioned electric endodontic motor, following the manufacturer’s recommendations, with an additional 10 ml of 2.5% NaOCl. The criteria adopted to finish the retreatment were a tactile sensation of rigid root canal walls, without any evidence of filling material traces. Thereafter, the canal was dried with X5 absorbent paper points (Dentsply-Maillefer). Finally, the specimens were submitted to another micro-CT scan according to the same previously described protocol, and the 3D images were reconstructed. At this time, the respective volumes of filling material remaining in both the total space and the apical third of the root canal were measured using the same aforementioned parameters and software and were called V1.

**Additional cleaning techniques**

At this phase of the study, the specimens were randomly divided into three groups (n. 12), according to the additional cleaning technique: PUI, EAS, and XPEFR. PUI was conducted using a special tip with no cutting power and with a #20 and 0.01 apical diameter and taper, respectively (Irrisonic E1; Helse, Santa Rosa de Viterbo, São Paulo, Brazil) and was activated by the ultrasound (Profi Neo US, Dabi Atlante, Ribeirão Preto, São Paulo, Brazil) at a power of 40%. In the EAS group, a medium tip (25.04) was used at 10,000 cycles/min. Finally, in the XPEFR group, the file was used in slow up-and-down movements, 7–8 mm long.

All the specimens received the same irrigation protocol, regardless of the system used as the additional cleaning technique. First, the canal was filled with 2 ml of 2.5% NaOCl using a NaviTip 31-gauge double sideport needle (Ultradent Products). The system was activated for 30 s, and the canal was irrigated with 5 ml of 2.5% NaOCl using this double sideport needle. The same procedures were carried out with 17% EDTA, followed by 5 ml of 2.5% NaOCl, as previously described. Next, the canal was irrigated with 5 ml of distilled water and dried with X5.
paper points (Dentsply-Maillefer). All the systems were activated at 1 mm of the WL.

Finally, all the specimens were submitted to a final micro-CT scan processed according to the same protocol described previously, and the 3D images were reconstructed. At this time, the respective volumes of the filling material traces in the total space and in the apical third of the root canal were determined by the same aforementioned parameters and software and were called V2.

**Statistical analysis**

Since all the data showed a normal distribution pointed out by the Kolmogorov–Smirnov test, the one-way ANOVA test was applied to assess the residual volumes of root canal filling materials before (V1) and after (V2) using the additional cleaning techniques, to evaluate the effectiveness of filling material removal, considering both the total space and the apical third of the root canal. The Games-Howel test was applied to conduct the pairwise comparisons. Statistical analyses were accomplished using the SPSS v. 23.0 software for Windows (SPSS, IL, USA), with a significance level of 5%.

**RESULTS**

Figure 1 shows the 3D image reconstructions of representative specimens from the three groups of the study. A relevant statistical difference was observed between V1 and V2 in all groups, regardless of the region under consideration (total space vs. apical root canal third) \( (P < 0.05) \). The percentage reductions in the volume of residual root canal filling materials obtained by PUI, EAS, and XPEFR were 28.38%, 28.12%, and 43.52%, respectively, considering the total space of the root canal \( (P > 0.05) \). However, these values in the apical third were 20.05%, 21.54%, and 48.82% \( (P < 0.05) \). Therefore, XPEFR performed better than PUI and EAS; meantime, there was no statistically relevant difference between the last two named \( (P > 0.05) \) [Table 1].

**DISCUSSION**

The major reason for endodontic failure is the maintenance of the intraradicular infection.[9] During endodontic retreatment, adequate cleaning and disinfection may be obtained only by removing root canal filling materials.[10] To this end, distinct techniques and instruments have been developed and investigated, especially for the use in flattened root canals, owing to their micro-depressions, recesses, and hard-to-reach areas. This study sought to assess the efficacy of PUI, EAS, and XPEFR as additional cleaning techniques for removing remnant root canal filling materials from flattened distal canals of extracted human first lower molars, by micro-CT. Both null hypotheses were rejected, because all the additional cleaning techniques enhanced the removal of filling materials and because XPEFR performed better than PUI and EAS in the apical third.

One of the major advantages of in vitro studies is the possibility of controlling the variables to carry out more accurate investigations and to obtain more reliable findings. Anatomical complexities play a crucial role in endodontic research, because their impacts cannot be controlled completely but can be limited. Micro-CT is a nondestructive approach that reconstructs samples on a micrometric and real scale.[11] It is considered the gold standard research device in endodontics for studying the root canal anatomy,[12,13] the quality of shaping and cleaning processes,[13] the performance of different obturation techniques,[14] and the removal of root canal filling materials,[6] because it allows accurate qualitative and quantitative analyses to be performed in multiple planes and at different time frames, when needed. Herein, micro-CT was initially used to limit the impacts of anatomical complexity, because it allowed selecting 36 specimens with very similar flattened distal roots and root canals, based on the following features: complete root apex, with a curvature of up to 20° in the BL and MD directions, and without previous endodontic treatment or root resorption, in addition to specific
Table 1: Average, lower and higher values, and percentage of filling materials removed from the root canals, according to the total space or apical root third, time points (V1 and V2), and groups analyzed

|                          | PUI       | EAS       | XPEFR     |
|--------------------------|-----------|-----------|-----------|
| Total space of the root canal |           |           |           |
| V1'                      | 1.60 (.55-4.35)a, A | 0.78 (.13-3.66)a, A | 1.90 (.03-4.93)a, A |
| V2'                      | 1.02 (.34-3.63)a, B | 0.40 (.11-3.36)a, B | 1.14 (.00-3.38)a, B |
| Percentage reduction in root canal filling materials | 28.38%a, A | 28.12%a, B | 43.52%a, B |
| Apical root canal third |           |           |           |
| V1'                      | 0.36 (0.01-1.00)0a, A | 0.12 (0.00-0.57)0a, A | 0.23 (0.01-0.61)0a, A |
| V2'                      | 0.24 (0.00-1.00)0a, B | 0.09 (0.02-0.27)0a, B | 0.10 (0.00-0.42)0a, B |
| Percentage reduction in root canal filling materials | 20.05%a, A | 21.54%a, A | 48.82%b, A |

*Values in mm³. *(V1-V2). V1: Volume of filling materials remaining after using the ProTaper Retreatment system (Dentsply-Maillefer) and conducting reinstrumentation with X5 file (ProTaper Next, Dentsply-Maillefer), V2: Volume of filling materials remaining after the supplementary cleaning technique. Different lowercase letters in rows indicate a statistically significant difference. Different uppercase letters in columns indicate a statistically significant difference. PUI: Passive ultrasonic irrigation, EAS: EndoActivator system, XPEFR: XP-endo Finisher R.

Numerical parameters, such as volume (mm³) – 7.23–7.73; area (mm²) – 37.52–42.83; SMI– 1.98–2.03; and diameter ratio– 3.80–3.90.[7,8] Later, micro-CT was also used to take volumetric measurements at different time points to analyze both the impact of using additional cleaning techniques to remove residual root canal filling materials, and to determine the most effective technique to reach this purpose (PUI, EAS, and XPEFR), considering the total space and the apical root canal third. The initial selection of similar teeth and subsequent analysis of the removal of the root canal filling materials by micro-CT are approaches that have already been carried out in previous investigations research.[15]

The first main result of the current study was that all the additional cleaning techniques (PUI, EAS, and XPEFR) had a substantial effect on the removal of residual filling materials after retreatment procedures, corroborating the results of previous papers.[6,15] In addition to performing additional cleaning, reinstrumentation enlarges apical diameters and provides a greater volume of irrigation, thus promoting better cleaning.[21]

Specifically concerning the additional cleaning techniques studied herein (PUI, EAS, and XPEFR), no statistically relevant differences were observed among them in the total root canal space (P > 0.05). Previous studies pointed out that the PTURS was effectively able to remove filling materials mainly from the cervical and middle root canal thirds. The three files of the system – D1, D2, and D3 – have diameters of 30, 25, and 20, and tapers of 0.09, 0.08, and 0.07. Their full length is 16 mm for D1, 18 mm for D2, and 22 mm for D3. These instruments have a convex, triangular cross-section, in addition to which D1 has an active working tip that predisposes its penetration into the root canal filling materials.[22] In a clinical setting, reinstrumentation at the WL, with greater size files than those used in the initial intervention, is needed to obtain adequate cleaning. Moreover, further enlargement might create enough space for effective irrigation, and reduce the quantity of residual filling material, mainly in the cervical and middle thirds of the root canal.[21] The small amount of filling material remaining in these thirds after using the PTURS plus X5 files for reinstrumentation, probably contributed to the absence of relevant statistical differences among the additional cleaning techniques, in regard to the total root canal space. Some studies have shown that apical enlargement by two sizes beyond the preparation size established in the primary intervention relevantly decreased the number of residual filling materials in the retreatment of straight root canals.[21] In the current research, apical enlargement was restricted to an increase only from size 40 (X4) to size 50 (X5). Similar approaches were adopted by Ma et al.,[23] and Silva et al.,[24] and according to the former,[23] this seems to represent an adequate balance between apical enlargement and root canal anatomy.
The findings of this investigation are in agreement with those reported by previous studies, which also observed greater effectiveness of XPEFR, compared with PUI and/or EAS in removing the remaining filling materials, considering the total space and the apical root canal third. This favorable result might be explained by the innovative alloy (MaxWire; FKG) used in manufacturing the XPEFR, which allows the material to expand at body temperature, leading to compression of its elliptical part, caused by the resistance settled by the root canal anatomy during instrumentation. In turn, the resistance presses the semiactive tip of the file against the root canal walls. This means that after the file expands inside the root canal space, it is able to scrape the dentinal walls with its semiactive tip. This mechanical action causes the tip of the instrument to touch and dislodge root filling material from the root canal walls, even in hard-to-reach areas, after which it may be removed by canal irrigation. The PUI does not touch the root canal walls. Its mechanism of action is based on the activation of the irrigating solution. Afterward, additional mechanical debridement and removal of residual material adhered to the root canal walls can be performed by cavitation and acoustic streaming. Thus, as corroborated by De-Deus et al., the present results also suggest that the abrasion and touching of the canal walls through the mechanical action of the XPEFR is more efficient in shifting existing root filling material than activation of irrigating solutions using PUI. According to Volponi et al., EAS is less effective than XPEFR in reducing the amount of residual filling materials, owing to the lower hydrodynamic phenomenon promoted by the blunt and flexible polymer tip.

Silva et al. evaluated the efficacy of filling material removed from oval-shaped canals after using XP-endo Finisher and XPEFR, by micro-CT. Removal of 66.8% and 59.4% of the filling material volume was observed for both the former and the latter techniques, respectively. Herein, this percentage was relevantly lower (43.52%). Important methodological differences among the studies might explain the discrepant findings. Silva et al. used extracted human maxillary single-rooted teeth. In the present research, distal canals of extracted human first lower molars were used. Considering the available additional cleaning techniques for removing residual filling materials, the study by Silva et al. proceeded by filling each canal with 1 ml of 2.5% NaOCl and then activating the XPEFR for 60 s up to the WL. Finally, each root canal was irrigated with 5 ml of 2.5% NaOCl at 1 mm of the WL, using a syringe/needle. In the present study, the canal was irrigated with 2 ml of 2.5% NaOCl, and the XPEFR was activated for 30 s at 1 mm of the WL. Then, the canal was flushed with 5 ml of 2.5% NaOCl. The same procedures were performed with 2 ml of 17% EDTA, followed by irrigation with 5 ml of 2.5% NaOCl, as previously described. Finally, the canal was irrigated with 5 ml of distilled water.

The present findings corroborate those found by a systematic review and a meta-analysis recently performed, i.e., no currently available technique is capable to render the root canals completely free from root canal filling materials. As long as the abiding of contaminated root canal filling materials compromises the prognosis of endodontic retreatment, the search for even more effective cleaning strategies or techniques must go on.

CONCLUSIONS

All additional cleaning techniques improved the removal of root canal filling materials, regardless of the region under study (total space vs. apical root canal third). XPEFR was more effective than PUI and EAS in removing residual root canal filling materials from the apical third of flattened distal canals of extracted human first lower molars. However, none of the techniques was capable to render the root canals completely free from filling materials.

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Conflicts of interest
There are no conflicts of interest.

Highlights
- The main reason for endodontic failure is the permanency of the intraradicular infection. During endodontic retreatment, adequate cleaning and disinfection processes may be only achieved by removing root canal filling materials.
- Distinct techniques and instruments have been developed and investigated, especially for use in flattened root canals, owing to their anatomical characteristics.
- This study was sought to assess the efficacy of passive ultrasonic irrigation (PUI), EndoActivator system (EAS), and XP-endo Finisher R (XPEFR) as additional cleaning techniques for removing remnant root canal filling materials from flattened distal canals of extracted human first lower molars, by micro-computed tomography (micro-CT).
- All the additional cleaning techniques enhanced the removal of root canal filling materials, and XPEFR performed better than PUI and EAS in the apical third.

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