Original Article

Root canal dentin wear during final irrigation in endodontic retreatment with passive ultrasonic irrigation and easy clean instruments

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Abstract

Context: Complementary procedures have been proposed to improve the endodontic retreatments.

Aim: The aim of this study was to evaluate, by microcomputed tomography (micro-CT), the dentin wear caused by passive ultrasonic irrigation (PUI) and easy clean (EC) instruments, when used for the final removal of filling material during endodontic retreatment.

Methods: Thirty-six mesial roots of the lower first molars were divided into four groups ($n = 9$), according to the final irrigation and sealer: PUI/AH Plus, EC/AH Plus, PUI/Total Fill (TF), and EC/TF. Canal volume was evaluated, both before and after the final irrigation, by micro-CT analysis. The Kruskal–Wallis test was used to compare the volumes among groups and the paired Wilcoxon test was used to compare the volume values before and after the final irrigation within each group.

Results: Both complementary cleaning procedures promoted dentin wear that was observed only when the volume was analyzed for each third of the root canal. In the apical third, both instruments showed significant wear, where the use of the EC instrument resulted in greater wear than the PUI, in teeth filled with both AH Plus and TF BC Sealers ($P < 0.05$).

Conclusion: Both complementary cleaning procedures promoted dentin wear and must be used cautiously.

Keywords: Dental wear; endodontics; root canal filling materials; root canal irrigant

INTRODUCTION

Cleaning the root canal system (RCS) is challenging due to its anatomical complexity, which includes isthmuses, apical deltas, and irregularities in the dentin walls.[1] These areas may harbor tissue remnants, smear layer, microorganisms, and their products, preventing efficient filling, and may consequently cause persistent periradicular pathology.[2] During endodontic retreatment, the complete removal of these products, sealer and gutta-percha is extremely difficult and, in the majority of cases, is not attained.[3,4]

Total Fill (TF) BC Sealer (FKG, La Chaux-de-Fonds, Switzerland) is a premixed bioceramic sealer that contains calcium silicate and calcium phosphate. It is hydrophilic, biocompatible, and chemically stable, has antimicrobial properties, and exhibits good chemical adhesion to the dentin.[5,6] The bioceramic sealers are considered hard to remove after stabilization, which is worrying in the context of retreatment.[7,8] The AH Plus Sealer (Dentsply-Maillefer, Ballaigues, Switzerland) is an epoxy resin-based sealer with good physicochemical properties and is used as an excellence standard in filling studies.[6]

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The final irrigation is an essential stage in cleaning the RCS.[9] Complementary procedures, passive ultrasonic irrigation (PUI), sonic irrigation with EDDY system, and the use of the GentleWave, EndoActivator, XP-endo Finisher, and Easy Clean instruments, have been proposed with the objective of improving the removal of the filling materials during endodontic retreatments.[3,4,10,11] PUI has well-established efficacy, speeding up the cleaning process and increasing the removal of filling materials from the root canals.[3,4,11,12] The easy clean (EC) instrument (Easy Equipamentos Odontológicos, Belo Horizonte, Brazil) is a polymeric instrument with point 25 taper 04 dimensions, designed as an aircraft wing, for inducing irrigant turbulence for better cleaning of the root canals.[13] This device was designed to be used by motor activation in either reciprocating or rotatory motion.[14] Some studies have shown that this instrument is as efficient as PUI at removing remnant filling material.[14,15] Although no complementary cleaning procedure is able to completely remove the filling materials, there is a consensus that PUI and EC improve the cleaning of the RCS.[13-19]

The complementary cleaning procedures may, however, wear down the dentin. Any unnecessary wear on the canal walls can be extremely harmful, causing perforations, canal deviation, or root fracture.[20] These complications may compromise the filling procedure and, consequently, the root canal treatment success.[20] Simezo *et al.* observed, by environmental scanning electron microscopy (SEM), that PUI and EC caused similar degrees of erosion to the dentinal surface.[21] However, there is a lack of more specific knowledge about the dentin wear caused by these procedures. Thus, the objective of the present study was to evaluate, by microcomputed tomography (micro-CT), the dentin wear caused by PUI and EC instruments, when used for the final removal of filling material during endodontic retreatment of teeth filled with AH Plus and TF BC Sealers. The null hypothesis is that both methods of agitation produce similar dentin wear and there is no difference in the dentin wear in teeth filled with the AH Plus and TF BC Sealers.

METHODS

The local ethics and research committee approved the present study with protocol no. 3,815,713. Sample calculation was performed using the G*Power software (Version 3.1.9.2, Germany). We used the *F*-test for repeated-measures analysis of variance, with a test power of 0.8 and a fixed $\alpha = 0.05$, necessitating at least 9 samples per group to obtain statistical significance. Thirty-six permanent mandibular molars, extracted for therapeutic reasons, were used. Inclusion criteria were roots with a fully formed apex; teeth without prior endodontic treatment; teeth with mesial roots with curvature of up to 30°; teeth without calcifications and resorptions; and teeth provided by patients who signed the term of assignment and agreed to participate in this study. The selected dental elements were stored in a 0.1% thymol solution at 4°C until the moment of use. Coronary access to the pulp chamber was performed with a spherical diamond bur and Endo-Z bur driven by a high-speed motor. The canals were explored with #10 and #15 Kerr manual endodontic files (Maillefer®, Ballaigues, Switzerland) and the working length was defined as 1 mm short of the total length.

Micro-CT images of the mesial roots of the lower molars were acquired using the method employed by de Almeida *et al*.[22] Briefly, an acrylic resin base was made for each sample, which was placed on an aluminum jig to maintain a standardized tooth position during imaging. The microtomography (SkyScan 1173, Bruker, Kontich, Belgium) was used with the following parameters: 70 Kv, 114 mA, 13.5 μm isotropic resolution, 360° rotation around the vertical axis, 0.5 rotation step, average of 5 frames, 250 ms exposure time, and a 1 mm thick aluminum filter. Images were reconstructed with NRecon software (v1.6.1.0, Bruker, micro-CT) using a beam hardening correction of 25%, ring artifact correction of 2, and smoothing of 2, resulting in the acquisition of 700 to 800 axial sections per sample.[23]

The chemical-mechanical preparation was performed using the crown–apex technique, starting with preenlargement using LA Axxess Diamond drills (SybronEndo, Glendora, CA, USA), followed by radiographic confirmation of odontometry and patency. The preparation was performed using NiTi K3XF rotary files (SybronEndo, Glendora, CA, USA), at a speed of 350 rpm and torque limited by the electric motor Bassi iRoot (Easy Equipamentos Odontológicos, Belo Horizonte, MG, Brazil). The files 25/08, 25/06, and 25/04 were used in the middle and cervical thirds and the files 25/06 and 30/04 in the apical region. At each instrument change, 3 mL of 5.25% sodium hypochlorite was used for root canal irrigation. At the end of the preparation, 3 mL of 17% ethylenediaminetetraacetic acid (EDTA) (Biodinanica, Ibiporã, PR, Brazil) was used for 3 min, at a rate of 1 mL/min, followed by 3 mL of 5.25% NaOCl, and the canals were dried using FM paper cones (SybronEndo, Glendora, CA, USA).

After the chemical-mechanical preparation, the samples were randomly assigned into two groups ($n = 18$) according to the endodontic sealer. In Group 1 ($n = 18$), the roots were filled with AH Plus sealer (Dentsply-Maillefer, Ballaigues, Switzerland) and gutta-percha cones of size FM or M (Dentsply-Maillefer, Ballaigues, Switzerland), adjusted at the working length. In Group 2 ($n = 18$), the roots were filled with TF BC Sealer (FKG, La Chaux-de-Fonds, Switzerland) and TF gutta-percha cones (Brasseler USA, Savannah, GA) size #30 or #35. After filling, radiographs were obtained to verify the quality of the filling, the absence of bubbles, and the homogeneity of the filling mass. The pulp chambers of all teeth were sealed with cotton and a temporary material based on zinc oxide and finally stored for 28 days at 37°C and 100% humidity for the total setting of the sealers.

First, 3 mm of the filling material from the cervical third was removed using Gates Glidden #3 drills (Maillefer®, Ballaigues, Switzerland). After that, NiTi ProTaper Universal Retreatment Rotary Files (PTUR) (Maillefer®, Ballaigues, Switzerland) were used as follows: D1 in the cervical third, D2 in the middle third, and D3 in the apical third, without any solvent. At each instrument change, 3 mL of 5.25% sodium hypochlorite was used for root canal irrigation. Removal of the filling material was considered complete when no residue of gutta-percha or endodontic sealer was observed in the instrument, the working length was reached, and no residue of filling material was observed in the root canals by clinical microscopy and radiographic analyses. The canals were then explored with #10 Kerr manual endodontic files (Maillefer®, Ballaigues, Switzerland) to obtain radiographic confirmation of odontometry and patency. The working length was defined as 1 mm short of the total length. Finally, the instrumentation was completed using a NiTi ProTaper Next X4 file (# 40.06) (Maillefer®, Ballaigues, Switzerland) up to the working length. At the end of the preparation, 3 mL of 17% EDTA (Biodinanica, Ibiporã, PR, Brazil) was used for 3 min, at a rate of 1 mL/min, followed by 3 mL of 5.25% NaOCl, and the canals were dried using FM paper cones (SybronEndo, Glendora, CA, USA). The teeth were then submitted to a second micro-CT imaging, as previously described.

The samples were divided into four groups according to the endodontic sealer and the complementary cleaning procedures as follows: PUI/AH Plus, EC/AH Plus (EC/AH Plus), PUI/TF (PUI/TF BC Sealer), and EC/TF (EC/TF BC Sealer). The PUI/AH Plus and PUI/TF groups were irrigated with 2 mL of 5.25% sodium hypochlorite and agitated using an E1 Irrisonic ultrasonic insert (Helse Ultrasonic, Ocoee, Florida, USA) driven at 40 kHz by a Delsonic 2000 ultrasonic device (Deldent Ltd., Valley Cottage, NY, USA). The insert was positioned 2 mm short of the working length and the sodium hypochlorite solution was replaced every 20 s, 3 times, over a total of 1 min. A final flow of 5 mL of saline solution was administered without activation (Van der Sluis *et al*. 2010). In the EC/AH Plus and EC/TF groups, the same irrigation sequence and time were used. The solutions were agitated using the EC instrument coupled to a micromotor and a counter-angle (KaVo Kerr Group, Charlotte, USA), with a continuous rotation rate of approximately 20,000 rotations/min, 2 mm short of the working length.[18] The teeth were then submitted to a new image acquisition by micro-CT, as previously described.

The initial images were evaluated to compare the anatomical volumes of the canals (V_0) among the groups and to confirm anatomical similarity. After recording the images before and after the complementary cleaning procedures, the respective cuts were registered by the Affine plugin of the 3D Slicer 4.4.0 program[24] and compared with each other, respectively, ensuring segmentation accuracy. Subsequently, the grayscale range needed to recognize dentin (range 60–255) and filling material remnants (range 210–255) was established on a density histogram by thresholding. At this stage, the filling material contained in the canal walls was excluded from analysis. The canal volume was calculated in mm^3 in the coronal, middle, and apical thirds of the root canal, before and after complementary cleaning procedures (PUI and EC). The volumes obtained before and after the complementary cleaning procedures were identified as initial volume (V_i) and final volume (V_f), respectively. The division into thirds (coronal, middle, and apical) was calculated from the number of cuts present in each tooth, considering the area between the furcation to the apical foramen. To assess dentin wear (ΔV), the initial volume (Vi) was subtracted from the final volume (Vf).[25] All image analysis procedures were performed using the ImageJ 1.50d program (National Institutes of Health, Bethesda, MD, USA).[26]

The Kolmogorov–Smirnov test was used to verify the normality of the initial volume (V_i), final volume (V_f), and dentinal wear volume (ΔV) distributions. As these values demonstrated nonnormal distribution, the Kruskal–Wallis test was used to compare the volumes among groups and the paired Wilcoxon test was used to compare V_i and V_f within each group. The significance level was set at 5% (SPSS version 25; SPSS Inc., Chicago, IL, USA).

RESULTS

The images obtained before the instrumentation of the root canals showed no difference among the groups in relation to V_0, confirming anatomical similarity between the groups ($P > 0.05$). Figure 1 shows micro-CT images of the mesial roots of the lower molars, obtained before and after the complementary cleaning procedure. In the images obtained after the complementary cleaning, it is not possible to observe significant differences in the root canal's overall volume.

Table 1 shows the values of initial volume (V_i), final volume (V_f), and dentinal wear (ΔV) of the canals in the different groups. There was no statistically significant difference between V_i and V_f in the different groups ($P > 0.05$), i.e. no evidence for dentin wear. There were also no differences in ΔV among the analyzed groups ($P > 0.05$).

When volumes were analyzed in the coronary, middle, and apical thirds of the root canal [Table 2], statistically significant differences were observed between V_i and

V_f in the coronary, middle, and apical thirds of all groups ($P < 0.05$), except in the coronary third of the PUI/TF group ($P > 0.05$). Table 2 also shows the values of dentin wear in the different thirds of the canal. The PUI/AH Plus group showed significantly greater wear than the other groups in the coronary and middle thirds ($P < 0.05$). The wear volume in the PUI/AH Plus and EC/AH Plus groups was greater in the coronary and middle thirds than in the apical third ($P < 0.05$). In the PUI/TF and EC/TF groups, the wear volume was greater in the coronary third, followed by the middle and apical thirds. Using the EC instrument resulted in the highest wear volume in the apical third in both sealer groups. The lower wear volume on the apical third was found in the PUI/TF group [$P < 0.05$, Table 2].

Table 1: Initial volume and final volume of the canal and dentin wear volume (mean±standard deviation in mm^3) in the different groups

	Vi	Vf	ΔV
PUI/AH Plus	8.24±1.84^{a}	9.73±2.24^{a}	1.49±0.79^{b}
EC/AH Plus	8.78±1.88^{a}	9.80±2.22^{a}	1.02±0.46^{b}
PUI/TF	9.42±3.26^{a}	10.22±3.49^{a}	0.80±0.43^{b}
EC/TF	8.61±0.66^{a}	9.58±1.09^{a}	0.97±0.58^{b}

Equal lowercase letters in the same column indicate that there was no statistical difference among the groups (Kruskal–Wallis test $P>0.05$) and equal lower letters in the same row denote that there was no statistical difference between the values of Vi and Vf (Wilcoxon paired test $P<0.05$). Vi: Initial volume, Vf: Final volume, ΔV: Wear volume, PUI: Passive ultrasonic irrigation, EC: Easy clean, TF: Total Fill

DISCUSSION

The present study evaluated the dentin wear caused by PUI and EC instrument used for the final removal of the filling material during endodontic retreatment of mandibular molars filled with AH Plus or the TF BC Sealer. Both complementary cleaning procedures promoted dentin wear that was observed only when the volume was analyzed for each third of the root canal. The higher wear volume was found in the coronal and middle thirds of the PUI/AH Plus group ($P < 0.05$). In the apical third, both instruments showed significant wear, where the use of the EC instrument resulted in greater wear than the PUI, in teeth filled with both AH Plus and TF BC Sealers ($P < 0.05$).

Micro-CT analysis was used in the present study because it allows accurate three-dimensional analysis and quantitative assessment without sample destruction.[24,27] However, even though micro-CT has become the gold standard in

Table 2: Initial volume and final volume and dentin wear volume (mean±standard deviation in mm^3) of the canal in the coronary, middle, and apical thirds in the different groups

	Vi			Vf			ΔV		
	Cervical	Medium	Apical	Cervical	Medium	Apical	Cervical	Medium	Apical
PUI/AH Plus	5.42±0.85^{aA}	2.26±0.95^{bB}	0.56±0.21^{cC}	6.13±1.06^{dD}	2.87±1.09^{eE}	0.72±0.37^{fF}	0.71±0.33^{gG}	0.62±0.35^{iG}	0.16±0.29^{kH}
EC/AH Plus	5.26±1.25^{aA}	2.75±0.62^{bB}	0.71±0.19^{cC}	5.79±1.48^{dD}	3.04±0.72^{eE}	0.88±0.22^{fF}	0.53±0.32^{hG}	0.30±0.15^{jG}	0.17±0.10^{lH}
PUI/TF	5.74±2.31^{aA}	2.72±0.78^{bB}	0.95±0.29^{cC}	6.19±2.44^{dA}	3.00±0.90^{eE}	1.04±0.27^{fF}	0.44±0.30^{hG}	0.28±0.18^{jH}	0.09±0.05^{mI}
EC/TF	5.68±0.94^{aA}	2.36±0.41^{bB}	0.58±0.29^{cC}	6.17±1.19^{bdD}	2.66±0.41^{eE}	0.75±0.28^{fF}	0.49±0.29^{hG}	0.30±0.30^{jH}	0.17±0.21^{lH}

Different lowercase letters in the same column (Kruskal–Wallis test $P<0.05$) and different uppercase letters in the same row indicate statistical difference (paired Wilcoxon test $P<0.05$). Vi: Initial volume, Vf: Final volume, ΔV: Wear volume, PUI: Passive ultrasonic irrigation, EC: Easy clean, TF: Total Fill

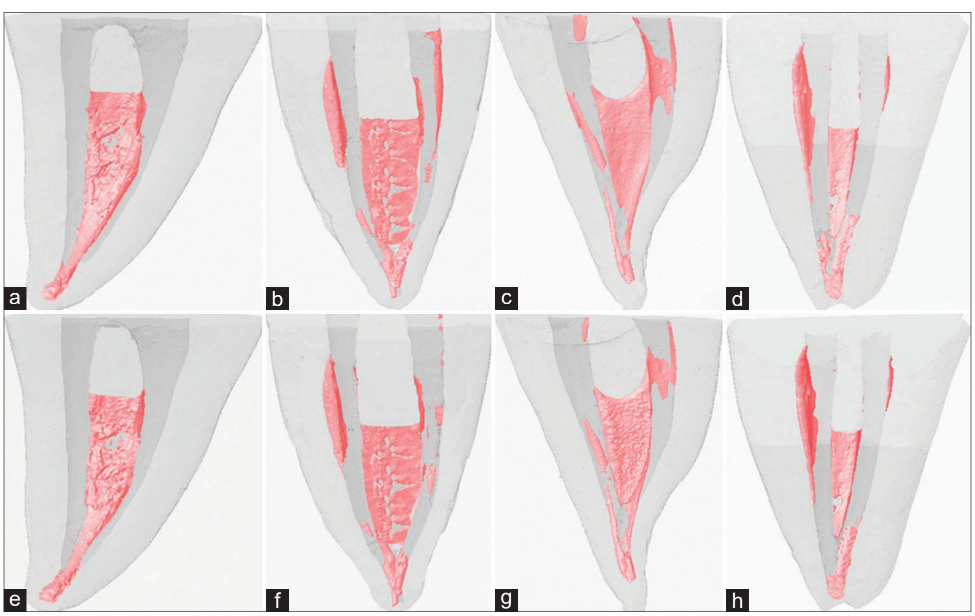

Figure 1: Computed microtomography images of the samples. (a-d) Initial and (e-h) final. (a and e) PUI/AH Plus, (b and f) EC/AH Plus, (c and g) PUI/TF, and (d and h) EC/TF. PUI: Passive ultrasonic irrigation, EC: Easy clean, TF: Total Fill

assessing the quality and quantity of mechanical referent to Root Canal System (RCS) preparation, we must bear in mind its inherent limitations. This imaging method relies on a human workflow for complex data processing and software management and may present problems related to image resolution.[28] In the present study, the same operator performed the analysis of all samples, and the method for comparing the amount of dentin wear in the complementary instrumentation step was the same as described by Haupt *et al*.[25] In addition, several checks were made to exclude factors that might change the results. Among these checks are the confirmation of anatomical similarity between the groups through imaging before the root canal preparation and the verification of segmentation accuracy via images before and after the complementary cleaning protocols.[28] In addition, filling material remnants were identified and excluded from the canal walls, and the dentinal wear was evaluated for each third of the tooth, rather than only from the total canal volume,[25] to avoid nondetection of some wear levels due to canal diameter varying by depth.

The irrigating solution used in the complementary irrigation step was 5.25% NaOCl, as in other comparative studies on the effectiveness of agitating the irrigating solution.[16,18] Such studies, despite using different concentrations of the NaOCl solution, demonstrated the effectiveness of removing intracanal debris using NaOCl in 3 cycles of 20 s, renewing the irrigating solution at each cycle. To eliminate possible biases, the 17% EDTA that was used by Simezo *et al.*[21] was not used at this stage, as it is a chelating substance that could favor the removal of the smear layer and alteration of the peritubular dentin.

Using two different sealer types was aimed at comparing different properties. AH Plus was used because it is considered the gold standard in the literature, and TF BC Sealer offers an example of a widely used bioceramic that is difficult to remove due to strong chemical adhesion to peritubular dentin.[6]

Several studies showed the efficacy of PUI and EC at removing debris, intracanal medication, and filling materials from root canals in both endodontic treatment and retreatment.[13-19] de Souza *et al.* used the EC instrument in continuous rotation to remove remnant filling materials and observed, by micro-CT, similar results to those for PUI.[14] In addition, Duque *et al.* demonstrated that three activations of the irrigating solution for 20 s, with the EC instrument used in continuous rotation and at low speed (20,000 rpm), provided a better cleaning of the canals and isthmuses.[18] Consequently, PUI and EC were used here as complementary cleaning procedures. As the continuous rotation kinematics of the EC instrument is more effective than reciprocating kinematics,[16,18] it was chosen to carry out this work.

The results of the present study showed that there was no significant dentinal wear in any of the groups evaluated, and there was also no difference between the groups in terms of wear values (ΔV) ($P < 0.05$). These results are in agreement with the study by Simezo *et al.*, who also did not observe any significant difference between the erosive effects of PUI and EC with alternating activation (ECR) on the dentin surface of the root canal, in an environmental SEM analysis.[21] However, when the volume values were analyzed by root canal thirds, statistically significant differences were observed between the values of V_i and V_f in the coronary, middle, and apical thirds of all groups ($P < 0.05$), except for the coronary third from the PUI/TF group ($P > 0.05$). These results show the need for segmented evaluation of the canal volume in studies of dentinal wear, because the canal taper entails a substantial difference among the volumes of different thirds of the same canal. In this context, the wear of similar wall thicknesses in different thirds can result in significantly different wear volumes, where the segments with greater volume and greater wall area tend to have greater dentin wear volume. This observation can be confirmed by the higher wear volume values in the coronary third, followed by the middle and apical in the PUI/TF and EC/TF groups and by the highest wear values in the coronary and middle thirds, followed by the apical third in the PUI/AH groups Plus and EC/AH Plus ($P < 0.05$).

The present results show that the EC instrument presented the highest wear volume in the apical third in both the AH Plus sealer and TF BC Sealer cement groups, followed by the PUI/AH Plus group. The least wear on the apical third was found in the PUI/TF group ($P < 0.05$). The greater apical wear provided by EC can be attributed to its continuous rotation, combined with the larger diameter and taper (25.04) of the instrument, compared to the ultrasonic insert E1 – Irrisonic (20.01), used for ultrasonic agitation. As the ultrasonic agitator requires space between the ultrasonic insert and the canal walls to induce acoustic flow and cavitation,[12] it tends to result in less contact of both structures.

Based on the findings of the present study, both complementary cleaning procedures promoted dentin wear when the volume was analyzed in different thirds of the root canal. In the apical third, both instruments showed significant wear, and the EC instrument caused greater wear than the PUI. Consequently, both complementary cleaning procedures must be used cautiously in the apical third to avoid interference within filling material's adaption.

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Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Ortigara GA, Prado M, Lopes RT, Dos Santos BC, Gusman H. Micro-computed tomographic evaluation of smear layer and accumulated hard tissue debris removal. J Conserv Dent 2020;23:249-53.
2. Wu MK, de Schwartz FB, van der Sluis LW, Wesselink PR. The quality of root fillings remaining in mandibular incisors after root-end cavity preparation. Int Endod J 2001;34:613-9.
3. Grischke J, Müller-Heine A, Hülsmann M. The effect of four different irrigation systems in the removal of a root canal sealer. Clin Oral Investig 2014;18:1845-51.
4. Santos-Junior AO, De Castro Pinto L, Mateo-Castillo JF, Pinheiro CR. Success or failure of endodontic treatments: A retrospective study. J Conserv Dent 2019;22:129-32.
5. Tanomaru-Filho M, Torres FF, Chávez-Andrade GM, de Almeida M, Navarro LG, Steier L, *et al.* Physicochemical properties and volumetric change of silicone/bioactive glass and calcium silicate-based endodontic sealers. J Endod 2017;43:2097-101.
6. Silva EJ, Cardoso ML, Rodrigues JP, De-Deus G, Fidalgo TK. Solubility of bioceramic- and epoxy resin-based root canal sealers: A systematic review and meta-analysis. Aust Endod J 2021;47:690-702.
7. Hess D, Solomon E, Spears R, He J. Retreatability of a bioceramic root canal sealing material. J Endod 2011;37:1547-9.
8. Shokouhinejad N, Hoseini A, Gorjestani H, Shamshiri AR. The effect of different irrigation protocols for smear layer removal on bond strength of a new bioceramic sealer. Iran Endod J 2013;8:10-3.
9. Ada KS, Shetty S, Jayalakshmi KB, Nadig PL, Manje Gowda PG, Selvan AK. Influence of different irrigant activation methods on apical debris extrusion and bacterial elimination from infected root canals. J Conserv Dent 2023;26:31-5.
10. Crozeta BM, Lopes FC, Menezes Silva R, Silva-Sousa YT, Moretti LF, Sousa-Neto MD. Retreatability of BC sealer and AH plus root canal sealers using new supplementary instrumentation protocol during non-surgical endodontic retreatment. Clin Oral Investig 2021;25:891-9.
11. Crozeta BM, Chaves de Souza L, Correa Silva-Sousa YT, Sousa-Neto MD, Jaramillo DE, Silva RM. Evaluation of passive ultrasonic irrigation and gentlewave system as adjuvants in endodontic retreatment. J Endod 2020;46:1279-85.
12. van der Sluis LW, Versluis M, Wu MK, Wesselink PR. Passive ultrasonic irrigation of the root canal: A review of the literature. Int Endod J 2007;40:415-26.
13. Kato AS, Cunha RS, da Silveira Bueno CE, Pelegrine RA, Fontana CE, de Martin AS. Investigation of the efficacy of passive ultrasonic irrigation versus irrigation with reciprocating activation: An environmental scanning electron microscopic study. J Endod 2016;42:659-63.
14. de Souza DS, S Silva AS, Ormiga F, Lopes RT, Gusman H. The effectiveness of passive ultrasonic irrigation and the easy-clean instrument for removing remnants of filling material. J Conserv Dent 2021;24:57-62.
15. Rodrigues CT, Duarte MA, Guimarães BM, Vivan RR, Bernardineli N. Comparison of two methods of irrigant agitation in the removal of residual filling material in retreatment. Braz Oral Res 2017;31:e113.
16. Cesario F, Hungaro Duarte MA, Duque JA, Alcalde MP, de Andrade FB, Reis So MV, *et al.* Comparisons by microcomputed tomography of the efficiency of different irrigation techniques for removing dentinal debris from artificial grooves. J Conserv Dent 2018;21:383-7.
17. de Oliveira RL, Guerisoli DM, Duque JA, Alcalde MP, Onoda HK, Domingues FH, *et al.* Computed microtomography evaluation of calcium hydroxide-based root canal dressing removal from oval root canals by different methods of irrigation. Microsc Res Tech 2019;82:232-7.
18. Duque JA, Duarte MA, Canali LC, Zancan RF, Vivan RR, Bernardes RA, *et al.* Comparative effectiveness of new mechanical irrigant agitating devices for debris removal from the canal and isthmus of mesial roots of mandibular molars. J Endod 2017;43:326-31.
19. Silva EJ, Carvalho CR, Belladonna FG, Prado MC, Lopes RT, De-Deus G, *et al.* Micro-CT evaluation of different final irrigation protocols on the removal of hard-tissue debris from isthmus-containing mesial root of mandibular molars. Clin Oral Investig 2019;23:681-7.
20. Mozo S, Llena C, Forner L. Review of ultrasonic irrigation in endodontics: Increasing action of irrigating solutions. Med Oral Patol Oral Cir Bucal 2012;17:e512-6.
21. Simezo AP, da Silveira Bueno CE, Cunha RS, Pelegrine RA, Rocha DG, de Martin AS, *et al.* Comparative analysis of dentinal erosion after passive ultrasonic irrigation versus irrigation with reciprocating activation: An environmental scanning electron study. J Endod 2017;43:141-6.
22. de Almeida BC, Ormiga F, de Araújo MC, Lopes RT, Lima IC, dos Santos BC, *et al.* Influence of heat treatment of nickel-titanium rotary endodontic instruments on apical preparation: A micro-computed tomographic study. J Endod 2015;41:2031-5.
23. De-Deus G, Simões-Carvalho M, Belladonna FG, Cavalcante DM, Portugal LS, Prado CG, *et al.* Arrowhead design ultrasonic tip as a supplementary tool for canal debridement. Int Endod J 2020;53:410-20.
24. Wolf M, Küpper K, Reimann S, Bourauel C, Frentzen M. 3D analyses of interface voids in root canals filled with different sealer materials in combination with warm gutta-percha technique. Clin Oral Investig 2014;18:155-61.
25. Haupt F, Pfitzner J, Hülsmann M. A comparative *in vitro* study of different techniques for removal of fibre posts from root canals. Aust Endod J 2018;44:245-50.
26. De-Deus G, Belladonna FG, Silva EJ, Marins JR, Souza EM, Perez R, *et al.* Micro-CT evaluation of non-instrumented canal areas with different enlargements performed by NiTi systems. Braz Dent J 2015;26:624-9.
27. de Siqueira Zuolo A, Zuolo ML, da Silveira Bueno CE, Chu R, Cunha RS. Evaluation of the efficacy of TRUShape and Reciproc file systems in the removal of root filling material: An *ex vivo* micro-computed tomographic study. J Endod 2016;42:315-9.
28. Fedorov A, Beichel R, Kalpathy-Cramer J, Finet J, Fillion-Robin JC, Pujol S, *et al.* 3D Slicer as an image computing platform for the quantitative imaging network. Magn Reson Imaging 2012;30:1323-41.