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A microcomputed tomography evaluation of the shaping ability of three thermally-treated nickel-titanium rotary file systems in curved canals

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Abstract

Objective: To evaluate the shaping ability of three thermally-treated rotary nickel-titanium (NiTi) systems including ProTaper Next (PTN), HyFlex^{TM} CM (HFCM) and HyFlex^{TM} EDM (HFEDM) during root canal preparation in simulated root canals.

Methods: A total of 45 simulated root canals were divided into three groups ($n = 15$) and prepared with PTN, HFCM or HFEDM files up to size 25. Microcomputed tomography (microCT) was used to scan the specimens before and after instrumentation. Volume and diameter changes, transportations and centring ratios at 11 levels of the simulated root canals were measured and compared.

Results: HFEDM caused significantly greater volume increases than HFCM and PTN in the entire root canal and in the apical and middle thirds. HFCM removed the least amount of resin in the coronal third compared with HFEDM and PTN. Overall, HFCM caused significantly less transportation in the apical 2 mm and was better centred than PTN in the apical 3 mm.

Conclusion: Under the conditions of this study, all systems prepared curved canals without significant shaping errors and instrument fracture. PTN and HFCM cut less resin than HFEDM. HFCM stayed centred apically and cut the least material coronally.

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Keywords

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Introduction

Root canal systems are complex, with fine structures such as inter-canal communications, loops and accessory canals, accompanying the main canal in each of the roots.[1] Instrumentation of the main canals is essential in facilitating the complete perfusion of the root canal system by bactericidal irrigants to disinfect these otherwise inaccessible areas of the root canal.[2] The mechanical shaping of root canals removes remnant pulp tissues, microorganisms and widens them to negate the effect of surface tension that prevents irrigation to the full extent of the root canal.[3]

The presence of primary and secondary curvatures in root canals dictates that instruments must be flexible to reduce the effect of restoring forces that tend to move the central axis of the file out of the central axis of the root canal,[4] thinning out parts of the canal excessively whilst under-instrumenting other parts, creating deviations in the prepared canal called zips and elbows.[5] Changes to instrument manufacture by the introduction of nickel-titanium (NiTi) alloys and later, further changes to the metallurgy and manufacturing processes of these instruments, have led to claims of improved strength, flexibility, cyclic and torsion fatigue in newer generations of NiTi instruments.[6]

Among these newer generations of instruments, the ProTaper Next file (PTN; Dentsply Sirona, Ballaigues, Switzerland) is made of M-wire, a unique NiTi alloy manufactured by a thermal treatment process. The PTN file, designed with an off-centre rectangular cross section, is claimed to rotate asymmetrically with a swaggering motion,[7] improving the flexibility and reducing cyclic fatigue whilst retaining cutting efficiency.[8]

The HyFlex™ Controlled Memory system (HFCM; Coltène/Whaledent, Allstätten, Switzerland) is produced by an innovative methodology that uses a unique thermomechanical process that controls memory of the alloy, making the files extremely flexible but without the shape memory behaviour of other NiTi files. The HFCM system is made from this CM-wire.[9] It has a lower nickel content (52%),[10] thus softening the metal, which would likely make the instrument less aggressive in cutting and hence more likely to stay centred during instrumentation.[11]

The HyFlex™ EDM file (HFEDM; Coltène/Whaledent), produced by electrical discharge machining, is manufactured from the same CM-wire and uses spark erosion to harden the surface to improve resistance to cyclic fatigue and fracture.[12] The HFCM has a triangular cross section whereas the HFEDM file has a roughly triangular cross section in the coronal section but a roughly rectangular cross section with rounded corners towards the apical parts.

Whilst it is valid to use extracted teeth in *ex vivo* comparisons of files, the *ex vivo* roots available today are mostly wisdom teeth, periodontally mobile teeth or premolars extracted prior to orthodontic treatment. These present with a great variety of confounding factors that make standardization of root canals almost impossible. The properties of resin blocks are however standardized; in terms of hardness, canal curvature, as well as radius of the curve, making comparisons using resin blocks removes many confounders that variations in teeth may bring about and are hence valid surrogates to replace teeth.[13]

Microcomputed tomography (microCT) imaging has high accuracy and is a non-destructive means to assess canals.[1] To the best of our knowledge, there is no publication comparing the shaping and centring abilities among the three NiTi file systems described above, although the flexibility and cyclic fatigue resistance have been compared.[14] The aim of this study was to investigate and compare the shaping abilities of the three NiTi file systems, namely PTN, HFCM and HFEDM.

Materials and methods

Preparation of resin block specimens

Forty-five resin blocks (Plastic Training Block V04 0245; VDW, Munich, Germany) with simulated curved root canals of 35° (Schneider method) were divided into three groups (15 in each), named group PTN, HFCM and HFEDM, according to the file systems used. No human subjects were used so ethical approval and informed consent were not required for this study. Each canal was 13-mm long, including a 6-mm curved section and a 7-mm straight section, with a radius of curve that was calculated to be about 5 mm; and with a simulated pulp chamber. All blocks were decontaminated in an ultrasonic cleaner (Bransonic B5510E-DTH; Branson Ultrasonics, Danbury, CT, USA) in distilled water for 15 min and then dried at 40°C for 24 h in a desiccator. Before instrumentation, all specimens were prescanned at an isotropic resolution of 20 μm using a microCT scanner (μCT 50; Scanco Medical AG, Brüttisellen, Switzerland) at 45 kV and 88 μA. Reconstruction of the slice images was performed automatically using μCT software version 6.1 (Scanco Medical AG) and then manually exported in a Digital Imaging and Communications in Medicine (DICOM) format and saved on a hard disk.

Instrumentation

Irrigation was standardized for all three groups. With each file use, the canal was irrigated with 2 ml of distilled water using a 27-gauge open-ended flat-tipped safety needle (Suyun Medical Materials, Jiangsu, China), recapitulated with a no. 10 K-file (Dentsply Sirona) and irrigated again before the next instrument. The needle was inserted as deep as possible without binding. The determination of working length (WL) was accomplished by inserting a no. 10 K-file until just visible at the apical foramen using 2× magnification loupes. This step verified the patency and created a glide path. A 6:1 contra-angle handpiece (VDW) driven by a VDW Silver (VDW) endodontic motor was used in the rotary mode only. Each group was prepared according to the manufacturers' guidelines by one operator (Z.H.) and each file was used only in one resin block.

The procedures used in the three groups were as follows. In group PTN, for each specimen, the WL of the root canal was determined by a no. 10 K-file. PTN X1 (17/04) and X2 (25/06) files were used in the WL at a speed of 300 rotations per minute (rpm) and a torque of 2 Ncm. In group HFCM, after determining the WL with a no. 10 K-file, the 25/08 file was used to prepare the coronal third of the canal at a speed of 500 rpm and a torque of 2.5 Ncm, followed by the use of 20/06 and 25/06 files in the WL. In group HFEDM, after the WL was determined by a no. 10 K-file, the 25/08 file of the

HFCM system was used to prepare the canal orifice at a speed of 400 rpm and a torque of 2.5 Ncm. Then, 10/05 and 25/08 files were used in the WL.

After preparation, all specimens were decontaminated in an ultrasonic cleaner with distilled water for 15 min and dried at 40 °C for 24 h in a desiccator as described above. The specimens were rescanned using the same microCT scanner and post-instrumentation DICOM images were acquired.

MicroCT measurements

The DICOM format images of each specimen were converted with the Materialise Interactive Medical Image Control System Mimics software (Medical version 17.0; Materialise, Leuven, Belgium). The software calculates accurate three-dimensional (3D) models from stacked information in DICOM format images using a special algorithm. The 'mask' (Figure 1), which was a software-generated image from the DICOM images of each canal, was equally divided digitally into three parts, namely the apical, middle and coronal sections. The volume (mm^3) of each mask obtained from each reconstructed 3D object was regarded as the volume of the corresponding canal. Volume increases of the canal were calculated by subtracting the volumes of the non-instrumented canals from the instrumented canals.

For measurement of diameter increases, canal transportations and centring ratios, each canal was resliced along the central axis of the canal to obtain pre- and post-instrumentation images (Figure 2).[15] The parameters at 11 levels from the apex at 1-mm intervals were calculated using the following formulae:[16]

$$\text{Diameter increase} = (X2–X1) + (Y2–Y1)$$
$$\text{Canal transportation} = (X2–X1)–(Y2–Y1)$$
$$\text{Centring ratio} = (X2–X1)/(Y2–Y1) \quad \text{if } (Y2–Y1) > (X2–X1)$$
$$\text{or centring ratio} = (Y2–Y1)/(X2–X1) \quad \text{if } (X2–X1) > (Y2–Y1)$$

Canal transportation toward the inner side of the curvature of the canal was denoted a positive number and a negative number was used if it was toward the outer

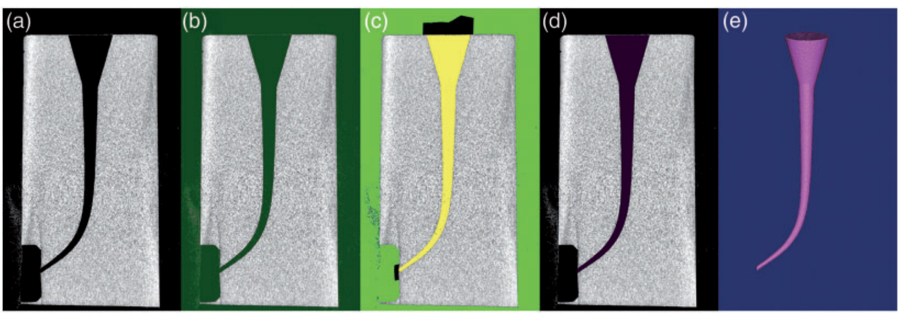

Figure 1. Steps for microcomputed tomography (microCT) measurements using the Materialise Interactive Medical Image Control System, Mimics software (Medical version 17.0): (a) one of the microCT slices of a typical post-instrumentation resin block; (b) 'thresholding' (window level –1024 ~ 2200 Hounsfield units); (c) a mask (in yellow) of the canal obtained by 'Edit Masks' and 'Region Growing' functions; (d) a precise mask (in purple) of the canal obtained by the 'Cavity Fill' function; (e) a three-dimensional (3D) reconstructed image of the simulated canal after 'Calculate 3D'. The colour version of this figure is available at: http://imr.sagepub.com.

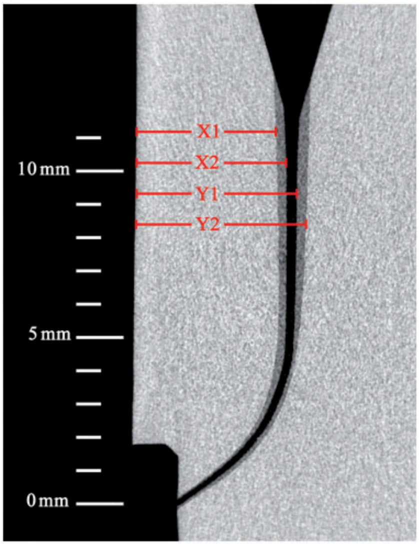

Figure 2. The superimposed image of the pre- and post-instrumentation microcomputed tomography slices. The pre-instrumentation canal is shown in black and the post-instrumentation canal is shown in dark grey. Measurements of inner and outer curve resin loss, transportation and centring ratio were done at 11 levels from the apex at 1-mm intervals shown by the reference lines (in white) on the left. These lines were perpendicular to the outer wall of the resin block. The colour version of this figure is available at: http://imr.sagepub.com.

side. The closer the centring ratio was to 1, the better the ability of the instrument to remain centred.

Statistical analyses

All statistical analyses were performed using IBM SPSS Statistics for Windows, version 22.0 (IBM, Armonk, NY, USA). The mean differences and SDs for different parameters were measured for each group. One-way analysis of variance (ANOVA) was used to compare each parameter between groups. For parameters that could not satisfy the prerequisites of one-way ANOVA (normal distribution and homogeneity of variance), the Kruskal–Wallis test was used. Bonferroni method

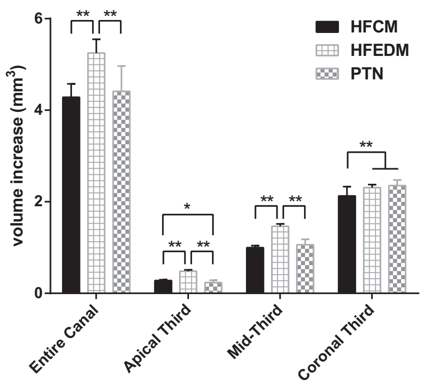

Figure 3. Volume increase of the entire canal and the apical, middle and coronal thirds of the canals after instrumentation using ProTaper Next files (PTN), HyFlex™ Controlled Memory (HFCM) files and HyFlex™ EDM files (HFEDM). *$P < 0.05$; **$P < 0.01$; one-way analysis of variance.

was selected for pair-wise comparisons. A P-value < 0.05 was considered statistically significant.

Results

Figure 3 shows the root canal volume increases after instrumentation. HFEDM had significantly higher volume increases compared with PTN and HFCM in the apical and middle thirds and in the entire root canal ($P < 0.01$ for all comparisons). In the apical third, HFCM caused a significantly greater volume increase than PTN ($P < 0.05$). In the coronal third, PTN and HFEDM both caused significantly greater volume increases than HFCM ($P < 0.01$ for both comparisons).

The diameter increases of the three groups at all 11 levels are shown in Table 1. In the apical and middle thirds of the canal (from 1 to 7 mm levels from apex), HFEDM produced the largest diameter increases among the three groups ($P < 0.05$ for all comparisons). In the coronal third (from 8 to 10 mm from apex),

Table 1. Diameter increases and centring ratios at 11 levels from the apex in the canals after instrumentation using ProTaper Next files (PTN), HyFlex™ Controlled Memory files (HFCM) and HyFlex™ EDM files (HFEDM).

	Diameter increase (mm)[a]			Centring ratio[b]		
Levels	PTN	HFCM	HFEDM	PTN	HFCM	HFEDM
1 mm	0.26 ± 0.04 (I)	0.28 ± 0.05 (I)	0.34 ± 0.03 (II)	0.27 ± 0.23 (I)	0.64 ± 0.20 (II)	0.38 ± 0.23 (I)
2 mm	0.24 ± 0.04 (I)	0.31 ± 0.03 (II)	0.40 ± 0.03 (III)	0.53 ± 0.23 (I)	0.75 ± 0.17 (II)	0.87 ± 0.12 (II)
3 mm	0.29 ± 0.03 (I)	0.33 ± 0.03 (II)	0.43 ± 0.03 (III)	0.60 ± 0.20 (I)	0.80 ± 0.18 (II)	0.88 ± 0.12 (II)
4 mm	0.34 ± 0.04 (I)	0.36 ± 0.02 (I)	0.48 ± 0.02 (II)	0.58 ± 0.21	0.58 ± 0.16	0.70 ± 0.17
5 mm	0.41 ± 0.04 (I)	0.39 ± 0.02 (I)	0.50 ± 0.03 (III)	0.62 ± 0.20	0.53 ± 0.17	0.70 ± 0.21
6 mm	0.44 ± 0.04 (I)	0.44 ± 0.03 (I)	0.52 ± 0.02 (II)	0.88 ± 0.12	0.81 ± 0.20	0.83 ± 0.12
7 mm	0.51 ± 0.03 (II)	0.47 ± 0.03 (I)	0.55 ± 0.03 (III)	0.82 ± 0.08	0.81 ± 0.12	0.76 ± 0.14
8 mm	0.56 ± 0.04 (II)	0.53 ± 0.01 (I)	0.58 ± 0.02 (II)	0.75 ± 0.08	0.81 ± 0.09	0.76 ± 0.11
9 mm	0.63 ± 0.04 (II)	0.58 ± 0.02 (I)	0.60 ± 0.03 (I, II)	0.77 ± 0.06	0.80 ± 0.14	0.74 ± 0.14
10 mm	0.68 ± 0.03 (II)	0.60 ± 0.02 (I)	0.63 ± 0.03 (I)	0.80 ± 0.07	0.79 ± 0.11	0.77 ± 0.10
11 mm	0.66 ± 0.03	0.64 ± 0.02	0.64 ± 0.04	0.79 ± 0.09	0.80 ± 0.12	0.80 ± 0.07

Data presented as mean ± SD.

[a,b]Data at the same level were compared with each other. The ranking order (I/II/III in parentheses) was obtained from the Bonferroni *post-hoc* test. Groups with different numerals were statistically different ($P < 0.05$); one-way analysis of variance.

[a]In the apical and middle thirds of the canal (from 1 to 7 mm levels from apex), HFEDM produced the largest diameter increases among the three groups ($P < 0.05$ for all comparisons). In the coronal third (from 8 to 10 mm from the apex), PTN caused larger diameter increases than HFCM ($P < 0.05$). No significant differences of diameter increase were found at the 11-mm level from the apex among the three groups.

[b]At the 1-mm level from the apex, HFCM presented a centring ratio significantly closer to 1 than PTN and HFEDM ($P < 0.05$ for both comparisons). HFEDM and HFCM were significantly better centred than PTN at the 2-mm and 3-mm levels from the apex ($P < 0.05$ for all comparisons). No significant differences of centring ratio were found at the other levels (from 4 to 11 mm from the apex) among the three groups.

PTN caused significantly larger diameter increases than HFCM ($P < 0.05$).

Canal transportations of the three groups at all 11 levels are shown in Figure 4. All of the groups presented canal transportations towards the outer side of the curvature at 1 mm and 2 mm from the apex. HFCM caused the least transportation among the three groups at 1 mm from the apex ($P < 0.01$ for both comparisons). At 2 mm from the apex, the highest transportation value was observed in the PTN group compared with HECM and HFEDM ($P < 0.05$ for both comparisons). No significant differences of transportation were found at other levels among the three groups. Overall, the HFCM file (0.001 ± 0.044) had the least canal transportation in curved root canals compared with the HFEDM (–0.036 ± 0.044) and PTN (–0.035 ± 0.033) files, but the differences were not statistically significant.

The centring ratios of the three groups at all 11 levels are shown in Table 1. All of the groups presented centring ratios < 1, which meant the occurrence of deviations of the root canal central axis after instrumentation. At the 1-mm level from the apex, HFCM presented a centring ratio significantly closer to 1 than PTN and HFEDM ($P < 0.05$ for both comparisons). HFEDM and HFCM were significantly better centred than PTN at the 2-mm and 3-mm levels from the apex ($P < 0.05$ for all comparisons). No significant differences of centring ratio were found at the other levels

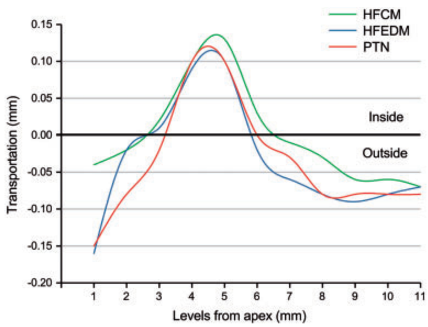

Figure 4. The direction and amount of canal transportation at the different measurement levels after instrumentation using ProTaper Next files (PTN), HyFlex^{TM} Controlled Memory (HFCM) files and HyFlex^{TM} EDM files (HFEDM). Values were calculated by subtracting the amount of resin removed at the inner side (concavity of the apical curvature) of the simulated canal from the amount of resin removed at the outer side. The colour version of this figure is available at: http://imr.sagepub.com.

(from 4 to 11 mm from the apex) among the three groups.

Discussion

In the choice of an endodontic file, the operator has to consider many factors, among which, restorability of the coronal structure remaining, curvature of the roots as well as their radii of curve, root thickness, pathological condition of the roots; and these factors are weighed against the characteristic of the instrument at cutting dentine to ensure safe preparation of the root canal to facilitate chemical disinfection.

Shaping ability is associated with achieving a continuous tapering canal shape, while centring ability refers to the ability of the axis of the file to be in-line with the axis of the canal during preparation and as such to cause no canal zipping, ledging or perforation.[17] Natural teeth are not perfect for comparisons between file systems. It has been argued that when natural teeth are used, the anatomical variations of these teeth affect the results more than the NiTi files.[18] The limitations of resin block simulated canals are acknowledged, although they have already been validated as satisfactory models for analysis of endodontic preparation techniques.[19–23] The resin blocks used in the present study were of radiopaque thermosetting epoxy resin. It is unlikely to be affected by heat and can be easily distinguished from the surroundings in microCT images, enabling precise measurements of different parameters and accurate repositioning.

It is important to have similar apical preparation diameters when comparing the shaping ability of different root canal instruments.[24] Simulated canals in the present study were prepared up to X2 (size 25, 0.06 taper in apical 3 mm) in the PTN group, 25/06 (size 25, 0.06 taper) in the HFCM group and 25/08 (size 25, 0.08 taper in apical 4 mm) in the HFEDM group. Having similar apical file sizes means that apical irrigation as well as file stiffness due to metal bulk would be more objectively comparable. Even so, the effects of metal bulk by the file design, such as a file with a larger taper, cannot be negated.

The correct cleaning and shaping of the apical zone are directly related to the success of the root canal treatment.[25] The apical transportation favours microorganisms and tissue remnants on the dentine walls, compromising disinfection as well as the sealing of the root canal system.[26] Of the files tested, HFCM had less transportation in the apical 2 mm and was better centred in apical 3 mm, which is in agreement with previous reports.[8,27] This shaping ability of HFCM files can be due to the increased flexibility, attributable to the thermal pre-treatment of the CM alloy during manufacturing making the alloy more ductile and thereby reducing the restoring forces.[8,28] The current study also found that HFEDM was better centred than PTN from 2 mm to 5 mm from the apex, although the differences were statistically significant only at the 2-mm and 3-mm levels from the apex. These current results partially agreed with a previous study,[29] in which the authors reported that in the bucco-lingual plane, HFEDM was better centred than PTN at every level including the most apical third median level. It was reported that deviation from the central axis by > 0.3 mm was considered to be clinically significant enough to affect the apical seal of root fillings and thus affect outcomes.[26] Based on the current findings, none of the files had transportation >0.3 mm, meaning that the three NiTi file systems are unlikely to cause deviations that affect clinical outcome. Thus, the three systems were clinically safe for the preparation of the apical region of the root canal, even when the HFEDM files were designed with a greater taper in their apical portion. This may be partially attributable to the thermal treatment that increases the flexibility of the NiTi alloy of CM-wire.

In relation to the enlargement produced by the three systems, significant differences were observed in the apical, middle and coronal portions. A greater volume increase in the apical portion was observed for HFEDM, which may be due to the fact that it has a 0.08 taper at the apical end. These current results also showed that the canal diameter was consistently wider in this group up to 7 mm from the apex. Irrigant volume change is important during root canal preparation, as this determines the total amount of available chlorine to disinfect the root canal. A bigger preparation of the root apex, in terms of both apical file size as well as apical taper, improves irrigation effectiveness by spreading the zone affected by irrigation pressure towards the apex.[30] It also means that the irrigating needle can be placed closer to the apex.

The smallest amounts of removed resin were observed for the HFCM in the coronal third of the root canals. This could be explained by the fact that this system has cross sections that result in their metal cores being small. Another factor that may be contributory to the conservative cutting format of HFCM instruments is the elongation of the pitch between the turns of the cutting stem of the file when it is subjected to tensile and compression stresses during the preparation of the root canals.[31] These characteristics may also explain the less enlargement of the canal prepared by HFCM from the 5- to 10-mm levels from apex (Table 1). It was noticed that PTN removed the least volume of resin in the apical third of the canal, which was synchronous with the smallest diameter increase. Conversely, PTN made the highest enlargement coronally (9 mm to 11 mm from the apex). These characteristics may be explained by its unique offset design that contributes to its two-point contact with the canal wall and swaggering motion in root canals. Operators must be cautious to limit the dentine removal in the coronal third, which is vital to maintain the strength of the final occlusal coverage restoration for a root canal-treated tooth.

Within the limitations of this study, the results presented can provide a useful to guide to file choice in clinical practice. The CM-wire instruments showed better centring ability, probably due to higher flexibility, than the M-wire instrument. It is reasonable to suggest that the improved flexibility of CM-wire or similarly heat-treated alloys could help to improve the root canal shaping qualities of files.

Dental clinicians design their root canal preparations through the choice of files. With a better understanding of the files, they may choose file combinations to suit the anatomy of the canal at hand, so as to achieve the objectives of enlargement and irrigation yet retaining sufficient dental tissues to prevent structural damage under normal stresses of function.

In conclusion, microCT is a valid technique to assess hard tissue removal by root canal instruments in a non-destructive way. The evaluated systems are technically safe to prepare curved canals. HFEDM caused greater volume increases than PTN and HFCM in the apical and middle thirds of the canal. HFCM stayed centred apically and cut the least material coronally.

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Declaration of conflicting interests

The authors declare that there are no conflicts of interest.

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