ORIGINAL RESEARCH

Shaping Ability of HyFlex EDM and ProTaper Next Rotary Instruments in Curved Root Canals: A Micro-CT Study

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Abstract

Aim: The aim of this study is to evaluate and compare the shaping ability of HyFlex™ EDM (HFEDM) and ProTaper Next (PTN) rotary instruments in curved root canals by using micro-computed tomography (micro-CT) imaging.

Materials and methods: A total of 22 mandibular molar teeth having separate mesial canals with 20 to 30° curvatures were randomly divided into two groups and instrumented with HFEDM (OneFile) or PTN (X1 and X2). Pre- and post-instrumentation micro-CT scans were obtained. Mesiodistal canal transportation and centering ability were evaluated in four cross-sections (2, 4, 6, and 8 mm from apex). Changes in canal volume and surface area were measured for a 10-mm standardized area of interest. Kolmogorov–Smirnov and Shapiro–Wilk tests were used to assess the normality and homogeneity. Independent and paired *t* tests and one-way ANOVA were used to analyze data at the $p < 0.05$ level.

Results: Compared to PTN, HFEDM showed significantly less mesiodistal canal transportation and improved centering ability in cross-section L6 ($p < 0.05$). The instruments showed similar increases in volume and surface area of the canals, with minor insignificant differences.

Conclusion: HFEDM and PTN files were safe to use in curved canals and showed similar shaping ability, while respecting the original anatomies. HFEDM OneFile performed better at the vicinity of the danger zone in terms of mesiodistal canal transportation and centering ability.

Keywords: Canal transportation, Centering ability, Curved canal, HyFlex EDM, Micro computed tomography, ProTaper Next.

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Introduction

Canal shaping in root canal treatment is a strategic phase aimed at removing pulp remnants, necrotic tissues, microorganisms, and debris, to prepare the canal for 3D root filling.[1] The shaping process should respect the original canal anatomy without changing the position of the apical foramen or excessively weakening the root.[2] However, canal transportation, zipping, ledging, or stripping can occur during preparation when using manual or rotary instrumentation techniques. Although NiTi rotary files reportedly maintain the original canal anatomy better than stainless-steel hand files,[3,4] instrumentation of severely curved canals remains challenging for most endodontic practitioners.[5]

To enhance the mechanical properties, performance, and safety of NiTi instruments, manufacturers have developed several new technologies, such as M-wire, R-phase, and the newly introduced controlled memory (CM) and proprietary thermal technology.[6] Thermal metallurgical processing and new instrument cross-sectional designs are considered major developments. ProTaper Next (PTN) (Dentsply Maillefer, Ballaigues, Switzerland) and HyFlex EDM (HFEDM) (Colténe/Whaledent, Altstatten, Switzerland) are examples of the latest generation of rotary instruments.

PTN is made of M-wire alloy and has an offset design, producing a "swaggering" effect. M-wire has higher flexibility and cyclic fatigue resistance than conventional NiTi.[2,7] Silva et al.[8] reported that PTN produced canal preparations that were more centered and had slightly higher apical transportation than canals produced by ProTaper Universal or WaveOne rotary instruments in simulated artificial curved canals. An off-centered rectangular cross-section with variable taper design (increasing to decreasing in the apicocoronal direction) reportedly enhances flexibility and debris removal, reduces engagement, and limits taper lock, screwing, and torque on any given file.[9]

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HFEDM is a third-generation single file that was introduced with an innovative manufacturing process using electric discharge machining (EDM) followed by CM treatment. CM is a proprietary metallurgical thermal treatment that reduces the shape memory of NiTi files[10] and enhances the flexibility and cyclic fatigue resistance of instruments.[11,12] The cross-sectional design of HFEDM instruments is variable, rectangular toward the tip and roughly triangular toward the shaft. In previous studies, these instruments showed very high resistance to cyclic fatigue compared to instruments produced by CM technology and M-wire.[11,13,14]

Numerous investigations have compared PTN to single-file systems; however, to the authors' knowledge, no study has investigated the shaping ability of the newly introduced HFEDM OneFile (25/0.08) in severely curved root canals. Therefore, the purpose of this study was to compare the shaping abilities of HFEDM and PTN rotary instruments in curved root canals by micro-computed tomography (micro-CT). The null hypothesis was that

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there would be no difference in shaping ability between these instruments.

METHODOLOGY

A total of 22 human mandibular first and second molars were selected from a pool of freshly extracted teeth. Selection criteria were as follows: teeth extracted for periodontal, prosthetic, or orthodontic reasons, having unfused mesial and distal roots, curved mesial roots, and mature apices. Teeth with root cracks, fractures, or external root resorption as confirmed by magnifying loops were excluded.

After being cleaned of debris and tissue remnants, teeth were placed in 5.25% NaOCl solution for 30 minutes. Digital radiographs of each tooth were taken at a standard position from the buccal and mesial views with a Heliodent MD X-ray unit (Siemens, Bensheim, Germany). Root curvature angles were measured in the buccolingual plane by using Image J software (Fiji) for teeth with a type IV "Vertucci" canal configuration. Teeth having moderate curvatures of 20–30° in mesial roots were included in the study. Teeth were stored in 0.1% thymol solution at 5 °C in separately labeled containers until time of use.

Specimen Preparation

All teeth preparation was conducted at the Faculty of Dentistry, King Abdulaziz University, Jeddah, Saudi Arabia. Straight-line access cavities were prepared in each tooth by high-speed diamond burs. Specimens were adjusted to a standard length of 18 ± 1 mm by decapitating crowns from the occlusal surfaces while using diamond discs under copious water-cooling. Patency of mesial canals was confirmed. An ISO size-10 K-file was inserted into the canal until it was observed at the apical foramen. Working length (WL) was calculated by subtracting 0.5 mm from that length. A smooth reproducible glide path was produced by using hand K-files up to size 15. The coronal 2 mm was preflared with size 1 and 2 Gates-Glidden drills (Dentsply Maillefer) in a crown-down manner. Specimens were randomly divided into two groups of 22 canals each and instrumented as follows. Each group included 11 mesiobuccal canals and 11 mesiolingual canals.

Group 1: HFEDM

According to the manufacturer's guidelines, HyFlex (25/0.08) OneFile was used to shape the root canal up to WL by the crown-down technique with full clockwise rotation. The X Smart Plus (Dentsply Maillefer) endodontic motor was used with a 16:1 reduction handpiece, a rotational speed of 400 RPM, and 2.5 N cm torque, as recommended by the manufacturer.

Group 2: PTN

ProTaper Next X1 (17/0.04) and X2 (25/0.06) files were used for shaping canals with a 16:1 reduction handpiece. The handpiece was powered by a preprogrammed X Smart Plus motor, which was set at 300 RPM and 4 N cm torque, according to the manufacturer's recommendations. The X1 file was used in a brushing motion, followed by irrigation and recapitulation before insertion of X2 to the full WL.

In both groups, a new file was used to prepare each canal. Canals were irrigated with 2 mL of 2.5% sodium hypochlorite (NaOCl) solution before and during instrumentation by using a 30-gauge side-vented needle (Hawe irrigation probe, Bioggio, Switzerland) in an intermittent manual flush technique. After instrumentation, canals were irrigated with 5 mL of 2.5% NaOCl followed by 5 mL of 17% ethylene-diamine-tetra-acetic acid (EDTA) applied for 60 seconds. Canals were rinsed with 2 mL of distilled water and dried with paper points.

Micro-CT Scanning and Study Parameter Calculations

All micro CT scanning and analysis were conducted at the College of Dentistry, Imam Abdulrahman Bin Faisal University, Dammam, Saudi Arabia. After resection of the distal roots, each sample was mounted in a custom-made resin holder (1 cm deep × 2 cm wide). Pre- and post-instrumentation images were scanned by using a SkyScan 1172 micro-CT scanner (Bruker, Luxemberg, Belgium) at a resolution of 8.99 µm. The volume of interest was set at 10 mm from the apical foramen for all specimens.[15] Images were reconstructed by NRecon Software (Bruker). Scanned images were evaluated for pre- and post-instrumentation at predetermined root canal cross-sections (2, 4, 6, and 8 mm from apex). The shaping ability was evaluated according to canal volume, surface area, transportation, and centering ability.

Canal Volume and Surface Area

Raw images of cross-section slices were reconstructed with SkyScan's NRecon version 1.6.4 software (Bruker) and saved as bitmap image (BMP) format. Then CTan v1.11.10.0 software (Bruker) was used for three-dimensional image reconstruction and measurement of the volume and surface area. The changes in root canal volume (ΔV/mm^3) and surface area (ΔS/mm^2) were calculated by subtraction of the pre- and post-instrumentation values and compared between the two tested shaping techniques.

Canal Transportation

Canal transportation was determined in the mesiodistal direction. Where X1 reveals the amount of dentin before instrumentation and X2 reveals the amount after instrumentation. Y1 reveals the distance from the furcation of the curved root to the periphery of the uninstrumented canal and Y2 reveals the distance from the inside of the curved root to the periphery of the instrumented canal. Mesial (X, Y) and distal (X, Y) dentin thicknesses were measured from pre- and post-instrumentation images in both groups at the four cross-sectional levels (2, 4, 6, and 8 mm from apex). Canal transportation at each level was calculated as described by Gambill et al.,[16] (Fig. 1), using the following equation: [(X1 – X2) – (Y1 – Y2)]. A transportation

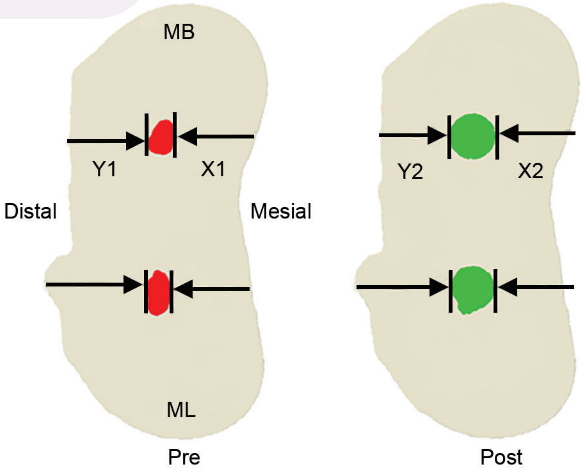


Fig. 1: Representative micro-CT coronal plane sample of a pre- and post-instrumentation depicting the measurement of mesial and distal dentin thicknesses according to Gambill et al.[16]

value of zero indicates no transportation; a positive value indicates transportation directed to the mesial side; and a negative value indicates transportation to the distal side of the canal.[16]

Centering Ability

Canal centering ability was determined in the mesiodistal direction at each cross-sectional level, by using the following equation:[16] $[(X1 - X2)/(Y1 - Y2)]$ or $[(Y1 - Y2)/(X1 - X2)]$. A centering ratio of one indicates perfect centering. The closer the ratio is to zero, the worse the ability of the instrument to maintain itself in the central axis of the canal (Fig. 1). The centering ability was defined as the ability of the file to remain in the center of the canal during the shaping cycle.[16]

Statistical Analysis

Data were analyzed by using the SPSS ver. 22 software package (SPSS Inc, Chicago, IL, USA). Kolmogorov–Smirnov and Shapiro–Wilk tests were used to assess normality of the data distributions. Data were presented as means ± standard deviations (SDs). Independent *t* tests were used to compare changes in volume, surface area, canal transportation, and centering ability between groups. Paired *t* test and one-way ANOVA for repeated measures were used to compare within groups for comparisons of more than two variables. The significance level was set at $p < 0.05$.

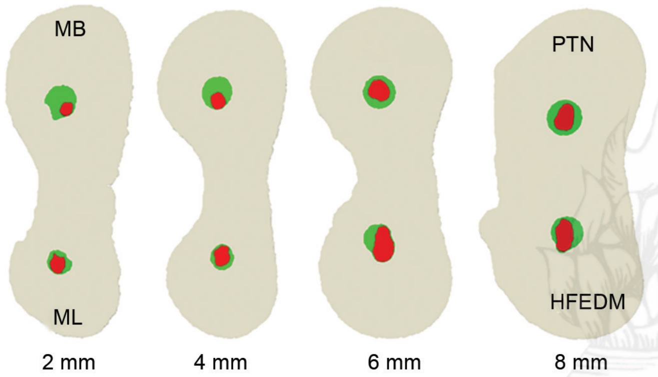


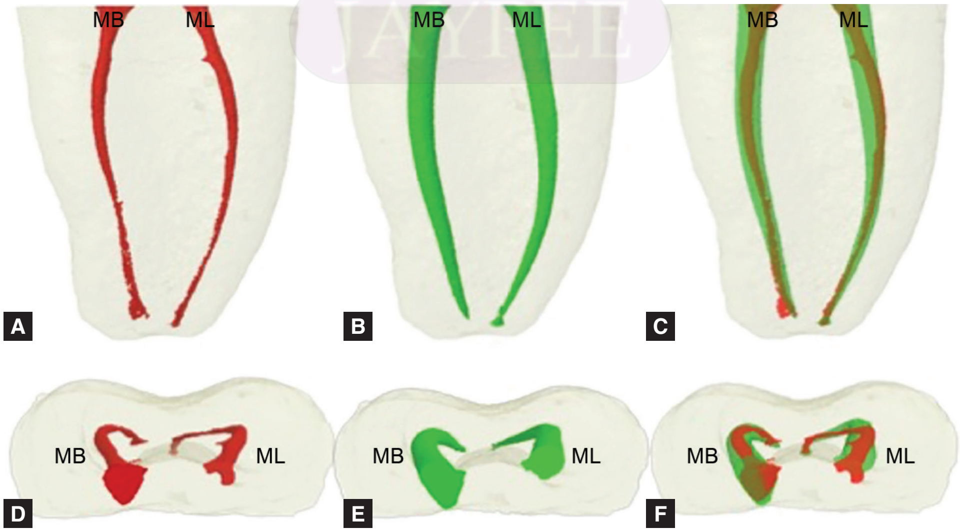
Fig. 2: Composite photograph of representative micro-CT coronal planes of superimposed samples. Pre-instrumentation canals are shown in red and post-instrumentation in green. In this sample, the upper canal (MB) was prepared by PTN X1 and X2 and the lower canal (ML) by HFEDM OneFile. Various degrees of transportation and centering ability can be seen at different cross-sections

RESULTS

No instrument fractured during instrumentation in either group. Figure 1 shows representative micro-CT coronal plane sample of a pre-and post-instrumentation depicting the measurement of mesial and distal dentin thicknesses. Figure 2 shows the composite photograph of representative micro-CT coronal planes of superimposed samples. Pre-instrumentation canals are shown in red and post-instrumentation in green. In this sample, the upper canal (MB) was prepared by PTN X1 and X2 and the lower canal (ML) by HFEDM OneFile. Various degrees of transportation and centering ability can be seen at different cross-sections. Figure 3 shows representative micro-CT images A–C of the mesial root of a mandibular molar in mesiodistal direction: canals before instrumentation (A), after instrumentation (B), and superimposed pre- and post-instrumentation images (C). Mesiobuccal canal was prepared by PTN X1 and X2 and the mesiolingual canal by HFEDM OneFile. In the three-dimensional images, original canal anatomy is depicted in red and shape produced by instrumentation is shown in green. Images D–E depict three-dimensional reconstruction of MB and ML canals from occlusal plane.

Canal Volume and Surface Area

Table 1 shows means and SDs for changes in root canal volume and surface area in both groups. Canal volume and surface area were higher after instrumentation than they were before instrumentation in both groups ($p < 0.05$). HFEDM produced greater changes in canal volume and surface area than PTN, but these differences were not significant.



Figs 3A to E: Representative micro-CT images (A–C) of the mesial root of a mandibular molar in mesiodistal direction. (A) Canals before instrumentation; (B) After instrumentation; and (C) Superimposed pre- and post-instrumentation images. Mesiobuccal canal was prepared by PTN X1 and X2 and the mesiolingual canal by HFEDM OneFile. In the three-dimensional images, original canal anatomy is depicted in red and shape produced by instrumentation is shown in green. Images (D–E) depict three-dimensional reconstruction of MB and ML canals from occlusal plane

Table 1: Changes (mean ± SD) in canal volume (mm^3) and surface area (mm^2) with different file systems

Groups	*Volume change (ΔV)*	*Surface area change (ΔS)*
HFEDM	2.689 ± 0.815	7.773 ± 3.849
PTN	2.326 ± 0.911	6.690 ± 4.960

Canal Transportation

Absolute values of the degree of canal transportation are presented in Table 2. Both file systems showed canal transportation at all tested levels ($p < 0.05$); with minimal transportation at the apical end (L2) and maximal transportation toward the coronal end (L8). Canal transportation was comparable between groups at L2, L4, and L8 (Table 2). At L6, lower transportation was detected for HFEDM than was observed for PTN ($p < 0.05$; Table 2). Most canals were transported toward the mesial side apically (+ve) and distal side coronally (−ve), with no significant differences between groups.

Centering Ability

Compared to PTN, HFEDM resulted in a more centered preparation at all tested levels (Table 3). A statistically significant difference was detected at L6, where HFEDM showed the highest centering ability ($p < 0.05$; Table 3). Differences between groups were small and not significant at any other level.

DISCUSSION

The present study evaluated the shaping ability of HFEDM and PTN files in curved canals using micro-CT. Based on the results, the null hypothesis that there is no difference in shaping ability between the two rotary instruments was rejected.

To the authors' knowledge, no study to date has evaluated the shaping ability of newly introduced HFEDM files in narrow curved canals. In a recent in vitro study, Venino et al.[17] investigated the shaping ability of HFEDM and PTN files. They considered both straight and wide canals of single- and multi-rooted teeth. Therefore, the results could not be compared directly to those of the present study, in which narrow and curved root canals were used.

In the present study, mesial roots of mandibular molar teeth with curvatures of 20–30°[18] were used to allow relative standardization of shape and curvature.[19,20] Such standardization has been recommended as an ideal model to evaluate and compare shaping abilities of different rotary instruments.[21] Comparable preoperative canal curvatures were utilized in most previous studies evaluating the shaping abilities of NiTi instrument systems.[22,23] The present investigation was based on the micro-CT scanning for the evaluation of the shaping ability of tested instruments. This method was recommended previously[16,24] and has been utilized by numerous studies.[8,17,25–28] Using a standardized nondestructive method for measurement facilitates later comparison between studies and helps in reaching a generalizable and dependable consensus.

Canal volume and surface area are parallel interdependent parameters that can give a full picture of the ability of a tested instrument to shape a larger volume and surface area, in terms of being gradually tapered and amenable for three-dimensional obturation.[8,26,29,30] The HFEDM group showed slightly greater changes in volume and surface area than the PTN group, but the differences were not significant. The HFEDM single file increased the canal volume and surface area to comparable levels as provided by the combined PTN X1 (#17/0.04) and X2 (#25/0.06) instrumentation. Previous studies comparing single-file systems (e.g., WaveOne Primary and OneShape) with PTN reported similar findings,[31,32] although the findings could not be generalized to all single-file designs. Madani et al.[31] found smaller canal volumes coronally when the NeoNiTi A1 single file was used compared to the ProTaper Universal multifile system.

Canal transportation of varying degrees from 100 to 200 μm has been observed when root canals are instrumented with rotary instruments.[5] Relatively less transportation was detected for both rotary instruments in this study, consistent with findings of previous studies evaluating the shaping abilities of HFEDM[17] and PTN.[2,8,17,27,31] A general trend of increased magnitude of canal transportation in the coronal direction was noted, in accordance with the findings of Gu et al.[33] They found that heat-treated NiTi instruments—specifically, Twisted Files (R-phase), WaveOne (M-wire), HyFlex CM, and V Taper 2H (CM-wire)—showed more transportation at coronal than at apical curvatures.

Statistically significant differences between the two instruments were observed for mesiodistal canal transportation and centering ability only in cross-section L6. This area represents the middle to coronal third of the root canal, where excessive removal of dentin (transportation) could result in weakening of the dentinal wall or stripping perforation.[17] Wu et al.[34] reported that transportation of more than 300 μm could compromise treatment outcomes. However, transportation values obtained here from both instruments were well below this 0.3 mm critical thickness.

Canal transportation and centering ability could be influenced by the flexibility, cross-sectional shape, and taper of instruments.[35] PTN X1 and X2 files present a variable taper design, with progressive tapering in the apical section and decreasing taper in the coronal section. HFEDM

Table 2: Transportation (mm) of the canals at different levels after instrumentation with tested files (mean ± SD)

	Canal transportation (mm from the apex)			
Groups	*L2*	*L4*	*L6*	*L8*
HFEDM	0.059 ± 0.045	0.113 ± 0.102	0.091 ± 0.068*	0.185 ± 0.122
PTN	0.068 ± 0.054	0.095 ± 0.070	0.137 ± 0.089*	0.199 ± 0.119

*Statistical significant difference ($p < 0.05$)

Table 3: Centering ratio of tested files at different measurement levels (mean ± SD)

	Centering ration (mm from the apex)			
Groups	*L2*	*L4*	*L6*	*L8*
HFEDM	0.52 ± 0.30	0.50 ± 0.32	0.63 ± 0.19*	0.47 ± 0.27
PTN	0.39 ± 0.31	0.47 ± 0.30	0.37 ± 0.27*	0.38 ± 0.25

*Statistical significant difference ($p < 0.05$)

OneFile (#25/0.08) has a decreasing taper design that starts 4 mm from the tip. The L6 cross-section was located 6 mm from the apex, which coincides with the greatest taper of the PTN files. Therefore, the significant difference in transportation observed at L6 could be related to the instrument taper.[17] Similar findings were reported in a study comparing the shaping abilities of the PTN, ProTaper Universal, and WaveOne instruments in L-shaped simulated root canals. PTN maintained the canal curvature with minimal apical transportation and the highest coronal transportation above the curvature.[36]

Transportation was directed mesially (+ve) at apical sections and distally (–ve) at coronal sections in both groups. PTN showed slightly higher values than HFEDM, but the differences were not significant. It may be that the PTN file has a higher tendency to straighten curved canals and causes transportation toward the furcation at the midcoronal level (distal) and toward the outer aspect of the curvature (mesial) at the apical 1–3 mm. A similar trend was reported for PTN in previous studies.[25,26,37,38]

HFEDM showed less transportation and better centering ability in all cross-sectional levels, although the difference from the PTN group was not significant. This finding is not surprising and could be
related to the greater flexibility of the HFEDM file
greater flexibility may be more suitable for the pre
curved root canals.[3] CM technology renders HyFle
than conventional NiTi and M-wire instruments
tapers.[12,39] On the one hand, Venino et al.[17] eval
abilities of HFEDM and PTN instruments in ext
files respected the original canal anatomy and s
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better centering than PTN in the middle and coro
canal curvature was not taken into considerati
study, similar shaping behavior was observed for
severely curved canals. On the other hand, Saber e
PTN caused significantly greater straightening of s
canals than HyFlex CM and iRaCe instruments. H
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of the study due to cost and financial issues. C
that only transportation in the mesial and dist
calculated while omitting the transportation
lingual direction.

CONCLUSION

HFEDM OneFile outperformed the PTN multifile system, producing less transportation and better centering at the 6 mm root level. Overall, HFEDM and PTN were safe and effective in curved canals and showed similar shaping ability while maintaining the original canal anatomies. Our results recommend using HFEDM in severely curved canals to avoid strip perforation.

CLINICAL SIGNIFICANCE

Based on the results of the study, it is recommended to use HFEDM in severely curved canals to avoid strip perforation and to maintain original canal curvature.

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