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Original Article

Evaluation of apical transportation and centering ability of three single-file systems in severely curved canals using micro-computed tomography

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ABSTRACT

Background: This study aimed to compare the apical transportation and centering ability of One Curve, HyFlex EDM, and EdgeFile X1 in curved mesiobuccal and mesiolingual canals of mandibular first molars.

Materials and Methods: In this *in vitro* experimental study, 60 mesiobuccal and mesiolingual canals of the mandibular first molars with a minimum length of 19 mm and 25°–40° curvature were randomly divided into three groups (n = 20) for root canal preparation with One Curve, HyFlex EDM, and EdgeFile X1. After access cavity preparation and confirming the glide path, the baseline micro-computed tomography (micro-CT) scans were obtained, and the root canals were instrumented with the respective systems according to the manufacturers' instructions. Apical transportation and centering ability were assessed at 1, 3, 5, and 7 mm from the apex by comparing pre- and postinstrumentation micro-CT scans. One-way ANOVA, independent t-test, and Duncan's *post hoc* test were used to statistically compare the groups, and data were analyzed by SPSS version 24 (alpha = 0.05).

Results: The three groups were not significantly different regarding apical transportation at 5 and 7 mm from the apex ($P > 0.05$). At 1 mm level, One Curve caused significantly lower apical transportation; while, at 3 mm level, HyFlex EDM resulted in significantly higher apical transportation ($P < 0.05$). No significant difference was noted in the centering ability of the three groups at 1, 3, and 5 mm from the apex ($P > 0.05$). At 7 mm level, EdgeFile X1 showed significantly lower centering ability ($P < 0.05$).

Conclusion: One Curve caused lower canal transportation in the apical third compared with EdgeFile and HyFlex EDM, but no significant difference was noted among the three in the coronal third of the roots.

Key Words: Root canal preparation, root canal therapy, X-ray microtomography

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INTRODUCTION

Cleaning and shaping of the root canal system is a fundamental step in endodontic treatment.[1] The quality of root canal shaping determines the efficacy and success of the subsequent steps to a great extent.

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Root canal instrumentation refers to mechanical debridement and shaping of the root canal system for the application of intracanal medicaments and subsequent root canal obturation.[2] Canal transportation is a common procedural error that may occur during root canal instrumentation. According to the American Association of Endodontists, canal transportation refers to the removal of the root canal wall from the outer side of the curvature in the apical half of the root, which occurs as the result of the tendency of the endodontic files to straighten up in curved canals.[3] Canal transportation changes the natural position of the apical foramen, compromises the integrity of the root canal system, decreases tooth resistance to fracture, and can eventually lead to root perforation.[4]

The rotary nickel-titanium (NiTi) files with increased flexibility and canal-centering ability were introduced to decrease the frequency of canal transportation and procedural errors, and are under constant development.[5]

In 2017, One Curve (Besançon, France) rotary system was introduced to the market by the Micro-Mega company. It is manufactured based on the CM-wire technology (known as C-wire) through heat treatment of the NiTi alloy. According to the manufacturer, the variable cross section of this file along with its continuous rotational movement is responsible for its high cutting efficiency while producing a centered preparation. This file preserves the original canal anatomy while performing efficient cleaning and shaping of the root canal system.[6]

HyFlex EDM (Coltene Whaledent) is another rotary system designed by the electrical discharge machining manufacturing technique. This technique increases the hardness of the file using spark erosion and enhances its fatigue resistance and cutting efficiency as such. Three cross sections are observed through the length of the cutting blade: a rectangular cross section at the apical third, a trapezoidal cross section at the middle third, and a triangular cross section at the coronal third.[7]

The EdgeFile X1 (EdgeEndo, Albuquerque, NM) reciprocal file is made of an annealed heat-treated alloy known as the FireWire, which has been shown to increase the cyclic fatigue resistance, torque strength, and centering ability of the file.[8]

Several methods are available for assessment of root canal morphology and quality of preparation, including obtaining histological sections, electron microscopy, radiography, micro-computed tomography (micro-CT), and cone-beam CT.[9] Micro-CT is a noninvasive and nondestructive imaging modality to obtain three-dimensional (3D) images and has been accepted as the gold standard for 3D assessment of the root canal system.[10]

To date, limited studies have evaluated the canal transportation and centering ability of single-file systems in curved canals. On the other hand, the assessment of procedural errors has always been an interesting research topic due to the time and cost spent for their correction and their impact on the final prognosis of treatment. Thus, this study aimed to compare the apical transportation and centering ability of One Curve, EdgeFile X1, and HyFlex EDM using micro-CT.

MATERIALS AND METHODS

The protocol of this *in vitro*, experimental study was approved by the Ethics Committee of Isfahan University of Medical Sciences (IR.MUI.RESEARCH.REC.1398.565). Sixty mesiobuccal and mesiolingual canals of 30 extracted mandibular first molars were selected for this study. The inclusion criteria were teeth with mature apices, root curvature between 25° and 40° according to Schneider's method,[11] minimum length of 19 mm, absence of canal calcification, and Vertucci's type IV anatomy (two separate canals). The teeth with visible cracks or fractures, previous endodontic treatment, or file fracture during root canal preparation were excluded.

The teeth were disinfected with 5.25% sodium hypochlorite and mounted in wax. Next, they underwent digital periapical radiography from the buccolingual direction from a 2 mm distance using the parallel technique. The mesial canal curvature was determined according to Schneider's method.[11] Teeth with root canal curvature between 25° and 40° (severe curvature) were selected and immersed in saline at 4°C until use.

The access cavity was prepared using a #4 cylindrical fissure bur (Dentsply Maillefer, Ballaigues, Switzerland). The mesiobuccal and mesiolingual canal orifices were negotiated using a #10 K-file (Dentsply Maillefer, Ballaigues, Switzerland). The teeth that did not allow the passage of a #10 K-file to the apical foramen were excluded and replaced. The working length was determined using a #10 K-file such that

the file was introduced into the canal until its tip was visible at the apex; 0.5 mm was subtracted from this length to determine the working length. A #15 K-file (Dentsply Maillefer, Ballaigues, Switzerland) was used to create a glide path in all canals, and then, a primary micro-CT was obtained from all teeth.

Micro-computed tomography scanning

Before micro-CT, the teeth were mounted on custom jigs for the purpose of standardization of their position during pre- and postintervention scanning. Next, all teeth underwent micro-CT (LOTUS-inVivo, Tehran, Iran) with the exposure settings of 80 kV, 95 μA, 30 μm resolution, 360° rotation around the longitudinal axis, 0.5° rotational step, and 0.5 mm aluminum filter. The obtained sections underwent 3D reconstruction with special 3D algorithms using Avizo software (Thermo Fisher Scientific, Berlin). Next, the teeth were randomly divided into three groups (n = 20). All teeth were prepared by the same operator (an endodontist). Each file of each system was used for the preparation of four canals and was then discarded.

Root canal preparation

After filling the pulp chamber with 5.25% sodium hypochlorite irrigating solution, cleaning and shaping were performed in the three groups as follows:

- Group 1: HyFlex EDM file with 8% taper and a tip size equal to that of a #25 file was used in a SILVER VDW motor operating at 500 rpm and 2.5 N/cm torque with continuous rotational movement for root canal preparation in this group. The file was introduced into the canal with gentle inward–outward movement. After proceeding toward the apical region by 3 mm, the file was removed from the canal, the flutes were cleaned with a gauze dipped in alcohol, and the canal was rinsed with 2 mL of 5.25% sodium hypochlorite followed by 0.5 mL of saline. The file was then reinserted into the canal. This process was repeated until the file reached the working length
- Group 2: One Curve file with 6% taper and a tip size equal to that of a #25 file was used in a SILVER VDW motor operating at 300 rpm and 2.5 N/cm torque with continuous rotational movement for root canal preparation in this group. The file was introduced into the canal with gentle inward–outward movement. After proceeding toward the apical region by 3 mm, the file was removed from the canal, the flutes were cleaned with a gauze dipped in alcohol, and the canal was rinsed with 2 mL of 5.25% sodium hypochlorite followed by 0.5 mL of saline. The file was then reinserted into the canal. This process was repeated until the file reached the working length
- Group 3: EdgeFile X1 file with 6% taper and a tip size equal to that of a #25 file was used with the Reciproc program in a VDW motor with reciprocal movement for root canal preparation in this group. The file was introduced into the canal with gentle inward–outward movement. After proceeding toward the apical region by 3 mm, the file was removed from the canal, the flutes were cleaned with a gauze dipped in alcohol, and the canal was rinsed with 2 mL of 5.25% sodium hypochlorite followed by 0.5 mL of saline. The file was then reinserted into the canal. This process was repeated until the file reached the working length.

Finally, to ensure root canal preparation with appropriate taper, a #25 gutta-percha with 6% taper was introduced into the canal. If it reached the working length, root canal preparation was found to be sufficient. In all three groups, the instruments were connected to a 16:1 handpiece and a Silver Reciproc electric motor (VDW, Munich, Germany). After root canal preparation, the teeth underwent micro-CT again with the same exposure settings as mentioned earlier.

Micro-computed tomography analysis

The apical end of the root canal observed on 3D images was considered as point zero. Next, according to the thickness of slices obtained by micro-CT (0.1 mm slice thickness), the sections at 1, 3, 5, and 7 mm from the apex were selected [Figure 1]. The changes in mesiodistal dimensions at 1, 3, 5, and 7 mm from the apex were recorded for all teeth. Apical transportation was then calculated according to the method described by Gambill *et al*.[12] using the formula below:

$$(a1-a2)-(b1-b2)$$

In this formula, a1 is the shortest distance between the mesial root border and the mesial border of the uninstrumented canal, a2 is the shortest distance between the mesial root border and the mesial border of instrumented canal, b1 is the shortest distance between the distal root border and the distal border of the uninstrumented canal, and b2 is the shortest distance between the distal root border and the distal border of the instrumented canal. In this formula, 0 indicates no apical transportation while negative

values indicate apical transportation toward the distal, and positive values indicate apical transportation toward the mesial.

Centering ability was evaluated using the (a1−a2)/(b1−b2) or (b1−b2)/(a1−a2) ratios. In these ratios, the smaller number was recorded as the standard for statistical analysis. Furthermore, a result of 1 in this formula indicates complete centering ability, while values other than 1 indicate deviation from the original central canal path.[12]

All the above-mentioned measurements were made at the aforementioned levels from the apex using ImageJ software (Fiji, Madison, WI, USA) by two examiners who were blinded to the group allocation of the teeth. The mean values were used for statistical analysis. To increase the measurement accuracy, the Find Edges filter of ImageJ software was applied to identify and outline the canal borders [Figures 2 and 3].

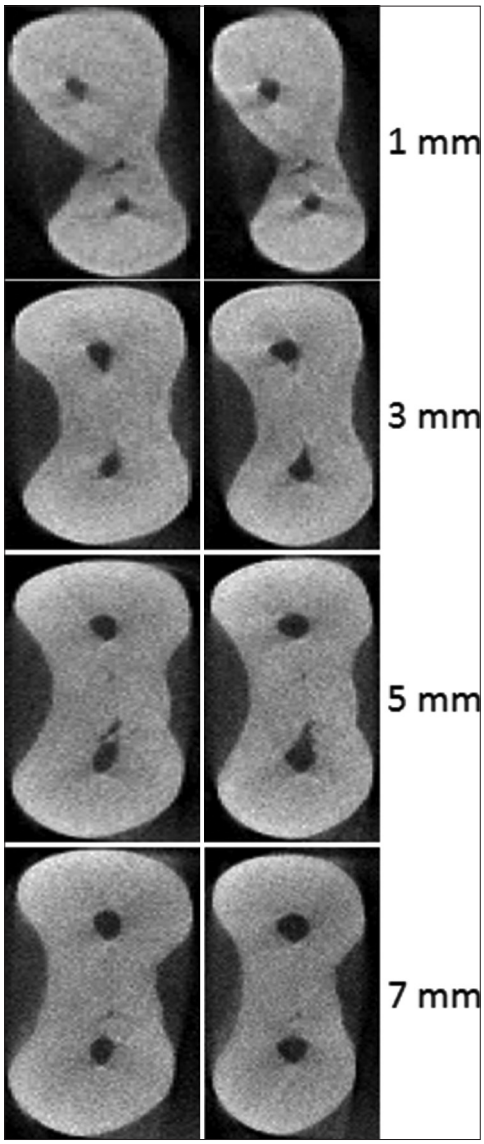

Figure 1: Micro-computed tomography scans of mesiobuccal and mesiolingual canal orifices before (left) and after (right) root canal preparation.

Statistical analysis

Data were analyzed by SPSS version 24 (SPSS Inc., Chicago, IL, USA). One-way ANOVA was used to compare the three groups at 1, 3, 5, and 7 mm from the apex regarding canal transportation and centering ability. In case of the presence of a significant difference among the groups, pair-wise comparisons were performed by Duncan's *post hoc* test. The independent *t*-test was used to compare the mesial and distal directions within each group. The level of statistical significance was set at 0.05.

RESULTS

Table 1 shows the mean and standard deviation of apical transportation at different levels from the apex in the three groups. At 1 and 3 mm levels from the apex, the One Curve rotary system yielded superior results regarding apical transportation. At 3 mm from the apex, the HyFlex EDM showed significantly higher apical transportation ($P < 0.05$). At 5 and 7 mm from the apex, the three groups were not significantly different regarding apical transportation ($P > 0.05$).

Diagram 1 shows the mean centering ability at different levels from the apex in the three groups. The three groups were not significantly different regarding centering ability at different levels from the apex ($P > 0.05$) except at 7 mm from the apex. At 7 mm level, EdgeFile X1 showed significantly lower centering ability ($P < 0.05$).

Table 2 presents the mean magnitude of canal transportation toward the mesial or distal in the three groups. Independent *t*-test revealed that the mean

Table 1: Comparison of the mean apical transportation (mm) at different levels from the apex among the three groups

Level from apex (mm)	EdgeFile X1		HyFlex EDM		One Curve		*P*
	Mean	SD	Mean	SD	Mean	SD	
1	0.172	0.038	0.136	0.028	0.076	0.020	0.04
3	0.125	0.032	0.200	0.035	0.082	0.017	0.02
5	0.134	0.032	0.135	0.022	0.106	0.031	0.72
7	0.136	0.028	0.133	0.027	0.132	0.024	0.99
P	0.77		0.38		0.16		-

SD: Standard deviation

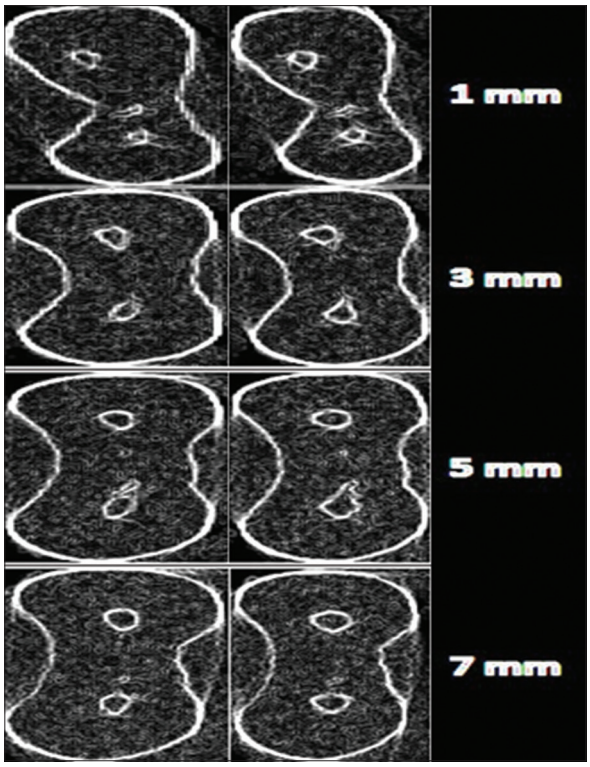

Figure 2: Micro-computed tomography scans of mesiobuccal and mesiolingual canal orifices before (left) and after (right) root canal preparation after applying the "Find Edges" filter in ImageJ software.

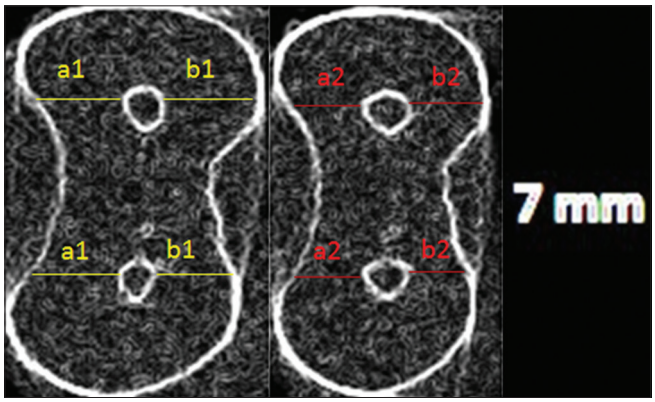

Figure 3: Measurement of a1, a2, b1, and b2 for the calculation of apical transportation and centering ability at 7 mm from the apex.

Table 2: Comparison of the mean transportation (mm) toward the mesial and distal in the three groups

Direction of deviation	EdgeFile X1		HyFlex EDM		One Curve	
	Mean	SD	Mean	SD	Mean	SD
Mesial	0.827	0.022	0.709	0.012	0.788	0.022
Distal	0.532	0.010	0.633	0.023	0.312	0.008
P	0.32		0.75		0.06	

SD: Standard deviation

apical transportation toward the distal or mesial was not significantly different among the three groups ($P > 0.05$); however, One Curve had a slightly higher tendency to cause transportation toward the mesial than the other two systems.

DISCUSSION

Single-file rotary systems are the most recent generation of engine-driven rotary file systems that can be divided into two groups with full rotation and reciprocal movement. The manufacturers claim that these systems are capable of complete cleaning and shaping of the root canal system with one main file. Evaluation of canal transportation and centering ability of the newly introduced rotary systems is important to provide dental clinicians with valuable information regarding the available endodontic rotary systems. By doing so, they can make a more informed decision regarding the selection of the most efficient and safest tool for root canal preparation.[13]

Root canal preparation is more difficult in curved canals because most instruments and techniques tend to transport the original canal path. All endodontic files are primarily fabricated of a straight hard metal wire, which results in nonuniform stress distribution at the contact area of the instrument with the canal. Thus, during root canal preparation, the file tends to straighten up in the root canal system, leading to ledge formation or even root perforation.[2,14]

Several techniques can be used for the assessment of the efficacy and performance of endodontic instruments in root canal preparation, including radiography, serial sectioning, cone-beam CT, and micro-CT.[15] Of the aforementioned techniques for the assessment of apical transportation and the efficacy of different instruments and preparation techniques for root canal shaping, micro-CT enables accurate 3D observation of the root canal system with adequately high resolution and precision. This imaging modality is highly accurate and does not require the destruction of specimens.[16]

This study evaluated the mesiobuccal and mesiolingual canals of mandibular first molars because the mandibular first molars more commonly require endodontic treatment. Furthermore, these canals often have curvature in two planes and mainly in the apical region, which is a risk factor contributing to the occurrence of apical transportation and root perforation. Their evaluation enables actual

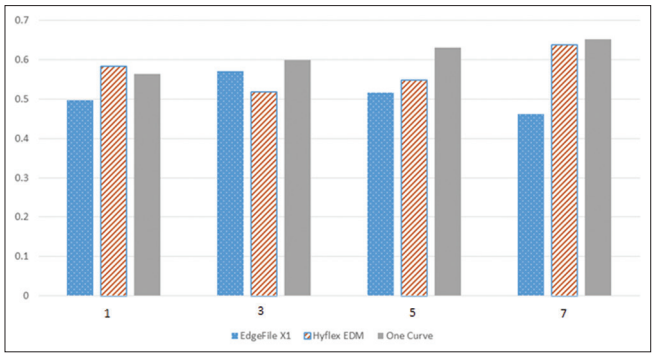

Diagram 1: The mean centering ability at different levels from the apex in the three groups.

assessment of the capabilities and characteristics of a file.[17,18]

Severely curved root canals (25°–40°) were evaluated in this study. This was done to assess the effect of severe root curvature, especially in the apical region (at 1 and 3 mm from the apex) on canal transportation and centering ability. All mesial canals were instrumented to file #25; this was a major prerequisite for the assessment of the shaping ability of the files.[19] This *in vitro* study compared the apical transportation and centering ability of One Curve, HyFlex EDM, and EdgeFile X1 in severely curved canals using micro-CT.

Hasheminia *et al*., in 2018, reported that EdgeFile X1 yielded superior results compared with WaveOne and Reciproc.[20] Thus, we selected EdgeFile X1 reciprocal file for the purpose of comparison with other rotary files. Previous studies compared the shaping ability of reciprocal files with rotary files, reporting controversial results. Some studies reported superior performance of reciprocal files,[21,22] while others reported poorer performance.[23,24] In the present study, EdgeFile X1 showed maximum apical transportation compared with the other two rotary files on the most apical section (closest to the root apex). It seems that the cross-sectional design of this file, in addition to its type of movement, results in greater canal transportation in the apical region.[25]

Regarding apical transportation, HyFlex EDM rotary files at 1 and 3 mm from the apex showed significantly poorer performance than One Curve; however, no significant difference was noted among the three file systems in other areas. This finding was in contrast to the results of three previous studies regarding this file.[26-28] This finding may be due to the more severe root curvature in the apical region of the teeth evaluated in the present study since previous studies either did not pay attention to root curvature as an inclusion criterion,[27,28] or considered moderate root curvature as an inclusion criterion.[26] Another reason for this result can be the taper of the HyFlex EDM file which is 0.08, while the other two files have a taper of 0.06.

In the present study, the One Curve rotary file yielded superior results regarding apical transportation at all levels from the apex compared with the other two file systems. This difference was more prominent in the apical region. It appears that the lower taper of this file (0.06), its asymmetrical cross-section, type of alloy (C-wire), and the thermal process of its production may be effective in decreasing canal transportation.[29,30]

The mean magnitude of apical transportation toward the mesial or distal was not significantly different among the three groups in the present study; however, all three groups showed greater deviation toward the mesial, which was in line with previous findings.[26,31] It appears that despite numerous attempts to increase the flexibility of the files, their tendency to straighten up in the root canal system still remains a predisposing factor to apical transportation toward the mesial (outer wall of curvature).

According to Kandaswamy *et al*., files with a noncutting tip, smaller cross-sectional area, and lower taper have superior centering ability.[32] In the current study, the three file systems had a significant difference in centering ability only at 7 mm from the apex, whereas EdgeFile X1 showed significantly lower centering ability. Overall, One Curve showed an averagely higher centering ability at all sections. Since all three file systems are made of NiTi, have a noncutting tip, and the taper of One Curve and EdgeFile X1 is the same, it seems that the larger cross-sectional area of EdgeFile X1 and the smaller cross-sectional area of One Curve are responsible for the obtained results.

Apical transportation >0.3 mm can compromise the treatment outcome since it would significantly decrease the sealing ability of the root canal filling.[33] In the present study, none of the tested files caused apical transportation >0.3 mm at any level from the apex; thus, they all can be safely used in curved canals.

CONCLUSION

Within the limitations of this *in vitro* study, the results revealed that the One Curve rotary file system yielded superior results compared with HyFlex EDM and EdgeFile X1 regarding apical transportation and centering ability. However, these results do not seem to make a dramatic clinical difference because the changes were within the acceptable range according to the literature.

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Conflicts of interest

The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or non-financial in this article.

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