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Geometric and Volumetric Changes Following Instrumentation with the One Curve and HyFlex EDM in Curved Root Canals: An In Vitro Micro-CT Study

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Abstract

Background

The study aimed to evaluate shaping ability and dentin preservation capacity of two advanced heat-treated NiTi systems in the mesial canals of mandibular molars using micro-CT.

Methods

Forty mesial root canals of human mandibular molars with moderate curvatures were randomly assigned to two groups (each group: n = 20). The specimens were scanned using micro-CT before and after instrumentation with either the One Curve or HyFlex EDM system. Canal transportation, centering ability, the percentage of removed dentin volume, and minimum remaining dentin thickness were analyzed at 3, 5, 7, and 9 mm from the apex. Data were statistically analyzed using the independent samples t-test and the Mann-Whitney U test ($p < 0.05$).

Results

Both file systems remained within the safe clinical threshold of 0.3 mm for canal transportation at all of the evaluated levels. At the 5-mm level (mid-root), the OC produced significantly less canal transportation compared to the HEDM ($p = 0.033$). At the 9-mm level (pericervical dentin), the One Curve achieved a higher median minimum dentin thickness (1.090 vs. 0.737 mm for the HEDM), preserving this area more conservatively. A significant negative correlation was observed between transportation and centering ability across all levels for both groups ($p < 0.05$). No significant differences were found between the systems regarding the percentage of removed dentin volume ($p > 0.05$).

Conclusion

Within the limitations of this study, both systems demonstrated a high degree of shaping safety. However, the One Curve exhibited a more conservative instrumentation pattern at the mid-root and PCD, aligning more effectively with the principles of minimally invasive endodontics.

INTRODUCTION

The success of root canal treatment depends on thorough chemomechanical debridement, which aims to eliminate microorganisms and preserve the structural integrity of the root dentin [1, 2]. This task becomes particularly challenging in narrow and moderate curved canals, such as those found in the mesial roots of mandibular molars. In such anatomies, the inherent tendency of NiTi instruments to straighten can lead to iatrogenic errors, such as canal transportation, ledging, and perforations, ultimately compromising the long-term prognosis of the tooth [3].

The evolution of NiTi rotary instruments has been marked by continuous metallurgical advancements aimed at overcoming these anatomical challenges. Among these, the HyFlex EDM (HEDM; Coltene/Whaledent, Switzerland), manufactured using electrical discharge machining (EDM), incorporates controlled memory (CM) wire technology, which provides exceptional flexibility and resistance to cyclic fatigue [4]. Conversely, the One Curve (OC; Micro-Mega, France) is a single-file system fabricated with C-wire technology. It is designed to preserve the original canal anatomy and minimize iatrogenic risks during complex preparations [5].

While chemomechanical debridement is essential for disinfection, the preservation of radicular dentin during canal preparation remains a critical determinant of long-term tooth survival, particularly concerning resistance to vertical root fractures [6, 7]. Excessive dentin removal, especially in the pericervical dentin (PCD; 1–4 mm below the cementoenamel junction (CEJ)), compromises the biomechanical integrity of the root because his region concentrates the highest functional loads and is therefore a biomechanically critical zone [8]. Consequently, a comprehensive safety assessment of any shaping protocol must extend beyond volumetric changes and include the evaluation of minimum remaining dentin thickness (RDT) at multiple root levels to provide a more clinically reliable indicator of fracture resistance [9].

Although the shaping performance of various NiTi systems has been extensively documented, direct comparative data that address the effects of the HEDM and OC in curved mandibular molars remain limited [1, 10]. To the best of our knowledge, no studies have simultaneously evaluated volumetric dentin changes and minimum RDT across four distinct anatomical levels, including the 9-mm level (PCD), following instrumentation with these two systems. This lack of evidence represents a significant gap in understanding how hese two heat-treated NiTi systems preserve radicular integrity in naturally curved canals.

Therefore, this micro-computed tomography (micro-CT) study aimed to compare the shaping performance and dentin preservation capacity of the OC and HEDM instruments in the mesial canals of mandibular first molars exhibiting moderate curvature (25°–35°). Canal transportation, centering ability, volumetric dentin loss, and minimum RDT were evaluated at 3, 5, 7, and 9 mm from the apex. The null hypothesis was that there would be no significant difference between the two systems for any of these variables.

MATERIAL AND METHODS

Sample Selection and Standardization

Ethics approval

for this *in vitro* study was obtained from the local research ethics committee before commencement. The sample size was calculated using G*Power software (version 3.1.9.7; Heinrich Heine University, Düsseldorf, Germany). When an effect size of 0.93 was anticipated for the comparison of two groups at a 95% confidence level (= 0.05) and 80% power (= 0.20), the minimum required sample size was determined to be 20 canals per group. A total of 40 canals (20 per group) was included in the study to ensure statistical validity, following the methodology of a similar shaping ability study in the literature [11].

Twenty freshly extracted human mandibular first molars with fully formed apices were selected. Only teeth with two separate mesial canals and separate apical foramina (Vertucci type IV configuration) were included. Teeth with previous endodontic treatment, root resorption, root fractures, calcifications, merged canals, or other anatomical irregularities were excluded. Initial canal morphology was assessed using digital periapical radiographs obtained in both the buccolingual and mesiodistal directions. Canal curvature was measured according to Schneider's method using ImageJ software (National Institutes of Health, Bethesda, MD, USA), and only teeth with moderately curved canals were included [12]. To improve the anatomical standardization among specimens, only teeth with similar mesial root lengths, measured from the CEJ to the apex, were selected.

Access Preparation and Working Length Determination

Standard endodontic access cavities were prepared using round diamond burs and refined with an Endo-Z bur (Dentsply Sirona, Ballaigues, Switzerland). The mesiobuccal (MB) and mesiolingual (ML) canals were explored using a size 10 K-file (Dentsply Maillefer, Switzerland) to confirm patency. The working length (WL) was established by advancing the file until its tip was just visible at the major apical foramen under 10× magnification and then subtracting 0.5 mm from this measurement. Canals with an initial apical diameter larger than a size 10 K-file were discarded. Specimens were randomly divided into two equal experimental groups (n = 20).

Root Canal Preparation

All canal preparations were performed by a single experienced operator to eliminate inter-operator variability, in accordance with the manufacturers' recommendations. The files were operated by a torque-controlled endomotor (WaveOne Gold, Dentsply Sirona, Ballaigues, Switzerland). In the OC group, coronal preflaring was performed with a OneFlare (25/.09; Micro-Mega, Besançon, France) at 300 rpm and 2.5 Ncm. A glide path was then established to full WL using a One G (17/.03) at 300 rpm and 1.2 Ncm, followed by canal preparation with the OC (25/.06) using gentle pecking motions to the full WL at 300 rpm and 2.5 Ncm.

For the HEDM group, coronal enlargement was first performed with the EDM Orifice Opener (25/.12; Coltene/Whaledent, Altstätten, Switzerland) at 400 rpm and 2.5 Ncm torque. Glide path preparation was then completed to the full WL using the EDM Glidepath File (10/.05, 21 mm) at 300 rpm and 1.8 Ncm torque, after which the canal was shaped to the full WL with the EDM OneFile (25/.~) at 400 rpm and 2.5 Ncm torque.

The instruments were advanced apically using light vertical strokes with an amplitude of 2–3 mm until the WL was achieved. After every three pecking cycles, the file was withdrawn from the canal to debride its flutes with sterile gauze. To maintain instrumentation safety and prevent instrument fatigue, each file was restricted to the preparation of only one tooth (two canals) and subsequently discarded. During instrumentation, 2.5% sodium hypochlorite was used for irrigation between each file cycle, and 17% EDTA gel served as a lubricant. Patency was maintained by recapitulation with a size 10 K-file. After completion of shaping, a final irrigation protocol consisting of 5 mL of 17% EDTA followed by 5 mL of 2.5% NaOCl was performed, and the canals were dried with sterile paper points.

Micro-CT Scanning and Image Processing

For reproducible pre- and post-instrumentation imaging, each tooth was mounted in silicone impression material within a custom holder to ensure standardized repositioning during scanning. Samples were scanned using a SkyScan 1172 micro-CT unit (Bruker, Kontich, Belgium). Projection images were reconstructed using NRecon software (Ver. 1.6.10.5, Bruker) with standardized beam-hardening and ring artifact correction settings. Reconstructed images were imported into DataViewer software (Ver. 1.6.0.0, Bruker) for co-registration of the pre- and post-instrumentation datasets. The postoperative scan was carefully aligned with the preoperative scan to ensure accurate spatial comparison. Subsequently, all datasets were analyzed using CTAn software (Ver. 1.16.4.1+, Bruker). Three-dimensional volume rendering visualization of the root canal systems were performed using CTvox software (Ver. 3.3.1, Bruker).

Evaluation of Parameters

Canal transportation and centering ratio

The canal transportation and centering ratio were evaluated at 3, 5, 7, and 9 mm from the apical foramen on axial cross-sectional images using the method described by Gambill et al [13]. Measurements were performed in the

mesiodistal direction by recording the shortest distance from the mesial and distal external root surfaces to the corresponding canal walls before and after instrumentation (Fig. 1a-h). Canal transportation was calculated using the formula (m1 − m2) − (d1 − d2), whereas the centering ratio was calculated as (m1 − m2)/(d1 − d2) or (d1 − d2)/(m1 − m2), with the smaller value used as the numerator. A transportation value of 0 indicated no deviation from the original canal path, whereas values approaching 1 for the centering ratio indicated superior centering ability.

Dentin volume change and minimum remaining dentin thickness (RDT)

Overall dentin volume was evaluated using pre-instrumentation and post-instrumentation micro-CT scans. Dentin volume reduction was calculated by subtracting the post-instrumentation dentin volume from the pre-instrumentation dentin volume and expressing the result as a percentage of the initial dentin volume using the following formula:

Dentin volume reduction (%) = [(pre-instrumentation dentin volume − post-instrumentation dentin volume) / pre-instrumentation dentin volume] × 100.

This parameter was used to quantify the amount of dentin removed during canal preparation. In addition, minimum RDT was assessed at 3, 5, 7, and 9 mm from the apex. At each level, the shortest distance from the canal wall to the external root surface was measured in millimeters, and the smallest value was recorded for analysis.

All measurements were performed by a calibrated examiner blinded to group allocation. To assess intraobserver reproducibility, measurements were repeated in 20% of the sample after a two-week interval, and the agreement between measurements was evaluated using the intraclass correlation coefficient.

Statistical Analysis

All statistical analyses were performed using R software (version 4.5.0, R Foundation for Statistical Computing, Vienna, Austria). Data distribution was assessed using the Shapiro-Wilk test. For normally distributed variables, intergroup comparisons were performed using the independent samples t-test; for non-normally distributed variables, the Mann-Whitney U test was used. Quantitative data were presented as mean ± standard deviation for parametric variables and median (minimum–maximum) for nonparametric variables. Statistical significance was set at $p < 0.05$. Effect sizes were reported together with 95% confidence intervals.

RESULTS

Canal Transportation and Deviation

The mean canal transportation values for the HEDM and OC systems are summarized in Table 1. Overall, both file systems exhibited low mean transportation values (< 0.20 mm) at all evaluated levels, and no specimen exceeded the 0.3-mm threshold considered critical for clinical prognosis. No statistically significant differences were observed between the groups at the 3-mm (apical), 7-mm (middle), or 9-mm (coronal) levels ($p > 0.05$). However, at the 5-mm level, the HEDM (0.103 ± 0.080 mm) produced significantly greater canal transportation compared to the OC (0.059 ± 0.064 mm) ($p = 0.033$).

Table 1
The Mean, Standard Deviation, Minimum and Maximum values of the transportation for each system

Level	HyFlex EDM				OneCurve				T value	P value	Effect size
	Mean	SD	Median	Range	Mean	SD	Median	Range			
3mm	0,080	0,086	0,048	0,002 – 0,336	0,046	0,039	0,030	0,010 – 0,135	-1,312	0,190	0,424
5mm	0.103	0.080	0.070	0.010–0.259	0.059	0.064	0.040	0.010–0.300	−2.137	**0.033***	0.718
7mm	0.126	0.151	0.106	0.010–0.710	0.081	0.067	0.055	0.002–0.230	−0.933	0.351	0.298
9mm	0.138	0.094	0.135	0.010–0.305	0.183	0.132	0.165	0.009–0.540	−1.232	0.226	−0.390

Unpaired t-test and Mann–Whitney U test were used according to data distribution. Values are presented as mean ± standard deviation (SD), median, and range. Effect size is expressed as Cohen's d. *p < 0.05, statistically significant.*

Transportation deviation followed a distinct anatomical pattern (Fig. 2). At the 3-mm level, the deviation was balanced between the mesial and distal aspects. At the 5-mm level, distal transportation predominated in both groups (70%), indicating a shift toward the "danger zone" of the MB root. Conversely, at the 9-mm level, both systems showed a strong tendency toward mesial transportation (85%), representing a deviation toward the "safety zone," or outer curvature.

Centering Ability

The results for centering ability are presented in Table 2. Both instrumentation systems demonstrated comparable centering ratios at the 3-, 7-, and 9-mm levels ($p > 0.05$). At the 5-mm level, although the OC group showed a higher mean centering ratio than the HEDM group (0.688 ± 0.173 vs. 0.567 ± 0.211), this difference was near the threshold of statistical significance ($p = 0.054$).

Table 2
The Mean, Standard Deviation, Minimum and Maximum values of the centering ratio for each system Unpaired t-test and Mann–Whitney U test were used according to data distribution. Values are presented as mean ± standard deviation (SD), median, and range. Effect size is expressed as Cohen's d with 95% confidence intervals. *p < 0.05 was considered statistically significant.*

Level	HyFlex EDM				One Curve				Test value	P value	Effect size
	Mean	±SD	Median	Range	Mean	±SD	Median	Range			
3mm	0,635	0,226	0,655	0,217-0,982	0,616	0,241	0,730	0,080 – 0,941	-0,135	0,892	0,043
5mm	0,567	0,211	0,562	0,276-0,875	0,688	0,173	0,750	0,301-0,935	-1,993	0,054	-0,630
7mm	0,609	0,177	0,587	0,314-0,971	0,618	0,252	0,661	0,167-0,972	-0,130	0,898	-0,041
9mm	0,549	0,231	0,474	0,296-0,948	0,427	0,283	0,414	0,032 – 0,961	-1,298	0,194	0,420

Correlation between Transportation and Centering Ability

The relationship between canal transportation and centering ability was assessed using Spearman's rank correlation (Table 3 and Fig. 3). A significant negative correlation was found between the two parameters at all root levels for both file systems ($p < 0.05$). For the HEDM group, the strongest negative correlation was recorded at the 5-mm level ($r = -0.932$, $p < 0.001$). For the OC group, high correlation values were noted at the 7-mm ($r = -0.907$) and 9-mm ($r = -0.806$) levels. The scatter plots (Fig. 2) visually confirmed this inverse relationship, indicating that as canal transportation increased, the centering ability of the instrument significantly decreased.

Table 3
The correlation between canal transportation and centering ability of the HyFlex EDM and One Curve groups.

Level	HyFlex EDM		One Curve	
	r value	p	r value	p
3mm	-0,780	< 0,001	-0,780	< 0,001
5mm	-0,932	< 0,001	-0,726	< 0,001
7mm	-0,672	0,001	-0,907	< 0,001
9mm	-0,565	0,009	-0,806	< 0,001

Spearman's rank correlation coefficient (r) was used to assess the relationship between canal transportation and centering ability due to non-normal data distribution. Statistical significance was set at p < 0.05.

Dentin Volume Change and Remaining Dentin Thickness (RDT)

The percentage of removed dentin volume change increased progressively from the apical toward the coronal levels in both groups (Table 4). No statistically significant differences were detected between the OC and HEDM groups regarding the percentage of dentin removal at any of the evaluated levels ($p > 0.05$), and the effect sizes remained small to moderate.

Table 4
Dentin volume change (V%) at different root levels

Level (mm)	Group	Mean ± SD	Median (Min–Max)	p	Effect Size (95% CI)
3 mm	HyFlex EDM	1.63 ± 1.926	1.145 (0.143–6.585)	0.706	0.170 (-0.711–1.046)
	One Curve	1.568 ± 1.894	0.769 (0.115–6.047)		
5 mm	HyFlex EDM	2.082 ± 1.526	1.894 (0.099–5.867)	0.762	0.136 (-0.744–1.011)
	One Curve	1.846 ± 0.811	1.733 (0.817–3.129)		
7 mm	HyFlex EDM	2.562 ± 1.338	2.675 (0.301–5.302)	0.512	0.299 (-0.587–1.177)
	One Curve	2.203 ± 1.045	1.767 (0.708–4.011)		
9 mm	HyFlex EDM	2.999 ± 1.481	3.082 (0.698–5.951)	0.406	0.379 (-0.512–1.258)
	One Curve	2.766 ± 0.786	2.485 (2.051–4.36)		

Values are presented as mean ± standard deviation (SD) and median (min–max) / mean ranks where appropriate. Group comparisons were performed using the independent samples t-test for normally distributed data and the Mann–Whitney U test for non-normally distributed data. Effect size is expressed as Cohen's d with 95% confidence intervals. *Statistical significance was set at p < 0.05.*

The minimum RDT values showed that both systems provided comparable dentin thickness at the 3-mm and 5-mm levels. Importantly, at no level did the RDT values fall below the critical threshold for root integrity. At the 9-mm level, the OC exhibited a higher median RDT (1.090 mm) compared to the HEDM (0.737 mm), suggesting more conservative preservation of the critical tooth structure in the coronal region.

DISCUSSION

Mandibular molars are among the teeth that most commonly require endodontic treatment [14]. Thus, the quality of root canal preparation in these teeth is an interesting topic of research. The mesial canals of these teeth often have mesiodistal and/or buccolingual curvatures. Due to more severe curves in the MB canal, this canal is highly susceptible to transportation during mechanical preparation by endodontic instruments. Maintaining the original canal path is particularly challenging in such curved systems, where the inherent restoring forces of endodontic files tend to straighten the canal, which results in an unintended deviation known as canal transportation. Such deviations not only weaken the root structure but also compromise the quality of subsequent irrigation and three-dimensional obturation. In the present study, the shaping ability and dentin preservation capacity of two advanced heat-treated NiTi systems, the HEDM and OC, were compared using micro-CT, which is widely accepted as the gold standard for the non-destructive, three-dimensional assessment of internal tooth anatomy.

The primary goal of root canal instrumentation is to achieve effective debridement while preserving the original canal anatomy. In the present study, both the HEDM and OC systems demonstrated mean canal transportation values below 0.2 mm at all of the evaluated levels, indicating a high level of shaping safety. This finding is clinically relevant because previous studies suggested a critical threshold for apical transportation. Wu et al. reported that apical transportation exceeding 0.3 mm may adversely affect the apical seal and compromise treatment outcomes [15]. Notably, none of the roots in the present study exceeded this threshold, suggesting that both systems are capable of maintaining canal integrity even in curved canals. Therefore, the results support the safe clinical use of both the HEDM and OC systems in terms of minimizing procedural errors related to canal transportation.

The HEDM is manufactured using EDM technology and is based on CM wire to provide enhanced flexibility. On the other hand, the OC is produced using C-wire heat treatment to offer controlled-memory characteristics [1]. Despite these advanced metallurgical properties, the geometric design of the instruments may explain the observed difference. When the shaping performance across various anatomical root levels was examined, site-specific variations emerged that underscored the significant influence of instrument design. At the 5-mm level, the OC system demonstrated significantly less canal transportation compared to the HEDM ($p < 0.05$). Notably, distal transportation predominated in both groups at this level (70%), indicating that the observed deviations were directed toward the furcal aspect of the mesial root—the anatomical region Abou-Rass et al. defined as the “danger zone” where the distal wall thickness is inherently minimal and the risk of strip perforation is highest [16].

More recently, Alovisi et al. reported that the presence of a danger zone below the furcation must be carefully considered during shaping because even instruments with advanced metallurgical properties may compromise this anatomically vulnerable region when a higher taper is employed, thereby underscoring the clinical significance of furcal deviations at the mid-root level [17]. This finding reflects the interdependent relationship between an instrument’s metallurgical properties and its geometric architecture. While both systems employ advanced thermal treatments to enhance flexibility, their mechanical behavior is inherently linked to their cross-sectional dimensions [18].

Recent research by Cordova et al. indicated that while phase transformations predominantly influence cyclic fatigue resistance, the instrument’s core diameter remains a primary determinant of its flexural stiffness [18]. In the present study, the higher transportation observed with the HEDM at the mid-root level can be explained by this principle; its

larger variable taper inherently resulted in a greater metallic core mass at the 5-mm level compared to the slender constant .06 taper of the OC [19]. This suggested that the inherent flexibility provided by advanced metallurgy may be suppressed by the file's geometric stiffness as the core diameter increases coronally.

In the present study, a significant negative correlation was observed between canal transportation and centering ability at all root levels for both file systems. This inverse relationship confirmed a fundamental biomechanical rule: As the amount of canal transportation increased, the instrument's ability to remain centered within the root canal space decreased significantly [3]. These findings align with the results of previous studies that utilized the formulas proposed by Gambill et al., thereby highlighting that the shaping predictability of advanced NiTi instruments is directly linked to their ability to resist lateral restoring forces.[13] Consistently, the centering ability results at the 5-mm level followed a parallel pattern, with the OC demonstrating a higher mean centering ratio than the HEDM (0.688 ± 0.173 vs. 0.567 ± 0.211), although this difference did not reach statistical significance ($p = 0.054$). Soliman et al. similarly reported this inverse relationship between transportation and centering ability in curved canals instrumented with the HEDM, thereby reinforcing the idea that these two parameters are inherently interdependent indicators of shaping performance [4].

Regarding the percentage of removed dentin volume, no statistically significant differences were found between the HEDM and OC groups at any of the evaluated levels. This outcome suggested that both systems exhibited similar cutting efficiencies, likely due to their advanced heat-treatment processes that balance flexibility and debridement capacity. The location on the mesial and distal canal walls where the thinnest RDT value was measured was also recorded. Maintaining adequate RDT is vital; Silva et al. demonstrated that reduced dentin thickness is significantly associated with an increased risk of vertical root fracture in endodontically treated teeth [20].

Beyond the overall volume changes, a more detailed analysis revealed site-specific advantages in dentin preservation, particularly at the 9-mm level, representing the PCD. Clark and Khademi defined this area as the "mechanical critical zone," describing it as roughly 4-mm coronal and 4-mm apical to the crestal bone, where preserving at least 1 mm of dentin is essential for the long-term functional resistance of the tooth [21]. At this level, the OC exhibited a higher median RDT (1.090 mm) compared to the HEDM (0.737 mm). This notable difference can be attributed to the synergistic effect of the system components. While the HEDM protocol utilizes a relatively aggressive .12 taper orifice opener, the OC system employs a more conservative .09 taper OneFlare. Since these auxiliary instruments are integral to their respective clinical protocols, their design directly influences the 'mechanical critical zone.' The inherent design of the OC pre-flaring protocol appears to align more closely with the goals of minimally invasive endodontics by avoiding excessive cervical dentin removal associated with larger taper openers. Consequently, the slender profile and .06 constant taper of the OC provided a more conservative approach in the coronal third, thus adhering to the principles of minimally invasive endodontics more effectively than the larger coronal mass of the HEDM. These relatively low RDT values at the coronal level were consistent with the inherent anatomical characteristics of mandibular molars. Vorster et al. reported that the thinnest RDT occurred in mandibular first molar mesial roots at levels 1–4 mm below the CEJ, indicating that this region represents an anatomically vulnerable zone regardless of the instrumentation system used [22]. Consequently, due to the significant variations observed at both the 5-mm and 9-mm levels, the null hypothesis was rejected.

Collectively, these findings indicated that while both the HEDM and OC remained within clinically acceptable transportation limits, their distinct metallurgical and geometric characteristics differentially influenced volumetric dentin removal and minimum RDT, which are determinants of particular relevance to the long-term structural integrity of mandibular molar roots. The more conservative instrumentation pattern observed with the OC at the mid-root and PCD levels highlights the importance of slender file geometry in minimally invasive endodontics.

CONCLUSION

Within the limitations of this *in vitro* study, both the HEDM and OC demonstrated clinically acceptable shaping performance in severely curved mesial canals, with canal transportation values remaining below the critical threshold at all of the evaluated levels. However, the OC exhibited superior centering ability and more conservative dentin preservation in the PCD, suggesting its potential advantage in minimally invasive endodontic approaches. Of particular clinical concern, the HEDM produced a median RDT below the critical 1-mm threshold at the 9-mm level, and the potential implications of this finding on long-term cervical root fracture resistance should be addressed in prospective clinical studies. Further research that incorporates microbiological efficacy, irrigant penetration, and long-term fracture resistance outcomes is also needed to validate these findings under in vivo conditions.

Declarations

Ethics approval

This study was approved by Inonu university Non-Interventional Clinical Research Ethics Committee 2018/21 – 1, 20.11.2018. The study was conducted in accordance with the Declaration of Helsinki and relevant guidelines and regulations. The requirement for informed consent was waived by the Inonu university Non-Interventional Clinical Research Ethics Committee because the study used anonymized extracted teeth that would otherwise have been discarded.

Consent to particiapte

Not applicable

Consent for publication

Not applicable

Competing interests

The authors declare that they have no competing interests.

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Author Contribution

L.A., N.S., E.B. conceived and designed the study. L.A. collected and prepared the samples. L.A. and E.B. performed the endodontic instrumentation. L.A. performed the micro-CT scanning and image analysis. N.S. performed the statistical analysis. L.A. and E.B. wrote the main manuscript text. L.A. and N.S. prepared the figures and tables. All authors reviewed and approved the final manuscript.

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Data Availability

The datasets generated and analysed during the current study (Micro-CT measurements of geometric parameters and volume before and after instrumentation) are not publicly available but are available from the corresponding author on reasonable request.

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Figures

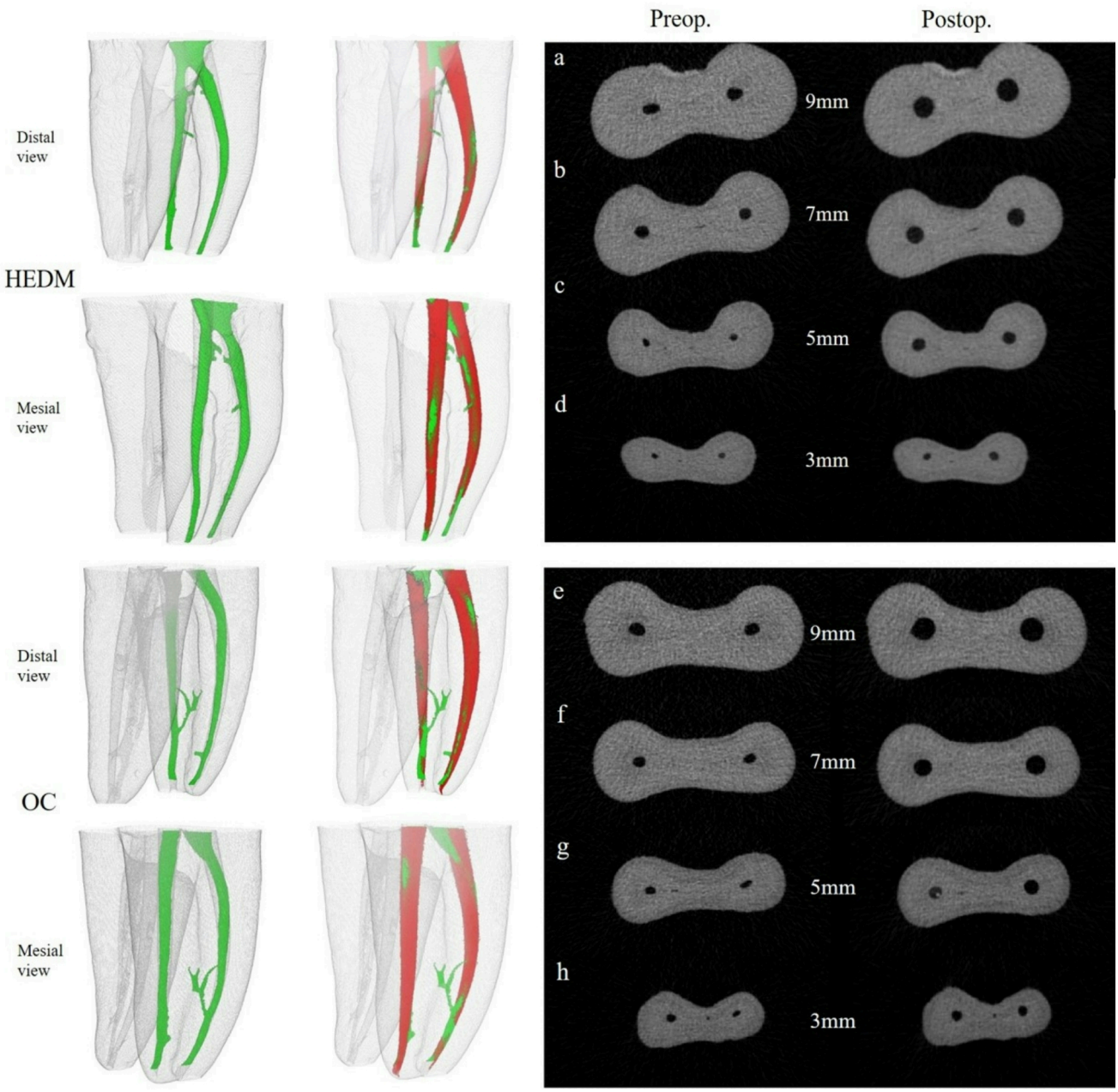


Figure 1

Representative samples of superimposed micro-CT images showing the effect of canal preparation with the **OC and HEDM** systems at different levels (green: preoperative canal, red: postoperative canal). (a-d) HEDM: 3, 5, 7 and 9 mm. (e-h) OC: 3, 5, 7 and 9 mm.

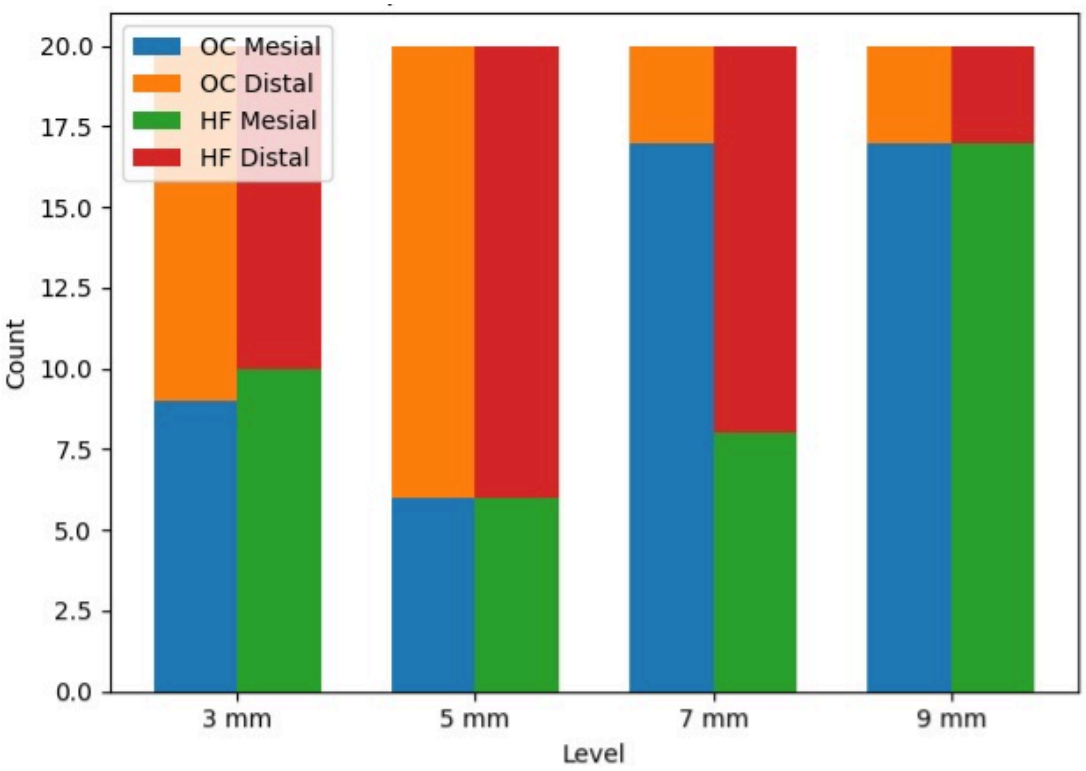


Figure 2

Distribution of deviation tendency at different root levels (3, 5, 7, and 9 mm from the apex) for the One Curve and HyFlex EDM systems. Stacked bar charts illustrate the number of samples exhibiting mesial and distal deviation in each group (n = 20 per group). Distal deviation predominated at the 5 mm level, whereas mesial deviation was more frequent at the 7 mm and 9 mm levels.

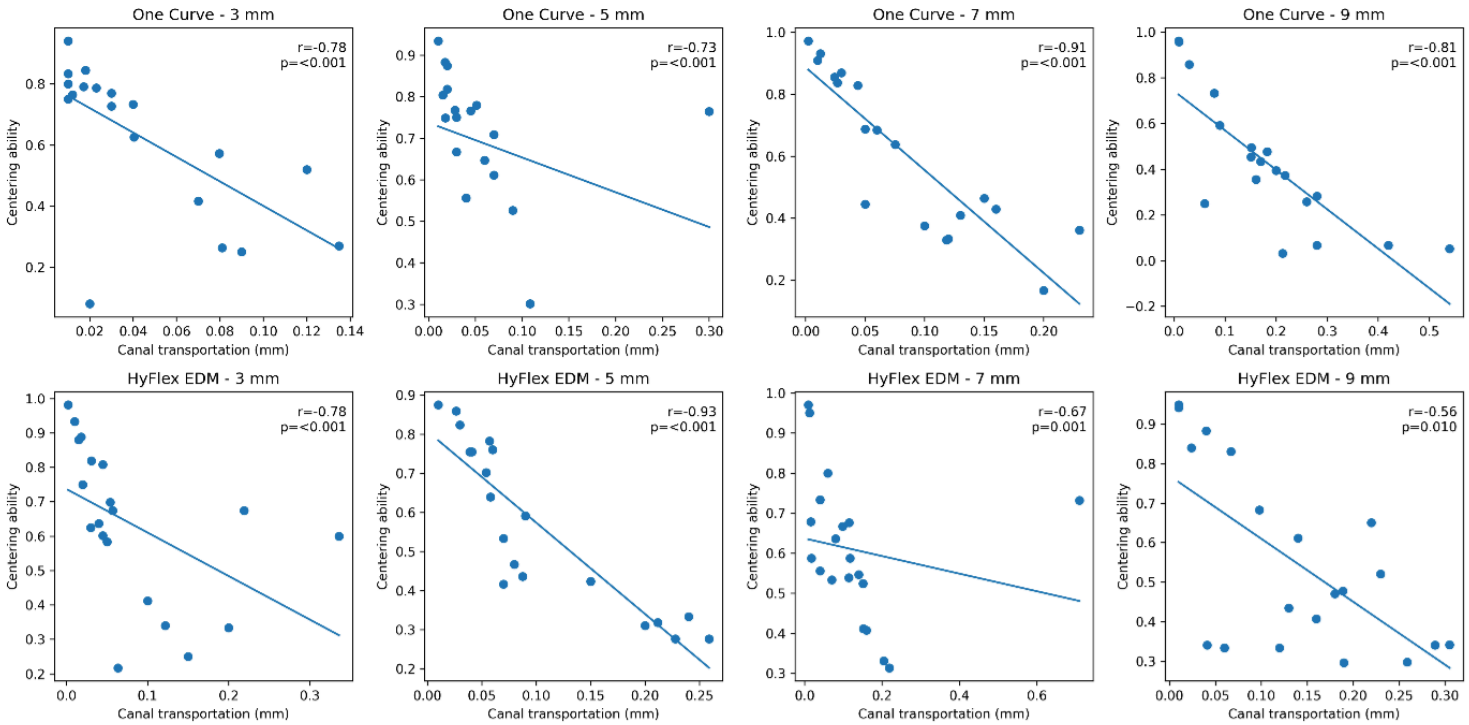


Figure 3

Relationship between canal transportation and centering ability at different root levels for One Curve and HyFlex EDM systems. Each plot shows individual data points, regression lines, and Spearman correlation coefficients (r) with p-values. Negative correlations indicate reduced centering ability with increased transportation.