ORIGINAL RESEARCH

Evaluation of Canal-centering Ability and Apical Transportation of Hyflex-EDM, OneShape, WaveOne Gold, and Reciproc Files: An *Ex Vivo* Study

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Abstract

Aim: To evaluate and compare canal-centering ability (CCA), canal transportation (CT), and dentinal crack formation by using Hyflex-electrical discharge machining (EDM), OneShape, WaveOne Gold, and Reciproc single file system in the mesiobuccal root of maxillary first molar at coronal, middle, and apical third using cone-beam computed tomography (CBCT) and scanning electron microscopy (SEM).

Materials and methods: Mesiobuccal roots of 120 freshly extracted maxillary molar teeth were divided into four experimental groups; Hyflex-EDM, OneShape, WaveOne Gold, and Reciproc (n = 30/group). Preinstrumentation scanning was done using CBCT for all samples at coronal one-third (4 mm), middle one-third (8 mm), and apical one-third (12 mm). After cleaning and shaping with standard irrigation protocol, the specimens were again scanned. Canal-centering ability and CT were calculated using pre- and postinstrumentation CBCT values. A scanning electron microscope was used to identify dentinal crack formation.

Results: No significant difference was found for CCA by any of the systems at coronal, middle, and apical third, respectively. However, OneShape was found to have better CCA at the coronal third and WaveOne Gold at the middle and apical third. There was a significant difference in canal transportation at the apical third ($p = 0.004$) with WaveOne Gold having the least CT followed by Reciproc at the apical third. OneShape resulted in more dentinal cracks in the coronal and middle thirds. Also, Hyflex-EDM was better in the apical third.

Conclusion: No difference in CCA was observed between the groups. The lowest values for CT were obtained for WaveOne Gold (similar to Reciproc) whereas both rotary files showed higher values for CT. Also, OneShape showed the most dentinal at all levels. Furthermore, Hyflex-EDM and WaveOne Gold produced the least dentinal cracks at all levels.

Clinical significance: Given that the Reciprocating file system had the least CT and least dentinal cracks, the clinical success rate of root canal treatment (RCT) with the Reciprocating file system can be a better choice to improve the longevity of root canal-treated teeth.

Keywords: Apical transportation, Canal-centering ability, Cone-beam computed tomography, Dentinal cracks.

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Introduction

The root canal system preparation is recognized as the most important stage in root canal treatment (RCT). Effective cleaning and shaping of the root canals are essential for achieving root canal therapy's biological and mechanical objectives. Mechanical debridement of root canals has evolved from hand instrumentation to rotary to reciprocal instrumentation, each of which has its advantages and disadvantages.

Rotary stainless steel (SS) root canal instruments, such as Gates Glidden drill and Peso reamers, can be safely used till the middle third of relatively straight root canals. There is a risk of root perforation at the middle third due to their stiffness.[1] With the introduction of nickel–titanium (Ni–Ti) files in 1988 and subsequent advancement, the mechanical preparation of root canal systems encountered fewer procedural errors due to their special shaping ability.[2] Reciprocal files were introduced to reduce the torsional fatigue associated with rotary instruments that oscillate in clockwise (CW) and counter-clockwise (CCW) directions. Nevertheless, both files are effective when flexed against the walls.

Recent advances in endodontic root canal preparation are directed toward a single-file shaping technique, which is cost-effective, has a simple instrumentation protocol that also

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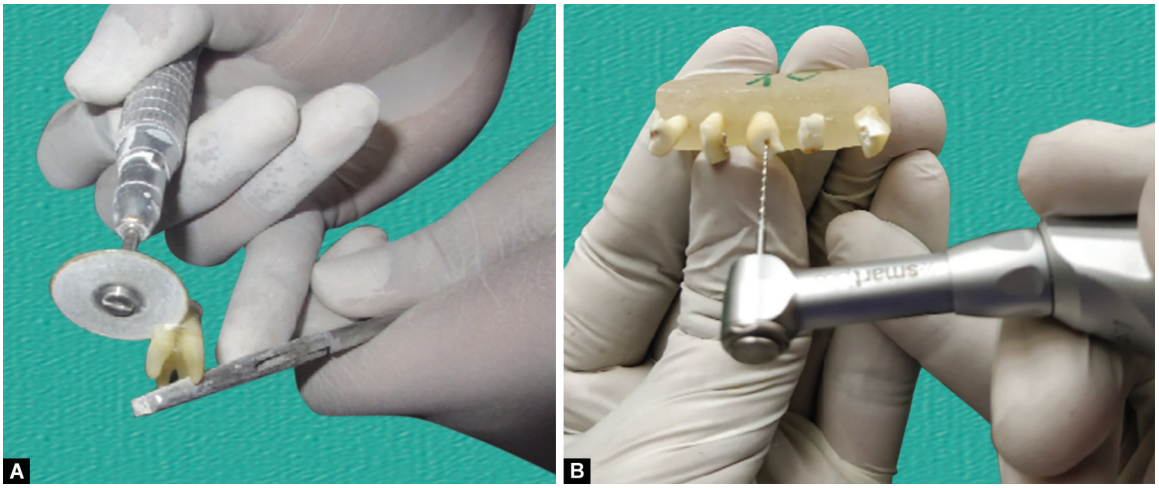


Figs 1A and B: (A) Sectioning the mesiobuccal root of permanent human maxillary first molar; (B) Biomechanical preparation of each sample

reduces the risk of instrument failure, and reduces the time of instrumentation and cross-contamination.[3] Single-file systems are characterized by diverse cross-sectional designs across the entire length of the working part of the instrument, eliminate the risk of instrument separation, and are relatively faster than conventional treatment.[4]

Maintaining the original curvature of root canals and enlarging the canals without canal deviation during instrumentation irrespective of various file systems can often be challenging since any change or deviation in canals can lead to the formation of the ledge, zipping, perforation, or canal transportation (CT) and affect the canal-centering ability (CCA) of the file are suggested as contributing factors to the induction of dentinal defects such as crack formation that decreases the longevity of the treated tooth.[5]

Each of Hyflex-electrical discharge machining (EDM), OneShape, WaveOne Gold, and Reciproc has a different metallurgy.[6] Hyflex-EDM files (Coltene/Whaledent AG, Altstatten, Switzerland) are produced using the EDM process and have three different cross-section designs in a single file providing superior fracture resistance with flexibility.[7–9] OneShape (Micromega, Besancon, France) has a unique design that incorporates various cross-sections along the file's active length and is electroplated which improves its cutting action in three zones of the root canal.[10] WaveOne Gold (Dentsply Sirona, USA) is a single reciprocating file system made from an M Wire Ni–Ti with gold treatment to increase the cyclic fatigue resistance.[11] Reciproc instruments (VDW, Munich, Germany) are slimmer at the end of the working part than most conical Ni–Ti instruments of comparable diameter, with no need to prepare a glide path and have a non-cutting tip.

The mesiobuccal roots of the maxillary first molar usually present an accentuated curvature and mesiodistal flattening and hence were used for the pertinent assessment of CT and CCA.[12] Canal-centering ability, CT, and Dentinal crack formation are some parameters that highlight the efficacy of instruments to maintain original canal curvature, the centering ability of instruments and the ability to preserve dentin thickness. The present study was conducted to compare four single file systems based on rotary (Hyflex-EDM and OneShape) and reciprocating (WaveOne Gold and Reciproc) instrumentation based on the above-mentioned parameters.

Materials and Methods

This *ex vivo* study was conducted in the Department of Conservative Dentistry and Endodontics, Government Dental College, Chennai, India, from 2015 to 2018. The study was approved by the authorities of the Institutional Ethical Committee (RC No.: 0421/DE/2016) A convenience sample of 120 (30 in each group) freshly extracted human permanent maxillary first molars for periodontal reasons were selected subject to inclusion and exclusion criteria.

Inclusion and Exclusion Criteria

Teeth with fully formed apices that were free of caries, cracks (observed under 25×), restorations, debris, and calculus, with no prior endodontic procedures and having a curvature in the range from 10 to 20° (>20°; according to Schneider method)[13] were included. Root canals with double or more curvatures and calcified root canals (encountered during instrumentation) were excluded from the study.

Sample Preparation

About 0.5% sodium hypochlorite (NaOCl) was used for the initial collection and as a storage medium for the teeth. After immersing in NaOCl for at least half an hour to dissolve organic tissue, teeth were cleaned with ultrasonic tips to remove gross debris and later transferred to separate jars containing physiologic saline mixed with 0.5% thymol. The teeth were then decorated using a diamond disc. The palatal and distobuccal roots were separated and the mesiobuccal root (specimen) was taken for instrumentation (Fig. 1).

Root Canal Instrumentation

The root length was standardized to 14–16 mm. A K-file of size 10 (Mani, Japan) hand file was used to establish the initial patency of the canal to full working length (WL), visible at the apical foramen, and the WL was established 0.5 mm short of this length. If the canals were found to be calcified, the specimen was discarded and a new specimen was prepared as per the criteria and methods. The specimens were then embedded into clear acrylic resin. The root canal was enlarged up to 20-size SS K-file. Cleaning and shaping were done with a torque-controlled Endomotor X Smart Plus motor with a handpiece (Dentsply-Maillefer, Switzerland) (Fig. 1). These roots were then divided into four experimental groups containing 30 specimens in each group.

- Group I – Hyflex-EDM files were used at 250 gm. The canals were finished with an apical diameter of 0.25 mm with a taper of 8%.
- Group II – OneShape files were used at 250 rpm. The canals were finished with an apical diameter of 0.25 mm with a 6% taper.
- Group III – WaveOne Gold files were used with torque control endomotor with reciprocation mode. The file system has a tip size of 0.25 mm and a taper of 0.07 in apical 3 mm.
- Group IV – Reciproc files were used with torque control endomotor with reciprocation mode. The file system has a tip size of 0.25 mm and a taper of 0.08.

During instrumentation, the canals were irrigated alternatively with 10 mL of 3% NaOCl and 17% EDTA for 2 minutes using a 27-gauge needle.

Cone-beam Computed Tomography Evaluation for Canal-centering Ability and Canal Transportation

All the specimens were subjected to pre- and postinstrumentation scanning using a cone-beam computed tomography (CBCT) (CARESTREAM CS9300C) at 4, 8, and 12 mm from the apex in an axial slice thickness of 0.1 mm. The images were acquired with exposure parameter settings (84 kVp, 5.0 mA, and exposure time of 20 s). The CCA and CT were evaluated at 4, 8, and 12 mm from the root apex in an axial slice thickness of 0.1 mm.

The formula used for the calculation of CT was as follows:

$$(M1–M2) – (D1–D2)$$

According to this formula, a result other than 0 indicates that transportation has occurred in the canal.

The following formula was used to calculate CCA:

$$(M1–M2)/(D1–D2) \text{ or } (D1–D2)/(M1–M2)$$

If these numbers are not equal, the lower figure calculated was considered as the numerator of the ratio. According to this formula, a value of 1 indicates perfect centering. For all groups, the shortest distance from the canal outline to the closest adjacent root surface was measured at each level.

Scanning Electron Microscopy Analysis for Dentinal Crack

For dentin crack evaluation, roots were sectioned at 4, 8, and 12 mm from the apex with a low-speed diamond disc and mandrel under water cooling. Scanning electron microscopy (SEM) (CEG 500 kV 690 mm × 100 SE 500-µm slice thickness) was used to evaluate dentinal cracks at 100× magnification. Postinstrumentation pictures were taken to examine the sections for dentin cracks. The results were expressed as the number of cracked roots in each group.

Statistical Analysis

The data were analyzed using the Statistical Package for the Social Sciences (SPSS) software for Windows (SPSS, version 20.0, IBM Corporation, Armonk, New York, USA). The CCA and CT of all the groups at the coronal third, middle third, and the apical third were compared using One-way ANOVA followed by the *post hoc* test and Kruskal–Wallis test. The Chi-square test was used to compare dentinal cracks between the groups. The level of significance was set at $p \leq 0.05$.

Table 1: Comparison of mean CCA values between different groups at the coronal third, middle third, and apical third

	N	*Mean*	*SD*	*F*	*p-value*
Coronal third					
Hyflex-EDM	30	0.715	0.24	1.88	0.136
OneShape	30	0.736	0.18		NS
WaveOne Gold	30	0.725	0.28		
Reciproc	30	0.724	0.2		
Middle third					
Hyflex-EDM	30	0.754	0.21	0.474	0.701
OneShape	30	0.735	0.16		NS
WaveOne Gold	30	0.797	0.61		
Reciproc	30	0.719	0.2		
Apical third					
Hyflex-EDM	30	0.745	0.2	0.528	0.664
OneShape	30	0.752	0.15		NS
WaveOne Gold	30	0.783	0.21		
Reciproc	30	0.764	0.25		

Level of significance at $p < 0.05$. N, number; NS, not significant; SD, standard deviation

Results

Canal-centering Ability

Table 1 shows the mean value and standard deviation (SD) of CCA of Hyflex-EDM, OneShape, WaveOne Gold, and Reciproc file system at the coronal third, middle third, and apical third of the root specimen. OneShape showed a maximum centering ratio (0.736 ± 0.18) at the coronal third while WaveOne Gold showed a maximum centering ratio at the middle third (0.797 ± 0.61) and apical third (0.783 ± 0.21), respectively (Fig. 2). It was found that there was no statistically significant difference in mean values of CCA between the groups at the coronal third ($p = 0.136$), middle third ($p = 0.701$), and apical third ($p = 0.664$) respectively, and therefore results from *post hoc* test is not provided (Table 1).

Canal Transportability

Table 2 shows the mean value and standard deviation of CT of Hyflex-EDM, OneShape, WaveOne Gold, and Reciproc file system at the coronal third, middle third, and apical third of the root specimen. Hyflex-EDM files had the least CT in the coronal third (0.066 ± 0.15) while Hyflex-EDM (0.073 ± 0.12) and WaveOne Gold (0.73 ± 0.19) had the least CT in the middle third. Also, Reciproc (-0.03 ± 0.1) had the lowest CT at apical third followed by WaveOne Gold (0.006 ± 0.1). It was found that there was no statistically significant difference in CT tendency between the groups at the coronal third ($p = 0.157$) and middle third ($p = 0.219$) of the specimen. In addition, it was observed that there was a statistically significant difference in values for CT at apical third ($p = 0.004$) (Fig. 3; Table 2). A *post hoc* comparison between groups at apical third found that OneShape files ($p = 0.034$), WaveOne Gold files ($p = 0.003$) and Reciproc files ($p = 0.004$) had significantly lesser CT that Hyflex-EDM files. In addition, WaveOne Gold files had significantly lesser CT than OneShape files. It was also found that OneShape, WaveOne Gold, and Reciproc had similar CT ($p > 0.05$) (Table 3).

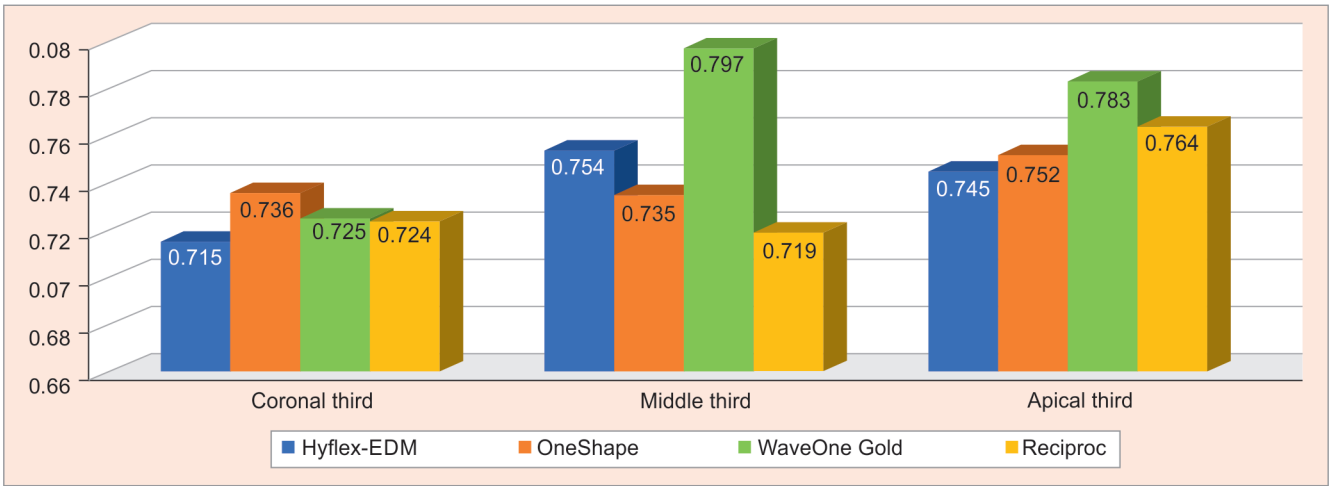


Fig. 2: Mean CCA values between different groups at the coronal third, middle third, and apical third

Table 2: Comparison of CT values between different groups at coronal third, middle third, and apical third

	N	*Mean*	*SD*	*df*	*p-value*
Coronal third					
Hyflex-EDM	30	0.066	0.15	3	0.157
OneShape	30	0.099	0.11		NS
WaveOne Gold	30	0.07	0.13		
Reciproc	30	0.093	0.14		
Middle third					
Hyflex-EDM	30	0.073	0.12	3	0.219
OneShape	30	0.078	0.12		NS
WaveOne Gold	30	0.073	0.19		
Reciproc	30	0.08	0.16		
Apical third					
Hyflex-EDM	30	0.047	0.09	3	0.004**
OneShape	30	0.016	0.09		
WaveOne Gold	30	−0.0067	0.11		
Reciproc	30	−0.03	0.1		

Level of significance at $p < 0.05$; **Statistically significant at $p < 0.01$ using Kruskal–Wallis test. df, degrees of freedom; N, number; NS, not significant

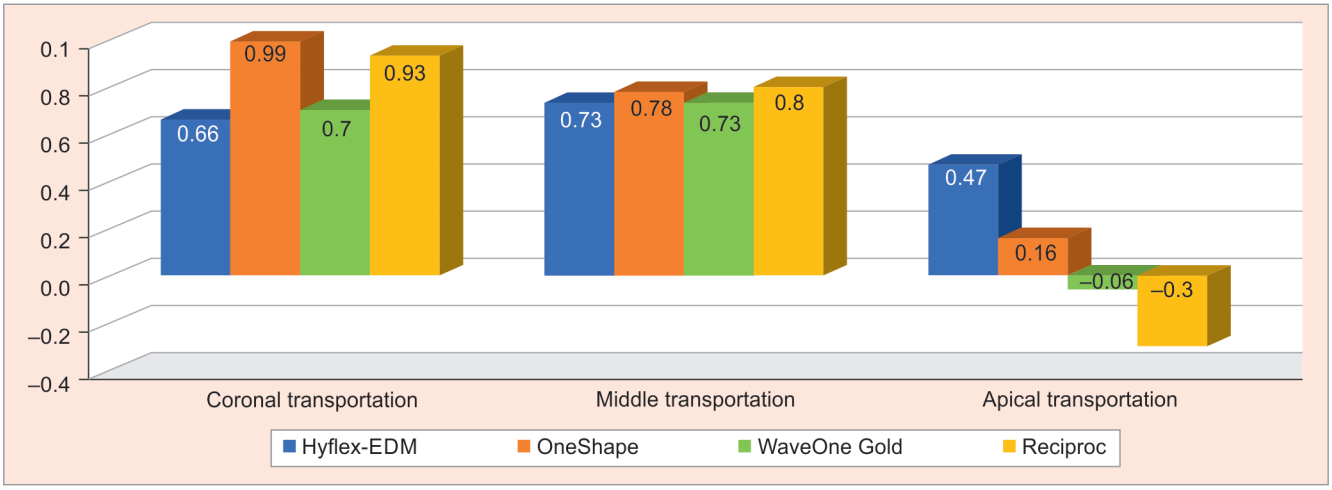


Fig. 3: Mean CT values between different groups at the coronal third, middle third, and apical third

Dentinal Cracks

It was found that OneShape file (Fig. 4) had more dentinal cracks at the middle third followed by Reciproc files (Fig. 5) that were not statistically significant ($p = 0.528$). No dentinal cracks were observed in the coronal third of Hyflex-EDM and WaveOne Gold files. Dentinal cracks in the apical third were more in WaveOne Gold and Reciproc flies which was statistically significant ($p = 0.016$). (Fig. 6; Table 4).

It can be reported that Hyflex-EDM files had high CCA at the middle third and low CT at the apical third and did not produce any crack in the coronal third. The OneShape files had high CCA at the apical third and low CT at the apical third in addition to dentinal cracks at the coronal third, middle third, and in all specimens at the apical third. The WaveOne Gold files had high CCA at the middle third low CT at the apical third and dentinal cracks at the middle third and apical third. Reciproc had a high CCA at the apical third, low CT at the apical third, and dentinal cracks at the middle third, apical third, and coronal third, respectively.

Table 3: Multiple comparisons between groups

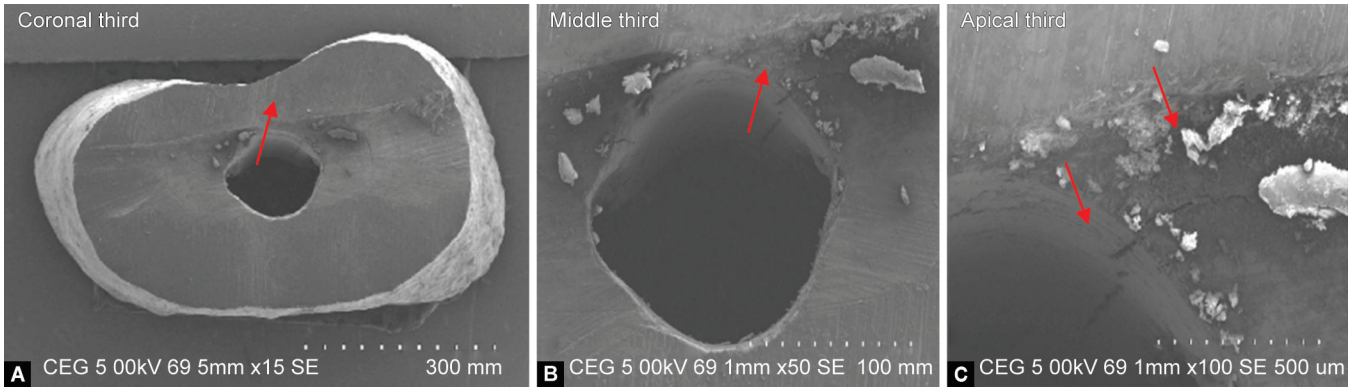
	p-value
Hyflex-EDM vs OneShape	0.034*
Hyflex-EDM vs WaveOne Gold	0.003**
Hyflex-EDM vs Reciproc	0.004**
OneShape vs WaveOne Gold	0.016*
OneShape vs Reciproc	0.22
WaveOne Gold vs Reciproc	0.55

Level of significance at $p < 0.05$. *Statistically significant at $p < 0.05$; **$p < 0.01$ using Mann–Whitney *U* test. NS, not significant

Discussion

Cleaning and shaping are challenging steps in root canal therapy due to intricate variations in root canal anatomy. Endodontic treatment of root canals with accentuated curvature can result in challenges that can make it difficult for clinicians to obtain a properly biomechanically prepared and obturated root canal and might lead to endodontic treatment failure. The present *ex vivo* study was conducted in the curved mesiobuccal root of the maxillary molar to evaluate the performance of both rotation and reciprocation file systems. This study evaluated CCA, CT, and dentinal crack formation at the coronal, middle, and apical third of the root using CBCT and SEM.[14]

The present study included curved mesiobuccal roots for pertinent assessment of CT and CCA as they usually present an accentuated curvature and mesiodistal flattening, with meticulous inclusion criteria taking into consideration the angle of root curvature. The WL of the root was also standardized for better comparison between the groups. CBCT imaging was used to evaluate the values related to CT and CCA. It is an effective method for measuring the selected parameters in the present study. Finally, the mathematical formula of Gambill et al was used in the present



Figs 4A to C: SEM images of group OneShape file presenting dentinal crack formation at (A) Coronal third (15×); (B) Middle third (50×); (C) Apical third (100×)

Figs 5A to C: The SEM images of group Reciproc file presenting dentinal crack formation at (A) Coronal third (100×); (B) Middle third (50×); (C) Apical third (100×)

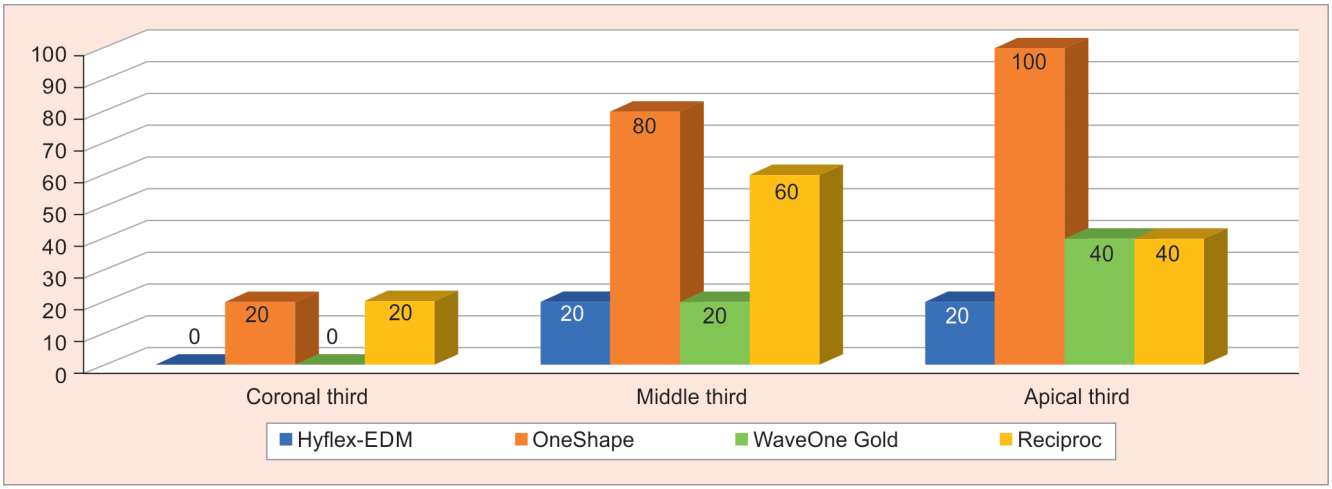


Fig 6: Distribution of dentinal cracks as observed in SEM in different groups according to the coronal third, middle third, and apical third

Table 4: Distribution of dentinal cracks as observed in SEM in different groups according to coronal third, middle third and apical third

	Hyflex-EDM		*OneShape*		*Wave-One Gold*		*Reciproc*		
Position	*Count*	*%*	*Count*	*%*	*Count*	*%*	*Count*	*%*	*p-value*
Coronal	0	0	1	20	0	0	1	20	0.528 (NS)
Middle	1	20	4	80	1	20	3	60	0.141 (NS)
Apical	1	20	5	100	2	40	2	40	0.016*

*Statistically significant at *$p < 0.05$ using Chi-square test. NS, not significant; %, percentage

study to quantify CCA to avoid subjective errors.[15] The evaluation of CCA and CT was done from apex to canal orifice at three different levels where the risk of procedural error is generally higher.

In the present study, it was found that both systems produced similar outcomes in terms of CCA at all levels of the specimen. Hence, both rotary and reciprocating systems provided centered preparations with minor changes. However, there was no statistically significant difference between the groups. The OneShape file was found to have higher CCA in the coronal third while WaveOne Gold had higher CCA in the middle third and apical third, respectively. This indicated that WaveOne files were better suited for the middle third and apical third of curved roots.[16] Similar results were reported in previous studies by Bürklein S et al. and Jain et al. that have compared similar systems.[17,18] This can be attributed to the unique design of WaveOne Gold file with varying cross-sections that improve its flexibility and unique gold treatment that improves fatigue resistance.[18–20]

All the file systems produced a certain degree of CT that was statistically significant only at the apical third of the specimen. Among the files, it was found that Hyflex-EDM files had significantly more CT than OneShape, WaveOne Gold, and Reciproc, respectively. In addition, OneShape files had more CT than WaveOne Gold with no significant differences between WaveOne and Reciproc. This indicated that similar to other studies by Dhingra A et al. and Goldberg A et al., reciprocating files had lesser CT than rotary files and among reciprocating files, Reciproc had the least CT.[21,22] Ozyurek T et al. obtained similar results where WaveOne Gold resulted in significantly less canal straightening and less apical transportation.[23]

This can be attributed to the special process of production that offers superior flexibility and increased resistance to cyclic fatigue. In addition, the reciprocal motion and S-shaped cross-section design of the Reciproc system have been associated with well-centered preparations, reduction in the incidence of procedural errors, and extension in the instruments' lifespan compared to continuous rotation.[24]

Rotary files can produce various degrees of radicular dentinal defects such as craze lines or incomplete cracks, when compared to reciprocating files. Hyflex-EDM, WaveOne Gold presented with the least number of dentinal cracks in this study while OneShape produced the most dentinal cracks. These findings were consistent with results from another study by Jamleh A et al., where WaveOne Gold produced fewer cracks than OneShape.[25,26] In addition, these cracks in the OneShape group were more in the apical third and middle third of the root except in the Reciproc file system where cracks were more in the middle third of the root. It is also established that rotary files produced more cracks than reciprocating files. This can happen in rotating movement due to the concentration of high levels of stress in root canal walls that may result in crack formation. On the other hand, the reciprocating movement was found to be more centered in the canal, and repeated CW and CCW rotations permit the continuous release of the file when it is engaged in the root canal during the cutting and shaping procedure.[27]

It has to be understood that this was an *ex vivo* design and the specimens were embedded in clear acrylic resin, hence, an exact oral environment cannot be simulated here. In addition, extracted teeth become more brittle and so do the chances of cracks. Though we included freshly extracted teeth, it is possible that the results and inferences from the study might not correlate with similar situations clinically. Further clinical studies are required to establish more reliable results with newer techniques, perhaps a three-dimensional (3D) reconstruction of a microcomputed tomographic scan of the mesiobuccal root for more accurate reliability.

Conclusion

Within the limitations, the present study concluded that CCA was similar for all the file systems at the coronal, middle, and apical third of root specimens. Canal transportation was found to be lowest in the apical third of the specimen with Recipro files while Hyflex-EDM had the highest CT. Dentinal cracks were found more at

the apical third of the specimen with the highest number of cracks from OneShape files and the least cracks from Hyflex-EDM files.

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