Transportation and Canal Centering Ability of Reciprocating vs Full Rotating Files after Instrumenting Severely Curved Canals. A Cone Beam Computed Tomography Comparative Study

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Abstract

***Background*: Canal curvature is a major risk factor for canal transportation, which in turn causes that many parts of the root canal system remain untouched leading to persistence of microorganisms and debris, promoting structural weakening, and compromising the apical seal. Aim: To compare canal transportation and centering ability of reciprocating systems vs full rotating systems after instrumenting severely curved canals, using CBCT.**
***Methodology*: Ninety curved roots from extracted human molars were scanned using CBCT, assigned to six groups according to the file system used for instrumentation, namely: WaveOne Gold, RECIPROC blue, R-motion, RACE-EVO, 2Shape and Hyflex EDM, then rescanned after chemo-mechanical. Centering ability and transportation were evaluated at three levels using Gambil's method.**
***Results*: All tested files caused minimal transportation at all levels. No significant differences were found between groups regarding transportation at the apical and coronal levels. Only at the middle level, R-motion showed significantly less transportation than WaveOne Gold and 2Shape. No significant differences were found between all the tested files regarding centering ability at all levels.**
***Conclusion*: File motion whether reciprocating or full rotating has no effect on canal transportation and canal centering ability while shaping severely curved canals.**

Keywords: Severely curved canals, Canal transportation, centering ability, CBCT, Reciprocation Vs Full Rotation.

Clinical Relevance

Canal curvature may predispose to procedural errors during root canal preparation, hence, differences in the performance of single reciprocating and multiple full rotating file systems should be investigated. Which motion kinematic provides a safer and more efficient clinical approach in shaping severely curved canals must be known, to minimize the risk of canal transportation and accordingly improve the longevity of root canal-treated teeth. This study is supposed to clear the confusion the clinician has while selecting the most convenient files for shaping severely curved canals.

Introduction

Canal instrumentation is an important step in endodontic treatment as it has a major impact on the effectiveness of canal cleaning, the quality of canal obturation and the prognosis of root canal therapy.[1] The performance of an optimal canal shaping in curved root canals is frequently difficult to achieve. In fact, canal curvature is well-known as a major risk factor for alteration of the initial pathway of the root canal during instrumentation, leading to procedural errors such as zipping, ledge formation and transportation.[2,3]
Transportation or deviation from the original pathway of the canal causes that many parts of the root canal system remain untouched, leading to the persistence of microorganisms and debris in these areas, which in turn results in endodontic failures.[4]

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In addition, the resulting excessive removal of sound dentin leads to structural weakening, thus predisposes the tooth to fracture.[5–7] Also, apical transportation alters the resistance form in the apical area which leads to overextension of the root canal filling material during obturation, thus compromises the apical seal.[8]
The introduction of instruments manufactured from nickel titanium alloys has tremendously promoted the quality of canal instrumentation by allowing better maintenance of the canal original shape even in severely curved canals.[9]
Numerous techniques have been used to evaluate the canal shape before and after instrumentation in order to assess the efficacy and the safety of different instruments developed for root canal shaping. However, canal transportation remains difficult to assess because no gold standard exists for this criterion.[10] Conventional in-vitro techniques such as cross-sectioning, longitudinal cleavage of teeth and radiographic imaging, either produce an irreversible damage of the samples or provide only a two-dimensional projection of the canal.[11] Cone beam computed tomography is a non-invasive technique that provides a three-dimensional reproduction of the root canal system.[12–14] It provides a reliable method to assess the behavior and the shaping efficiency of different files by comparing the root canal geometry before and after instrumentation without destruction of the specimen.[15,16]
the aim of this study was to compare canal centering ability and canal transportation of three reciprocating systems namely: WaveOne Gold, RECIPROC blue and R-motion, and three full rotating systems namely: RACE-EVO, 2Shape and Hyflex EDM using CBCT. The null hypothesis was that there would be no difference among full rotating and reciprocating files systems regarding canal centering ability and canal transportation.

Materials and methods

The present in-vitro experimental study was conducted after the approval of the Institutional Review Board of Beirut Arab University (BAU). IRB approval code: 2021-H-0093-D-M-0452.

Informed consent

This study was performed on extracted teeth for BAU patients, who have signed a consent that we can use their data and/or extracted teeth, for educational and research purposes, without any identification of their identity.

Sample size calculation

The ANOVA: fixed effects, omnibus, one-way test was selected from the F tests family in G*Power 3.1.9.4 software for Windows. The fixed parameters were error type α=0.05, statistical power β=0.8, number of groups=6, and the effect size was set at 0.4. Accordingly, a total of 90 specimens (15 samples per test group) were indicated as the ideal size required for observing significant differences. Hence, fifteen roots were included in each group using the convenience sampling.

Sample selection

Roots with the following criteria were included in this study:

- Mesial roots from extracted human mandibular molars with two separate mesial canals and apical foramina.[17]
- Roots with severe canal curvature according to Schneider classification.[18]
- Roots with a radius of curvature smaller than 10 mm.[11,19]
- Initial apical diameter equal to or smaller than size 15 K-file.[20]

While roots with Calcification[21] , open apices[20] , and/or resorption[20] were excluded from this study.

Sample preparation

Periapical digital x-rays (x-ray machine: Acteon, Italy; x-ray sensor: Sopix, France) taken for each sample, to confirm the presence of two separate mesial canals with two separate apical foramina. The angle of curvature "α" was measured based on the Schneider's technique.[18] (Figure 1**).**

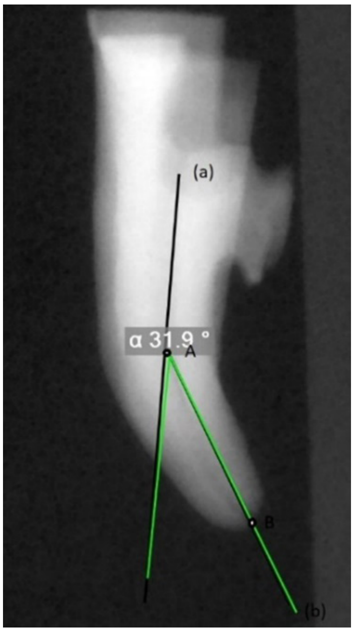

Figure 1. Measurement of angle of curvature accorrding to Schneider's technique (47).

The radius of curvature was measured according to Schafer's Technique being AB/2sinα.[19]
The crowns were removed using a diamond disc under water cooling. The curved root was separated from the rest of the tooth using a diamond disk, then access cavity was refined on all samples. Apical patency was checked by placing a #10 k-file (Mani, Japan). Working length was established under a dental operating microscope by allowing the tip of #10 k-file to pass beyond the apex and by withdrawing 1mm from the measurement.[22]

Biomechanical preparation

The canals were randomly divided into two main groups according to the files motion: Reciprocating files, Group I, (GI: N=45) and full rotating files, group II (GII: N=45), each group was further subdivided in 3 equal subgroups (n=15) according to the file system used for instrumentation that was done according to manufacturers' instructions.

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Group I:
Group 1 (G1): WaveOne Gold (Dentsply Maillefer, Ballaigues, Switzerland)
Group 2 (G2) RECIPROC blue (VDW, Munich, Germany)
Group 3 (G3) R-motion (FKG Dentaire, La Chaux-de-Fonds, SA, Switzerland)
Group II :
Group 4 (G4) RACE EVO (FKG Dentaire, La Chaux-de-Fonds, SA, Switzerland)
Group 5 (G5) 2Shape (MicroMega, Besancon, France)
Group 6 (G6) Hyflex EDM (Colten-Whaledent, Allstätten, Switzerland)
Root canal preparation was performed in all groups by one investigator. An endodontic motor with both full rotation and reciprocating motion: VDW Silver endodontic motor (VDW, Munich, Germany) was used for the six groups. Each rotary file was used for only four canals and was then discarded.[23] thirty-gauge side vented needle was used for irrigation where a total volume of 10 ml of 5.25% sodium hypochlorite was used for each canal during instrumentation. After the completion of the preparation, each canal was rinsed with 3ml of 17% EDTA solution, 3ml of normal saline, 5ml of 5.25% sodium hypochlorite, and finally 3ml of normal saline. [23–25]

CBCT Analysis

Roots were fixed in specific molds using impression silicone material that held the samples in a reproducible position during the exposure. Each mount was placed with its occlusal plane parallel to the mounting table to obtain standardized images before and after root canal preparation. The samples were scanned with the same exposure parameters using Carestream CBCT device (Kodak 9000 3D, Carestream/Trophy, Marne-la-Vall´ee, France) with 90 kV, 0.9 A, and a 17-second exposure setting.

Assessment of the centering ability and canal transportation

The centering ability and the canal transportation were evaluated using CS 3D Imaging software v3.5.15 based on the method created by Gambil et al., [26] which measures the distance from the periphery of the canal to the edge of the root (mesial and distal) on pre- and post-instrumentation scans.[26]

The following formulas were used to calculate canal centering ability:
(X-X’) / (Y-Y’) or (Y- Y’) / (X- X’).
X and X’ refer to the shortest distance from the mesial margin of the root to the mesial edge of the unprepared and prepared canal respectively. Y and Y’ refer to the shortest distance from the distal margin of the root to the distal edge of the unprepared and prepared canal respectively.[26] (Figure 2) The fraction with the lesser value was selected for statistical analysis. Based on this formula, a result of 1 will reveal a perfect centering ability. The closer the value to 0 is the lower the ability of the instrument to keep itself in the central axis of the canal.
The following formula was used to calculate canal transportation:

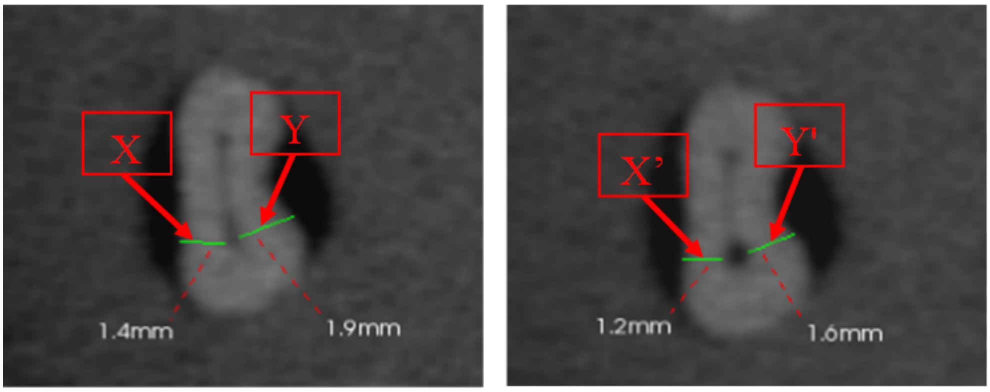

Figure 2. Representative axial view of CBCT scans showing the measurements taken on (a) pre- and (b) post- instrumentation images to calculate the centering ability and the transportation.

(X’-X) - (Y’-Y)
In this formula, results lower or greater than 0 indicate canal transportation. The absolute value of this formula indicates the extent of canal transportation. The total value determines the direction of transportation. A negative value indicates transportation toward the furcal aspect of the curvature whereas a positive value indicates transportation toward the lateral aspect of the curvature.[26,27]
The centering ability and canal transportation were calculated at 3 cross-section levels that correspond to 3-, 6-, and 9-mm distance from the apical end of the root[28]. The pre- and post-preparation assessment were performed at the same number of scanned slices from the apex.[21,23,24] (Figure 3 to 5)

Statistical analysis

The normality of the variables distribution in each group was verified by Shapiro Wilk tests. Because none of the variables were normally distributed in each group (p-values <0.05), non-parametric tests were used.
The Kruskal Wallis tests were used to test the homogeneity of the groups in terms of angle and radius of curvature.
The one-sample Wilcoxon signed rank tests were conducted to find out whether the canal transportation for each group and at each level was significantly different from 0. Similarly, one-sample Wilcoxon signed rank tests were conducted to find out whether the centering ability for each file and at each level was significantly different from 1 or 0.

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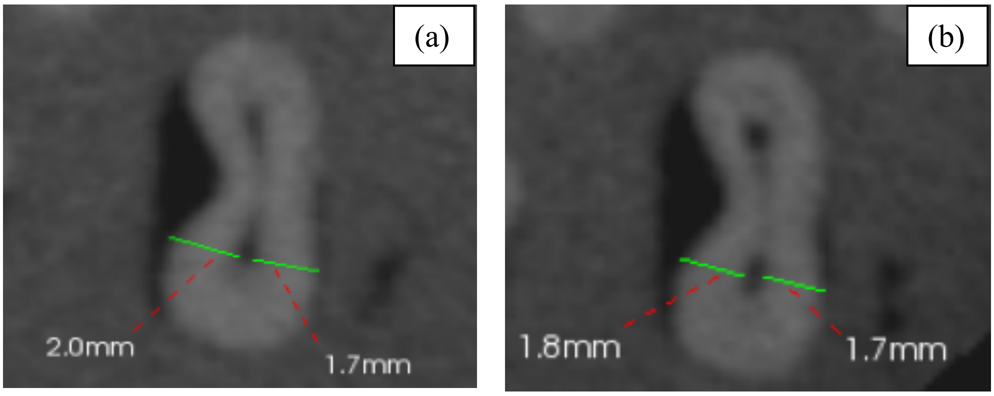

Figure 3. Representative axial view of CBCT scans showing the measurements taken on (a) pre- and (b) post-instrumentation images at the coronal third of the root canal.

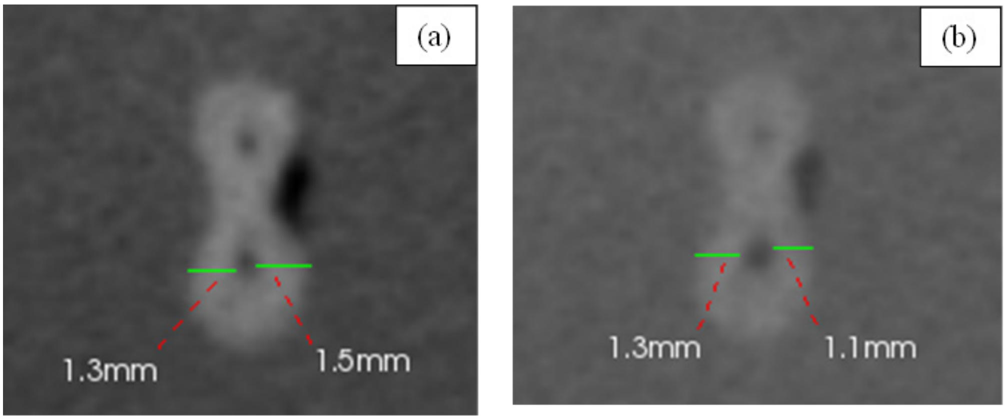

Figure 4. Representative CBCT scans showing the measurements taken on (a) pre- and (b) post- instrumentation images at the middle third of the root canal.

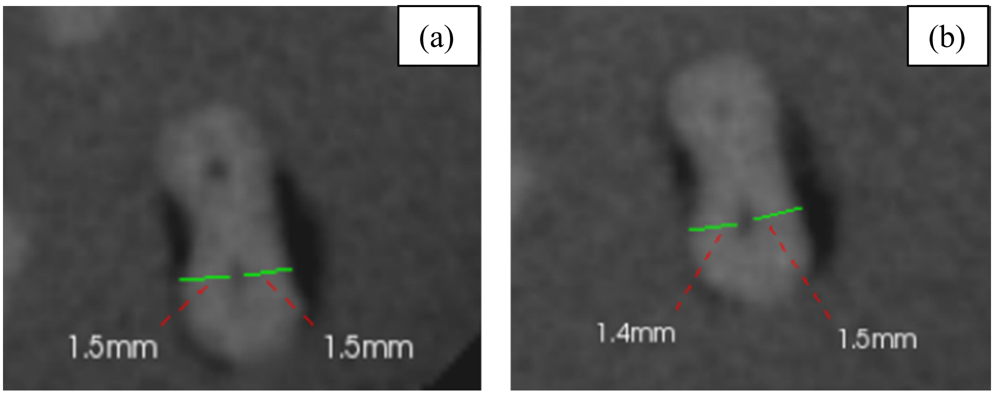

Figure 5. Representative CBCT scans showing the measurements taken on (a) pre- and (b) post- instrumentation images at the apical third of the root canal.

To compare canal transportation and centering ability between the groups at each level, Kruskal Wallis tests were used followed by post hoc Dunn's multiple comparison test adjusted by the Bonferroni correction for multiple tests. Transportation values were treated in absolute values.

Data analyses were conducted using IBM SPSS statistics software version 26 for Windows. The level of significance for all tests was set at 0.05.

Results

Homogeneity of groups

The homogeneity of different groups was confirmed: no significant differences were found between groups concerning the angle (25-60 degrees) and the radius of curvature ($<$10mm) (p-values: 0.783 and 0.909, respectively).

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Transportation

Transportation values were significantly different from 0 in all groups and at each level (all p-values < 0.05), meaning that all instruments caused canal transportation (transportation values were treated in absolute values).

No Significant differences were found in transportation values between different groups at the apical and coronal levels (p-values: 0.14 and 0.979, respectively). Only at the middle level, significant differences between groups in transportation values were found (p-value 0.001) **(**Table 1**)**.

Table 1: Absolute mean values of canal transportation (±standard deviation) at the apical, middle, and coronal levels for different subgroups.

Groups	Subgroups	Canal transportation (absolute value)		
		Apical	Middle	Coronal
		Mean ± SD	Mean ± SD	Mean ± SD
Group I: Reciprocating Files	G1: WaveOne Gold	0.047 ± 0.064	0.207 ± 0.128	0.14 ± 0.135
	G2: RECIPROC blue	0.153 ± 0.164	0.133 ± 0.154	0.167 ± 0.111
	G3: R-motion	0.12 ± 0.086	0.053 ± 0.074	0.16 ± 0.135
Group II: Full rotating Files	G4: RACE EVO	0.12 ± 0.137	0.16 ± 0.13	0.167 ± 0.18
	G5: 2Shape	0.14 ± 0.118	0.207 ± 0.096	0.187 ± 0.217
	G6: Hyflex EDM	0.127 ± 0.149	0.113 ± 0.106	0.153 ± 0.141
	P-value	0.140	0.001*	0.979

*Statistically significant difference as p-value <0.05 (Kruskal Wallis test)

Post hoc Dunn's multiple comparison test showed that the significant differences across groups were detected between groups 3 and 1, and between groups 3 and 5; whereby group 3 showed significantly less transportation than groups 1 and 5 respectively (p-values 0.005 and 0.003, respectively).

The directions of transportation at each level of experimental groups are shown in Figure 6**.** At the apical level all groups showed transportation towards the lateral aspect of the curvature except for WaveOne Gold and Hyflex EDM groups which showed transportation toward the furcal aspect of the curvature. At the middle third, all groups demonstrated transportation tendency toward the furcal aspect of the curvature. At the coronal level, WaveOne Gold, R-motion and Hyflex EDM groups showed transportation tendency toward the lateral aspect of the curvature while RECIPROC blue, RACE EVO and 2Shape groups showed transportation toward the furcal aspect of the curvature.

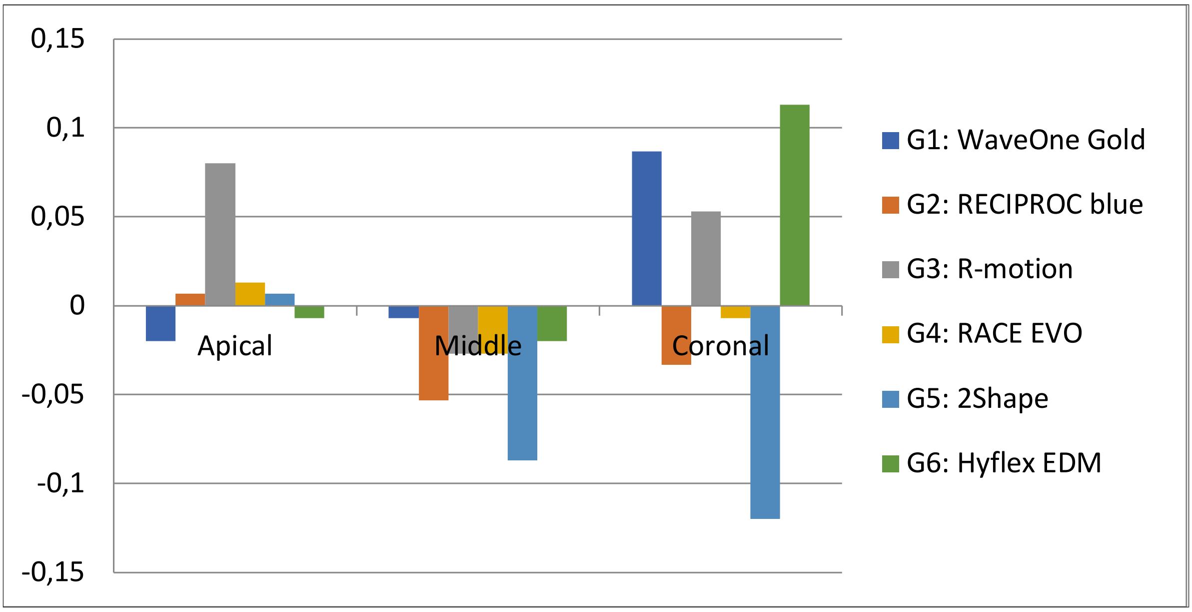

Figure 6. Multiple bar diagram showing the transportation tendencies of groups at each level. Positive values indicate transportation towards the lateral aspect of the curvature, while negative values indicate transportation towards the furcal aspect of the curvature.

Centering ability

Centering ability values were significantly different from 1 and 0 (all p-values < 0.05) in all subgroups and at each level.

No Statistically significant differences in centering ability between different files at all levels were detected (p-values: 0.11, 0.076 and 0.953 at apical, middle, and coronal levels, respectively) **(**Figure 7**)**.

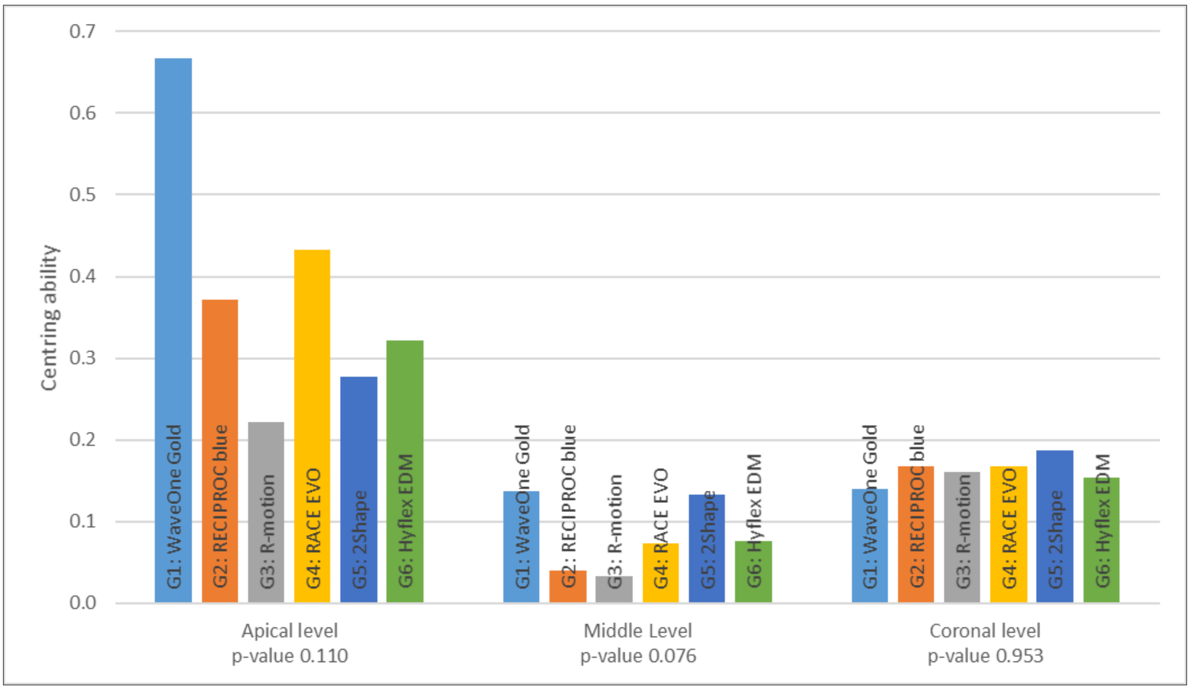

Figure 7. Multiple bar diagram showing the mean of centering ability at the apical, middle and coronal levels for different subgroups.

Reciprocation V/S Full rotation

When comparing reciprocating groups versus full rotating groups (GI: G1-G2-G3 versus GII: G4-G5-G6), no statistically significant difference in transportation values and in centering ability values was found at the apical, middle, and coronal levels (all p-values> 0.05) (Table 2 and 3).

Table 2: Absolute values of mean canal transportation (±standard deviation) at the apical, middle and coronal levels for GI and GII.

Group	Transportation (in ABS values)		
	Apical	Middle	Coronal
	Mean ± SD	Mean ± SD	Mean ± SD
GI: G1-G2-G3	0.107 ± 0.119	0.131 ± 0.136	0.156 ± 0.125
GII: G4-G3-G6	0.129 ± 0.132	0.16 ± 0.116	0.169 ± 0.178
P-value (differences across groups)	0.420	0.139	0.692

Table 3: Mean values of centering ability (±standard deviation) of reciprocation vs full rotating instruments.

Group	Centric ability		
	Apical	Middle	Coronal
	Mean ± SD	Mean ± SD	Mean ± SD
GI: G1-G2-G3	0.42 ± 0.473	0.07 ± 0.108	0.156 ± 0.125
GII: G4-G5-G6	0.344 ± 0.439	0.093 ± 0.105	0.169 ± 0.178
P-value (differences across groups)	0.431	0.194	0.692

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Discussion

Root canal preparation is a major step during endodontic treatment, it aims to remove pulpal tissues, necrotic debris, and micro-organisms to procure adequate environment for optimal root canal filing and periapical healing.[29] One of the most frequent complications during root canal preparation is canal transportation. The first clinical outcome of transportation is inadequate cleaning of the root canal system.[30] Improved and innovative file systems and motion kinematics were developed to decrease such outcome.[31] On the other hand, conflicting results were found in the literature regarding the shaping ability of full rotating versus reciprocating files. This study was conducted to compare canal transportation and centering ability of six rotary Niti systems available in the market, which have different metallurgy, cross-section, taper and kinematics. The null hypothesis was that there would be no difference among full rotating and reciprocating files systems regarding canal centering ability and canal transportation.

In this study, curved mesial canals of extracted human mandibular molars were used as samples. These canals are more difficult to instrument because of their complex anatomy and due to the convexities and the concavities of the canal walls.[18,32] Accordingly, these canals help to point out the differences in performance between various rotary files more accurately and closer to realistic clinical conditions.[33,34]

The independent characteristics that define canal shape are the angle and the radius of curvature. The traditional technique of recording canal curvature created by Schneider [18] in 1971 helped to estimate canal shape using only one parameter which is an estimated random angle. This technique does not consider curvature radius as a measurable characteristic to describe the canal shape. In fact, two canals having the same angle of curvature as measured by the Schneider method, could have completely different radii of curvatures, and thus could have completely different effect on the instrument fatigue and the complexity of canal instrumentation. The more accurate technique that defines the canal curvature and geometry is the one that considered both the angle of curvature and the radii of curvature. The radius of curvature was determined in this study according to the method created by Schafer et al. which calculates the radius of curvature based on the length of the cord joining two points: the point where the canal deviates from its long axis and the apical foramen[19] Only root canals with an angle of curvature ranging between 25 and 60 degrees and with a radius of curvature lesser than 10 mm were used in this study. All groups were assessed homogeneous concerning the angle and the radius of curvature, having all the same range of angle and radius of curvature without statistically significant difference between them. This homogeneity regarding these two inclusion criteria ensured more accurate comparison of the shaping ability between different NiTi instruments.[19]

CBCT is an accurate tool used in many recent studies for assessing canal transportation, dentine thickness and centering ability.[35–37] In this study, CBCT was used to provide accurate three-dimensional scans at a small field of view prior and following root canal instrumentation. It is a non-invasive method, however, has a lower resolution than micro-computed tomography.[38] Nevertheless, in this study since a manual glide path with K file #15 was possible, a voxel size of 0.125mm was considered adequate for detecting the root canal and performing precise measurements.[39]

The lack of coronal flaring may have been a factor that contributed to increased transportation values among different groups in the present study. However, coronal flaring was intentionally not performed as it was previously demonstrated that pre-flaring significantly decreased canal curvature.[40] Accordingly, for accurate evaluation of the effect of the instruments in the coronal level of the canal and for preventing the effective reduction in canal curvature, coronal flaring was not used in this study.[41]

In the present study, a glide path was achieved using manual K-file #15 in all groups for standardization. However, several previous studies demonstrated that NiTi glide path files led to less canal transportation when compared to manual K-files due to the higher flexibility of NiTi instruments,[42,43] and due to the enlargement of the middle and coronal thirds of the canal by rotary glide path files, which in turn minimized the torsional stress on the subsequent rotary shaping files.[34] Also, studies showed that when glide path was achieved with rotary files, less canal transportation was noted after the completion of the root canal preparation by rotary shaping files.[34,44,45] Nevertheless, the aim of this study was to compare the effect of different shaping files on curved canals and to detect their ability to remain centered within the canal, and not to assess the effect of rotary glide path.

The mathematical formulas of Gambil et al.[26] were used in this study to assess the transportation and the centering ability of different instruments, hence preventing any bias of subjective assessment by multiple evaluators.

Clinically, canal transportation of up to 0.15mm was considered acceptable,[11] and apical transportation of more than 0.3mm may alter the sealing of the permanent root canal filling.[46] Overall, none of the evaluated instruments exceeded the 0.3mm margin for transportation at any level which is considered critical for clinical outcome.[46] The supermajority of canal transportation values obtained were up to 0.15mm at the apical and middle levels, which is considered acceptable.[9] Accordingly, based on the results of this study, the six assessed NiTi systems can be safely used to prepare curved canals without significantly affecting the original canal anatomy.

In this study, all rotary systems resulted in canal transportation as it was demonstrated in other studies,[23,33,47–49] with no significant differences between them at the apical and coronal levels. Only at the middle level, R-motion files caused significantly less transportation than WaveOne Gold and 2Shape files. This may be explained by the differences between the rounded triangular cross section of R-motion files, the off-centered parallelogram cross section of WaveOne Gold files, and the modified triple helix cross-section of 2Shape files, as triangular cross section is known to cause less canal transportation.[41]

The smaller canal transportation caused by R-motion files at the middle level could also be explained by the reciprocating movement of the file, which helps in maintaining the instrument centered within the canal. It may also be explained by the thermal treatment of the file resulting in enhanced flexibility of R-motion files,[50] thus decreasing the lateral forces applied on the root canal walls. This results in better preservation of the original canal anatomy and root structure.

When assessing the direction of transportation, it was found that transportation occurred in both distal and mesial directions. Nevertheless, at the apical third, most of the files demonstrated a tendency to transport the canal toward the lateral aspect of the curvature. These findings are consistent with those of several previous studies which showed a higher tendency to transport the canal toward the mesial direction in the apical third.[26,46,51] However, as the distance to the apex increased, the transportation toward the furcal aspect of the curvature increased especially at the middle third where all instruments transported the canal toward the inner side of the curvature or the danger zone. Also, it was noted that more transportation (in absolute value) occurred in the coronal third. Similar results were obtained by previous investigators.[5,36,51] A possible reason for these outcomes could be the greater taper of NiTi files, as greater taper is associated with higher risk of canal straightening and transportation.[52]

Regarding centering ability, none of the tested files showed the ideal centering ability of 1, demonstrating the tendency of all instruments to deviate from the initial pathway of the canal with no statistically significant difference in centering ability values between them. These findings were consistent with those found in other investigations by Bürklein et al.[53] who found that WaveOne Gold and RECIPROC blue preserved the original curvature of the root canal well with no significant differences between them,Click or tap here to enter text. Nehme et al.[54] who concluded that 2Shape and ProTaper Gold had similar shaping ability, Click or tap here to enter text.and Venino et al. who found that Hyflex EDM and ProTaper NEXT were similarly safe in preparing the root canals and respecting their original pathways.[55] Conflicting findings were found by Elashiry et al.[23] who showed that WaveOne Gold resulted in a more centralized canal instrumentation with a lesser degree of transportation at the apical area than RECIPROC blue and Hyflex EDM,[23] and by Singh at al. who demonstrated that 2Shape files had better centering ability and lesser transportation than ProTaper Gold files.[49] A possible reason for these conflicting results could be the difference in the inclusion criteria between these previous studies and the present study. Elashiry et al. and Singh et al. used extracted root with 25 to 35 degrees curvature,[23,49] whereas in the present study, curved mesial canals having severe curvature ranging from 25 to 60 degrees were included. Canal curvature is considered as a principal risk factor for the alteration of the initial canal pathway.

The rotary systems used in the present study used either full rotating or reciprocating motion. These motions have been compared in several investigations with conflicting results. Some studies demonstrated that reciprocation led to decreased canal transportation and more centralized canal preparations in comparison to full rotation,[56,57] while a systematic review [58] showed that both motion kinematics led to comparable shaping outcomes regarding canal transportation and centering ability. The results of this study corroborate with those of the aforementioned review, as no significant differences were found between reciprocating and full rotating files regarding transportation and centering ability. These results are also consistent with several previous studies which demonstrated that the performance of a file during instrumentation may not be directly influenced by different kinematics.[51,59–61]

R-motion and RACE-EVO are new systems, and only few studies have been published regarding their shaping ability. Guedes et al.[62] found that no significant differences existed between RACE EVO and EdgeSequel regarding transportation and centering ability, also Liu et al. found that RACE EVO and R-motion had similar shaping ability as RECIPROC blue and VDW.Rotate.[63] Similarly, in this study, R-motion and RACE-EVO demonstrated promising ability regarding the assessed parameters. They showed comparable results with the other tested systems. At the middle level, R-motion even showed less canal transportation than WaveOne Gold and 2Shape, thus better ability to conserve the initial canal anatomy. These promising results could be related to the non-cutting tip of the files and the heat treatment which leads to lower dentinal stress and higher flexibility.

Conclusion

Curved canals can be safely shaped with reciprocating as well as full rotating NiTi systems up to a tip size of 25. Further investigation should be made for larger tips sizes.

Conflict of interest statement

The authors declare that they have no conflict of interest in connection with this article.

Ethical approval

The present in-vitro experimental study was conducted after the approval of the Institutional Review Board of Beirut Arab University (IRB approval code: 2021-H-0093-D-M-0452)

Acknowledgment

The authors affirm that they have no financial affiliation (e.g., employment, direct payment, stock holdings, retainers, consultantships, patent licensing arrangements or honoraria), or involvement with any commercial organization with direct financial interest in the subject or materials discussed in this manuscript. Any other potential conflict of interest is disclosed.

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