

Assessment of canal centering and dentinal integrity following root canal preparation with different NiTi file systems

An in vitro CBCT and stereomicroscopic study

Suheel Manzoor Baba, MDS^a, Nik Rozainah Nik Abdul Ghani, MSc^{b,*}, Mohammed Alqarni, MSC^a, Johari Yap Abdullah, PhD^c, Shabina Shafi, MDS^d

Abstract

The success of root canal treatment largely depends on the canal shaping procedure, which influences subsequent steps, such as cleaning, obturation, and sealing. The present study aimed to evaluate the canal-centering ability, dentin removal, and dentinal crack incidence following root canal preparation with different rotary and reciprocating nickel–titanium file systems using cone beam computed tomography (CBCT) and a stereomicroscope. Forty freshly extracted single-rooted human mandibular premolars were selected and scanned preoperatively by CBCT (KAVO OP 3D Pro, Germany) to evaluate canal curvature. The samples were then randomly distributed into 4 groups (n = 10): Group 1 – ProTaper Next (continuous rotary), Group 2 – MicroMega One RECI (reciprocating), Group 3 – Race Evo (continuous rotary), and Group 4 – R-Motion (reciprocating). Root canals were prepared in accordance with the respective manufacturer's recommendations. Post-instrumentation CBCT scans were obtained to assess canal centering and remaining dentin thickness at 3, 6, and 9 mm from the apex. Root sections were also examined under a stereomicroscope to assess dentinal cracks. The MicroMega One RECI (Group 2) demonstrated superior canal centering, with mean ratios of 0.20 ± 0.05 , 0.18 ± 0.04 , and 0.17 ± 0.03 in the apical, middle, and coronal thirds, respectively. In contrast, ProTaper Next (Group 1) showed the highest centering ratio (0.35 ± 0.08 at 3 mm), indicating greater deviation from the canal axis. Reciprocating systems exhibited better dentin preservation and fewer dentinal cracks compared with continuous rotary systems. Based on observations from this in vitro study, it can be concluded that the variations in design of file systems and motion patterns critically determine the efficiency and safety of root canal shaping. Reciprocating and rotary motions show different effects on canal centering, dentin removal, crack propagation, and the preservation of root integrity.

Abbreviations: CBCT = cone beam computed tomography, CI = confidence interval, kVp = kilovoltage peak, mA = milliamperage, mm = millimeter, MMOR = MicroMega One RECI, N-cm = newton centimeter, NiTi = nickel–titanium, PTN = ProTaper Next, RM = R-Motion, rpm = revolutions per minute.

Keywords: canal centering, CBCT, dentin crack, remaining dentin thickness, rotary file

1. Introduction

Canal shaping is a critical step in endodontic therapy as it influences subsequent procedures, such as irrigation and obturation, and impacts the final treatment outcome.^[1] Instrumentation aims to develop a constantly tapering canal that preserves the natural anatomic configuration, maintaining a small apical foramen and preventing any deviation from the original canal curvature.^[2] The efficiency of an instrument

or technique is determined by its ability to shape all canal surfaces uniformly, retaining the central axis of the prepared canal with an unaltered canal, a factor extremely relevant in curved canals.^[1] Some of the procedural errors that might occur during canal preparation with stainless-steel hand files include canal transportation, ledge formation, perforations, straightening of curved canals, zipping, and even loss of working length.^[2]

The authors have no funding and conflicts of interest to disclose.

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

This study protocol was approved by the Ethics Committee at College of Dentistry, King Khalid University, Saudi Arabia, and University Sains Malaysia.

^a Department of Restorative Dental Science, College of Dentistry, King Khalid University, Abha, Saudi Arabia, ^b Conservative Unit, School of Dental Science, Health Campus University Sains Malaysia, Kubang Kerian, Malaysia, ^c Basic Sciences Unit, School of Dental Sciences, Health Campus Universiti Sains Malaysia, Kubang Kerian, Kelantan, Malaysia, ^d Saudi Dent Group, Khamis Mushait, Saudi Arabia.

* Correspondence: Nik Rozainah Nik Abdul Ghani, Conservative Unit, School of Dental Science, Health Campus University Sains Malaysia, Jalan Raja Perempuan Zainab 2, Kubang Kerian, Kelantan 16150, Malaysia (e-mail: rozainah@usm.my).

Copyright © 2026 the Author(s). Published by Wolters Kluwer Health, Inc. This is an open-access article distributed under the terms of the Creative Commons Attribution-Non Commercial License 4.0 (CCBY-NC), where it is permissible to download, share, remix, transform, and build upon the work provided it is properly cited. The work cannot be used commercially without permission from the journal.

How to cite this article: Baba SM, Nik Abdul Ghani NR, Alqarni M, Abdullah JY, Shafi S. Assessment of canal centering and dentinal integrity following root canal preparation with different NiTi file systems: An in vitro CBCT and stereomicroscopic study. *Medicine* 2026;105:17(e48483).

Received: 13 November 2025 / Received in final form: 31 March 2026 / Accepted: 7 April 2026

<http://dx.doi.org/10.1097/MD.0000000000048483>

The introduction of superelastic nickel–titanium (NiTi) rotary instruments has considerably reduced these complications due to better maintenance of the natural canal curvature and anatomy.^[3] These NiTi systems are specifically engineered to operate under continuous rotational motion with controlled torque and speed for more efficient cutting and more predictable shaping, especially in narrow or curved root canals.^[4] Further to enhance the performance and durability of the instrument, the use of a reciprocating motion was introduced. It is a technique that involves alternating movements – a primary counterclockwise cutting rotation followed by a smaller clockwise release. It reduces the mechanical stress on the instrument; hence, it shows enhanced cyclic fatigue resistance and reduced risk of canal deformation. Thus, the file advances smoothly toward the apex.^[5] Mandibular first and second premolars have similar morphology, with approximately 95% of first premolars and 98% of second premolars being single-rooted. The canals are usually round or oval in these premolars, with the geometry of the second premolar being more consistent and straightforward than the first premolar.^[6]

A crack in the root dentin is defined as a structural defect involving a fracture line that extends from the internal canal wall continuously to the external root surface. Dentinal cracks or root fractures are developed when the tensile forces created within the canal wall exceed the inherent tensile strength of the dentin tissue.^[7,8] The use of NiTi rotary instruments with larger tapers increases frictional contact against the canal walls, producing localized stress concentrations that may initiate or propagate cracks within the dentin.^[9] Although NiTi rotary systems have distinct advantages in terms of shaping efficiency, flexibility, and preservation of canal curvature, a number of investigations have demonstrated that the use of these instruments is still associated with the development of dentinal defects, such as incomplete and complete crack lines during instrumentation.^[9,10] Such defects may further develop as microcracks, craze lines, or even vertical root fractures depending on the magnitude and direction of the root structure's internal stress distribution.^[11]

Cone beam computed tomography (CBCT) is a reliable and noninvasive imaging tool for assessing root canal morphology and for the evaluation of shaping performed by endodontic instruments. It allows 3-dimensional comparisons of the geometry of the canal and dentin thickness before and after mechanical preparation with high precision.^[10,12]

However, the combined use of CBCT and stereomicroscopic analysis to compare root canal preparation outcomes across different rotary systems, in both continuous and reciprocating modes, remains underexplored.

Therefore, a clear need exists to determine which instrument systems and motion kinematics provide optimal shaping performance with minimal canal aberrations. This knowledge is essential for guiding clinical decision-making and improving endodontic treatment outcomes.

The objective of the present study was to evaluate the canal-centering ability, dentin removal, and dentinal crack incidence following root canal preparation using different rotary and reciprocating NiTi file systems. CBCT and stereomicroscopic analyses were used in this study for observations.

1.1. Null hypothesis

There are no significant differences among rotary and reciprocating NiTi file systems regarding canal-centering ability, remaining dentin thickness, dentinal crack formation, or the overall volume of residual dentin following root canal preparation.

2. Materials and methods

This study was conducted at the College of Dentistry, King Khalid University, Abha, Saudi Arabia, after obtaining ethical

clearance from the Ethics Committee at the College of Dentistry, King Khalid University, Abha, Saudi Arabia (IRB/KKUCOD/ETH/2022-2023/002).

2.1. Sample size calculation

To ensure that the sample size would be statistically robust, a power analysis using G*Power software version 3.1 (Germany), one-way analysis of variance, was used. The analysis was conducted with an expected effect size $f = 0.25$ (to represent a medium effect that was based on previous endodontic studies), α (significance level) = 0.05, a target power of 0.8, and 4 groups, indicating a total of 44 samples. To ensure feasibility and maintain consistency with prior in vitro research on rotary instrumentation, the study included a total of 40 teeth, with 10 samples allocated to each group and 1 tooth in each group kept as an extra in case any defective samples required replacement.

2.2. Sample selection and preparation

Forty freshly extracted human mandibular premolars with a single root, obtained for orthodontic purposes, were randomly selected for this study. Soft tissue remains, calculus, and other debris were eliminated from all the teeth using ultrasonic scalers. The samples were stored in 0.9% physiological saline to keep them hydrated during this period until further use.

2.2.1. Inclusion criteria.

1. Intact mandibular premolar teeth extracted for orthodontic reasons with a single root canal with a completely formed apex
2. Age group between 17 and 25 years
3. Crown-root length of 14 mm after decoronation

2.2.2. Exclusion criteria.

1. Teeth with calcified canals
2. Severely curved canals more than 20 degrees
3. Multiple root canals
4. Any preexisting craze lines or cracks

Digital radiographs were taken using a long-cone paralleling technique (Dentsply Sirona) in order to confirm canal curvature. The angle of curvature and radius were measured using the Schneider method.^[13] Only the teeth whose curvature angle did not exceed 20° were considered.

The crowns of all teeth were sectioned at the cemento-enamel junction by means of a diamond disk (Hager & Meisinger, Germany) under continuous water irrigation. All roots had a standardized length of 14 mm. Each prepared root was mounted vertically in a square acrylic resin block made of transparent, self-cured resin. The dimensions of the blocks were 2.5 × 2.5 × 3 cm, allowing for easy handling and imaging alignment.

2.3. Initial CBCT scanning

Initial scanning by CBCT was done in order to record the baseline geometry of the root canal. All scans were made with a KAVO OP 3D Pro CBCT unit (Kavo Dental, Germany) at 90 kVp and 5 mA, with a voxel size of 0.08 mm. The specimens were placed so that their long axes were perpendicular to the beam axis, ensuring consistency in the scanning parameters.

2.4. Root canal preparation

The working length for each tooth was determined by placing a size 10 K-file (Dentsply Maillefer, Ballaigues, Switzerland) into

Group 2: Micro mega Reci one Pre and post instrumentation CBCT scan

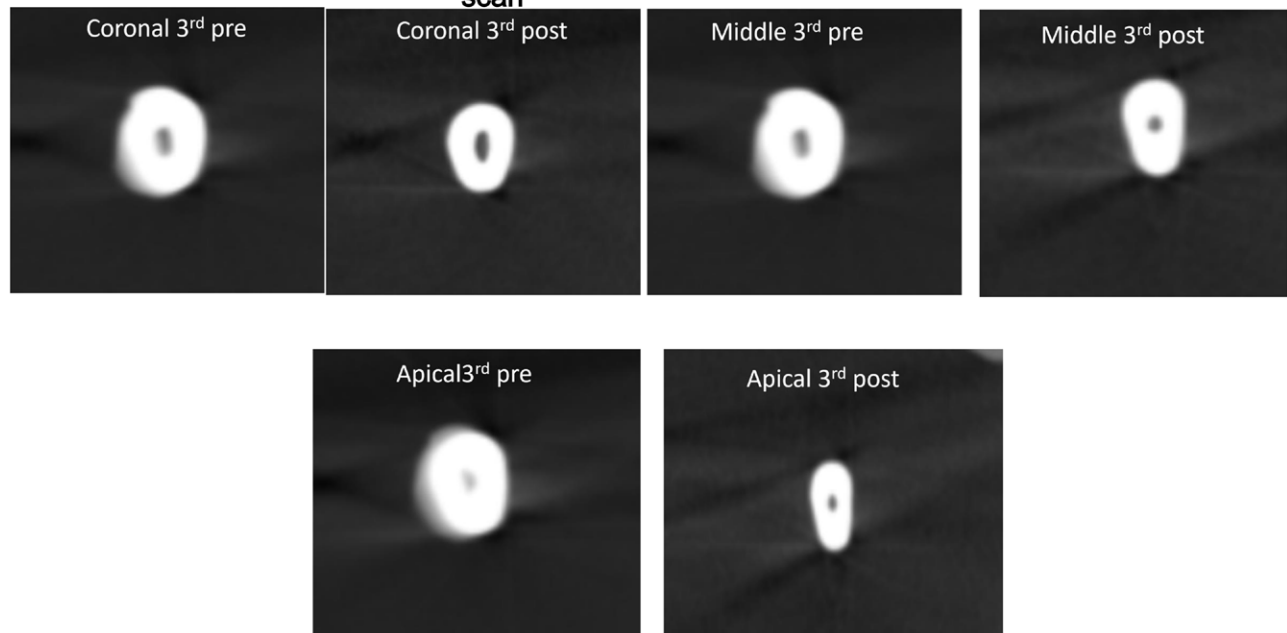


Figure 1. MicroMega One RECI pre- and post-instrumentation CBCT scan. CBCT = cone beam computed tomography.

the canal until the file tip could be seen at the apical foramen. One millimeter was subtracted from this measurement to determine the final working length. Specimens were then randomly distributed into 4 experimental groups (n = 10 per group), each subjected to canal preparation with a different NiTi rotary or reciprocating file system, as follows:

- Group 1: Instrumentation with ProTaper Next (PTN) (Dentsply Sirona) up to size X2 using continuous rotary motion at 300 rpm and 2 Newton centimeter (N·cm) torque.
- Group 2: Instrumentation with MicroMega One RECI (MMOR) files up to size 25 using a reciprocating motion at 400 rpm and 1.2 N·cm torque.
- Group 3: Instrumentation with Race Evo RE3 (FKG Dentaire) up to size 30 with 6% taper in continuous rotation at 800 rpm and 1.5 N·cm torque.
- Group 4: Instrumentation with R-Motion (RM) files up to size 25 using reciprocating motion at 300 rpm and 5 N·cm torque.

For every group, 3 mL of 5.25% sodium hypochlorite was administered via syringe irrigation between each file use. One milliliter of 15% ethylenediaminetetraacetic acid was used for 1 minute after root canal instrumentation was finished, and the canals were then flushed once more with 3 mL of sodium hypochlorite.

Following completion of the canal preparation, a second CBCT scan was made using the same imaging parameters (90 kVp, 5 mA, voxel size 0.08 mm, field of view 5 × 5 cm, exposure time 3.6 seconds). Images were taken at 3 standardized levels along the root: 3 (apical third), 6 (middle third), and 9 mm (cervical third) from the apex.

2.5. Evaluation of canal-centering ability

The centering ability of the canal was evaluated by comparing the pre- and post-instrumentation CBCT images. All the measurements were made from the shortest distance between the outer root surface and the canal wall at the mesial and distal

aspects before and after instrumentation. The following parameters were measured:

- A1: Distance from mesial root surface to uninstrumented canal wall.
- B1: Distance from distal root surface to uninstrumented canal wall.
- A2: Distance from mesial root surface to instrumented canal wall.
- B2: Distance from distal root surface to instrumented canal wall.

Canal centering was calculated according to the method described by Gambill et al^[14] using the formula:

$$\text{Centering ratio} = \frac{(B_1 - B_2)}{(A_1 - A_2)} \text{ or } \frac{(A_1 - A_2)}{(B_1 - B_2)}$$

A ratio approaching 1.0 indicates superior centering ability.

2.6. Assessment of dentin removal

Pre- and post-instrumentation canal volumes were determined using ITK-SNAP 3D imaging software (University of Pennsylvania, Philadelphia). The amount of dentin removed during preparation was found by the difference between these 2 values: post-instrumented volume minus pre-instrumented volume in cubic millimeters (mm³).

2.7. Dentinal crack evaluation

After instrumentation, the roots were sectioned perpendicular to their long axis at 3, 6, and 9 mm from the apex using a diamond disk (Hager & Meisinger, Germany) under continuous water cooling.

2.7.1. Interobserver calibration.

2.7.1.1. Number of cases used for calibration. Two examiners jointly calibrated their assessments using 10 representative root

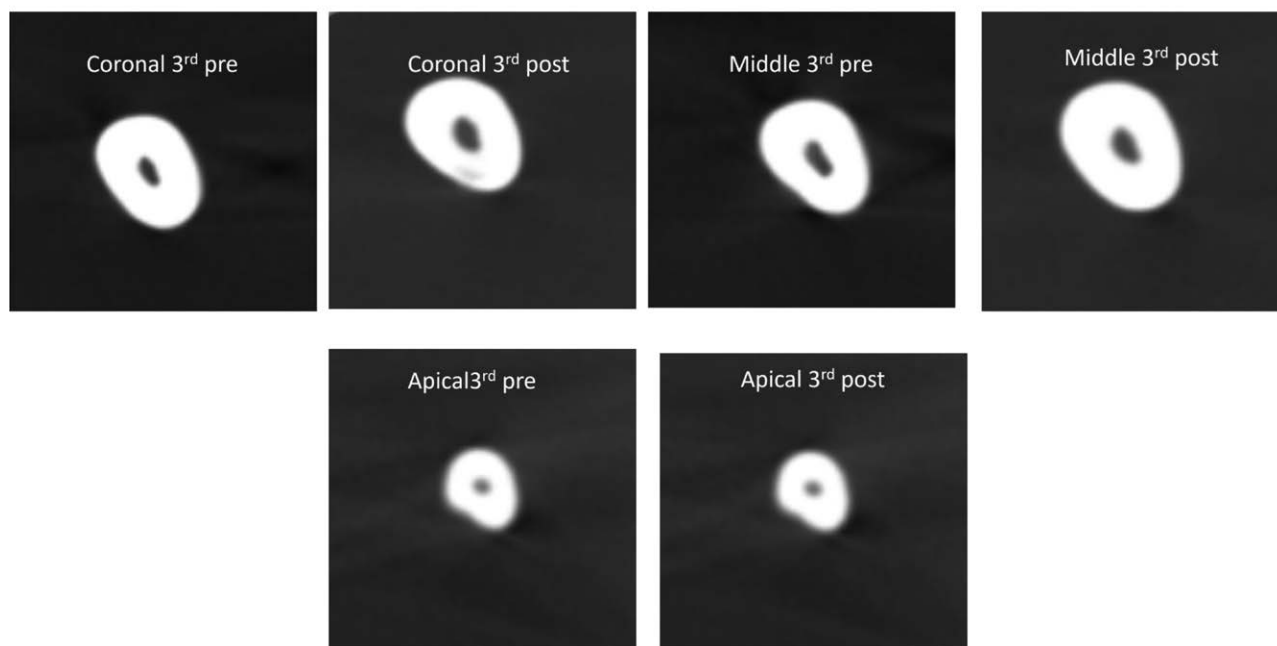
Group 4: R motion Pre and post instrumentation CBCT scan

Figure 2. R-Motion pre- and post-instrumentation CBCT scan. CBCT = cone beam computed tomography.

sections (not included in the final analysis), each comprising 3 levels (3, 6, and 9 mm), resulting in a total of 30 calibration images.

2.7.1.2. Total number of observations for kappa calculation. For the main study, dentinal defects were evaluated at 3 levels (3, 6, and 9 mm) in all 40 teeth, yielding 120 sections. Each section was independently scored by both observers, resulting in 120 paired observations for the presence/absence analysis and 120 paired observations for the 3-category classification.

2.7.1.3. Type of kappa. We used Cohen simple kappa for the dichotomous assessment (presence vs absence of any radicular dentinal defect) and weighted Cohen kappa (ordinal weighting) for the 3-category classification (no fracture, partial fracture, complete fracture).

2.7.1.4. Kappa values and 95% confidence intervals (CI). Presence/absence of defects, $\kappa = 0.82$ (95% CI: 0.74–0.90), indicating excellent agreement. Three-category classification, $\kappa = 0.71$ (95% CI: 0.62–0.80), indicating good agreement.

2.7.1.5. Statistical software. All kappa analyses were conducted using SPSS version 24.0 (IBM Corp., Chicago), consistent with the software used for the other statistical analyses in the study.

Each section was then observed under a stereomicroscope (Zeiss, Germany) at 25 \times magnification, and images were taken for evaluation. The sections were evaluated by 2 independent observers for the presence of dentinal defects; the defects were classified as:

1. No fracture: Absence of visible cracks or craze lines in both the internal and external root surfaces.
2. Partial fracture: A crack originating from the canal wall that does not extend to the external root surface.
3. Complete fracture: A crack line propagating from the canal lumen through to the external surface of the root.

2.8. Statistical analysis

The data collected were compiled and analyzed using SPSS version 24 (IBM Corp., Chicago). The results regarding canal-centering ratio and dentin removal were expressed as mean and SD. One-way analysis of variance was followed by Tukey's post hoc test to detect any statistically significant differences among the experimental groups. The level of significance was set at $P < .05$.

3. Results

The root canals, which were instrumented using reciprocating motion, exhibited better centering ratios at all levels, particularly Group 2, which had the lowest deviation values, indicating superior performance in maintaining the canal axis, followed by Group 4, which also showed a good centering ratio (Figs. 1 and 2).

The lowest centering ratio values, which indicate better canal centering, were observed in Group 2 (MMOR), with mean ratios of 0.20 ± 0.05 , 0.18 ± 0.04 , and 0.17 ± 0.03 in the apical, middle, and coronal thirds, respectively. In contrast, Groups 1 and 3, which were instrumented using continuous rotational motion (PTN and Race Evo; Figs. 3 and 4), exhibited the highest centering ratio values at all levels, with mean ratios of 0.35 ± 0.08 at 3 mm, indicating more deviation from the canal center (Table 1).

Reciprocating systems preserved more dentin, with Group 2 showing the highest thickness at all levels. Group 1 showed the thinnest residual dentin, especially in the apical third (Table 2).

Complete cracks were observed in Groups 1 and 3 (Figs. 5 and 6), with a higher frequency at the apical level, whereas root canals prepared under reciprocating motion (Groups 2 and 4; Figs. 7 and 8) showed minimal or no complete cracks, indicating safer biomechanical preparation (Table 3).

Comparison of centering ratios vertically shows Group 2's superior centering ability across apical to coronal thirds, with ratios consistently closer to 0.2. Group 1 had the highest deviation from the central axis (Fig. 9).

The volumetric comparison between pre- and post-instrumentation CBCT images revealed that the reciprocating systems (Group 2 and Group 4) removed significantly

Group 1: Pro-taper Pre and post instrumentation CBCT scan

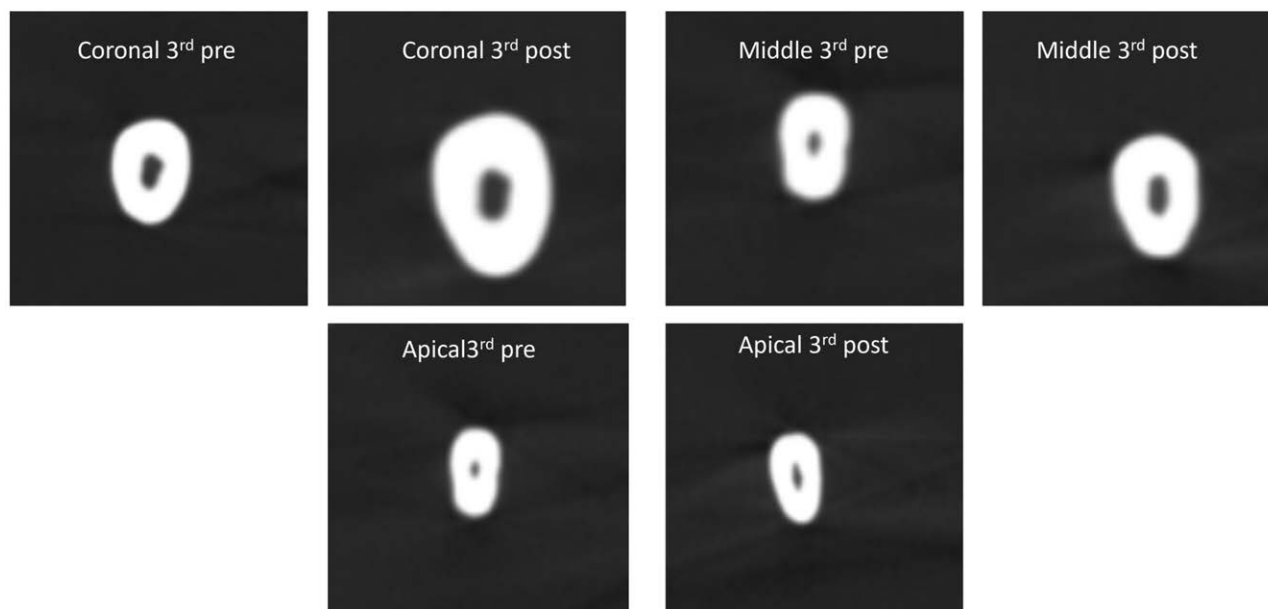


Figure 3. Pro-taper pre- and post-instrumentation CBCT scan. CBCT = cone beam computed tomography.

Group 3: Race Evo pre and post instrumentation CBCT scan

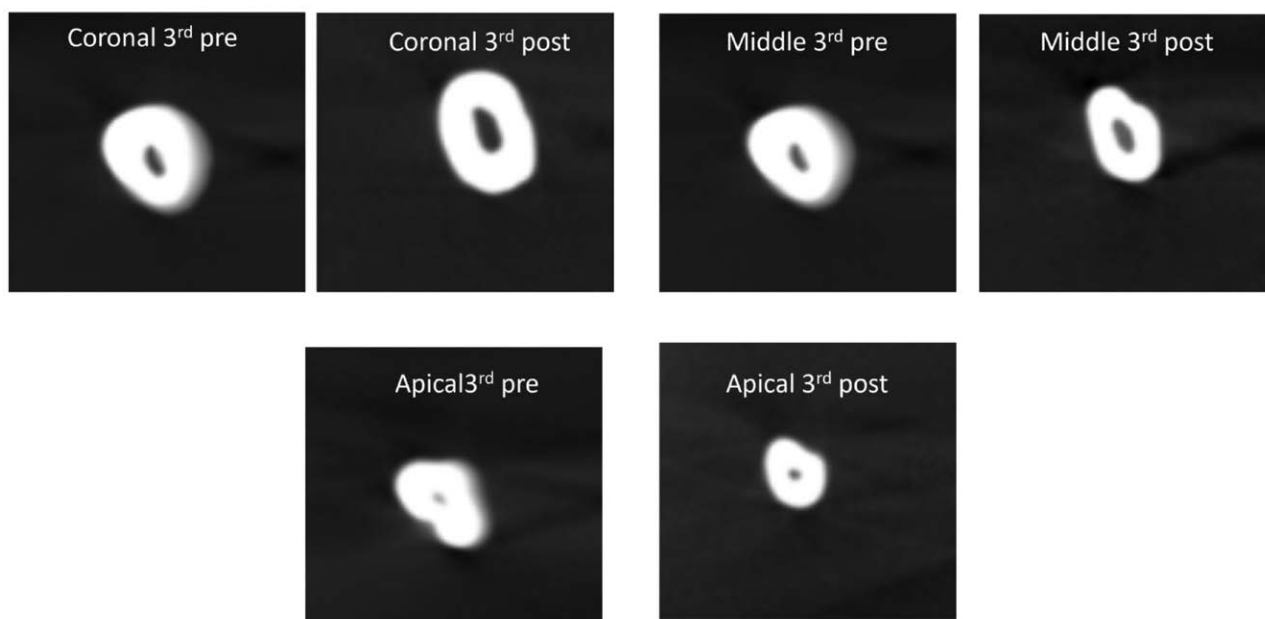


Figure 4. Race Evo pre- and post-instrumentation CBCT scan. CBCT = cone beam computed tomography.

less dentin compared with continuous rotary systems. Group 2 (MMOR) demonstrated the lowest net dentin removal (5.3 mm³), indicating a conservative shaping approach. In contrast, Groups 1 and 3 (PTN and Race Evo) showed higher dentin removal (7.0 mm³), suggesting a more aggressive cutting action (Fig. 10).

When analyzed cumulatively across all 3 root levels (Fig. 11), Group 2 (MMOR) and Group 4 (RM) demonstrated the highest percentages of specimens with no cracks (72% and 70%,

respectively), while Group 1 (PTN) showed the highest incidence of complete cracks (7%).

Interobserver agreement for the presence or absence of radicular dentinal defects was excellent ($\kappa = 0.82$), whereas agreement for the 3-category fracture classification was good ($\kappa = 0.71$).

The findings from this study led to the rejection of the null hypothesis, as there were significant differences among the groups in terms of canal-centering ability, remaining dentin

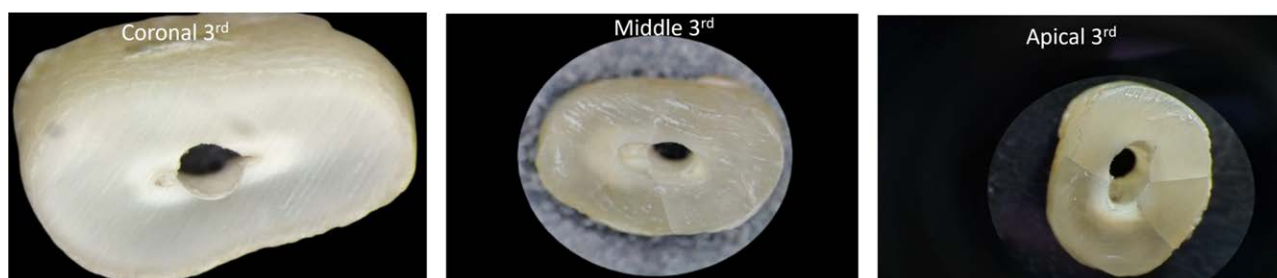
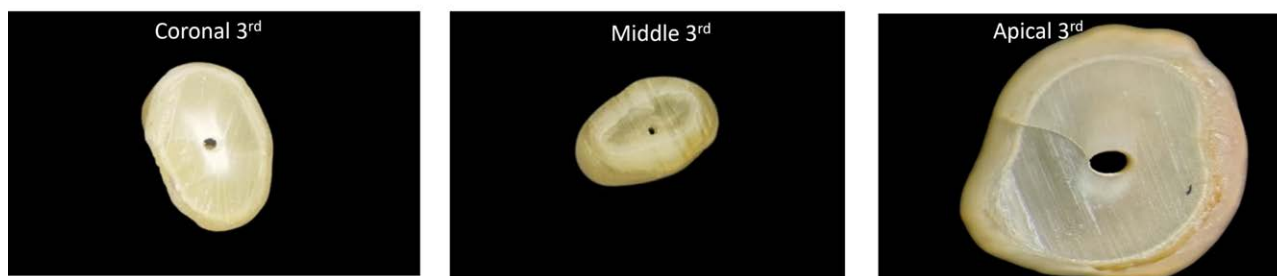
Table 1**Canal-centering ability at the apical, middle, and coronal third.**

Group	File system	Motion type	Apical third (3 mm)	Middle third (6 mm)	Coronal third (9 mm)
1	ProTaper Next	Continuous	0.35 ± 0.08	0.30 ± 0.07	0.28 ± 0.06
2	MicroMega One RECI	Reciprocating	0.20 ± 0.05	0.18 ± 0.04	0.17 ± 0.03
3	Race Evo	Continuous	0.32 ± 0.07	0.29 ± 0.06	0.27 ± 0.05
4	R-Motion	Reciprocating	0.22 ± 0.06	0.19 ± 0.05	0.18 ± 0.04

Table 2**Remaining dentin thickness (mean ± SD).**

Group	File system	Motion type	Apical third (3 mm)	Middle third (6 mm)	Coronal third (9 mm)
1	ProTaper Next	Continuous	0.65 ± 0.10	0.80 ± 0.12	1.00 ± 0.15
2	MicroMega One RECI	Reciprocating	0.75 ± 0.09	0.90 ± 0.11	1.10 ± 0.14
3	Race Evo	Continuous	0.68 ± 0.11	0.85 ± 0.13	1.05 ± 0.16
4	R-Motion	Reciprocating	0.73 ± 0.10	0.88 ± 0.12	1.08 ± 0.15

SD = standard deviation.

Group 1: Dentinal Cracks at 3 root levels by Protaper next**Figure 5.** Dentinal cracks at 3 root levels by ProTaper Next.**Group 3: Dentinal Cracks at 3 root levels by Race Evo****Figure 6.** Dentinal cracks at 3 root levels by Race Evo.

thickness, and dentinal crack formation when various rotary and reciprocating file systems were used.

4. Discussion

The preservation of the natural curvature and original configuration of the root canal system is a fundamental principle in endodontic therapy. Endodontic file systems, therefore, should be designed to respect the inherent morphology of the canal. Proper centering of the instrument minimizes the removal of unnecessary dentin from 1 side of the canal wall and prevents common iatrogenic errors like ledge formation, zipping, or canal perforation.^[16]

Although rotary NiTi instruments have improved the efficiency and predictability of canal preparation, variations in instrument design and motion kinematics – specifically continuous rotation and reciprocating motion – may influence shaping ability, canal transportation, centering ability, and incidence of procedural errors.^[15]

Recent advances in rotary NiTi file systems have created a paradigm shift in root canal therapy. Thus, it is vital to evaluate the efficiency of newly manufactured root canal-shaping systems using different parameters.

This study evaluated the canal-centering ability, amount of dentin removal, and dentinal crack formation following root

Group 2: Dentinal Cracks at 3 root levels by Micro Mega Recipro One

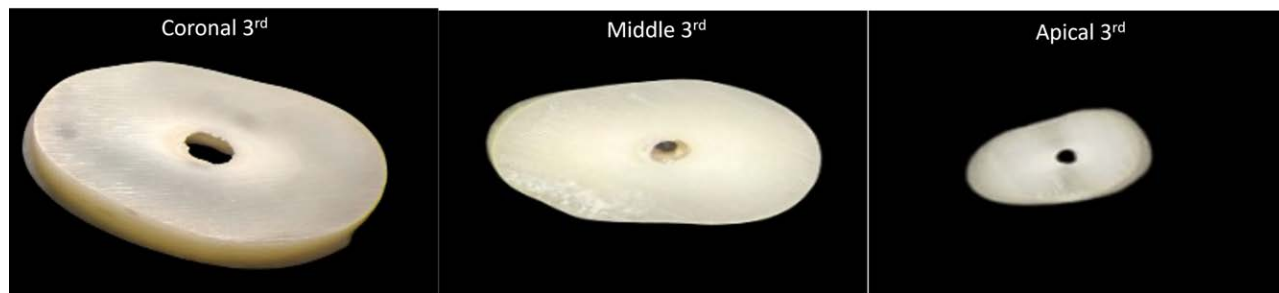


Figure 7. Dentinal cracks at 3 root levels by MicroMega One RECI.

Group 4: Dentinal Cracks at 3 root levels by R Motion



Figure 8. Dentinal cracks at 3 root levels by R-Motion.

Table 3
Incidence of dentinal crack formation at different root levels.

Group	File system	Level from apex	No cracks (%)	Craze lines (%)	Partial cracks (%)	Complete cracks (%)
1	ProTaper Next	3 mm	30	25	30	15
		6 mm	40	30	25	5
		9 mm	50	30	20	0
2	MicroMega One RECI	3 mm	60	25	15	0
		6 mm	70	20	10	0
		9 mm	80	15	5	0
3	Race Evo	3 mm	35	30	25	10
		6 mm	45	30	20	5
		9 mm	55	25	20	0
4	R-Motion	3 mm	65	20	15	0
		6 mm	70	20	10	0
		9 mm	75	20	5	0

canal preparation using different rotary file systems in continuous and reciprocating motions.

Single-canal mandibular premolars with an apical curvature of <20 degrees were used in this study. An advantage in using such teeth is that they are frequently extracted for orthodontic reasons and thus are relatively easily available for study purposes.^[17] In addition, they assure uniformity in anatomy, provide a reasonable level of difficulty that is clinically relevant, reduce the number of complicating variables, improve internal validity and reproducibility, and hence enable instrumentation systems to be fairly compared.

In the present study, CBCT was chosen as the main evaluation tool because of its higher spatial resolution, better measurement accuracy, and lower radiation dose compared with other imaging methods. The canal-centering ability was evaluated at

3 standardized levels along the root: the apical (3mm), middle (6mm), and coronal (9mm), using the calculations of the centering ratio derived from the CBCT-based assessments of canal transportation.

Among the tested groups, MMOR (Group 2) consistently demonstrated the best centering ability, with the lowest mean deviation values across all 3 levels. This was closely followed by RM (Group 4), another reciprocating system. In contrast, PTN (Group 1) and Race Evo (Group 3), both rotary file systems used in continuous motion, showed significantly higher centering ratios, indicating greater canal deviation.

The superior performance of the MMOR reciprocating file system may be attributed to its unique design features, such as off-center cross-sections and progressive tapering at the apical section, which together enhance centric engagement with the

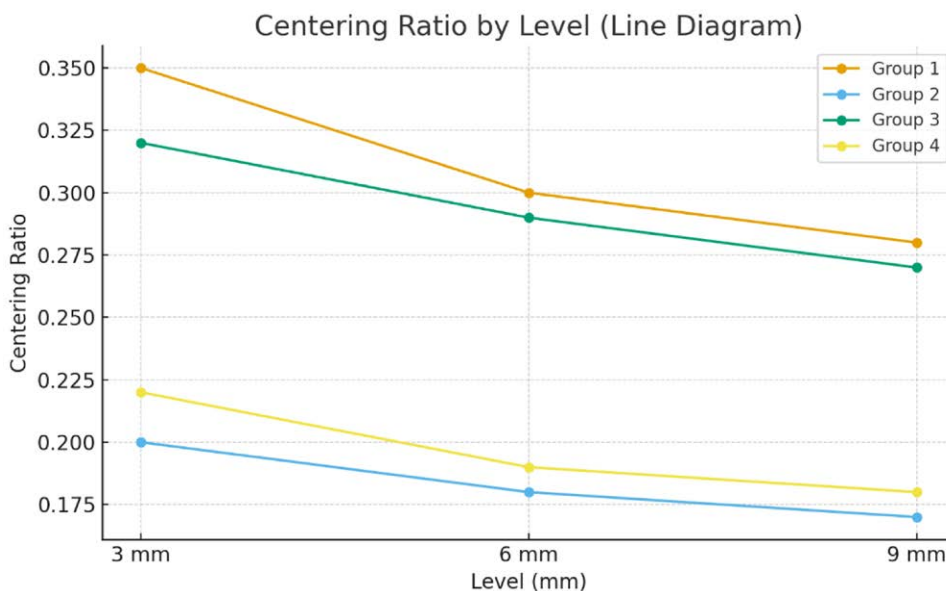


Figure 9. Comparison of centering ratio vertically.

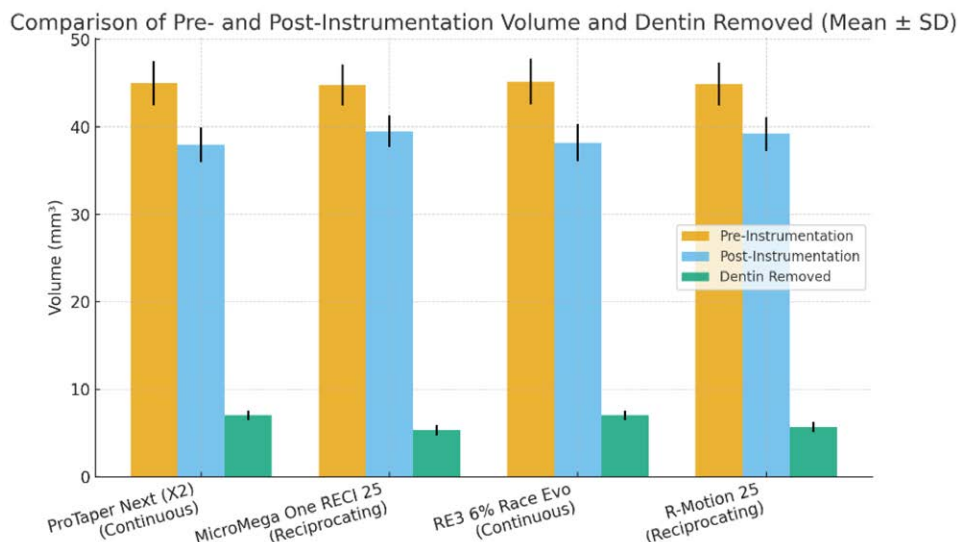


Figure 10. Volumetric comparison between pre- and post-instrumentation CBCT images. CBCT = cone beam computed tomography, SD = standard deviation.

canal walls. In addition, the variable and asymmetrical section of the MMOR reciprocating file system might enhance cutting efficiency and debris clearance, potentially facilitating better canal centering during the procedure. The shaping ability of this reciprocating file system in preparation of complex canals has been subject to several studies,^[18,19] highlighting its effectiveness in maintaining original canal anatomy.

The findings of our results reinforce the concept that reciprocating systems exert reduced torsional stress on canal walls, allowing the file to better follow the natural curvature of the canal.^[20,21] Our results are in agreement with Jain et al^[22] and Grande et al,^[23] who stated that reciprocating rotary files preserve the original canal curvatures better when compared with continuous motion. This advantage can be attributed to the file's reciprocating motion. A substantial counterclockwise rotation angle governs the instrument's progression within the canal and its interaction with dentin for cutting, whilst a smaller clockwise angle enables prompt disengagement and secure navigation along the canal trajectory to maintain its curvature.

The advantages of reciprocating motion are based on the principles of physics relevant to root canal preparation, resulting in a technique defined by balanced force.

RM rotary files used in reciprocating motion also performed better in our study in maintaining canal-centering ability, which could be attributed to their thinner core size, sharper cutting edges, enhanced file tips, rounded triangular cross-sections, and flexibility. Because of this, root canal wall dentin is preserved, and the dentin itself experiences less stress; hence, it is capable of improving canal shape with better canal-centering ability.^[24] These results are supported by studies by AlSulaiman et al and Islam et al, who have also supported the fact that RM files lead to better canal-centering ability and less dentin removal.^[24,25]

In the present study, PTN and Race Evo rotary files in continuous motion showed less canal-centering ability compared with the reciprocating rotary files, indicating deviation from the normal canal curvature. This could be due to their offset rectangular cross-section design, resulting in a swaggering motion of PTN and, hence, non-centered canal preparations. It can also be attributed to PTN's variable taper of the cutting blade along its length. It has

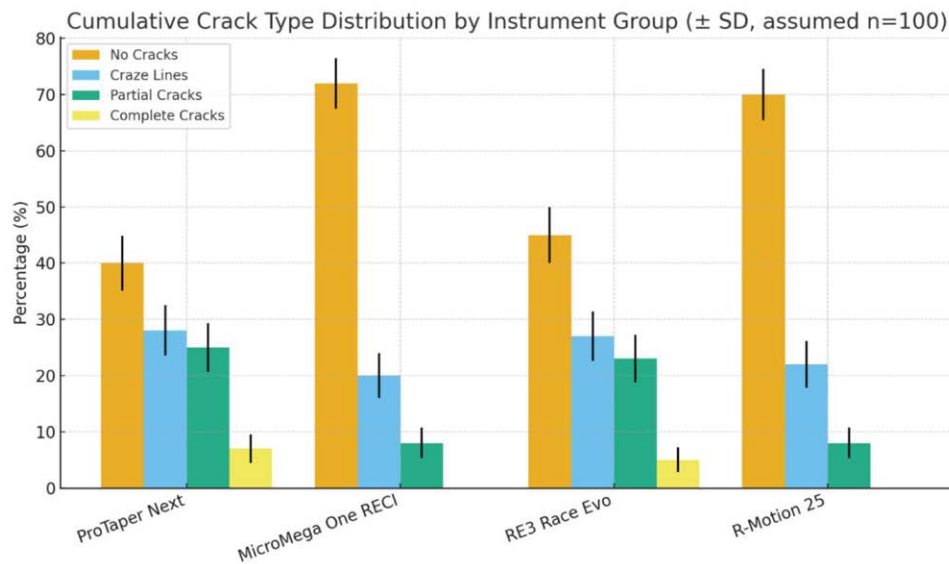


Figure 11. Cumulative crack type distribution by instrument group. SD = standard deviation.

been established that instruments with constant apical inclination demonstrate superior centering ability compared with those with variable taper along the blade because this inclination increases stiffness and decreases file flexibility and can lead to canal transportation.^[26,27] Our results are in accordance with Tonetto et al, who in their study concluded that the PTN instrument achieved the worst ratio values at levels 2 and 3 in the outer part of the curvature, demonstrating this instrument's tendency to produce greater wear on the apical portion of the canal.^[28]

The amount of remaining dentin thickness and the presence of dentinal cracks after canal preparation using 4 rotary NiTi systems used in continuous and reciprocating motion were also evaluated in this study. The findings in our results suggest that the reciprocating systems showed better dentin preservation and less incidence of cracks as compared with rotary systems. Among all groups, the samples instrumented with the reciprocating file, Group 2 (MMOR), showed the highest dentin thickness in all levels considered, followed by Group 4 (RM), while Group 3 (Race Evo) and Group 1 (PTN) showed the least remaining dentin, especially within the apical third. The quantitative measure showed that the reciprocating MMOR system had mean dentin thicknesses of 0.75 ± 0.09 mm in the apical third, 0.90 ± 0.11 mm in the middle third, and 1.10 ± 0.14 mm in the coronal third. The PTN system from Group 1, on the other hand, had more aggressive cutting behavior and thus thinner remaining dentin: 0.65 ± 0.10 mm, 0.80 ± 0.12 mm, and 1.00 ± 0.15 mm, respectively.

The reason for excess dentin removal by PTN is believed to be due to its characteristics, which may be explained by its unique offset design that contributes to its 2-point contact with the canal wall and swaggering motion in root canals.^[29] A study by Van der Vyver et al and Huang et al further supports the fact that PTN rotary files resulted in more dentin removal by virtue of the fact that the “envelope of motion” of PTN instruments causes them to extract more dentin from the outer surface than other files.^[30,31]

Among the rotary systems in continuous motion examined, the PTN (Group 1) induced the highest rate of dentinal cracks in most of the samples. This could be explained by the increased stress concentration occurring in the curved mid-root area and by the file's offset rectangular design, which induces a characteristic swaying or “snake-like” motion during operation.^[25] Such a movement pattern increases the envelope of canal contact compared with instruments that have symmetric mass and an axis

of rotation; this may lead to excessive removal of dentin and increase the risk of structural defects in the form of dentinal cracks.^[32,33] The observation of the present study is in accordance with Capar et al, who reported the incidence of dentinal crack formation after instrumentation with the PTN X2 file. Also, the results are consistent with the findings reported by Nagy and Fahmy, who stated that because of higher levels of stress concentrations in root canal walls created by PTN files, it can lead to crack formation,^[34] and by Cirakoglu and Ozbay, who concluded that PTN file leads to a mechanical wave of motion similar to the oscillation. This causes cutting off a bigger envelope of motion compared with other files with the same size but having a symmetrical mass and axis of rotation.^[35]

5. Conclusion

Based on observations from this in vitro study, it can be concluded that the variations in the design of file systems and motion patterns critically determine the efficiency and safety of root canal shaping. Reciprocating and rotary motions show different effects on canal centering, dentin removal, crack propagation, and the preservation of root integrity.

5.1. Limitations of the study

1. Straight canals only: Only mandibular premolars with mild canal curvature were selected. The performance of these systems in moderate to severely curved canals was not evaluated.
2. Sample size: The study was limited to 40 teeth. A larger sample may enhance the statistical power of the findings.
3. Short-term assessment: Long-term consequences, such as crack propagation, obturation integrity, or restoration compatibility, were not studied.
4. No CF testing: Instrument longevity and fracture resistance were not assessed, which are also critical to clinical decision-making.

Acknowledgments

The authors would like to express their sincere gratitude to Dr Zubair and Mr Arif for providing technical support with the

CBCT and stereomicroscope procedures. Their expertise and support greatly contributed to the success of this study.

Author contributions

Conceptualization: Suheel Manzoor Baba.

Methodology: Suheel Manzoor Baba, Nik Rozainah Nik Abdul Ghani.

Visualization: Suheel Manzoor Baba, Shabina Shafi.

Formal analysis: Johari Yap Abdullah.

Validation: Shabina Shafi.

Supervision: Nik Rozainah Nik Abdul Ghani, Mohammed Alqarni, Johari Yap Abdullah.

Writing – original draft: Suheel Manzoor Baba.

Writing – review & editing: Nik Rozainah Nik Abdul Ghani, Mohammed Alqarni.

References

- El-Kishawi M, Khalaf K. An update on root canal preparation techniques and how to avoid procedural errors in endodontics. *Open Dent J*. 2021;15:318–24.
- Scarlatescu SA, Gheorghiu I, Nicola G, Al Aloul AO, Perlea P. Frequent procedural errors and structural complications on endodontical treated teeth. *Rom J Stomatol*. 2021;67:101–6.
- Grande NM, Castagnola R, Minciocchi I, Marigo L, Plotino G. A review of the latest developments in rotary NiTi technology and root canal preparation. *Aust Dent J*. 2023;68:S24–38.
- Agarwal RS, Agarwal J, Jain P, Chandra A. Comparative analysis of canal centering ability of different single file systems using cone beam computed tomography - an in vitro study. *J Clin Diagn Res*. 2015;9:ZC06–10.
- Ahn S-Y, Kim H-C, Kim E. Kinematic effects of nickel–titanium instruments with reciprocating or continuous rotation motion: a systematic review of in vitro studies. *J Endod*. 2016;42:1009–17.
- Alfawaz H, Alqedairi A, Al-Dahman YH, et al. Evaluation of root canal morphology of mandibular premolars in a Saudi population using cone beam computed tomography: a retrospective study. *Saudi Dent J*. 2019;31:137–42.
- Tejaswi S, Singh A, Manglekar S, Ambikathanaya UK, Shetty S. Evaluation of dentinal crack propagation, amount of gutta percha remaining and time required during removal of gutta percha using two different rotary instruments and hand instruments-an in vitro study. *Niger J Clin Pract*. 2022;25:524–30.
- Das S, Pradhan PK, Lata S, Sinha SP. Comparative evaluation of dentinal crack formation after root canal preparation using ProTaper Next, OneShape, and Hyflex EDM. *J Conserv Dent*. 2018;21:153–6.
- Harandi A, Mirzaeeraad S, Mehrabani M, Mahmoudi E, Bijani A. Incidence of dentinal crack after root canal preparation by ProTaper universal, Neolix and SafeSider systems. *Iran Endod J*. 2017;12:432–8.
- Mustafa M. Comparative evaluation of canal-shaping abilities of RaceEvo, R-Motion, Reciproc Blue, and ProTaper Gold NiTi rotary file systems: a CBCT study. *J Contemp Dent Pract*. 2021;22:1406–12.
- Pawar AM, Thakur B, Kfir A, Kim HC. Dentinal defects induced by 6 different endodontic files when used for oval root canals: an in vitro comparative study. *Restor Dent Endod*. 2019;44:e31.
- Venkatesh E, Elluru SV. Cone beam computed tomography: basics and applications in dentistry. *J Istanbul Univ Fac Dent*. 2017;51:102–21.
- Kosturkov D, Radeva E, Uzunov T. Digital determination of curvature of root canals of extracted teeth. *Acta Med Bulg*. 2020;47:32–5.
- Gambill JM, Alder M, del Rio CE. Comparison of nickel-titanium and stainless-steel hand-file instrumentation using computed tomography. *J Endod*. 1996;22:369–75.
- Zanza A, D'Angelo M, Reda R, Gambarini G, Testarelli L, Di Nardo D. An update on nickel–titanium rotary instruments in endodontics: mechanical characteristics, testing and future perspective—an overview. *Bioengineering (Basel)*. 2021;8:218.
- Damkoengsunthon C, Wongviriyaya A, Tantanapornkul W, et al. Evaluation of the shaping ability of different rotary file systems in severely and abruptly curved root canals using cone beam computed tomography. *Saudi Dent J*. 2024;36:1333–8.
- Mahtani A, Jain RK. Frequency of premolar teeth extractions for orthodontic treatment. *Bioinformation*. 2020;16:1080–7.
- Jain A, Al Wahaibi A, Singh G, Qutieshat A. Comparative evaluation of canal transportation and centering ability of TruNatomy and MicroMega One RECI in curved root canals. *J Endod Restor Dent*. 2024;2:8–11.
- Mustafa M, Attur K, Bagda KK, Singh S, Oak A, Kathiria N. An appraisal on newer endodontic file systems: a narrative review. *J Contemp Dent Pract*. 2023;23:944–52.
- Patil PG, Banga KS, Metkari S, et al. Canal centering ability of various file systems during endodontic treatment and re-treatment: a systematic review. *Euro Soc Med*. 2024;12:1–16.
- Atigre PD, Jobanputra LH, Sharma AR, Kashiyani SK, Iyer JV, Kumari P. Canal transportation and centering ability of HyFlex CM and TruNatomy rotary file systems in moderately curved root canals using CBCT: an in vitro study. *Endodontology*. 2023;35:223–7.
- Jainaen A, Mahakunakorn N, Arayatrakullikit U, Sutthiprapaporn P, Noisombat R. Cone-beam computed tomography evaluation of curved root canals prepared using reciprocal rotary files and rotational rotary files. *J Conserv Dent*. 2018;21:32–6.
- Grande NM, Ahmed HM, Cohen S, Bukiet F, Plotino G. Current assessment of reciprocation in endodontic preparation: a comprehensive review-part I: historic perspectives and current applications. *J Endod*. 2015;41:1778–83.
- Alsulaiman M, Alsofi L, Alhabib MA. Shaping ability of NiTi reciprocating file systems R-motion and WaveOne Gold in mesial canals of mandibular molars; micro CT study. *Sci Rep*. 2025;15:747.
- Islam A, Unsal G, Almashharawi A. Canal transportation and volumetric dentin removal abilities of Ni-Ti rotary file systems in curved primary root canals: CBCT study. *Appl Sci*. 2021;11:9053.
- Al-Abady AM, Al-Zaka IM. Evaluation of the canal transportation and centering ability of different rotary NiTi systems in simulated curved canals. *Indian J Forensic Med Toxicol*. 2021;15:1396–406.
- Saleh AM, Gilani PV, Tavanafar S, Schäfer E. Shaping ability of 4 different single-file systems in simulated S-shaped canals. *J Endod*. 2015;41:548–52.
- Tonetto MR, Maia Filho EM, dos Reis Santos RM, et al. Shaping ability of ProTaper Next, WaveOne, and Reciproc in simulated root canals. *J Contemp Dent Pract*. 2017;17:902–6.
- Kumar T, Mittal S, Keshav V, Kaur R, Maakhni E. A comparative evaluation of remaining dentin thickness following biomechanical preparation of teeth using different rotary file systems: an in vitro study. *J Conserv Dent*. 2022;25:32–6.
- van der Vyver PJ, Paleker F, Vorster M, De Wet FA. Root canal shaping using nickel titanium, M-Wire, and gold wire: a micro-computed tomographic comparative study of One Shape, ProTaper Next, and WaveOne Gold instruments in maxillary first molars. *J Endod*. 2019;45:62–7.
- Huang Z, Quan J, Liu J, et al. A microcomputed tomography evaluation of the shaping ability of three thermally-treated nickel-titanium rotary file systems in curved canals. *J Int Med Res*. 2019;47:325–34.
- Jacob J, Paul M, Sara B, Steaphen P, Philip N, Mathew J. Comparative analysis of dentinal crack formation following root canal instrumentation with hand K-Flex files, ProTaper Next, and self-adjusting files. *J Contemp Dent Pract*. 2019;20:935–9.
- Capar ID, Arslan H, Akcay M, Uysal B. Effects of ProTaper Universal, ProTaper Next, and HyFlex instruments on crack formation in dentin. *J Endod*. 2014;40:1482–4.
- Nagy MM, Fahmy SH. Incidence of dentinal crack formation after root canal preparation using different rotary files. *Ain Shams Dent J*. 2021;24:35–42.
- Çirakoglu NN, Özbay Y. Evaluation of apical crack formation associated with root canal preparation with ProTaper Next, ProTaper Gold, and TruNatomy systems. *Endodontology*. 2021;33:191–5.