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Original Article

Comparative Evaluation of Canal Transportation and Centering Ability of ProTaper Next, NeoNiTi, and R-Motion by CBCT Analysis in the Curved Root Canals of Permanent Mandibular First Molar: An In Vitro Study

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Abstract

Background: The success of root canal therapy hinges on various factors, with biomechanical preparation standing out as a crucial step. Equally significant is the meticulous preservation of the canal's natural shape, as any deviation from it can lead to complications such as canal aberrations or transportation. The aim of the study was to evaluate the canal transportation and canal centering ability of ProTaper Next (PTN), NeoNiTi, and R-Motion (RM) file systems using cone-beam computed tomography (CBCT).

Methods: Thirty human mandibular molar roots with an angle of curvature between 10^0 and 20^0 were chosen into three groups of ten samples each from the pool of collected samples that met the inclusion and exclusion criteria, including PTN (group I), NeoNiTi (group II), and RM file systems (group III). To achieve reproducibility of pre- and post-operative CBCT scans and to ease instrumentation, the tooth was placed in a template created using silicon impression material. Using CBCT software, pre- and post-instrumentation pictures were obtained from the apex at three different levels (3 mm, 6 mm, and 9 mm). One-way analysis of variance and post hoc analysis were used to evaluate the amount of transportation and centering ability.

Results: RM demonstrated better canal centering ability than PTN and NeoNiTi at 3 mm and 6 mm, but there was no statistically significant difference in canal transportation between the three groups at levels of 3 mm, 6 mm, and 9 mm from the apex.

Conclusion: PTN, NeoNiTi, and RM all exhibited similar behaviour under the study's in-vitro conditions in terms of canal transportation and centering ability. However, the RM group outperformed the other systems in terms of both canal transportation and centering ability, with NeoNiTi and PTN systems coming in second and third, respectively.

Keywords: Canal transportation, Canal centering ability, Cone-beam computed tomography, PTN, RM

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Background

As a cornerstone of endodontic therapy, root canal treatment focuses on removing bacteria and debris from the dentin and carefully preparing the canals (1). Root canal instrumentation, a pivotal step in root canal treatment, involves intricate mechanical processes, employing irrigants and medicaments to effectively shape canals. The success of subsequent treatment phases hinges on the precision of this step. It might be difficult to prepare a root canal most effectively, especially in curved canals where there is a greater possibility of procedural errors such as canal transportation (2). Instrumentation is greatly hampered by canal transportation, iatrogenic deviance from the original canal course, especially in curved canals. The incidence of transportation varies across different root canal levels, with the apical region being more susceptible. Various factors, including root canal anatomy complexity, instrumentation techniques, and operator skill, contribute to the occurrence of transportation (3). The prevalence of traditional stainless-steel instruments is hindered by their limited flexibility, often resulting in iatrogenic complications. The field of root canal preparation experienced a historic shift with the development of nickel-titanium (NiTi) instruments, which are distinguished by special features such as shape memory and super flexibility (4). Furthermore, the application of novel techniques guaranteed the continued preservation of the original canal geometry by utilizing a more accurate, centrally aligned rotary file system. The introduction of these systems into endodontics signifies a crucial advancement, aiming at enhancing the efficiency of canal instrumentation, resulting in a faster and more accessible process.

Continuous rotary systems, such as the ProTaper Next (PTN) from Dentsply Maillefer, have been in use for the past 25 years and fall into the category of fifth-generation rotary shaping file systems. Unlike previous rotating NiTi instruments, PTN uses a wave-like mechanism of motion, is distinguished by its offset axis of mass and rotation, and aims to reduce transportation. Utilizing M-Wire technology for enhanced flexibility and cyclic fatigue resistance, PTN features an asymmetric design with advantages such as efficient debris removal coronally and high resistance to cyclic fatigue. It is comprised of five files, namely, X1 (17/0.04), X2 - (25/0.06), X3 - (30/0.07), X4 - (40/0.06), and X5 - (50/0.06). Taper lock and the screw effect can be prevented using varying percentage tapers, which decrease the degree of friction between a file and dentin (5). Research indicates that PTN, in comparison to other file systems such as WaveOne (Dentsply Maillefer), BT-Race (FKG), and ProTaper Universal (Dentsply Maillefer), is linked to lower levels of debris extrusion and less canal transportation (6).

Through the use of wire-cut electrical discharge machining, the NeoNiTi (Orikam) rotary file system is developed with outstanding surface finishing, low residual stresses, and great precision. The system comprises two main components, namely, the orifice opener (NeoNiTi C1) and the single shaping file system (NeoNiTi A1), available in yellow (20/6%), red (25/6%), and black (30/4%) tapers. They are designed with a rectangular cross-section, providing enhanced cutting edges, an abrasive surface, and progressive flexibility (7).

Recently, the development of NiTi alloys and endodontic torque control motors has led to a resurgence of interest in reciprocating motion. The balanced force approach (Roane et al., 1985) gave rise to the idea of reciprocation, which enables hand devices to shape even highly curved canals into larger apical diameters (8). The R-Motion (RM) file system is a recent introduction in endodontics. Because of their smaller core sizes, these file systems are more versatile in design and have optimized file tips and rounded triangular cross-sections with keen cutting edges. The unique design of RM files minimizes the screwing effect, allowing clinicians to maintain higher control efficiency during root canal instrumentation. The files, titled RM G (15/0.03), RM 25 (25/0.06), RM 30 (30/0.04), RM 40 (40/0.04), and RM 50 (50/0.04), show alternate percentage tapers. RM files undergo heating treatment between 32 degrees and 35 degrees Celsius, during which they go through a phase change from martensite to austenite (9).

Considering that there is no literature available on Canal Transportation and Centering Ability comparing NeoNiTi and RM. Accordingly, this study explores two innovative NiTi rotary systems, NeoNiti (continuous rotation) and RM (reciprocation), comparing their shaping abilities, specifically focusing on canal transportation and centering ability in curved root canals. The well-established PTN serves as a benchmark for comparison. Utilizing CBCT, this research seeks to evaluate the anatomical changes in root canals before and after instrumentation. The null hypothesis posits no significant differences among the evaluated NiTi rotary systems for the analyzed parameters.

Materials and Methods

The Institutional Research Committee granted ethical clearance for the study (No. IECVDC/23/PG01/CE/IVT/92).

Sample Size Calculation

A prior study (10) with a *P* value of less than 0.05 and G*Power software with 80% confidence was the basis for calculating sample size. After calculations, a minimum of 10 teeth were included in each group.

Sample Selection and Methodology

After approval by the Institutional Review Board, 30 intact human permanent mandibular molars, extracted for periodontal reasons, were collected one month prior to the commencement of the study. They included mesiobuccal canals with fully developed apices that had an angle of curvature between 10° and 20° as per the Schneider approach (11) and a minimum length of 19 mm, as selecting this range ensures a focus on canals that present a realistic challenge in clinical practice. Extreme curvatures (either very high or very low) might not represent typical cases encountered by practitioners. The length of 19 mm ensures that the samples are representative of the average size of human teeth and allows for the application of standard endodontic tools and methods. Before being used, every tooth was cleansed, sanitized, and kept in saline at 4 °C. Teeth with immature teeth, fractures, pathological root resorptions, calcifications, or any prior endodontic therapy were eliminated from the investigation. Fractures were clinically evaluated by utilizing the dental operating microscope with 12x magnification. Every single specimen was calibrated to have a length of 13 mm. Calculating the length of the root canal involved advancing a 10-K-file (Mani, Japan) into the canal until it reached the tip of the apex and then deducting 0.5 mm. The specimens were inserted into putty blocks to achieve constant location and divided into three groups (Figure 1A).

Initial Scanning

To align the occlusal plane of the chin support with the plate, the template is fitted horizontally. Every tooth requires a pre-CBCT scan performed before it is instrumented. To analyze pre- and post-instrumentation data later on using DICOM software, the images were stored on the hard drive of the computer, and 3.0 seconds of exposure were conducted at 2.0 mA and 75 kV (Figure 1B-D).

Final Root Canal Preparation

Initial scans were conducted prior to the instrumentation in each group.

- Group 1: Canals were shaped with the PTN rotary file system (Dentsply Sirona Ballaigues, Switzerland). The PTN-SX file works as an orifice modifier, and then X1- (17/0.04) and X2- (25/0.06) are used till reaching the working length. Following each instrumentation, irrigation and recapitulation were performed using a 10-K file.
- Group 2: NeoNiTi (Neolix, Chatres-La-Foret, France) rotary files were employed to sculpt the canals. A sequence of NeoNiTi A1 (20/0.06) and NeoNiTi A1 (25/0.06) and the NeoNiTi C1 orifice modifier are utilized, respectively. With a torque of 4 Ncm and a rotational pace of 300 rpm, files were used in a brushing action. Similar to Group 1, irrigation and recapitulation were performed in this group.
- Group 3: The RM (FKG Dentaire SA, La Chaux de Fonds, Switzerland) was employed to shape the canals. RM Glider (15/0.03) and RM 25 (25/0.06) were utilized, respectively. With a torque of 4 Ncm and a rotational speed of 500 rpm, files were utilized in a brushing action. Similar to Group 1, irrigation and recapitulation were conducted in this group. All tools and methods used in this study followed the manufacturer's guidelines. Biomechanical preparation was performed using the appropriate files. The final irrigation was conducted using 0.9% normal saline, 17% ethylenediaminetetraacetic acid, and 3% sodium hypochlorite solution (NaOCl).

Final Scanning and Evaluations

The samples underwent postoperative CBCT scanning using consistent parameters. Pre-instrumentation data were saved, and using CBCT software (Kodak 9000 DICOM Software CS 9000 3D), a comparative analysis was performed with post-instrumentation data (1). Each specimen was illustrated by three axial tomograms (apical third, middle third, and cervical third), which were obtained at the root apex at 3 mm, 6 mm, and 9 mm, respectively.

Evaluation of Canal Transportation

The shortest stretch from the margin of the pre-instrumented canal and the outermost aspect of the root on the mesial and distal aspects was estimated, and the findings were compared with the same measurements created from the instrumented images (Figure 2) (12). This allowed for the determination of the amount of canal transportation using the formula presented by Gambill et al (14).

1. (a1– a2) – (b1– b2)
2. $(c_1 - c_2) - (d_1 - d_2)$

Before Instrumentation

a1: The shortest path between the root's mesial boundaries and the canal

b1: The shortest path between the canal and the distal limits of the root

c1: The shortest path between the canal and the buccal borders of the root

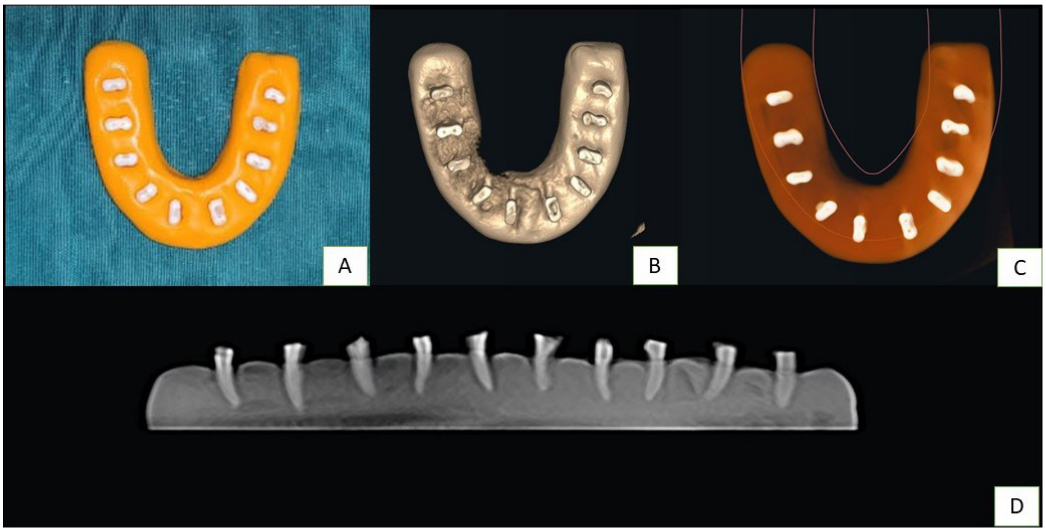

Figure 1. (A) Samples Stabilized with Silicon Impression Mould, **(B-C)** Preoperative CBCT Scanning Modalities With Various Filters, and **(D)** CBCT Scanning of the Samples in Longitudinal Section. *Note*. CBCT: Cone-beam computed tomography

d1: The shortest path between the canal and the lingual borders

After instrumentation

a2: The shortest path between the mesial margins of the root and the canal
b2: The shortest path between the distal boundaries of the root and the canal
c2: The shortest path between the canal and the buccal borders
d2: The shortest path between the canal and the lingual borders

The results of these calculations point out that 0 denotes no canal transportation.

Evaluation of Canal Centering Ability

The ratio (A1 – A2)/(B1 – B2) or (B1 – B2)/(A1 – A2) is used to calculate canal centering ability. A score of one in this formula represents perfect centering. Pre- and post-operative CBCT images for canal centering ability were evaluated using the mentioned formula (Figure 3).

Statistical Analysis

The obtained data were analyzed using SPSS (Statistical Package for Social Sciences) version 20 software. The confidence interval was set at 95%, and the *P* value was set at 0.05. Any value equal to or less than was considered to be significant. Canal transportation was assessed using the Kruskal-Wallis test, followed by Tukey's post hoc test. Centering ability was evaluated using a one-way analysis of variance, followed by Tukey's post hoc test.

Results

Canal Transportation

The results in Table 1 demonstrate the means ± standard

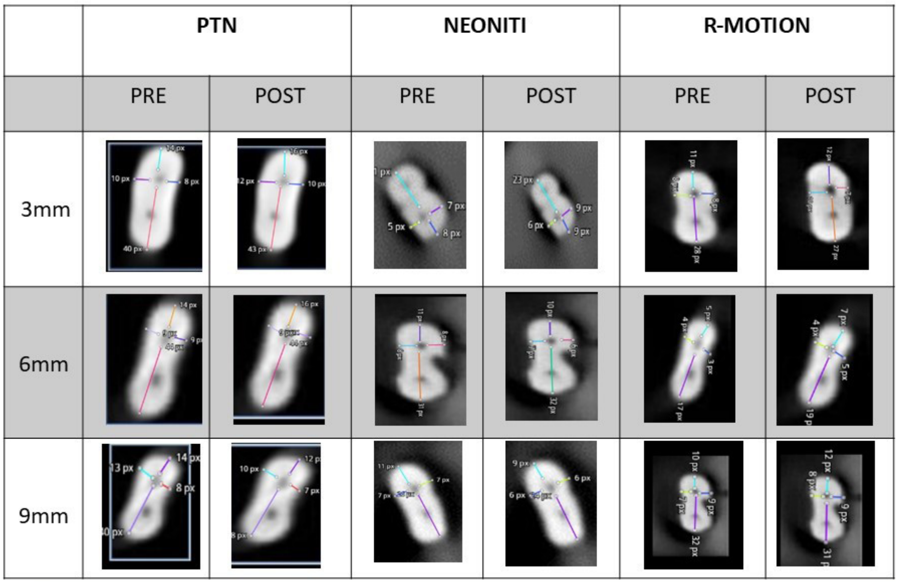

Figure 2. Pre- and Post-operative CBCT Images for Assessing Canal Transportation. *Note*. CBCT: Cone-beam computed tomography

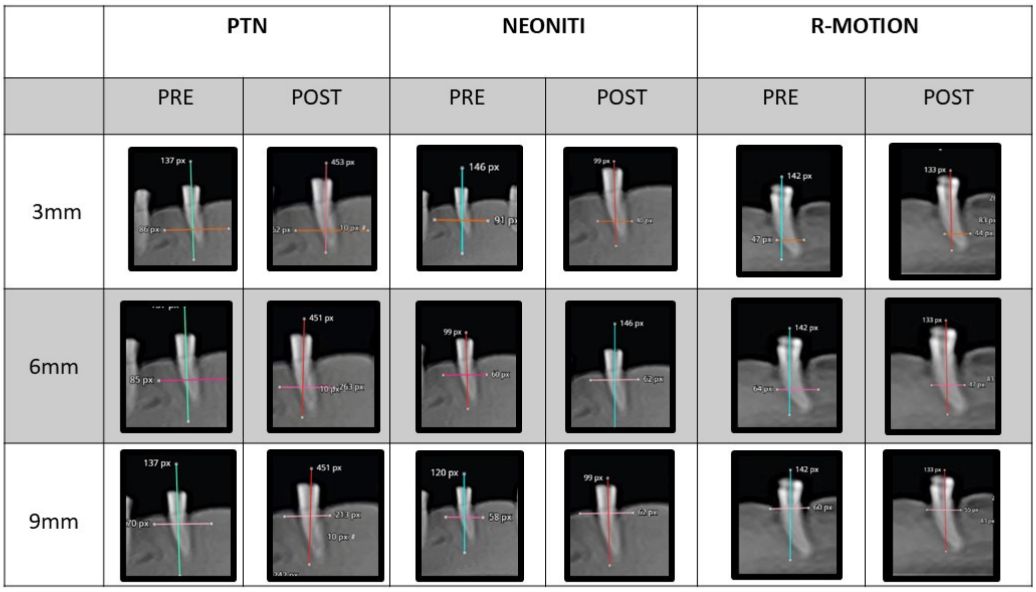

Figure 3. Pre- and Post-operative CBCT Images for Canal Centring Ability. *Note*. CBCT: Cone-beam computed tomography

deviations (SD) of canal transportation at 3 distinct apex levels (3 mm, 6 mm, and 9 mm) among the PTN, NeoNiTi, and RM groups. Group I exhibited mean transportation of 0.1 ± 0.18, 0.03 ± 0.24, and - 0.05 ± 0.21 at 3 mm, 6 mm, and 9 mm, respectively, from the apex. For group II, the mean transportation was 0.6 ± 0.17, 0.1 ± 0.11, and - 0.02 ± 0.13 mm at 3 mm, 6 mm, and 9 mm, respectively. At 3 mm, 6 mm, and 9 mm apical region, the mean transportation of Group III was 0.0 ± 0.06, -0.01 ± 0.05, and 0.02 ± 0.12, respectively. No statistically significant difference was detected among these groups for canal transportation at 3 mm, 6 mm, and 9 mm ($P > 0.05$, Figure 4).

Canal Centering Ability

Table 2 presents mean and SD values of the canal centering ability at 3 distinct apex levels (3 mm, 6 mm, and 9 mm) among the PTN, NeoNiTi, and RM groups. Group I represented the mean centering ability of 1.64 ± 0.98, 1.37 ± 0.86, and 0.65 ± 0.32 at 3 mm, 6 mm, and 9 mm, respectively, from the apex. For group II, the mean centering ability was 1.5 ± 1.2, 1.48 ± 0.78, and 1.0 ± 0.40 at 3 mm, 6 mm, and 9 mm, respectively. Group III demonstrated mean centering ability of 1.1 ± 0.5, 1.0 ± 0.4, and 1.2 ± 0.83_at 3 mm, 6 mm, and 9 mm, respectively, from the apex. There was a significant difference among the groups ($P > 0.05$) at 9 mm. No statistically significant difference was observed among these groups at 3 mm and 6 mm ($P > 0.05$, Figure 5).

Discussion

The major objectives of endodontic therapy are to eradicate microbes and their by-products from the root canal system and to stop infection recurrence. This involves accessing, shaping, cleaning, and ultimately sealing the root canal.

Table 1. Comparison of Canal Transportation at 3 mm, 6 mm, and 9 mm Among ProTaper Next, NeoNiTi, and R-Motion Groups

	Mean and SD	F-value	*P*-value
3 mm			
Group 1	0.1 ± 0.18		
Group 2	0.6 ± 0.17	1.132	0.337
Group 3	0.0 ± 0.06		
6 mm			
Group 1	0.03 ± 0.24		
Group 2	0.1 ± 0.11	0.164	0.850
Group 3	-0.01 ± 0.05		
9 mm			
Group 1	- 0.05 ± 0.21		
Group 2	- 0.02 ± 0.13	0.464	0.633
Group 3	0.02 ± 0.12		

Note. SD: Standard deviation.

Table 2. Comparison of Canal Centering Ability at 3 mm, 6 mm, and 9 mm Among ProTaper Next, NeoNiTi, and R-Motion Groups

	Mean and SD	Test-value	*P*-value
3 mm			
Group 1	1.64 ± 0.98		
Group 2	1.5 ± 1.2	0.915	0.412
Group 3	1.1 ± 0.51		
6 mm			
Group 1	1.37 ± 0.86		
Group 2	1.48 ± 0.78	1.214	0.305
Group 3	1.0 ± 0.40		
9 mm			
Group 1	0.65 ± 0.32		
Group 2	1.12 ± 0.63	2.740	0.083
Group 3	1.2 ± 0.83		

Note. SD: Standard deviation.

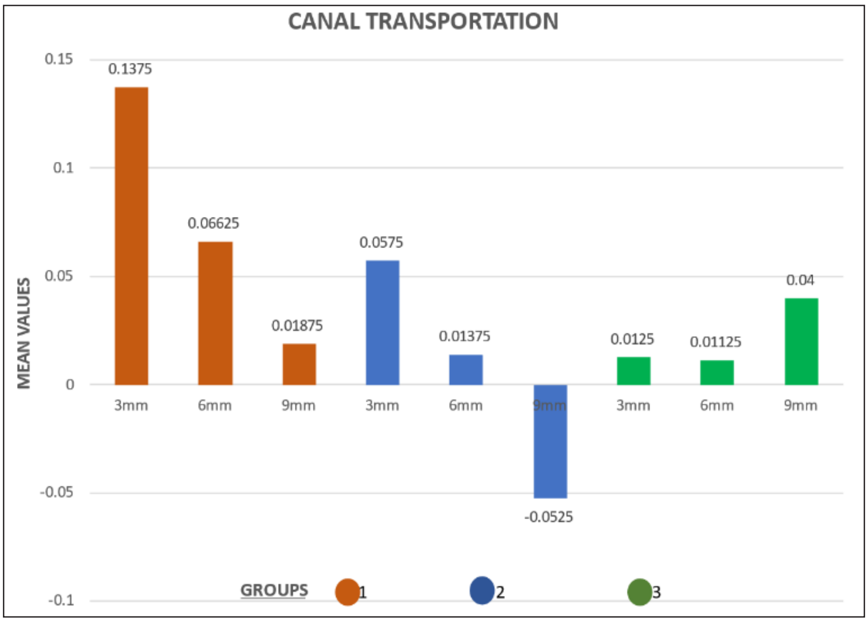

Figure 4. Comparison of Canal Transportation at 3 mm, 6 mm, and 9 mm

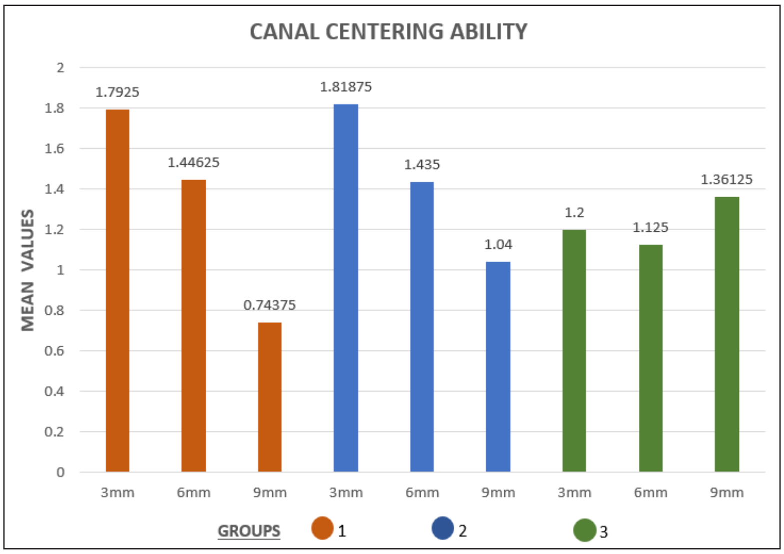

Figure 5. Comparison of Canal Centering Ability at 3 mm, 6 mm, and 9 mm

A successful treatment necessitates the creation of a meticulously prepared root canal with a smooth, gradually tapered shape that maintains the original anatomy. The canal should narrow progressively from the coronal to the apical end, and the preparation should not exceed its original dimensions. This meticulous preparation allows for effective chemical debridement and subsequent sealing, preventing the possibility of reinfection (2). Root canals often exhibit complex curvatures, making it challenging to shape and clean them effectively. As the degree of curvature increases, the instruments used in these procedures can undergo stress, making it difficult to achieve the desired taper in curved canals. As a result, dentin is frequently removed from the canal walls during cleaning and shaping operations in these types of canals rather than from the original tooth axis in all directions, a phenomenon known as canal transportation (3).

Historically, stainless steel hand files were the standard tools used for root canal instrumentation, but they were associated with procedural errors in curved root canals, such as elbows, zips, danger zones, and canal transportation. To address these issues, NiTi alloy was introduced in endodontics (10), offering greater flexibility and super elasticity. In spite of these benefits, torsional overload and cyclic fatigue have caused NiTi instruments to abruptly separate during root canal instrumentation. To tackle these issues, thermomechanical processing techniques, such as M-wire, R-phase wire, and controlled memory files, have been applied to NiTi instruments to improve their performance. Several approaches have been used to evaluate the performance of root canal instruments and methods (12). Before and after instrumentation, non-destructive technologies, such as computed tomography and CBCT, have been suggested for the assessment of root canals. These methods provide more precise and non-invasive ways to assess root canal preparation by offering repeatable three-dimensional evaluations of the tooth's internal and external morphology (13).

CBCT was employed in this research to assess and compare the canal transportation and centering ability of three different file systems in the curved mesiobuccal (MB) root canal of permanent mandibular first molars, including PTN (Dentsply, Mallifer), NeoNiTi (Orikam), and RM (FKG, Dentaire, Switzerland).

The three groups in the current investigation did not differ statistically significantly at the apical, middle, or coronal thirds of the canal transportation ($P > 0.05$). The coronal third's centering ability did not, however, differ statistically significantly ($P > 0.05$) across any group.

Among all the experimental groups used in the study, RM (group 3) illustrated lesser canal transportation and more centered preparations. These results and favourable scores obtained by RM (group 3) as these reciprocal systems are designed with thinner core sizes, providing increased flexibility. They feature rounded triangular cross-sections with sharp cutting edges and optimized file tips. The unique design of this file minimizes the screwing effect, allowing clinicians to maintain higher control efficiency during root canal instrumentation, which is in line with the findings of other studies (9,14,15).

Enhanced canal centering ability is one of the distinctive features of reciprocating motion, which was mainly intended to reduce the possibility of root canal abnormalities. The same results were published by Tambe et al, showing that WaveOne files stayed more centrally in the canal and caused less transportation than OneShape and Rotary ProTaper files (16). These results conform to those of studies by Tambe et al and Saber at al evaluating shaping abilities of OneShape, Wave one ,and Reciproc file systems (17,18). Likewise Hwang et al, Franco et al, and Maia Filho et al reported that when compared to instruments used in continuous motion ,those utilized in reciprocation motion produced the least amount of canal transportation and had the best centering ability (19,20,21).

In line with earlier studies that produced comparable findings, the PTN demonstrated higher transportation in comparison to the other file systems assessed in this research, along with a reduced ability to remain in the canal's center (21-23). Given that the PTN is designed with progressive tapers, it is less flexible overall and stiffer in particular areas. As the taper advances, the instrument's flexibility reduces, increasing the probability of canal straightening (24,25). Its offset rectangular cross-section shape could render transportation in curved canals due to its high "screw-in" force (26).

When compared to the RM file findings in this investigation, the NeoNiTi showed better centering ratios and greater transportation values, but still better than the PTN values. These results may be explained by the increased flexibility of NeoNiTi instruments as a result of manufactured methods and controlled memory technology, which allows the file to better negotiate curvatures and respect the anatomy of the canals (27,28).

Given that this study was conducted under in-vitro conditions, a notable limitation is the variability observed in the canals of natural teeth. Therefore, care is required when applying these results to clinical settings. To validate the findings, further in vivo and future studies are required to assess the efficacy of the RM system in other teeth with variable degrees of root curvature in comparison with other rotary systems.

Conclusion

Within the parameters of this study, the following deductions can be made:

1. The data analysis revealed that each system assessed for this study generated different levels of canal transportation during the instrumentation.
2. When it involved canal transportation and centering capabilities, the RM group fared better than the other systems, followed by Neolix and ProTaper Next.

Authors' Contribution

Conceptualization: D. Praveen.
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Formal analysis: Tashmeem Mohammad, Kalyan Satish R.
Investigation: Tashmeem Mohammad, Kaladhar Amarapu.
Methodology: Tashmeem Mohammad.
Project administration: D. Praveen, Kalyan Satish R.
Resources: Tashmeem Mohammad, D. Praveen.
Software: K. Durga Prasad.
Supervision: D. Praveen.
Validation: Tashmeem Mohammad.
Visualization: D. Praveen.
Writing–original draft: Tashmeem Mohammad, D. Praveen.
Writing–review & editing: Tashmeem Mohammad, D. Praveen.

Competing Interests

There is no conflict of interests to declare.

Ethical Approval

The Institutional Research Committee granted approval under the institution Vishnu Dental College with the ethical clearance number IECVDC/23/PG01/CE/IVT/92.

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