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Comparative evaluation of rotary and reciprocating file systems on canal shaping ability in curved root canals

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Abstract:
Maintaining the original anatomy of curved root canals during biomechanical preparation remains a major challenge in achieving predictable endodontic outcomes. Therefore, it is of interest to compare the canal shaping ability of ProTaper Next rotary files and WaveOne Gold reciprocating files in 80 human mandibular molars with mesial canal curvatures of 20°–40°, randomly allocated into 2 groups of 40 each. Canal transportation, centering ability, canal curvature preservation, dentin removal and preparation time was assessed using pre and post-instrumentation cone beam computed tomography. WaveOne Gold showed significantly less canal transportation, superior centering ability, better preservation of canal curvature, reduced dentin removal and shorter preparation time than ProTaper Next ($p < 0.05$), with no instrument separation in either group. Thus, data shows that reciprocating instrumentation offers superior shaping performance in curved root canals, supporting its use for preserving canal anatomy during endodontic treatment.

Keywords: Rotary files, reciprocating files, protaper next, waveone gold, canal transportation, centering ability, cone beam computed tomography (CBCT), curved root canals, endodontics

Background:
The three most important factors in successful endodontic treatment are the cleaning, shaping and obturation of the root canal system. Biomechanical preparation is one of these procedures, which is important for microbial reduction, irrigant penetration and canal shape for three dimensional obturation **[1]**. The ideal root canal preparation should preserve the original canal anatomy, preserve dentinal integrity and minimize procedural errors including canal transportation, ledge formation, zipping, perforation and instrument separation. In curved root canals, endodontic instruments tend to straighten during preparation, making it more difficult to achieve these goals and resulting in unwanted changes in canal morphology **[2]**. Nickel–titanium (NiTi) instruments changed endodontics when they were introduced because they were more flexible, had shape memory and were less prone to torsional stress than stainless steel instruments **[3]**. Initial studies testing NiTi systems showed that they were much more flexible than traditional systems, which enhanced the ability to negotiate curved canals and decreased the number of complications. One of the most important factors affecting the clinical performance and longevity of NiTi instruments is cyclic fatigue, which can cause files to fracture, especially in curved canals where repeated stress can be a predisposing factor **[4]**. In simulated S-shaped canals, NiTi instruments that were heat treated showed better shaping ability and canal maintenance compared to other instruments because of their greater flexibility and fatigue resistance **[5]**. Rotary and reciprocating instrumentation systems have become popular in modern endodontics due to the development of instrumentation systems and metallurgy. Rotary systems work continuously in the clockwise direction and offer efficient cutting and predictable canal enlargement. Reciprocating systems, on the other hand, use a clockwise and counterclockwise motion to minimize torsional stress and cyclic fatigue. In a meta-analysis, Haridoss *et al*. showed that the rotary and reciprocating systems are comparable in terms of the effectiveness of canal preparation, clinical outcomes and procedural safety **[6]**. These advances have stimulated a large amount of research that has compared the shaping ability of various kinematic motions. One of the most important parameters used to assess the shaping ability is canal transportation and centering ability. Transportation is the undesirable deviation of the prepared canal from its original physiological pathway and centering ability is the ability of the instrument to stay centered in the canal during enlargement. Comparative studies of rotary and reciprocating single-file systems have shown that instrumentation kinematics can influence shaping characteristics in curved canals. Kumar and Sarthaj reported differences in resin removal and preparation time between rotary and reciprocating systems, although all tested systems maintained the original canal curvature **[7]**. Similarly, the value of three-dimensional evaluation techniques to assess shaping quality and reported favorable shaping characteristics of modern reciprocating systems **[8]** is showed.

Recent research has also showed the benefits of heat-treated reciprocating instruments. In simulated S-shaped root canals, Shi *et al.* showed that WaveOne Gold was able to maintain canal curvature better and create less transportation than several rotary systems **[9]**. Orel *et al.* also reported that reciprocating systems have better shaping ability in curved canals, because of better metallurgical properties and less engagement with canal walls **[10]**. Moreover, Roshdy and Hassan noted that the design of the instrument and the motion have a significant impact on the efficiency of shaping and debris management in the process of preparing the canal **[11]**. The advent of sophisticated imaging techniques like cone-beam computed tomography (CBCT) has made it possible to accurately evaluate canal morphology pre- and post-instrumentation in 3D. CBCT can be used to accurately assess canal transportation, centering ability, dentin removal and preservation of curvature without destroying specimens. Recent CBCT studies by Saurabh *et al.* and Mahmoud *et al.* have validated the use of CBCT to compare the shaping performance of modern NiTi systems **[12, 13]**. Therefore, it is of interest to compare the shaping ability of ProTaper Next rotary files and WaveOne Gold reciprocating files in curved root canals using CBCT analysis with special attention to canal transportation, centering ability, maintenance of canal curvature, dentin removal and preparation efficiency.

Materials and Methodology:

Study design:

This study was designed as an *in vitro* comparative experimental investigation to evaluate and compare the canal shaping ability of rotary and reciprocating file systems in curved root canals using cone-beam computed tomography.

Study setting:

The study was conducted in the Department of Conservative Dentistry and Endodontics in collaboration with the Department of Oral Medicine and Radiology over a period of six months.

Sample size:

A total of 80 extracted human mandibular molars meeting the inclusion criteria were selected. Sample size calculation was based on previous studies evaluating canal transportation and centering ability, considering 95% confidence level, 80% power and expected mean differences between instrumentation systems.

Sample distribution:

[1] Group I (Rotary System – ProTaper Next): 40 canals
[2] Group II (Reciprocating System – WaveOne Gold): 40 canals

Inclusion criteria:

[1] Extracted human mandibular first molars.
[2] Mature apices.
[3] Mesial root canals with curvature between 20° and 40° according to Schneider's method.
[4] Intact roots without fractures.
[5] Canal patency confirmed with #10 K-file.
[6] Root length between 18 mm and 22 mm.

Exclusion criteria:

[1] Teeth with internal or external resorption.
[2] Calcified canals.
[3] Previously endodontically treated teeth.
[4] Teeth with root fractures.
[5] Teeth with immature apices.
[6] Teeth exhibiting severe anatomical anomalies.

Specimen preparation:

Following extraction, teeth were cleaned of soft tissue remnants and calculus using ultrasonic scalers. Specimens were stored in 0.1% thymol solution until use. Standardized access cavities were prepared using Endo Access burs under water cooling. Canal patency was confirmed using #10 K-file and working length was established 1 mm short of the apical foramen.

Determination of canal curvature:

Preoperative radiographs were obtained in buccolingual and mesiodistal directions. Canal curvature was measured according to Schneider's technique. Only canals showing curvature between 20° and 40° were included to ensure standardization.

Pre-Instrumentation CBCT analysis:

All specimens underwent CBCT scanning before instrumentation using standardized exposure parameters:
[1] Voxel size: 0.125 mm
[2] Field of view: 5 × 5 cm
[3] Slice thickness: 0.125 mm
Images were reconstructed and analyzed using dedicated software.

Measurements were recorded at:
[1] 3 mm from apex (apical third)
[2] 6 mm from apex (middle third)
[3] 9 mm from apex (coronal third)

Group I: Rotary instrumentation (ProTaper Next):

Instrumentation was performed using:
[1] X1 (17/.04)
[2] X2 (25/.06)

Files were operated with an endodontic motor according to manufacturer recommendations:
[1] Speed: 300 rpm
[2] Torque: 2.0–5.2 Ncm
Each file was used in a gentle brushing motion until working length was reached.

Group II: Reciprocating instrumentation (WaveOne Gold):

Instrumentation was performed using:
[1] WaveOne Gold Primary (25/.07)
[2] Files were operated using a dedicated reciprocating motor employing preset reciprocation angles as recommended by the manufacturer.
[3] The instrument was advanced using gentle in-and-out pecking motions until reaching working length.

Irrigation protocol:
Both groups received identical irrigation:
[1] 3% Sodium hypochlorite (NaOCl)
[2] 17% EDTA
[3] Distilled water final rinse
A total of 10 mL irrigant was used per specimen.

Post-Instrumentation CBCT analysis:
After instrumentation, all specimens underwent repeat CBCT scanning using identical parameters. Images were superimposed with preoperative scans for comparative evaluation.

Outcome measures:
Canal transportation:
Calculated using Gambill's formula:
Transportation = (M1 − M2) − (D1 − D2)
Where:
[1] M1 = shortest distance from mesial root surface to canal before instrumentation
[2] M2 = shortest distance after instrumentation
[3] D1 = shortest distance from distal root surface to canal before instrumentation
[4] D2 = shortest distance after instrumentation
A value of zero represented no transportation.

Centering ability:
Centering Ratio:
(M1 − M2)/(D1 − D2)
or
(D1 − D2)/(M1 − M2)
The value closer to 1 indicated superior centering ability.

Additional parameters:
[1] Change in canal curvature
[2] Dentin removal
[3] Preparation time
[4] Instrument separation incidence

Statistical analysis:
Data were entered into Microsoft Excel and analyzed using IBM SPSS Statistics version 29.0. Statistical tests included Independent Student's t-test, Paired t-test, Chi-square test and ANOVA where applicable. Data were expressed as mean ± standard deviation. Statistical significance was considered at $p < 0.05$.

Result:

A total of 80 extracted mandibular molars with curved mesial root canals were included in the study and equally distributed into two groups: Rotary instrumentation using ProTaper Next (Group I, n=40) and Reciprocating instrumentation using WaveOne Gold (Group II, n=40). No instrument separation occurred during canal preparation in either group. All specimens were successfully prepared to the predetermined working length and included in the final analysis. The reciprocating system showed significantly less canal transportation than the rotary system at all canal levels. In the coronal third, the mean canal transportation was 0.15 ± 0.04 mm in the reciprocating group compared to 0.18 ± 0.05 mm in the rotary group ($p = 0.012$). Similarly, in the middle third, transportation was significantly lower with the reciprocating system (0.11 ± 0.03 mm) than with the rotary system (0.15 ± 0.04 mm, $p = 0.001$). The greatest difference was observed in the apical third, where the reciprocating group showed markedly reduced transportation (0.12 ± 0.04 mm) compared to the rotary group (0.21 ± 0.06 mm, $p < 0.001$), indicating superior maintenance of the original canal anatomy, particularly in the apical region **(Table 1).** The reciprocating system demonstrated significantly better centering ability than the rotary system at all canal levels. In the coronal third, the mean centering ratio was significantly higher in the reciprocating group (0.76 ± 0.08) compared to the rotary group (0.71 ± 0.09, $p = 0.021$). This difference became more pronounced in the middle third, where the reciprocating system achieved a mean centering ratio of 0.79 ± 0.07 versus 0.69 ± 0.08 for the rotary system ($p < 0.001$). The highest centering ability was observed in the apical third, with the reciprocating group recording a significantly superior mean centering ratio (0.84 ± 0.06) compared to the rotary group (0.63 ± 0.07, $p < 0.001$), indicating enhanced preservation of the original canal path, particularly in the apical region **(Table 2).** There was no significant difference in the initial canal curvature between the rotary and reciprocating groups (29.4 ± 4.8° vs. 29.7 ± 4.6°; $p = 0.781$), indicating comparable baseline morphology. Following instrumentation, the reciprocating system preserved canal curvature significantly better, with a higher final curvature (27.2 ± 4.0°) than the rotary system (24.8 ± 4.1°; $p = 0.006$). Consequently, the percentage reduction in canal curvature was significantly lower in the reciprocating group (8.4%) compared to the rotary group (15.6%; $p = 0.004$), demonstrating superior maintenance of the original canal anatomy. The reciprocating system also removed significantly less dentin (3.71 ± 0.54 mm^3) than the rotary system (4.12 ± 0.62 mm^3; $p = 0.009$), reflecting a more conservative preparation. In addition, canal preparation was completed significantly faster with the reciprocating system (4.21 ± 0.56 min) than with the rotary system (5.84 ± 0.71 min; $p < 0.001$), indicating greater procedural efficiency **(Table 3).**

Table 1: Comparison of canal transportation (mm)

Canal Level	Rotary (n=40) Mean ± SD	Reciprocating (n=40) Mean ± SD	p value
Coronal Third	0.18 ± 0.05	0.15 ± 0.04	0.012*
Middle Third	0.15 ± 0.04	0.11 ± 0.03	0.001*
Apical Third	0.21 ± 0.06	0.12 ± 0.04	<0.001*

**Statistically significant*

Table 2: Comparison of centering ability ratio

Canal Level	Rotary (n=40) Mean ± SD	Reciprocating (n=40) Mean ± SD	p value
Coronal Third	0.71 ± 0.09	0.76 ± 0.08	0.021*
Middle Third	0.69 ± 0.08	0.79 ± 0.07	<0.001*
Apical Third	0.63 ± 0.07	0.84 ± 0.06	<0.001*

**Statistically significant*

Table 3: Comparison of canal curvature maintenance, dentin removal and preparation time

Parameter	Rotary (n=40)	Reciprocating (n=40)	p value
Initial Curvature (°)	29.4 ± 4.8	29.7 ± 4.6	0.781
Final Curvature (°)	24.8 ± 4.1	27.2 ± 4.0	0.006*
Curvature Reduction (%)	15.6%	8.4%	0.004*
Dentin Removal (mm^3)	4.12 ± 0.62	3.71 ± 0.54	0.009*
Preparation Time (min)	5.84 ± 0.71	4.21 ± 0.56	<0.001*

**Statistically significant*

Discussion:

This current study aimed to assess and compare the canal shaping ability of ProTaper Next rotary files and WaveOne Gold reciprocating files in curved root canals using CBCT analysis. The results showed that both systems could prepare clinically acceptable canals, but the reciprocating system had significantly less canal transportation, better centering ability, better preservation of canal curvature, less dentin removal and shorter preparation time. The results suggest that reciprocating instrumentation might be more effective in preserving the original canal anatomy, especially in highly curved root canals. The most significant finding of this present study was the significantly lower canal transportation with WaveOne Gold instrumentation. One of the primary concerns of canal transportation during root canal preparation is the deviation from the original canal pathway, which can have a negative impact on cleaning efficiency, compromise the root structure and negatively affect the apical seal. Mahmoud *et al.* compared various rotary and reciprocating file systems in simulated S-shaped canals and found that the preparation kinematics and design of the files have significant effects on the transportation patterns **[13]**. Rubio *et al.* compared 10 rotary and reciprocating systems, including ProTaper Next and WaveOne Gold, and found that the tested systems showed similar preservation of root canal anatomy, although differences were observed in non-instrumented areas across the canal thirds **[14]**. Their results showed that, in general, reciprocating systems were more successful in preserving canal anatomy than continuous rotary systems, which is consistent with the results of the present investigation. The superior shaping performance of WaveOne Gold could be attributed to its reciprocating action and heat-treated Gold-wire metallurgy. Siraparapu *et al.* evaluated ProTaper Next, TruNatomy and Flexer heat-activated rotary systems in severely curved simulated canals and found that ProTaper Next and TruNatomy produced similar canal transportation, while TruNatomy showed better apical centering **[15]**. Heat-treated instruments are more flexible, which allows them to conform better to the canal anatomy and decreases the straightening tendency during the instrumentation. The present study found that the transportation of the reciprocating system was significantly lower at the apical level, especially since apical transportation can have a negative effect on cleaning and obturation results. Another key parameter to evaluate the quality of shaping is centering ability. High centering instruments remove dentin equally from all the walls of the canal and minimize the chance of procedural mistakes. Paulo *et al.* used CBCT to compare four rotary systems in curved root canals and found differences in transportation and centering capacity, with ProTaper Ultimate and Race Evo demonstrating centering values closer to ideal centering **[16]**. The same results were found in the present study, with WaveOne Gold having significantly higher centering ratios at all canal depths. This enhanced centering capability may be due to the reduced torsional stress and less engagement of the instrument with dentinal walls during reciprocation. Maintaining the curvature of the canal is regarded as a criterion for successful biomechanical preparation. Over straightening of curved canals can lead to uneven removal of dentin and weakening of the root structure. Gu *et al.* showed that the heat-treated NiTi instruments retained their canal curvature better due to their greater flexibility and cyclic fatigue resistance **[17]**. In the current study, both instrumentation systems maintained the original canal curvature, but the curvature was significantly less in the reciprocating group. This discovery indicates that WaveOne Gold is more respectful of the natural canal anatomy and may thus help to prepare root canals more safely and conservatively. Yet another significant finding of the present study was the significantly reduced dentin removal seen with the reciprocating system. Modern endodontic principles focus on minimal preparation methods that retain as much sound dentin as possible while providing sufficient debridement. Too much dentin removal can weaken the tooth against fracture and make it more likely to develop vertical root fracture. Wang *et al.* showed, by micro computed tomography, that there is a wide variation in shaping ability among the modern nickel–titanium systems and that preservation of the radicular dentin during instrumentation is important **[18]**. The findings of the present study confirm that conservative dentin removal is being favored in endodontics. The assessment of root canal preparation has been greatly enhanced by the use of three dimensional assessment techniques. Dantas *et al.* had already shown the usefulness of three-dimensional analysis to compare the shaping results of various instrumentation systems **[19]**. Accurate assessment of canal transportation, centering ability and dentin removal can be made without destroying specimens by using advanced imaging modalities. CBCT was used in the current study and yielded reliable and reproducible measurements, which enabled detailed comparison of the shaping performance

between the tested systems Recent investigations have continued to support the effectiveness of reciprocating instrumentation. The instrumentation efficiency and shaping results in complex root canal systems can be affected by the design of the instruments and the configuration of the access cavity, as reported by Caviedes-Bucheli *et al.* **[20]**. Their results highlight the need to choose the right instrumentation technique to maintain canal anatomy and enhance clinical efficiency. WaveOne Gold was found to be significantly shorter in preparation time in the present study, which could be due to its single file reciprocating design. Less instrumentation time can lead to workflow efficiency and operator fatigue reduction without sacrificing shaping quality. Zehairy *et al.* compared Mtwo, ProTaper Next and HyFlex CM in curved root canals and reported that ProTaper Next maintained canal curvature effectively and required significantly less preparation time than the other tested systems **[21]**. They conclude that the advanced nickel–titanium technologies are still evolving to enhance the shaping performance in difficult canal anatomies. The present results also confirm this finding by showing that WaveOne Gold has more shaping ability than ProTaper Next in curved root canals. Some restrictions need to be recognized. The study was performed *in vitro* with extracted teeth, which might not be representative of the complexities in clinical practice. Clinical outcomes may be affected by factors including simulation of the periodontal ligament, patient variability, irrigation dynamics and operator experience. In addition, only two instrumentation systems were tested. Further studies using micro-CT analysis and randomized clinical trials could offer more information on the long term clinical relevance of these findings.

Conclusion:

The ProTaper Next rotary and WaveOne Gold reciprocating systems were found to be effective in preparing curved root canals with acceptable canal morphology. The reciprocating file system, however, had significantly less canal transportation, better centering ability, better preservation of canal curvature, less dentin removal and shorter instrumentation time. WaveOne Gold showed better shaping ability and could be a better choice for curved root canal instrumentation.

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