



Original Article

Comparative evaluation of the shaping ability of single-file system versus multi-file system in severely curved root canals



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Abstract *Background/purpose:* Reciprocating single-file systems are the latest nickel-titanium instruments and little information is available concerning the shaping ability of these new systems. Comparison of these single-file systems with well-known rotary multi-file systems is necessary. The purpose of this study was to compare the shaping ability of single-file system (WaveOne, WO) versus multiple-file system (ProTaper Next, PTN) in severely curved canals. *Materials and methods:* A total of 20 severely curved canals were prepared with WO or PTN. Micro-computed tomography was used to scan the specimens before and after instrumentation. Differences between two groups in canal surface area, volume, Structure Model Index (SMI), thickness, straightening, the ratio of uninstrumented surface area and canal transportation were evaluated.

Results: The outline of the canals after preparation showed smooth taper in both groups. Canal surface area, volume, SMI, Thickness and canal curvature were significantly increased after preparation in both groups, and no significant difference was found between groups. At apical third, canals prepared with WO showed larger values of transportation compared with those in PTN group in the direction of main curvature. Approximately 29–34% of the root canal surface remained uninstrumented after preparation and no significant difference was noticed between groups.

Conclusion: Both of the two instrument systems maintained the original outline of the canals well. The canals prepared with PTN had less transportation and were better centered in the apical region.

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Introduction

Canal preparation is one of the most important procedure in endodontic treatment and directly influences subsequent root canal disinfection and obturation.¹ A prepared root canal should have a continuously tapered funnel shape and maintain the original outline form of the canal.² These objectives are often difficult to achieve because of the highly variable root canal anatomy and canal curvature, especially when preparing severely curved canals.³

During shaping of severely curved canals, occurrence of iatrogenic errors, such as ledges, zips, perforations, and apical transportation is common.⁴ To minimize these iatrogenic errors several preparation techniques and lots of instrument systems have been developed. However, the mechanical preparation of a curved root canal is still challenging because of the common factors, such as inflexibility of the canal preparation instruments, degree and radius of a canal curvature, unseen canal curvatures in the two-dimensional radiographs.⁵

The introduction of nickel-titanium (NiTi) rotary instruments brings well-tapered root canal preparations, reduced operator fatigue, and less time required for shaping, whilst also minimizes the risk of root canal transportation.⁶ Since their first appearance, progress has been made on design, rotation motion, as well as in alloy processing.^{7,8} Reciprocating single-file systems are the latest stage NiTi instruments for the preparation of root canals. The concept of reciprocating motion based on balanced force technique was introduced by Yared, and single F2 ProTaper instrument in a reciprocating motion was proposed to use for the preparation of curved root canals.⁹ This was shown to be as effective as the full ProTaper system in cleaning around root canals. Reciprocating single-file systems are claimed to be able to completely prepare root canals with only one instrument and reduce the risk of instrument failure and cross contamination.^{10–12} Recently, a new reciprocating WaveOne (WO, Dentsply Maillefer) single-file system has been developed. The WO system consists of 3 single-use files: small (#21/0.06) for small canals, primary (#25/0.08) for majority of canals, and large (#40/0.08) for large canals. These files are made of a special NiTi alloy called M-Wire that is created by an innovative thermal treatment process.¹³ The M-Wire NiTi beneficially increased the flexibility of the instruments and improved the resistance to cyclic fatigue.¹⁴

Up to now, little information is available concerning the shaping ability of the reciprocating file. Hence, comparison of these single-file systems with well-known rotary multi-file (full-sequence) NiTi systems is necessary to assess the properties of these new files.

ProTaper Next (PTN, Dentsply Maillefer, Ballaigues, Switzerland) is a novel multi-file system incorporating a variable regressive taper design and an off-centered rectangular cross section, which are designed to reduce points of contact with the canal walls to generate less fatigue in the instrument during use.¹⁵ This system is composed of 5 instruments with different tip size and taper (X1 #17/0.04, X2 #25/0.06, X3 #30/0.07, X4 40/0.06, and X5 50/0.06), and is also made of M-Wire NiTi.

The use of micro-CT (μ CT) imaging has been recommended to evaluate the effectiveness of NiTi rotary instruments in respecting and maintaining the original anatomy of root canals and to measure the possible transportation produced.^{16,17} μ CT can be used for qualitative and quantitative assessments of root canals in three dimensions.¹⁸ Furthermore, with the development of software, algorithms allow measurement of geometrical parameters such as volume, surface area, structure model index (SMI), straightening, and thickness.^{16,19,20}

Although there have been several studies about shaping ability of PTN and WO up to now, the results differ from each other in separate studies. Thus, the purpose of this study was to evaluate and compare the shaping ability of single-file reciprocating system and multi-file rotary system, using WO and PTN as their representative products respectively, in severely curved root canals of extracted human molar teeth by μ CT. The null hypothesis is that there is no difference between two systems.

Materials and methods

Preparation of specimens

All the procedures of the present investigation were approved by Research Ethics Committee of Wuhan University. A total of ten extracted mandibular first molars were selected from a pool of extracted teeth for this study. Only the tooth that had a curved mesial root (20° – 35°) according to Schneider's method²¹ and 2 separated mesial canals with width near the apex at approximately size 15 was selected. The standard access cavities were prepared, and then the crowns of teeth were sectioned slightly above the cemento-enamel junction. The mounting of each specimen on scanning electron microscopy stubs was performed as described previously.¹⁶

Root canal preparation

The canals were localized and explored with #10 K-file (Dentsply Maillefer). The working length (WL) was determined by inserting a #10 K-file to the root canal terminus and subtracting 0.5 mm from this measurement under $8\times$ magnification of a surgical microscope. The buccal and lingual canals in each mesial root were randomly assigned to WO or PTN group.

In the WO group, the primary file #25/0.08 was used in a programmed reciprocating motion generated by the X-Smart motor (Dentsply Maillefer) in the "WaveOne" mode. File was used in a slow in-and-out pecking motion (amplitude less than 3 mm, 3 pecks) according to the manufacturer's instruction. The flutes of the instruments were cleaned after 3 pecks.

In the PTN group, PTN instruments were used in a crown-down fashion with brushing motion at a speed of 300 rpm generated by the X-Smart motor. The ProTaper Universal SX was used to enlarge the coronal aspect of the canal. This was followed by using the X1 to full WL, and canal finishing was performed with the X2 to full WL.

Apical patency was checked with a size #15 K-file between two instruments. Before the use, each instrument was lubricated with Glyde (Dentsply Maillefer). Irrigation was performed with copious 5.25% NaOCl after the use of each file and when root canal instrumentation was complete.

Micro-CT measurements and evaluation

A μ CT system (μ CT-20; Scanco Medical, Bassersdorf, Switzerland) with a resolution of 36 μ m was used to scan the specimens before and after instrumentation. Three-dimensional images were reconstructed and the volume of interest was selected extending from the furcation region to the apex of the root for the evaluation of root canal geometry. The following measurements were performed by using proprietary software supplied by Scanco. Volume and surface area of the root canals before and after instrumentation were evaluated from the triangulated data by using the "Marching Cubes" algorithm, which was described previously.²⁰ Increases in volume and surface area were calculated by subtracting the scores for the pre-instrumented canals from those recorded for the post-instrumented canals. Structure Model Index (SMI) and thickness of the canals were also determined from the triangulated data. SMI was originally used to characterize trabecular bone with a structure as being ribbon-shaped versus cylindrical, which ranges from 0 (parallel flat planes) to 4 (an ideal ball).²⁰ The thickness of the canal was measured by using Distance Transformation Techniques as described previously.²²

Then, exact superimposing two sets of three-dimensional root canals (pre- and post-instrumentation) was performed to obtain reproducible results for "centers of mass". Each scanning slice was defined by a series of paratactic data for the x-, y- and z-axes. The "centers of mass" of the canals were connected along the z-axis of each slice by a fitted line.²² This fitted line was further used to evaluate canal curvature mathematically. Straightening (%) was expressed as difference in canal curvature in relation to initial scores. The mean canal transportation was also calculated by comparing the "centers of mass" before and after instrumentation at the apical, middle, and coronal thirds of the canals.²² The canal transportation was measured in two directions: the direction of main curvature (DC) and the tangential direction to main curvature (TC, a side shift). Finally, matched images of the surface area voxels of the canals before and after preparation were analyzed to evaluate the amount of uninstrumented surface area, which was determined by calculating the number of static voxels (voxels present in the same position on the canal surface before and after instrumentation). The uninstrumented area were expressed as a percentage of the total number of voxels present on the canal surface.

Statistical analysis

Mean scores were calculated, and differences between groups or within groups were analyzed statistically by using *t* test or analysis of variance with SPSS (SPSS Inc, Chicago, IL).

Results

Qualitative assessment of instrumentation

Representative superimposed three-dimensionally reconstructed root canals before and after canal instrumentation in two groups were shown in Fig. 1. After preparation, all the canals showed a continuously smooth taper and maintained the original outline well. No obvious iatrogenic errors such as apical zips, perforations or ledges were detected. At apical part, WO removed more dentin in the outer wall of the canal and removed limited dentin in the inner wall, which resulted in transportation towards the outer aspect of the curve. However, PTN removed dentin symmetrically at this region. At the coronal third, both of the two instruments resulted in transportation toward outer wall of the canals. Uninstrumented areas (green color) were found in both groups.

Initial parameters of experimental groups

No statistical differences were found between two groups with respected to surface area, volume, SMI, thickness, and curvature of the uninstrumented root canals (independent-samples *t* test, data not shown). This confirmed the homogeneity of the canals in two groups before instrumentation.

Changes in surface area, volume, structure model index, and thickness

The changes in canal surface area, volume, SMI, and thickness after preparation with the two instrument systems are presented in Table 1. With preparation, the canal surface area, volume, SMI, and thickness significantly increased in both groups ($P < 0.001$, paired-samples *t* test), which indicated the canals were larger and more rounded after preparation. However, there was no significant difference between the two instrumentation groups regarding these parameters.

Straightening

Overall, straightening was highly significantly different before and after preparation in both groups ($P < 0.01$, paired-sample *t* test), which indicated canals preparation in both groups led to a loss of canal curvature. The relative degrees of canal straightening were $13.11 \pm 2.86\%$ and $10.86 \pm 3.31\%$ for WO and PTN groups, respectively. Although the canals prepared with WO showed a higher straightening degree, there was no statistically significant difference between two groups ($P = 0.094$, independent-samples *t* test).

Canal transportation

The mean absolute values for transportation at the coronal, middle, and apical thirds in two directions (the direction of main curvature and the tangential direction to main curvature) are summarized in Table 2. In the directions of main

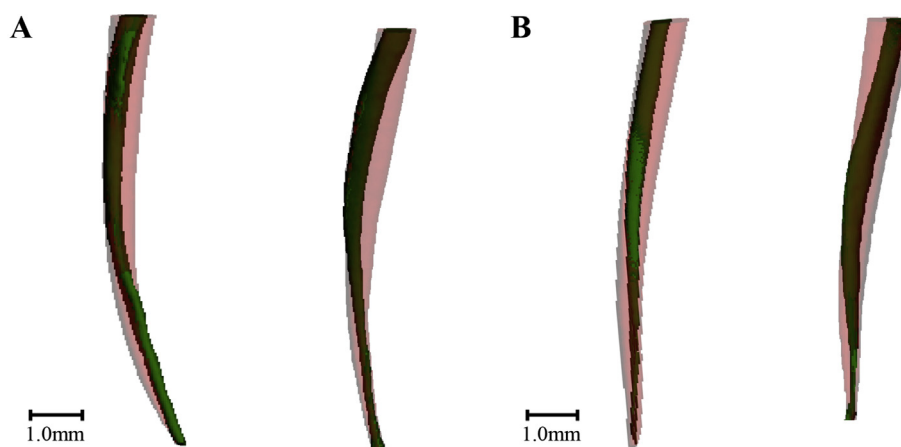


Figure 1 Representative examples of superimposed root canals before and after canal instrumentation. A, WO; B, PTN. Green color demonstrates the canal surface before instrumentation, pink color demonstrates the canal surface after instrumentation, and the brown color represents the overlapped area.

Table 1 Absolute and relative increases^a (mean \pm standard deviation) in canal surface area, volume, SMI, and Thickness after preparation.

Instrument	Δ Surface (mm ²)	Δ Surface (%)	Δ Volume (mm ³)	Δ Volume (%)	Δ SMI	Δ SMI (%)	Δ Thickness (mm)	Δ Thickness (%)
WaveOne	6.45 \pm 1.40	65.08 \pm 11.54	1.96 \pm 0.55	153.95 \pm 32.92	0.33 \pm 0.10	12.15 \pm 3.10	0.28 \pm 0.05	77.25 \pm 16.66
PTN	6.08 \pm 1.33	62.96 \pm 11.74	2.02 \pm 0.68	146.77 \pm 35.96	0.36 \pm 0.08	13.37 \pm 3.66	0.33 \pm 0.08	85.16 \pm 12.47
<i>P</i> value	0.549	0.688	0.8310.28	0.647	0.469	0.431	0.123	0.256

^a Relative score expressed as percentages of initial values.

Table 2 Mean Canal Transportation (μ m, mean \pm standard deviation) at the coronal, middle, and apical thirds after preparation in two directions.

Transportation	Canal regions		
	Coronal third	Middle third	Apical third
Direction DC			
WaveOne	65.11 \pm 20.16	61.42 \pm 25.54	101.3 \pm 35.73 ^a
PTN	57.30 \pm 18.14	42.25 \pm 21.57	57.41 \pm 18.09
<i>P</i> value	0.375	0.087	^c
Direction TC			
WaveOne	64.91 \pm 23.85 ^b	11.6 \pm 3.93	10.3 \pm 4.36
PTN	63.35 \pm 23.81 ^b	8.6 \pm 3.07	9.2 \pm 4.10
<i>P</i> value	0.919	0.075	0.602

DC, direction of main curvature; TC, tangential direction to main curvature.

^a Difference at apical third compared with coronal and middle thirds ($P < 0.01$, analysis of variance).

^b Difference at coronal third compared with middle and apical thirds ($P < 0.001$, analysis of variance).

^c Difference between groups at apical third ($P < 0.01$, independent-samples *t* test).

curvature, there was no significant difference in canal transportation values between WO and PTN groups both at the coronal and middle thirds; however, the canals prepared with WO showed larger values of transportation compared with those in PTN groups at the apical third ($P < 0.01$, in dependent-sample *t* test). Larger

transportation was found at the apical third compared with the coronal and middle thirds in the canals prepared with WO ($P < 0.01$, analysis of variance), but no such difference was found in PTN group. In the tangential direction to main curvature, the canals in both groups showed a higher side-shift (transportation) in the coronal third compared with the middle and apical thirds ($P < 0.001$, analysis of variance), and no difference was found between groups.

Uninstrumented canal surface area

The absolute and relative amounts of static voxels before and after preparation (uninstrumented area) were detailed in Table 3. Approximately 29–34% of the root canal surface were not prepared after instrumentation. Although canals prepared with WO had larger mean amounts of uninstrumented surface area, no statistically significant

Table 3 Mean and relative scores^a of static voxels (mean \pm standard deviation) recorded by superimposing matched images before and after preparation.

Instrument	Voxels ($\times 10^3$)	Voxels (%)
WaveOne	2.27 \pm 0.73	34.32 \pm 7.94
PTN	1.93 \pm 0.63	29.21 \pm 6.83
<i>P</i> value	0.169	0.141

^a Relative scores are expressed as percentage calculated in relation to surface area after preparation.

difference was observed between two groups (independent-samples *t* test).

Discussion

Up to now, two sorts of file system composition have been developed, which are single-file system and multi-file system. Single-file system usually associates with reciprocating motions (ie, WO and Reciproc), while multi-file system associates with continuous rotation (ie, ProTaper Universal and PTN). The aim of this study was to compare the shaping ability of a reciprocating single-file system (WO) and a multi-file system with continuous motion (PTN) in extracted teeth using μ CT. For evaluating the efficacy of instruments for altering root canal anatomy, a number of techniques are available, among which the double radiographic superimposition method allows two-dimensional images. The mesiodistal and buccolingual views are used for evaluation of apical transportation. However, teeth do not always show their maximum curvatures in these planes and real canal transportation is not always reflected.²³ The morphology of pre- and post-instrumentation in resin simulated root canal is visible, but the extrapolation of the results to the use of endodontic instruments in real root canals is controversial because of the difference between the nature of resin and dentin.²⁴ The "Bramante technique"²⁵ is a commonly used technique to directly view the shape of the root canal by sectioning and reassembling root canals for pre- and post-instrumentation evaluation. However, many teeth are lost because of "ledging" caused by gaps between sections of the root. Since μ CT is practical and nondestructive, it has been widely adopted for evaluation of new endodontic file systems.

When comparing the shaping abilities of different preparation systems of different root canal instruments, it is important to standardize the tip size of the last file used during root canal preparation.²⁶ Although increasing the apical preparation size may improve the cleaning efficiency and irrigation of the apical portion of the root canals, the risk of canal transportation also increases because the flexibility of the root canal instruments decreases.²⁷ For this reason, WO primary file and PTN X2 were used as final files in the single-file and multi-file systems, respectively. Therefore, canal preparation was standardized to a final shape of ISO #25 tip size in the present investigation.

The effects of canal instrumentation were analyzed quantitatively by using a set of parameters including canal volume, surface, SMI and uninstrumented canal surface area. All these results are mean values over the entire canal length, measured three-dimensionally using μ CT. The present investigation showed that root canal instrumentation with either WO or PTN resulted in significant gains in canal volume, SMI and surface area. Canal volume is widely used to analyze the effects of canal instrumentation on dentin removal.^{10,13} SMI involves a measurement of surface convexity in a three-dimensional structure. An ideal plate, cylinder and sphere have SMI values of 0, 3, and 4, respectively.²² Before preparation, the value of SMI ranged from 2.51 to 2.72 (data not shown), indicating a conical frustum-like geometry of the root canal system, which became more cylindrical (rounded) after preparation (an increased value

of 0.33–0.36). Concerning the uninstrumented canal surface, none of the two instrument systems was able to instrument completely the entire root canal wall; approximately 29–34% of the canal surface area was found uninstrumented in both groups after preparation, which is consistent with previous studies.^{28,29} Thus, mechanical preparation must be combined with the chemical preparation to disinfect the root canals effectively.

The most important parameter for root canal preparation is transportation. The *Glossary of Endodontic Terms* of the American Association of Endodontists defines transportation as "the removal of canal wall structure on the outside curve in the apical half of the canal due to the tendency of files to restore themselves to their original linear shape during canal preparation".³⁰ Apical transportation might hamper adequate cleaning and proper sealing of the root canal and might cause reduced treatment outcome.³¹ Capen et al.³² demonstrated that there was no significant difference of canal transportation and centering ratio among PTN and WO. Other researchers found shaping procedures with PTN showed a better centering ability and less transportation than WO in simulated resin canals.³³ This study showed no significant difference between WO and PTN groups in the coronal and middle thirds of the canals in the extracted teeth. However, significantly less transportation was found after using PTN files than WO files in the apical third of the canals, which was in agreement with previous investigations.^{34,35} Taper and cross-sectional design could explain the better results observed here in the PTN group, as compared with WO group. PTN X2 shows a 0.06 taper in the apical part, but WO primary file has a larger taper (0.08) in the apical part. The taper size plays an important role for reducing transportation in severely curved canals. Less tapered instruments caused less canal transportation compared with more tapered instruments.²⁷ PTN X1 and X2 have a progressive taper at the apical section and a decreasing taper at the coronal section, while WO primary has a decreasing taper. It is claimed that progressive taper increases the flexibility of files while decreasing taper makes files much stiffer.³⁶ The progressive taper of PTN makes it more flexible than WO at the apical section. Compared with the modified triangular convex cross-section at the tip region of WO, PTN instruments with a design of off-centered rectangular cross-section have smaller cross-section areas, which increase their flexibility. Furthermore, WO is used without first performing preliminary coronal enlargement, which may result in a greater engagement of the flutes and may produce consequently more torque and apply pressure on the file resulting in a higher incidence of canal transportation.³⁷

In conclusion, both of the two instrument systems significantly increased canal surface area, volume, SMI, thickness and canal curvature after preparation. In terms of transportation, at the apical third, PTN resulted in less transportation and performed significantly better than WO. However, no such difference was found at the coronal and middle thirds of the canals between two groups.

Conflicts of interest

The authors deny any conflicts of interest related to this study.

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