A micro-computed tomography-based comparison of the canal transportation and centering ability of ProTaper Universal rotary and WaveOne reciprocating files

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Objective: Since the development of nickel titanium (NiTi) rotary files a number of file systems have been developed, including ProTaper continuous rotary files and the recently developed WaveOne reciprocating files. Previous studies have demonstrated better fatigue resistance of the WaveOne file compared to the ProTaper file. However, no study has compared the effects of reciprocation and continuous rotary motion on transportation and centering ability. Hence, the aim of this study was to compare the two file systems in their transportation and centering ability in mesial roots of mandibular molars using microCT imaging. Method and Materials: Twenty seven extracted mandibular molars with mesiobuccal and mesiolingual canals with separate foramina were used. Pre-instrumentation scans of all teeth were taken, canal curvatures were calculated, and the teeth were randomly divided into two groups. In group 1, the mesiobuccal canals were instrumented with ProTaper files and the mesiolingual canals with WaveOne files. In group 2, the mesiobuccal canals were instrumented with WaveOne files and the mesiolingual canals with ProTaper files. Post-instrumentation scans were performed and the two scans were compared to determine centering ability and transportation at 1, 3, 5, and 7 mm from the apical foramen. Results: Although the WaveOne appeared to stay slightly more centered at the 1, 3, and 5 mm levels and ProTaper showed less transportation at the 1 and 3 mm levels, these differences were not statistically significant. Conclusion: Overall, this study does not support the use of one file system over the other (ProTaper or WaveOne) when comparing transportation and centering ability. Both file systems proved safe for endodontic instrumentation. (Quintessence Int 2014;45:101–108; doi: 10.3290/j.qi.a30998)

Key words: centering ability, microCT, ProTaper, transportation, WaveOne

Cleaning and shaping of the root canal system is recognized as one of the most important phases in endodontic treatment. Proper cleaning and shaping removes infected pulp tissue, bacteria and their byproducts, and also allows for adequate irrigation and subsequent obturation of the canal system. To achieve optimal cleaning and shaping results, the clinician must maintain a continuously tapering funnel form, from the coronal access cavity to the root apex, as well as the original canal shape and apical foramen in their original
spatial relationship both to the periapical tissues and to the root surface. However, it is more difficult to adhere to these principles in curved canals because instrumentation is more likely to divert the canal away from its original axis. This increases the likelihood of procedural errors, including canal transportation, strip perforations, ledging, and apical zipping.

A number of root canal preparation techniques and instrument modifications have been developed to address the complications that curved canals present. Rotary nickel titanium (NiTi) systems were developed with the aim to increase flexibility and centering ability, thus allowing for a more tapered funnel-shaped canal and reducing the occurrence of canal transportation and procedural errors. NiTi is a nickel titanium alloy developed by William Buehler in 1962 at the Naval Ordnance laboratory. Later, in 1988, Walia et al introduced NiTi for the manufacturing of endodontic instruments. Since the invention of NiTi, multiple NiTi rotary files have been developed.

One of the NiTi file systems used currently is the ProTaper Universal system introduced to the market in 2001 by Dentsply Tulsa Dental Specialties. The ProTaper Universal files feature some unique properties that include a progressive taper, which allows increased flexibility, cutting efficiency, and faster shaping, along with a convex triangular cross section. Variable helical angle and pitch, and a modified guiding noncutting tip prevent the screwing in effect and decrease transportation of ProTaper files. Furthermore, previous reports have shown that the ProTaper rotary system has greater ability to remain centered in the canal, allowing for a safer and more regular canal preparation.

The NiTi rotary files currently available are based on a continuous rotary motion. However, there have been some recent studies that have suggested a reciprocating rotary motion as an alternative to the continuous rotary in order to increase fatigue resistance and decrease procedural errors, while still increasing efficiency and decreasing procedural times. The reciprocating rotary movement is based on the balanced force technique, which is designed to maintain the curvature without distorting the shape of the root canal.

In 2011, Dentsply Tulsa Dental Specialties introduced the WaveOne reciprocating system. The WaveOne Primary file has the same tip size and taper features as the ProTaper F2 but a variable section and reverse cutting blades. WaveOne differentiates itself from other reciprocating systems by reciprocating in an unequal clockwise (CW)/counter clockwise (CCW) bi-directional movement. These files are manufactured with M-wire NiTi and have a variable pitch and helical angle, a reverse helix, and two distinct cross sections along the active cutting portion of the file. These qualities have been shown to increase flexibility and fracture and fatigue resistance, decrease instrument separation, improve debris removal, conserve root structure, and increase safety.

There have been multiple techniques used to compare instrumentation of different file systems. More recently, a number of studies have used micro-computed tomography (microCT)-based imaging to look at the effects of various instrumentation techniques and efficiencies. Newer microCT machines have vastly improved resolution and minimize the projection errors from which earlier microCT machines suffered. MicroCT has been particularly useful for studies on endodontic instrumentation because it permits a two-dimensional (2D) and three-dimensional (3D) evaluation of root canal geometry and quantitative measurements of dentin removal from the canal walls. Furthermore, microCT also allows a noninvasive look into the root canal system and its morphologic characteristics in a detailed and accurate manner without destruction of the tooth.

With new treatment methods like reciprocating rotary motion systems emerging, it is imperative to assess the shaping ability and safety of these systems. Previous studies have shown WaveOne to have higher fracture resistance than ProTaper. Other studies have compared the fatigue resistance of the reciprocating motion to a continuous rotary motion, but studies comparing transportation and centering ability are lacking. Recently, Berutti et al compared WaveOne and ProTaper in preservation of canal anatomy in plastic blocks, but no studies have compared these files in
extracted human teeth. Hence, the aim of this study is to assess transportation and canal centering ability in curved canals using a reciprocating motion system, WaveOne, as compared to a continuous rotary motion system, ProTaper Universal.

METHOD AND MATERIALS

Sample preparation
Transportation and centering ability were evaluated based on the protocol from Yamamura et al. Thirty extracted mandibular molars in which the mesiobuccal (MB) and mesiolingual (ML) canals had separate foramina were initially selected for use in this study. The teeth were radiographed and the initial root curvatures were determined as previously stated by Pruett et al. Teeth with curvatures of 20 to 40 degrees were selected. The initial widths of the canals were also determined from the preoperative microCT scans. The coronal accesses for the selected teeth were completed, and the chambers were irrigated with 6% NaOCl. Pre-instrumentation scans of all teeth were captured with the Model 1076 MicroCT machine (SkyScan) at 35 μm resolution using 100 kV, 100 μA, 1 mm aluminum filter, 240 millisecond exposure with 3 frame averaging, and a rotation step of 0.5 degrees. These same settings were used for subsequent scans. Raw scan data were reconstructed using the computer program, NRecon v1.6.1.0 (SkyScan). After reconstruction, root and canal morphology were evaluated by rendering each dataset in 3D using the volume exploration software, Drishti v2.0 (http://sf.anu.edu.au/Vizlab/drishti). These 3D renderings suggested a higher degree of curvature of the root canals than expected based on the radiographic measurements. Consequently, curvature was recalculated from the rendered 3D data and compared with the original 2D radiographic determinations. Three of the original selected teeth were found to have canal curvatures greater than 40 degrees and thus were eliminated.

The working length of each canal was determined by using a size 10 K-file (Dentsply Tulsa Dental Specialties). The files were inserted into the canals until visually seen past the apical foramen then backed up 1 mm. A reproducible glide path was created using the size 10 K-file. The 54 canals from 27 teeth were randomly assigned to the two groups and instrumented. A single operator who was competent in both instrumentation techniques performed the instrumentation. New files were used for each instrumented canal.

In group 1, the MB canals were instrumented with ProTaper files using continuous rotary motion. The ML canals were instrumented with WaveOne using reciprocating rotary motion.

In group 2, the MB canals were instrumented with WaveOne using reciprocating rotary motion. The ML canals were instrumented with ProTaper files using continuous rotary motion.

The ProTaper files were operated by the e3 motor (Dentsply Tulsa Dental Specialties) at 300 rpm. Instrumentation with ProTaper was completed to working length in both groups using the sequence S1, S2, F1, F2, as suggested by the manufacturer. Each instrument was taken to working length and then changed. After each change, the canal was irrigated with 1 mL 6% NaOCl and recapitulated with a size 10 K-file. The WaveOne system was operated using the e3 motor (on the “WaveOne” setting in reciprocating motion (150 degrees CCW and 30 degrees CW) at 400 rpm. Instrumentation in both groups was carried out according to manufacturer’s recommendations with a single 25/.08 taper Primary file. The Primary file was allowed to advance until resistance and then removed and the flutes cleaned. The canal was then irrigated with 6% NaOCl and recapitulation was completed with a size 10 K-file. This sequence was carried out until working length was reached.

After canal shaping, postinstrumentation microCT scans were completed. The program NRecon v1.6.1.0 was used again to reconstruct the data as described above.

Evaluation of canal centering ability and canal transportation
3D datasets for pre- and postinstrumentation were first registered to each other (aligned and oriented in the same multidimensional space) using the program Ana-
lyze 10.0 (Mayo Clinic). These datasets were then used to measure canal centering ability and transportation at 1, 3, 5, and 7 mm in both mesial canals using the CTan software (SkyScan). The canal transportation direction and extent was determined as previously described by measuring the shortest distance from the edge of the uninstrumented canal to the edge of the tooth in both a mesial and distal direction and then comparing this with the same measurements taken from the instrumented canal images. The following formula was used to calculate transportation: \( (M_1 - M_2) - (D_1 - D_2) \). \( M_1 \) and \( M_2 \) represent the shortest distance from the outside of the mesial surface of the tooth to the edge of the uninstrumented and instrumented canals, respectively. \( D_1 \) and \( D_2 \) represent the shortest distance from the distal surface of the root to the edge of the uninstrumented and instrumented canals, respectively. A result of zero from this formula would indicate no transportation. A negative result indicated transportation away from the furcation region, and a positive result indicated transportation towards the furcation region.

The mean centering ratio is a measure of the ability of the instrument to stay centered in the canal. This ratio was calculated for each section by using the following ratio: \( \frac{(M_1 - M_2)}{(D_1 - D_2)} \). The numerator for the centering ratio formula was the smaller of the two numbers \( M_1 - M_2 \) or \( D_1 - D_2 \), if these numbers were unequal. A result of one indicates a perfect centering ratio.

All measurements related to canal instrumentation were repeated in the volume exploration software Drishti v2.0 (http://sf.anu.edu.au/Vizlab/drishti/). Drishti also permitted visual assessment of the instrumentation in 3D. This was achieved following segmentation of the pre-instrumented and postinstrumented canals using Analyze 10.0 (Mayo Clinic). The instrumentation of each tooth was assessed by applying different transfer functions to each of three volumes imported into Drishti: (1) pre-instrumented unsegmented data for surface rendering, (2) pre-instrumented data from which the canals had been segmented, and (3) postinstrumented and segmented canals.

**Statistical analysis**

SigmaPlot 11.0 (Systat Software) was used for data analysis. The data of the widths of the canals preoperatively at the same levels (1 mm, 3 mm, 5 mm, 7 mm) were compared using a student t test. The data for canal transportation and centering ability were statistically analyzed using a two-way analysis of variance (ANOVA) with a Holm-Sidak post hoc test and the level of significance was \( P \leq .05 \).

**RESULTS**

There were no statistically significant differences between the widths of the both canals of the two groups preoperatively at any of the levels that were analyzed (\( P \) values: at 1 mm = .928; 3 mm = .657; 5 mm = .768; 7 mm = .937).

Figure 1 shows an example of “transparent” 3D rendered pre- and postinstrumented scans from the buccal and the lingual aspects. The areas in green are the pre-instrumented or the uninstrumented areas and those in red are the superimposed postinstrumented areas. Figure 2 shows the registered pre- and postinstrumented scans in 2D virtual sections at selected distances from the apex. The areas in red on the sections represent those of transportation in the mesial canals. All measurements were made from slices at these selected distances and a two-way analysis of variance (ANOVA) was used to analyze the data. As can been seen in Fig 3a, both file systems appeared to transport away from the furcation at the 1 and 3 mm levels, and toward the furcation at the 5 and 7 mm levels. Although the ProTaper system tended to demonstrate less transportation at the 1, 3, and 7 mm levels, the apparent differences between the two files systems did not reach statistical significance at any level (\( P = .760 \)). However, when the same file was analyzed at different levels, the ProTaper and WaveOne files both showed statistically significant differences in transportation when comparing 5 and 7 mm with the 1 and 3 mm levels, respectively.

With respect to centering ability, WaveOne tended to stay slightly more centered at the 1, 3, and 5 mm
Canal instrumentation visualized by 3D rendering of pre- and postinstrumented teeth. 3D voxel-based rendered images of a single representative microCT-scanned tooth are shown. Three separate data volumes (the unsegmented tooth, the pre-instrumented segmented canal, and the postinstrumented segmented canal) were loaded simultaneously into Drishti. To permit visualization of the pre-and postinstrumented canals, transparency was applied to the tooth voxels and the segmented pre- and postinstrumented canals rendered in complementary colors. The pre-instrumented canals are shown in green, while the instrumentation is shown in red. The top two figures represent the scan taken from the buccal aspect and the lower two figures are the scans of the same tooth taken from the lingual aspect. For this tooth, the mesiobuccal canals were instrumented with ProTaper files and the mesiolingual canals were instrumented with the WaveOne files.

Pre-and postinstrumentation analysis of 2D slices at set planar levels. The left columns of grayscale tooth sections (column 1, mesial root; column 2, distal root) shows the slices at 1, 3, 5, and 7 mm from the apex of a pre-instrumented tooth. The right columns represent an overlay of the same slices from the pre-instrumented tooth with those of the postinstrumentation data. For ease of visualization in this image, the pre-instrumented data are shown in red, whereas the postinstrumented data is in green. In this example, only the mesial roots have been instrumented: the distal canals were left uninstrumented. Because of the registration of the two datasets, the majority of each slice appears yellow (ie, concordance of green and red). The differences, highlighted in red, represent the transportation. For this tooth, ProTaper files were used in the mesiobuccal canal (top), and WaveOne files in the mesiolingual canal (bottom).

Comparison of canal transportation and centering ability. (a) Canal transportation. Measurement of transportation comparing ProTaper and WaveOne files at 1, 3, 5, and 7 mm from the apex. (b) Centering ratio. The centering ratio of the ProTaper and the WaveOne files measured at 1, 3, 5, and 7 mm levels from the apex.
levels while ProTaper was more centered at the 7 mm level (Fig 3b). However, the differences between ProTaper Universal and WaveOne in their mean centering ratio were also not statistically significant at any level \((P = .178)\). Even when analyzing the same file, neither file type showed statistical differences in centering ability at any level.

**DISCUSSION**

The purpose of this study was to compare the ability of two NiTi instruments, the WaveOne Primary and the ProTaper system, used up to an F2 file, in preserving original canal anatomy. Human mandibular molars were used in this study. The mesial roots of mandibular molars were chosen for this study because these contain canals that usually curve in two planes. The canal curvatures were confirmed with the help of the microCT to avoid using any teeth with canal curvatures greater than 40 degrees. To minimize the impact of variability in dentin hardness on the results obtained from the two groups, only those molars that had two separate canals were used: one canal from each tooth being placed into one of the two groups and instrumented with one of the two different file systems.

In this study two different file systems were used: the ProTaper Universal continuous rotary file system, and the reciprocating file system, WaveOne. Both file types have a similar taper and tip diameter thus eliminating the possibility of these factors being variables between the two groups. One of the main reasons we compared this specific file size and taper was because a number of previous studies have looked at other variables such as cyclic fatigue, debris extrusion, and cleaning effectiveness in regard to this tip size and taper. However, no study as yet has analyzed the effects on transportation and centering ability with this tip size and taper. Furthermore, the ProTaper F2 was the first file tested by Yared as a single reciprocating file.

MicroCT was used because it allows for accurate, high resolution, and fully quantitative data for 3D assessment of the root canal system without any destructive sectioning of specimens and eliminates radiographic or photographic error, as exemplified by our own example measuring root curvature using both 2D radiographic and 3D microCT-based methodologies.

The WaveOne system appeared to show less centering ability at the 7 mm level when compared to the 1, 3, and 5 mm levels. This could be attributed to the introduction of such a large rotary file tip size and taper with only the use of size 10 K-file preceding it. Both file systems showed a statistically significant difference when comparing the degree of transportation at different levels, specifically at 5 and 7 mm compared to the 1 and 3 mm levels. Both systems transported towards the furcation at the 5 and 7 mm levels and away from the furcation at the 1 and 3 mm levels. This could possibly be attributed to the taper of the files which caused them to transport more coronally. Previous studies have also shown that ProTaper files tend to cause transportation toward the furcation in the coronal and middle thirds and away from the furcation in the apical third. Our results therefore corroborate these earlier findings for the ProTaper files, and overall this study showed that the WaveOne reciprocating motion followed the same tendencies as ProTaper. It is interesting to note that the type of metal from which the files were manufactured (M-wire versus NiTi) did not affect the results of the study. Hence, it is a possibility that M-wire did not have any effect on centering ability or transportation of files as compared to cyclic fatigue and file separation. However, this variable would need to be evaluated in future studies.

The present results demonstrated that both file types with the tip size and taper of 25/.08 do not differ in the amount of transportation and centering ability. These results are in contrast to those from Berutti et al, who demonstrated that canal modifications were reduced when the WaveOne system was used as compared to the ProTaper files. This could be possibly due to the fact that this current study was conducted in extracted teeth versus plastic blocks. This difference suggests that further studies to investigate the impact of larger taper and tip sizes (40/.06) for both file systems on transportation and centering ability are warranted.
CONCLUSION

As studies have shown reciprocating motion to be more efficient and to increase the life of files over conventional continuous rotary techniques, it is important to know the safety and the canal shaping ability of reciprocating systems. Within the limitations of this study, we found that there are no statistically significant differences in centering ability or transportation between ProTaper and WaveOne file systems, although both showed similar transportation toward the furcation in the upper half of the canals and away from the furcation in the lower half. Overall, the present study does not support the use of one file over another when comparing transportation and centering ability. This is important information for the practitioners to know before they start using any new file system as this would help them to decide which file system they could successfully use in their practice. The results showed that both file systems were equally safe for use during endodontic treatment procedures.

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REFERENCES


