Comparison of the shaping abilities of three nickel–titanium instrumentation systems using micro-computed tomography

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KEYWORDS
- canal shaping
- centering ratio
- micro-computed tomography
- nickel-titanium instruments
- transportation

Abstract  Background/purpose: The purpose of this study was to compare the canal transportation (CTR) and centering ratio (CR) of ProFile (PF), Twisted File (TF), and WaveOne (WO) nickel-titanium instrument systems and evaluate canal volume (CV) and surface area (SA) using micro-computed tomography (CT).

Materials and methods: Eighteen extracted human mandibular molars with two separate mesial canals were selected. The specimens were randomly divided into three groups of six teeth. Therefore, twelve root canals were allocated for each group (n = 12): group 1, PF(#30/.06); group 2, TF(#30/.06); group 3, WO (primary) instrument systems. Working lengths were determined 0.5 mm short of the apical foramen. Specimens were scanned before and after root canal preparation. Scanned images were reconstructed and the effects of root canal preparation on the CV and SA were evaluated. Pre- and post-instrumentation cross-sectional images of 1, 3, 5, and 7 mm from the anatomical apex were obtained and the CTR and CR were compared. The data were analyzed by the Kruskal-Wallis test and linear mixed model with Bonferroni’s correction. A P < 0.05 was considered to be significant.

Results: Postoperative canals were larger and had greater SA, although these changes were not statistically significant (P > 0.05). At any levels (1-, 3-, 5-, and 7-mm), no significant difference was found in the amount of CTR among the groups (P > 0.05). At the 1-, 3-,
and 7-mm levels there was no significant difference in the CR among the groups (P > 0.05). However, at the 5-mm level, WO group showed significantly smaller CR than PF group (P < 0.05).

**Conclusion:** Within the limitations of this study, WO showed smaller CR than PF, which imply that careful use of WO in curved canals is recommended.

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**Introduction**

Cleaning and shaping of the root canal is one of the major procedures of endodontic treatment. When curvatures are present, root canal preparation becomes more difficult, and there is a tendency to divert the prepared canal away from the original axis. In the glossary of endodontic terms of the American Association of Endodontists, root canal transportation is defined as “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; may lead to ledge formation and possible perforation”. The preservation of the original canal shape and the lack of canal transportations are associated with sealing efficiency and reduced weakening of the tooth structure.

The introduction of nickel–titanium (NiTi) rotary instrumentation has not only enabled easier and faster preparation of the root canal system but has also provided consistent, predictable, and reproducible shaping with considerably less iatrogenic damage.

Recently, a new generation of the NiTi rotary instrument with higher flexibility and greater cutting efficiency has been introduced: the Twisted Files (TF) (SybronEndo, Orange, CA, USA). The manufacturer claims that R-phase heat treatment, surface conditioning and twisting of the metal significantly increases instrument resistance to cyclic fatigue and provides greater flexibility, maintaining the original canal center and minimizing canal transportation even in severely curved root canals. Freire et al. found that at 3 mm and 4 mm from the anatomical apex, the TF system had lower levels of apical transportation and better centering ability than the EndoSequence (Brasseler, Savannah, GA, USA) system. The more recently introduced single-file NiTi system, WaveOne (WO) (Dentsply Maillefer, Ballaigues, Switzerland) is claimed to be able to completely prepare root canals with only one instrument. The system is designed to be used with a dedicated reciprocating motion motor, which might decrease the impact of cyclic fatigue on the NiTi rotary instrument, compared with rotational motion. The files are made of a special NiTi alloy called M-Wire that is created by an innovative thermal treatment process. The benefits of this M-Wire NiTi are increased flexibility of instruments and improved resistance to cyclic fatigue. Bürklein et al. have shown that root canal shaping with the WO instrument can be performed with a good centering ability in regularly curved canals of extracted teeth.

Micro-computed tomography (micro-CT) is particularly useful for studies on endodontic instrumentation because it allows two-dimensional (2D) and three-dimensional (3D) evaluation of root canal geometry and quantitative measurements of dentin removal from the canal walls. Indeed, a number of studies have used micro-CT-based imaging to look at the effects of various instrumentation efficiencies and techniques.

The purpose of this study was to compare the amount of transportation and centering abilities of PF (Dentsply Maillefer), TF, and WO NiTi instrumentation systems and quantitatively evaluate canal volume and surface area produced by each system using micro-CT.

**Materials and methods**

Eighteen human mandibular molars with two separate mesial root canals were used. To facilitate the experimental set-up of micro-CT scanning, a mounting zig was prepared for the precise repositioning of the teeth. The occlusal surfaces of the teeth were ground flat and perpendicular to the long axis by a diamond disc. Then, the teeth were placed in the center of the object stage (13 mm in diameter and 2 mm in height) with the occlusal surface towards the floor. After pouring acrylic resin mixture (Ortho-Jet Powder and Liquid; Lang Dental, Wheeling, IL, USA) into the object stage, the teeth with mounting zigs were immersed in hot water. After 10 minutes, excess of acrylic resin was trimmed out. Thereafter, the access cavities were prepared, and mesial canals were localized and explored with a size 10 K-flexofile (Dentsply Maillefer), which was inserted into the canals until the tip was just visible at the apical foramen. Radiographs were taken in a mesio-distal projection to confirm the presence of two separate canals. Radiographs in the bucco-lingual direction were also taken to determine the root canal curvature. According to the Schneider method, only canals with a curvature between 10° and 20° were used. Individual working lengths (WLS) were calculated 0.5 mm short of the apical foramen, ranging from 13 mm to 17 mm.

Specimens were randomly assigned to three groups (n = 12).

**Group 1 (PF)**

A glide path was established by using a size 10 and 15 K-flexofile. The canals were prepared in a crown-down fashion by an electric motor (Endo-Mate DT, NSK, Tokyo, Japan) with 2.0N cm of torque at 300 rounds per minute (RPM). A size 25/0.06 PF was used to two-thirds of the WL. The instrument was withdrawn when resistance was felt, and then followed by a size 30/0.06 PF to the same length.
After using a size 20/0.06 PF to three-quarters of the WL, a size 15/0.06, 20/0.06, 25/0.06, and 30/0.06 PF were sequentially used to the WL. After the use of each instrument, all canals were irrigated with 2.5% NaOCl by using a 30-G irrigating tip (Max-i-Probe; Dentsply International, York, PA, USA) and apical patency was verified by a size 08 K-flexofile.

**Group 2 (TF)**

A glide path was established by using a size 10 and 15 K-flexofile. The canals were enlarged using Endo-Mate DT with 1.0N-cm of torque at 500 RPM. A size 25/0.08 TF was used to resistance and then withdrawn immediately. If the WL was reached, a size 30/0.06 TF was used to the WL. After the use of each instrument, root canals were irrigated with 2.5% NaOCl by using a 30-G irrigating tip and apical patency was verified by a size 08 K-flexofile.

**Group 3 (WO)**

A glide path was not established according to the manufacturer’s guideline, which does not mandate the establishment of glide path. Because a size 10 K-flexofile was inserted to the WL easily, WO primary files were selected. Each canal was shaped using a WaveOne motor (Dentsply Maillefer), with a pecking motion, until reaching full WL. After three pecking motions, all canals were irrigated with 2.5% NaOCl by using a 30-G irrigating tip and apical patency was verified by a size 08 K-flexofile.

Root canal preparation was done by one operator with new files for each tooth in all three groups. RC-Prep (Premier Dental Products, Norristown, PA, USA) was used during canal preparation. A total volume of 10 mL of 2.5% NaOCl was used for each canal. After root canal preparation, final irrigation was conducted with 1 mL of 17% EDTA for 1 minute, followed by 5 mL of 2.5% NaOCl.

Specimens were scanned prior to and after instrumentation at 100 kV and 100 μA with an isotropic resolution of 19.7 μm by using a micro-CT scanner (Skyscan 1172, Skyscan, Aartselaar, Belgium). Scanned images were reconstructed using the software N-Recon (Skyscan). Approximately 500 cross-sectional images were obtained for each specimen.

Using the software CTan (Skyscan), the region of interest extending from the apex of root to the bifurcation area was selected, and the volume and surface area were determined. The mean changes in these parameters were calculated by subtracting the scores for the instrumented canals from those recorded for the uninstrumented counterpart. The region of interest of canals prior to and after instrumentation was also shown (Fig. 1).

Cross-sectional images at four different levels, located at 1 mm, 3 mm, 5 mm, and 7 mm short of the anatomical apex, were used to evaluate canal transportation and centering ratio. Cross-sectional images of the instrumented and uninstrumented canals were superimposed using the
The methods of calculation for canal transportation and centering ratio are as follows. The extent of canal transportation was determined by measuring the shortest distance from the edge of the uninstrumented canal to the

Adobe Photoshop 7.0 (Adobe Systems Incorporated). Fig. 2 shows the representative superimposed instrumented and uninstrumented cross-sectional images at selected distances from the apex.
edge of the tooth in both mesial and distal directions and then comparing them with the same measurement values taken from the instrumented canals. The following formula was used for the transportation calculation: 

\[ (X_1 - X_2) \times (Y_1 - Y_2) \]

where \(X_1\) represents the shortest distance from the outside of the curved root to the periphery of the uninstrumented canal, \(Y_1\) represents the shortest distance from the inside of the curved root to the periphery of the uninstrumented canal, \(X_2\) represents the shortest distance from the outside of the curved root to the periphery of the instrumented canal, and \(Y_2\) represents the shortest distance from the inside of the curved root to the periphery of the instrumented canal (Fig. 3).

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 using the following ratio: 

\[ \frac{(X_1 - X_2)}{(Y_1 - Y_2)} \]

The numerator for the centering ratio formula was the smaller of the two numbers, either \((X_1 - X_2)\) or \((Y_1 - Y_2)\), when these numbers were unequal. Using this formula, a result of 1 for the centering ratio would indicate perfect centering.

### Table 1
<table>
<thead>
<tr>
<th>Assessment</th>
<th>PF Value (± SD)</th>
<th>TF Value (± SD)</th>
<th>WO Value (± SD)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\Delta)Volume (mm(^3))</td>
<td>129.73 ± 44.34</td>
<td>147.88 ± 88.64</td>
<td>100.41 ± 36.28</td>
<td>0.529</td>
</tr>
<tr>
<td>(\Delta)Surface area (mm(^2))</td>
<td>28.72 ± 13.85</td>
<td>24.83 ± 17.33</td>
<td>13.40 ± 7.3</td>
<td>0.209</td>
</tr>
</tbody>
</table>

Values are mean ± SD. CV = canal volume; SA = surface area; PF = ProFile; TF = Twisted Files; WO = WaveOne. No statistically significant difference within rows (\(P > 0.05\)).

### Table 2
<table>
<thead>
<tr>
<th>Level</th>
<th>Transportation (mm)</th>
<th>PF Value (± SD)</th>
<th>TF Value (± SD)</th>
<th>WO Value (± SD)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 mm</td>
<td>Transportation</td>
<td>0.03 ± 0.03</td>
<td>0.04 ± 0.04</td>
<td>0.04 ± 0.03</td>
<td>1.000</td>
</tr>
<tr>
<td></td>
<td>Centering ratio</td>
<td>0.45 ± 0.27</td>
<td>0.47 ± 0.33</td>
<td>0.44 ± 0.32</td>
<td>1.000</td>
</tr>
<tr>
<td>3 mm</td>
<td>Transportation</td>
<td>0.05 ± 0.04</td>
<td>0.04 ± 0.05</td>
<td>0.08 ± 0.06</td>
<td>0.182</td>
</tr>
<tr>
<td></td>
<td>Centering ratio</td>
<td>0.55 ± 0.25</td>
<td>0.63 ± 0.31</td>
<td>0.45 ± 0.30</td>
<td>1.000</td>
</tr>
<tr>
<td>5 mm</td>
<td>Transportation</td>
<td>0.08 ± 0.07</td>
<td>0.13 ± 0.11</td>
<td>0.23 ± 0.14</td>
<td>0.187</td>
</tr>
<tr>
<td></td>
<td>Centering ratio</td>
<td>0.57 ± 0.30*</td>
<td>0.42 ± 0.29</td>
<td>0.26 ± 0.26*</td>
<td>0.030</td>
</tr>
<tr>
<td>7 mm</td>
<td>Transportation</td>
<td>0.12 ± 0.07</td>
<td>0.15 ± 0.13</td>
<td>0.28 ± 0.14</td>
<td>0.342</td>
</tr>
<tr>
<td></td>
<td>Centering ratio</td>
<td>0.47 ± 0.21</td>
<td>0.48 ± 0.35</td>
<td>0.27 ± 0.23</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Values are mean ± SD. PF = ProFile; TF = Twisted Files; WO = WaveOne. *Statistically significant difference between two groups (\(P < 0.05\)).
ratio is that transportation is calculated by $|X_1 - X_2| - |Y_1 - Y_2|$ and centering ratio is the ratio of $(X_1 - X_2)$ to $(Y_1 - Y_2)$.

The data were analyzed by the Kruskal-Wallis test and linear mixed model with Bonferroni’s correction. A $P$-value < 0.05 was considered to be statistically significant for all analysis.

Results

The mean and standard deviation, for the changes of the canal volume, surface area, the canal transportation, and the centering ratio at the 1 mm, 3 mm, 5 mm, and 7 mm from the apex for the experimental groups are presented in Tables 1 and 2.

Table 1 shows that instrumented canals were larger and had greater surface area than uninstrumented canals. However, the amount of increase in canal volume and surface area after instrumentation showed no significant difference among the three groups ($P > 0.05$).

At any levels (1 mm, 3 mm, 5 mm, and 7 mm), no significant difference was found in the amount of canal transportation among the groups ($P > 0.05$) (Table 2). At the 1 mm, 3 mm, and 7 mm levels, there was no significant difference in the canal centering ratio among the groups ($P > 0.05$). However, at the 5 mm level of canals, the WO group showed a significantly smaller centering ratio than the PF group ($P < 0.05$) (Table 2).

Discussion

The micro-CT scanning system used in this study generates fully quantitative data, allowing 3D assessment of both the external morphology and internal root canal system along with measurement of changes of the canal. It seems to be reproducible and excellent to examine the shape of the root canal prior to and after instrumentation. No destructive sectioning of the specimens is required, and each virtual cut plane can be accurately positioned with respect to the entire canal length and precisely oriented at right angles to the root canal. However, it was impossible to automatically obtain accurate superimpositions, although a specially designed mounting zig was used in the experiment for accurate repositioning in the scanning process. For this reason, the process of superimposition was manually done.

In the present study, root canal instrumentation resulted in an increase in canal volume and surface area with no statistically significant difference among the three groups (Table 1). The mean pre-instrumentation canal volumes and surface areas were comparable, indicating similar root canal sizes. Another study using micro-CT, which has compared changes in volume and surface area instrumented with PF and other instrument systems, such as NiTi K-Files (Dentsply Maillefer), Lightspeed (LightSpeed Technology Inc., San Antonio, TX, USA), and GT Rotary files (Dentsply Maillefer), has also found no statistically significant differences.

There was no significant difference among the three groups with respect to the amount of canal transportation (Table 2). The results are aligned with the previous study, which has compared the centering ability in mesial canals of mandibular molars instrumented by TF using continuous rotary motion, by ProTaper (PT) (Dentsply Maillefer) using continuous rotary motion and PT using reciprocating motion. In the present study, although the difference was not large enough to be statistically significant, the WO group showed more transportation than both the PF and TF groups, especially in the 5 mm and 7 mm level of canals. The statistically significant difference was found only between the WO and PF groups in the centering ratio at the 5 mm level of canals. No use of a glide path, suggested by the clinical procedure flow chart given by the manufacturer, might affect the performance of WO. According to the study of Berutti et al., WO-reciprocating files produced less modification in canal curvature when the glide path was established. Therefore, the creation of a glide path prior to both rotary and reciprocating motion instrumentation appears to be appropriate especially in the case of curved canals. Different instrument designs might also affect the results of this study. The PF system is a U-shaped design with radial land areas to cut equally over 360° with a planning action and to be self-centering. The TF system is manufactured by twisting an NiTi wire into a triangular cross-section, which makes it more flexible than ground instruments and consequently causes less canal transportation. The WO system is characterized by the existence of different cross-sectional designs over the entire length. In the tip region, the cross-section presents a modified triangular convex design with radial lands, whereas in the middle part, the cross-sectional design changes to a neutral rake angle with a triangular convex design. This design of the WO system seems to increase the stiffness of files at the 5 mm level, resulting in its lower centering abilities despite the use of a reciprocating motion. Moreover, a study using nondestructive high-resolution scanning tomography to assess changes in the paths of canals prepared with four different NiTi preparation techniques showed that the postoperative canal geometry is dependent on the individual canal anatomy rather than the NiTi preparation techniques.

The instruments used in this study did not have the same tip size and taper, which could have influenced the results. This could be one of the limitations of this study. Future research with a better experimental design to explain the results of this study is necessary.

Within the limitations of this study, it was shown that WO could cause more canal transportation than PF in the apical part of root canals. Therefore, making glide path prior to use of WO in curved canals might be helpful.

Conflicts of interest

The authors have no conflicts of interest relevant to this article.

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References