Comparison of root canal transportation induced by three rotary systems with noncutting tips using computed tomography

Senem Yiğit Özer, DDS, PhD, Diyarbakir, Turkey
DICLE UNIVERSITY

Objective. The purpose of this study was to compare the shaping ability (apical transportation and straightening) of 3 nickel-titanium rotary instruments (ProTaper Universal, Hero 642 Apical, FlexMaster) with noncutting tips in curved root canals of extracted human teeth using cone beam computed tomography (CBCT).

Study design. Sixty mesiobuccal root canals of maxillary molars with curvatures of 25° to 47° were equally divided into 3 groups and embedded in silicone impression material. The root canals were scanned using CBCT (Next Generation i-CAT) and after scanning working length was determined with a hand file to preserve the original curvature. After preparation, teeth were placed into their original positions on the silicone impression material and postinstrumentation scans were performed using the same parameters (4-cm field of view at 0.125-mm voxel). Pre- and postinstrumentation images obtained from root cross-sections located 2, 3, and 4 mm above the apical foramen were compared using Adobe Photoshop software. Transportation was measured by superimposition of final and initial images. Any distance (mm) between prepared and anatomic canal centers was defined as apical transportation. Canal curvatures were measured before and after instrumentation using computed tomography and images were exported to ImageJ software. Differences in the degree and radius of curvature were regarded as straightening. Data were analyzed by ANOVA.

Results. Mean transportation values were 0.10 ± 0.03 mm for ProTaper Universal, 0.09 ± 0.03 mm for Hero 642 Apical, and 0.07 ± 0.02 mm for FlexMaster, and the differences were not significant. Mean values for straightening among the groups were not significantly different (P > .05). The performances of all instruments were similar.

Conclusion. Apical transportation occurred with all the instruments despite their noncutting tips. (Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2011;111:244-250)
different tip designs with different cross sections indicated less apical transportation with noncutting tips than with cutting-tipped files. Noncutting tips thus conserve the inner curve of curved root canals.

Several methodologies have been used to evaluate the efficacy of NiTi instruments in remaining centered during preparation. These include radiographic comparisons, cross sections using the technique of Bramante et al., longitudinal cleavage of the teeth, high-resolution computed tomography (hrCT), and microtomography (μCT). Both hrCT and μCT allow detailed 3-dimensional observation of objects, and have been shown to be useful in endodontic evaluations because they nondestructively measure the amount of dentin removed from root canal walls. µCT is the compact form of conventional computed tomography (CT), but it has higher resolution and thus allows a more precise determination of changes in prepared root canals. Both imaging systems have advantages and disadvantages regarding their technical features. The major disadvantages of hrCT are low resolution when compared with μCT, and difficulties when assessing the effects of root canal instrumentation techniques on canal shape as the evaluated area may be as small as 0.1 mm. Cone-beam computed tomography (CBCT) is a high-resolution scanning system that has been used clinically and for endodontic investigations when evaluating root canal morphology, fractures, and changes in root canals after instrumentation. It has a lower radiation dose but a lower spatial resolution than μCT, which can result in problems when enhancing data during imaging.

This study used CBCT to compare the occurrence of canal transportation and the changes in canal curvature in mesiobuccal (MB) root canals of maxillary molars instrumented using 3 NiTi systems with noncutting tips.

MATERIAL AND METHODS
Specimen selection
The study sample consisted of 75 maxillary molars with fully formed apices that had been extracted for periodontal and/or prosthetic reasons. The teeth were stored in saline at 4°C until use. Access cavities were prepared with round diamond burs (Diatech Dental AG, Heerbrugg, Switzerland). The root canals were not probed for patency by a torque-controlled electric motor (VDW, GmbH; Munich, Germany) were used for instrumentation. The characteristics of all instruments are summarized in Table I. The rotation speed of each NiTi rotary instrument was set with a 6:1 reduction handpiece powered by a torque-controlled electric motor (VDW Gold; VDW, GmbH) and recorded in the memory of the endodontic motor. All canals were instrumented by the same operator (S.Y.O.); the manufacturer’s recommended sequences were modified and are shown in Table II.

Preparations were performed from the crown to the root apex of each tooth. Each instrument was coated with RC Preparatory lubricant (Premier Products, Ply-
mouth Meeting, PA). Irrigation was performed with 10 mL of 2.5% NaOCl after each filing action using a disposable syringe and a 27-gauge irrigation needle (Max-I-probe; Hawe Neos, Bioggio, Switzerland). One set of instruments was used for the preparation of 5 canals in the Hero 642 Apical and PTU groups, whereas 1 set was used for each canal in the FlexMaster group to prevent file breakage. To achieve uniform master apical size in all groups, canal preparation was completed with a number 30 master apical file. The instrumented canals were scanned with CBCT using the same protocol and parameter settings. All CBCT images were assessed by a qualified endodontist.

### ASSESSMENT OF ROOT CANAL PREPARATION

#### Apical transportation

The initial and final CBCT images taken at 2, 3, and 4 mm above the apical foramen were exported to Adobe Photoshop software (version 7.0; Adobe Systems Inc., San Jose, CA). The protocol described by Hartmann et al.\textsuperscript{12} was modified and applied to all images (Fig. 1). The relevant image was selected, cropped to $5 \times 5$ cm, viewed at 100%, and converted to grayscale with 8 b/channel. The root canal was outlined using the magic wand tool with tolerance set to 18. For the PREI image, the size of the brush tool was adjusted to suit the size of the root canal and the canal was painted green. Tolerance was set to 32, the dentin border was outlined, and PREI dentin was painted yellow. The PREI image was zoomed to 1200% to facilitate visual accuracy for the next step. The center of the canal was marked in black with the pencil tool and the superimposed image was zoomed to 1200% for better visualization of the white and black center markings. The distance between noncorresponding markers formed the “sum of canal transportation.”

#### Straightening (change in the degree and radius of curvature)

All images scanned by CBCT were exported to ImageJ image analysis software before and after instrumentation to determine straightening using the method reported by Estrela et al.\textsuperscript{16} Two semistraight lines of equal length were used (Fig. 3). The first line (green) repre-

### Table I. Design features of instruments used in the study

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Cross-section</th>
<th>Rake angle</th>
<th>Tip property</th>
<th>Working speed, rpm</th>
</tr>
</thead>
<tbody>
<tr>
<td>ProTaper Universal</td>
<td>Convex triangular, U-shaped</td>
<td>Slightly positive</td>
<td>Noncutting</td>
<td>250-350</td>
</tr>
<tr>
<td>Hero 642 Apical</td>
<td>Triple helix</td>
<td>Positive</td>
<td>Noncutting</td>
<td>300-600</td>
</tr>
<tr>
<td>FlexMaster</td>
<td>Convex triangular</td>
<td>Positive</td>
<td>Noncutting</td>
<td>150-300</td>
</tr>
</tbody>
</table>

### Table II. Instruments used, sequence of preparation, taper, size and working length

<table>
<thead>
<tr>
<th>PreTaper Universal</th>
<th>Hero 642 Apical</th>
<th>FlexMaster</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taper</td>
<td>Size</td>
<td>WL</td>
</tr>
<tr>
<td>3-19 SX 1/3-2/3 coronal</td>
<td>12 Endofile 1/3-2/3 coronal</td>
<td>11 Intro 1/3-2/3 coronal</td>
</tr>
<tr>
<td>2-11 S1 2/3 coronal</td>
<td>6 30 2/3 coronal</td>
<td>6 25 2/3 coronal</td>
</tr>
<tr>
<td>4-11.5 S2 WL-1 mm</td>
<td>4 25 WL-1 mm</td>
<td>4 25 WL-1 mm</td>
</tr>
<tr>
<td>7 F1 WL</td>
<td>4 20 WL</td>
<td>4 20 WL</td>
</tr>
<tr>
<td>8 F2 WL</td>
<td>4 30 WL</td>
<td>4 25 WL</td>
</tr>
<tr>
<td>9 F3 WL</td>
<td>6 30 WL</td>
<td>6 30 WL</td>
</tr>
</tbody>
</table>

WL, working length. Taper values are given as (%).
sented the continuity of the apical region and the second line (blue) followed the middle and coronal thirds of the root canal. The midpoints of each line were determined and a circle (red) was drawn to pass over the midpoints. The center of the circle was marked and two lines representing the radius ($r$) were drawn to the midpoints. The magnitude of the curve was determined geometrically ($\alpha$) and canal curvature was expressed in degrees ($^\circ$). The radius of the curve was defined in millimeters (mm); this parameter represents how abruptly a specific angle of curvature occurs as the canal deviates from a straight line.16

The following protocol describes in detail the process performed with ImageJ for analysis of the PREI and POSTI images. The image was converted to 32-bit and the “Find Edges” option was selected under the “Process” menu. The image was posterized, and image enhancement was performed with minimum and maximum intensity values of 0.75 and 29.25, respectively. The “Segmented Lines” option was chosen to draw the major lines, and the midpoints were determined. The image was captured using “Capture Screen” under the “Dev” menu and a circle passing over the midpoints was generated. The image was captured again to record the drawings using the same protocol. The “Angle Tool” was selected, and lines were drawn to meet the midpoints. The angle between the lines determined the canal curvature. As the lines were “$r$” no other measurement was needed. Differences in the degree and radius of curvature were cal-

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Fig. 1. Sequence of image superimposition. A, Determination of preinstrumented root canal borders. B, Determination of postinstrumented root canal borders. C, Superimposition of the initial and final images.

Fig. 2. After transforming both images, canal centers were marked with white (preinstrumentation) and black (postinstrumentation) pixels, and canal transportation was measured (red line) with the “Measure tool” of Adobe Photoshop.

Fig. 3. Posterized image showing the radius R, and angle ($\alpha$) of the curve determined using ImageJ software ($\neq$) indicates that some coded lengths are equal to each other (mm).
Table III. Mean degree of straightening (changes in degree and radius of the curvature) values with SD

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Degree ° (x ± SD)</th>
<th>Radius (mm) (x ± SD)</th>
<th>Transportation (mm) (x ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ProTaper Universal</td>
<td>1.69 ± 0.19*</td>
<td>1.58 ± 0.14*</td>
<td>0.10 ± 0.03*</td>
</tr>
<tr>
<td>Hero 642 Apical</td>
<td>1.66 ± 0.17*</td>
<td>1.55 ± 0.12*</td>
<td>0.09 ± 0.03*</td>
</tr>
<tr>
<td>FlexMaster</td>
<td>1.61 ± 0.15*</td>
<td>1.52 ± 0.12*</td>
<td>0.07 ± 0.02*</td>
</tr>
</tbody>
</table>

*Values followed by the same superscript letter do not differ (P > .05).

Fig. 4. Apical transportation values (mm) of the 3 rotary NiTi instruments.
is larger (i.e., increased voxel size) than the area evaluated, alterations in root canal anatomy are not detected with sufficient accuracy, thus preventing correct analysis. The limitations of the method should be considered and the most appropriate voxel size should be chosen according to the size of the area of interest. Furthermore, the accuracy of the results may be negatively influenced when repositioning the images taken before and after instrumentation; the PREI and POSTI images must be distorted to allow proper superimposition with each other.

In a previous study, Hartmann et al. used hrCT and axial sections 0.6-mm thick to compare the occurrence of transportation in the apical third of root canals instrumented with hand and rotary file systems. In the present study, CBCT was used to construct images of the root canals 0.125-mm thick for better and more detailed image definition. As the values (minimum, 0.07 mm; maximum, 0.10 mm) were below the voxel size used (0.125 mm), the image analysis may have been prone to error. In its present form, CBCT scanning may not be adequate to quantify shaping outcomes with these rotary instruments due to the technical limitations of the systems used. Although our quantitative results could not reflect the real situation because of these possible errors, they provide an informative comparison among the evaluated experimental groups.

Wenzel et al. reported that image enhancement could be performed to improve the sensitivity of high-resolution CBCT images. Gao et al. suggested that a highly developed software package with a framework based on MeVisLab (MeVis Research, Bremen, Germany) would enable endodontists using CBCT to clinically simulate procedures. Taking these results into consideration, image enhancement was performed in this study using ImageJ and Adobe Photoshop software. This enhancement allowed a detailed investigation of the preparation of curved root canals. Similar studies with CBCTs may be performed using MeVisLab to evaluate the differences between the supporting software.

Mesio-buccal root canals of maxillary molars were used in this study because they usually present an accentuated curvature. Although small files, such as the number 20 size (corresponding to PTU F1; diameter, 0.20 mm), may suffice for apical preparation of curved canals, all files were used for the NiTi systems to achieve the same apical enlargement and to enable comparison. In addition, Khademi et al. reported that apical instrumentation to a number 30 size with a 0.06 coronal taper was effective for removal of debris and smear layers from the apical portions of root canals. In the present study, the parameters of all the instruments fulfilled the requirements discussed by Khademi et al.

Studies evaluating the effect of tip type on transportation have indicated that instruments with noncutting tips create less transportation at the inner curvature of curved root canals than similar instruments with cutting tips. However, noncutting tips have also been shown to produce transportation in severely curved canals, and thus taper size plays an important role. An increasing taper is directly related to increased cross-section areas and decreased flexibility. The cross-sectional designs are known to affect the bending properties of instruments. Turpin et al. reported that the area of a triple-helix cross section was approximately 30% greater than that of a triple-U file as the triple helix file had a larger structure, which caused decreased flexibility.

In previous studies, ProTaper showed more apical transportation than other rotary systems. Javaheri and Javaheri compared the ProTaper, Hero 642, and RaCe systems, and suggested that the ProTaper file system should be implemented in combination with files of decreasing taper size to prepare the apical third of the root canal to prevent apical transportation. Guelzow et al. compared the effects of 6 rotary NiTi systems (FlexMaster, System GT, Hero 642, K3, ProTaper, RaCe) and hand filing for root canal preparation. ProTaper showed the highest degree of straightening (1.2°), in comparison with 0.9° for FlexMaster and K3, 0.7° for RaCe and hand filing, 0.6° for Hero 642, and 0.5° for System GT. In contrast to these reports, in the present study, all the file systems showed apical transportation despite their noncutting tips. The similar transportation and straightening results (Fig. 4, Table III) of the PTU, Hero 642 Apical, and FlexMaster may be related to the modified cross section design of the PTU. The manufacturer reported a decrease in the area in contact with the dentin wall, and that U-shaped grooves had been added at each of the instrument’s convex triangular sides to improve flexibility and reduce transportation. Decreasing tapers of the finishing files and increased flexibility of S1 and F1 may have had favorable effects on the performance of the PTU. The PTU instruments showed better performance than the conventional ProTaper files evaluated previously, probably because the file tip has been changed from the “modified guiding tip” to the “rounded safe tip.” Camara et al. reported that when tip angle was reduced from 66 to 39° for shaping files, and increased from 66 to 95° for finishing instruments, there was reduced canal transportation. They suggested that these instruments showed performance similar to those with smaller taper as they had less stiffness and greater flexibility. A reduction in the tip angle of the shaping files probably centered the instrument within the canal. Increasing the diameter of the S2 led to a larger coronal preparation.
size, which allowed the instruments to reach their working length with decreased torsional stress, and to safely shape the apical third of the canal. These changes in the PTU instruments may give rise to favorable clinical behavior.\(^\text{30}\)

CONCLUSIONS

Within the limitations of this study, our results suggest that all 3 rotary systems showed similar results during preparation of curved root canals and transportation despite their noncutting tips.

REFERENCES


Reprint requests:
Senem Yiğit Özer, Assistant Professor
Dicle University
Faculty of Dentistry
Department of Operative Dentistry and Endodontics
21280, Diyarbakir, Turkey
senemyg@hotmail.com