Microscopic computerized tomographic evaluation of root canal transportation prepared with twisted or ground nickel-titanium rotary instruments

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Objective. The aim of this study was to evaluate, ex vivo, canal transportation and the centering ability of nickel-titanium rotary instruments manufactured by twisting and by traditional grinding, with the use of microscopic computerized tomography (μCT).

Study design. Fifteen mandibular molars were embedded in a rubber-based impression material and submitted to μCT before and after instrumentation. Images were reconstructed, and cross-sections corresponding to distances 1, 2, 3, 4, 5, 6, and 7 mm from the anatomic apex were selected for analysis. Statistical analysis was performed with Mann-Whitney test.

Results. Canal transportation and centering ability results were similar for both instruments. Statistically significant differences ($P < .05$) were observed only at the 3 and 4 mm cross-sections, with lower levels of apical transportation and a better centering ratio associated with twisted instruments than with ground instruments.

Conclusions. Our findings showed that twisted and ground instruments behaved similarly, allowing the preparation of curved canals with little transportation, which occurred in both mesial and distal directions. **(Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2011;112:e143-e148)**

Despite ongoing research aimed at consolidating a safe instrumentation technique, one that promotes effective cleaning and shaping and does not cause root canal transportation, the need to enlarge curved canals and at the same time preserve dental anatomy will always involve the challenge of selecting appropriate endodontic instruments. After the introduction of instruments manufactured from nickel-titanium alloys (NiTi)[1] there was a significant improvement of the quality of root canal shaping, with predictable results and less iatrogenic damage, even in severely curved root canals.[2] Moreover, in the past few years, important modifications to the design and manufacturing process of rotary instruments have been proposed with the aim of increasing their reliability, effectiveness, and safety.[2,3]

Instruments manufactured by twisting are based on a concept that differs completely from all other endodontic instruments currently available. By using a heating and cooling process (R-phase), the instruments are twisted and cutting flutes created.[4] According to the manufacturer, the heat treatment used, the twisting manufacturing process, and the advanced surface conditioning/deoxidation treatment to which the instruments are submitted significantly increase their flexibility and resistance to cyclic fatigue, allowing them to remain in a central position even in severely curved canals.[5]

Different methodologies have been used to assess the effects of different endodontic instruments on canal transportation. Classical in vitro methods of studying the morphologic characteristics of root canal systems either produce an irreversible change in the specimen or provide only a 2-dimensional projected image.[6,7]

Computerized tomography (CT) has been shown to be useful in endodontic evaluations, because it nondestructively measures the amount of dentin removed from root canal walls.[8-10] The major disadvantages of CT are low resolution and difficulties when assessing the effects of root canal instrumentation techniques in the apical third.[11]

In this scenario, special attention has been paid to microscopic CT (μCT), which allows both quantitative

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and qualitative assessments of the canal in 3 dimensions.[12-14] Although earlier studies have assessed twisted and ground instruments regarding cyclic fatigue and fracture,[5,15-17] there are no reports available in the literature describing canal transportation associated with these 2 types of instruments, assessed with the use of μCT.

Therefore, the aim of the present ex vivo study was to examine the effect of the different manufacturing methods (ground vs. twisted) on the amount and direction of root canal transportation and on the instruments' centering ability.

MATERIALS AND METHODS

The study protocol was approved by the Research Ethics Committee at the School of Dentistry, University of São Paulo (USP; protocol no. 161/2008), São Paulo, Brazil.

Fifteen mandibular molars with intact pulp chambers, fully formed roots, 2 mesial canals with independent foramina, severe curvature (25-35°),[18] and a curvature radius <10 mm[19] were selected from the human permanent tooth bank of the School of Dentistry at USP.

Tooth size was standardized at 18 mm by grinding the occlusal surfaces with a diamond disk (Buehler, IL, USA). After surgical access, the mesial canals were instrumented using K file sizes 10 and 15 (Maillefer, Ballaigues, Switzerland) until the tip of the file became visible at the apical foramen with the help of an operating microscope (Alliance, São Paulo, Brazil), at ×8 magnification. Working length was established 1.0 mm short of the distance measured on the K file.

Teeth were embedded in high-precision rubber-based (vinyl polysiloxane) impression material (Vigodent, Rio de Janeiro, Brazil), with the access cavities facing down, and were mounted on a holder with an internal diameter of 15 mm.[20] The negative replicas of the coronal structure and of the access cavity allowed for precise repositioning of the tooth on the holder for the acquisition of pre- and postoperative μCT scans.

Specimens were scanned with the use of an x-ray microtomograph (SkyScan 1172; Aartselaar, Belgium) at a voltage of 89 kV and a current of 112 μA, with a 0.5-mm aluminum filter. Cross-section radiographs were produced at a resolution of 11.84 μm, from multiple angle projections along 180 degree rotation, at every 0.4 degrees. Each specimen was scanned for a total of 45 minutes.

Pre- and postoperative distances were measured using the CTan software (SkyScan 1172). Axial sections corresponding to distances 1, 2, 3, 4, 5, 6, and 7 mm from the anatomic apex were selected (Fig. 1), and distances between the edges of uninstrumented canals and the root edges were measured in mesial and distal directions. After instrumentation, the same reference points were adopted for the acquisition of postoperative measurements (Fig. 2).

Root canal instrumentation

Before the use of the rotary systems, cervical interferences were removed with Gates-Glidden burs size 2 and 3 (Maillefer) in a crown-down movement, with a penetration depth of 3 mm, which corresponds to the head size of the Gates-Glidden bur size 3. Mesiobuccal canals were instrumented with the Twisted File system (TF group; SybronEndo, Orange, CA, USA), and mesiolingual canals were instrumented with the EndoSequence system (ES group; Brasseler, Savannah, GA, USA), using the crown-down technique according to the manufacturers' instructions. Instruments were used following a predetermined size/taper sequence (30/0.06, 25/0.06, and 25/0.04), coupled to an electric motor (X-Smart; Maillefer) at a constant speed of 500 rpm and no torque control.

Instruments were used 5 times and then discarded. At each instrument change, root canals were irrigated with 3 mL 1% sodium hypochlorite (Fórmula e Ação, São Paulo, Brazil). Final irrigation was conducted with 5 mL 17% EDTA (Fórmula e Ação), followed by 5 mL 1% sodium hypochlorite.

Canal transportation

Canal transportation was calculated in millimeters with the formula $[(X1 - X2) - (Y1 - Y2)]$, as described by Gambill et al.,[21] where X1 is the distance between the mesial portions of the root and the uninstrumented canal, X2 is the distance between the mesial portions of the root and the instrumented canal, Y1 is the distance between the distal portions of the root and the uninstrumented canal, and Y2 is the distance between the distal portions of the root and the instrumented canal (Fig. 2). Pre- and postoperative measurements were compared to reveal the presence or absence of deviations in canal anatomy and to identify the most affected region.

Centering ability

The centering ratio, which measures the ability of the instrument to remain in a central position within the canal, was calculated for each cross-section using the values obtained in the assessment of root canal transportation, using the ratio of $(X1 - X2)$ to $(Y1 - Y2)$.[21]

Whenever these numbers were not equal, the lower figure was considered to be the numerator of the ratio. According to this formula, a result of 1 indicates optimal centering ability.

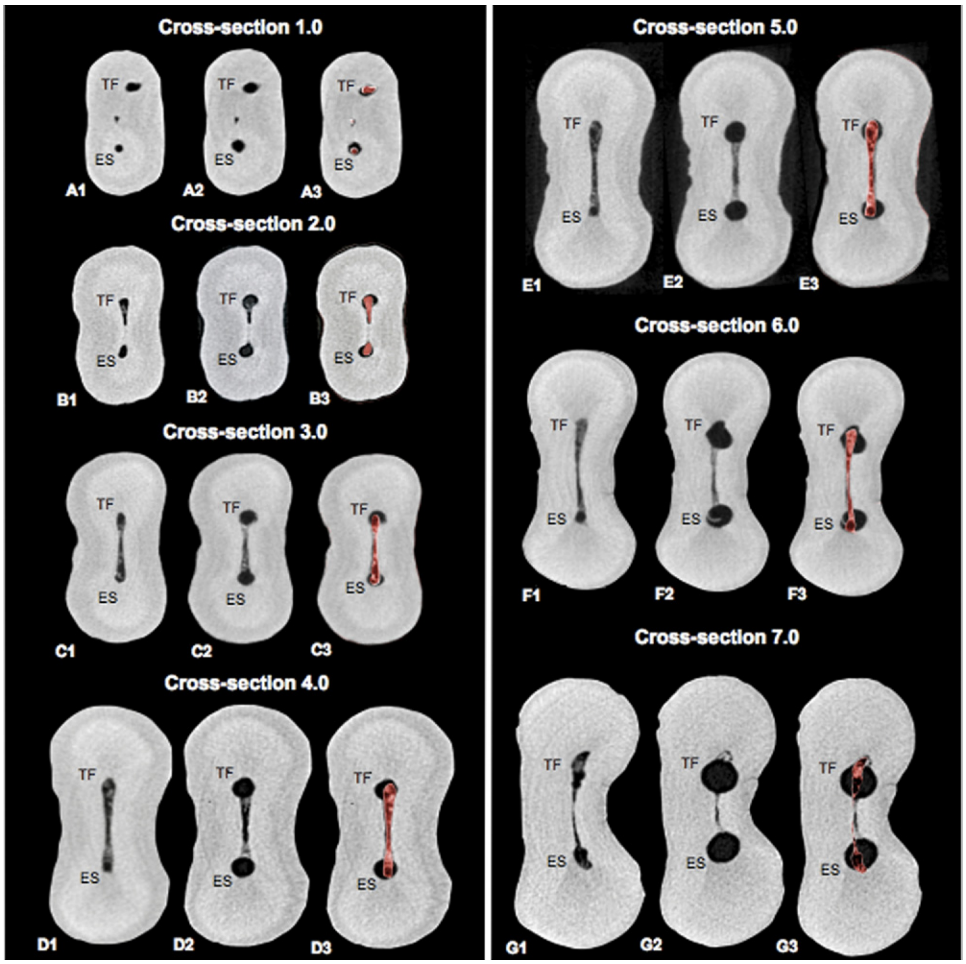

Fig. 1. Representative cross-sections of microscopic computerized tomography data 1, 2, 3, 4, 5, 6, and 7 mm (**A-G**, respectively) from the anatomic apex of root canals prepared with Twisted File (TF) and EndoSequence (ES) rotary files: (**1**) preoperative, (**2**) postoperative, and (**3**) superimposed cross-sections (*red*, preoperative).

Statistical analysis

Results obtained for the 2 groups were compared with the use of Mann-Whitney test ($P < .05$).

RESULTS

Table I shows the means ± SDs obtained for root canal transportation and centering ability in association with the TF and ES systems. Similar behavior was observed in the 2 groups, without significant differences when considering the sum of the cross-sections ($P = .0968$; Table I). Figure 1 shows representative images for each of the cross-section assessed.

In the analysis of each cross-section independently, the TF system was found to promote a significantly lower amount of canal transportation at cross-sections 3 mm ($P = .0155$) and 4 mm ($P = .0027$) compared with the ES system. Consequently, the TF system also obtained a higher centering ratio at cross-sections 3 mm ($P = .0244$) and 4 mm ($P = .0107$; Table I).

Regarding direction of root canal transportation, TF and ES presented canal transportation in both mesial and distal directions (Table II).

DISCUSSION

Literature focusing on the mechanical and chemical preparation of root canals consistently points to the importance of disinfection.[2,22] The need for canal enlargement, and at the same time the need to preserve root canal anatomy, represents a paradigm for clinicians and specialists: On the one hand, the wear commonly associated with the use of endodontic instruments should be controlled; on the other hand, contaminated dentin needs to be removed.[22]

Few studies so far have assessed root canal transportation results associated with twisted versus traditionally ground files.[9] The present study was therefore conducted to contribute to assess the performance of TF and ES rotary instruments regarding root canal transportation at

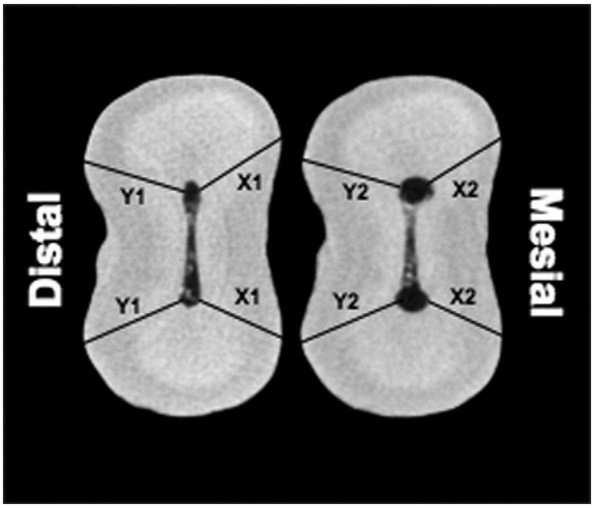

Fig. 2. Representative cross-section of microscopic computerized tomography data: X1 and X2 correspond to the distances between the mesial portions of the root and the uninstrumented and instrumented canal, respectively. Y1 and Y2 represent the distances between the distal portions of the root and the uninstrumented and instrumented canal, respectively.

distances 1, 2, 3, 4, 5, 6, and 7 mm from the anatomic apex, based on μCT analysis of curved canals.

According to the results obtained in the present study for root canal transportation and centering ability, both TF and ES rotary systems had a similar behavior and allowed the preparation of mesial canals of mandibular molars with little deviation.

Only cross-sections 3.0 and 4.0 mm showed a statistically significant difference between the groups, with the TF system promoting lower levels of transportation than the ES system, consequently leading to a better centering ratio. Probably these differences could be detected because at this point of the curvature there is a higher stress on the instrument owing to the critical changes on the relationship of diameter and flexibility. TF is manufactured by twisting NiTi wire, which possibly makes it more flexible than ground instruments and consequently causes less canal transportation.

Gergi et al.[9] had already reported less transportation associated with TF instruments compared with manual K files and with a combination of PathFile and ProTaper instruments, corroborating the findings of the present study. Although some authors have not found differences in canal transportation associated with manual versus continuous rotary preparation,[12,13] our findings are in accordance with several other studies which have shown the ability of rotary Ni-Ti instruments to stay centered in the canal with minimal risk of transportation.[8,9,22-25]

Some authors emphasize that several factors may affect the flexibility and performance of rotary instruments. López et al.[26] found an increased tendency toward canal transportation as the diameter of files increased. Kunert et al.[27] referred to taper as one of the main factors involved in apical transportation, and suggested that ProTaper Universal F3 and F4 should be used with care in the apical third of root canals owing to the taper of 9% along the apical 3 mm of F3 files, with diameters of 0.30 mm, 0.39 mm, and 0.48 mm. Moreover, according to Shäfer et al.,[28] NiTi files with tapers >0.06 should not be used for the apical enlargement of curved canals, because these files are considerably stiffer than those with 0.02 or 0.04 tapers. These results corroborate our findings, in the sense of recommending the use of NiTi instruments with a maximum taper of 0.04 for apical enlargement and emphasizing the importance of this procedure for adequate disinfection and preservation of the anatomical characteristics of the root canal.

The occurrence of up to 0.15 mm of canal transportation has been considered to be acceptable.[2] Conversely, canal transportation reaching above 0.30 mm may have a negative impact on apical seal after obturations, and it may escape the dental professional's attention, influencing the prognosis of endodontic treatment.[22] In the present study, none of the specimens presented transportation levels >0.16 mm. In fact, in 7.61% of the sections, the TF system yielded zero canal transportation, consequently achieving a centering ratio of 1. The same was observed in 3.80% of the sections prepared with the ES system. These low canal transportation results may be explained by the inherent characteristics of the instruments assessed, i.e., a small taper, which allows the file to stay centered in the root canal.

Nickel-titanium instruments from different manufacturers present distinct behavior as a result of their flexibility properties. Manufacturing processes change the phase constitution and transformation temperatures of the instruments and may also influence their flexibility.[3]

TF instruments present high flexibility and resistance to cyclic fatigue, especially as a result of their twisting manufacturing process, the heat treatment to which the instruments are submitted, and the special conditioning treatment applied to the surface of the instruments.[4,9] These characteristics were consistently described in the study of Gambarini et al.[5] These files also have a triangular cross section with constant tapers, noncutting tip, and a variable pitch that alleviates the "pull-in" effect when the file is shaping the canal.

ES instruments have a precision tip, which is defined as a noncutting tip that becomes fully engaged after 1 mm, an active cutting triangular cross-section without lands, variable pitch, and variable helical angles. Its design also incorporates a unique "alternating contact point" geometry, which, according to the manufacturer, enables the instrument to remain centered in the canal,

Table I. Canal transportation and centering ability associated with Twisted File (TF) and EndoSequence (ES) systems considering each cross-section and the whole root canal (mean ± SD)

	Canal transportation			*Centering ability*		
Cross-section	*TF*	*ES*	*P value*	*TF*	*ES*	*P value*
1.0 mm	0.03 ± 0.02	0.03 ± 0.01	.3937	0.61 ± 0.19	0.62 ± 0.12	.3167
2.0 mm	0.06 ± 0.05	0.03 ± 0.03	.0823	0.43 ± 0.31	0.60 ± 0.30	.0762
3.0 mm	0.04 ± 0.03	0.07 ± 0.04	.0155*	0.63 ± 0.27	0.42 ± 0.28	.0244*
4.0 mm	0.03 ± 0.04	0.06 ± 0.02	.0027*	0.67 ± 0.30	0.47 ± 0.18	.0107*
5.0 mm	0.06 ± 0.03	0.05 ± 0.04	.2807	0.49 ± 0.21	0.58 ± 0.32	.2404
6.0 mm	0.05 ± 0.03	0.06 ± 0.02	.0704	0.57 ± 0.18	0.49 ± 0.24	.1106
7.0 mm	0.06 ± 0.04	0.05 ± 0.03	.4917	0.50 ± 0.24	0.59 ± 0.23	.1415
Total	0.05 ± 0.01	0.05 ± 0.01	.0968	0.56 ± 0.09	0.54 ± 0.08	.2110

*Significant difference, Mann-Whitney test.

Table II. Frequency and direction of root canal transportation associated with Twisted File (TF) and EndoSequence (ES) systems considering each cross-section and the whole root canal, n (%)

	TF			*ES*		
Cross-section	*Mesial*	*Distal*	*None*	*Mesial*	*Distal*	*None*
1.0 mm	15 (100)	0 (0)	0 (0)	15 (100)	0 (0)	0 (0)
2.0 mm	8 (53.33)	5 (33.33)	2 (13.33)	6 (40)	7 (46.66)	2 (13.33)
3.0 mm	9 (60)	3 (20)	3 (20)	13 (86.66)	1 (6.66)	1 (6.66)
4.0 mm	7 (46.66)	6 (40)	2 (13.33)	11 (73.33)	4 (26.66)	0 (0)
5.0 mm	8 (53.33)	7 (46.66)	0 (0)	5 (33.33)	9 (60)	1 (6.66)
6.0 mm	1 (6.66)	14 (93.33)	0 (0)	0 (0)	15 (100)	0 (0)
7.0 mm	2 (13.33)	13 (86.66)	1 (6.66)	0 (0)	15 (100)	0 (0)
Total	50 (47.61)	47 (44.76)	8 (7.61)	50 (47.61)	51 (48.57)	4 (3.80)

thus preventing apical transportation.[29] The results of the present study are in line with those reported by Karabucak et al.,[30] who also assessed ES files and recommended their use in root canal instrumentation.

Some methodologic characteristics of our study may have contributed to the adequate centering ability shown by the instruments assessed. Among such characteristics, it is possible to mention the previous enlargement of the canal entrances, the lower taper of instruments used in the apical third, and the use of a size 25 file for final apical third preparation in both groups.

Regarding the direction of root canal transportation, TF and ES instruments presented transportation toward both mesial and distal directions. However, a trend toward canal transportation toward the mesial direction was observed at the cross-sections located more apically. Peters et al.[13] also have shown that root canal transportation may present different directions. Several studies have suggested a predominance of transportation toward the outside of the curvature in apical regions as a result of the increased pressure exerted on this area when instruments are inserted in the apical third of a curved canal.[21,22]

The use of μCT for the examination of very small structures is well established, with important advantages compared with conventional tomography,[9,22,25] namely, higher magnification and significantly higher resolution.[11-14,20] μCT allows a complete and detailed analysis of the root canal in all planes.[31] One example of the advantages of μCT is described by Paqué et al.,[14] who studied apical geometry after root canal preparation using data available from earlier studies that had compared several rotary NiTi systems with the use of identical μCT-based methodologies. Sections with a thickness of 34-68 μm produced images of acceptable quality for the assessment of internal anatomy, once the changes observed along the long axis of the root canal occur gradually.[13] In the present study, μCT provided images at a resolution of 11.84 μm, proving to be an excellent method for the evaluation of the apical millimeters of instrumented root canals with very precise images.

CONCLUSION

Canal transportation occurred in both mesial and distal directions, but at levels that can be considered irrelevant in the clinical practice. TF and ES systems presented similar behavior regarding root canal transportation and centering ability and therefore can both be considered as adequate options for the preparation of curved canals, with minimal transportation.

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