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Comparison of centring ability and transportation between four nickel titanium instrumentation techniques by micro-computed tomography

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Abstract

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Aim To compare the centring ability and transportation of ProTaper Next (PTN), ProTaper Universal (PTU), Race 123 and RevoS using micro-computed tomography (μCT).

Methodology Sixty mesial root canals of thirty mandibular molars were divided virtually into coronal, middle and apical thirds, and two reproducible reference points were marked on the external surface of the roots creating 360 measurement points. Samples were randomly allocated to four NiTi instrumentation techniques. Group 1: PTU up to F2 ($n = 16$), group 2: PTN up to X2 ($n = 18$), group 3: Race 123 up to T2 ($n = 12$) and group 4: RevoS up to SU ($n = 14$). To reproduce a clinical situation, samples were prepared on a phantom head using a surgical operating microscope. Samples were scanned pre- and postoperatively using μCT to compare and calculate the transportation and centring ratio. The data were analysed using parametric statistics.

Results In the coronal and middle third of the root canals, there were significant differences in centring between PTN and PTU (coronal $P < 0.001$), PTN and RevoS (coronal $P < 0.001$), Race and PTU (coronal $P < 0.01$), Race and RevoS (coronal $P < 0.01$), PTN and RevoS (middle $P < 0.01$) and Race and RevoS ($P < 0.05$). Furthermore, there were significant differences in centring between PTN root canal preparations and other instruments in the apical third (PTN and PTU $P < 0.01$, PTN and Race $P < 0.001$, PTN and RevoS $P < 0.001$). In terms of transportation, in the coronal third, there was a significant difference between PTN and PTU ($P < 0.05$). However, there were no significant differences between the other instruments. In the middle third, significant differences were observed between PTN and PTU ($P < 0.05$), PTN and RevoS ($P < 0.05$), Race and PTU ($P < 0.05$) and Race and RevoS ($P < 0.05$). However, there were no significant differences between other systems. There was no significant difference in terms of transportation between the four systems in the apical third.

Conclusions ProTaper Next prepared more centred root canal shapes when compared with Race, PTU and RevoS. In the coronal and middle third of the root canals, the differences in centring between PTN and PTU/RevoS were significant. PTN root canal preparations were more centred than those achieved with all other instruments in the apical third.

Keywords: canal transportation, centring ratio, micro-CT, NiTi, ProTaper Next, RevoS.

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Introduction

The value of endodontic hand and rotary instruments in shaping and cleaning root canals, as an essential part of endodontic chemo-mechanical disinfection, is well established (Byström & Sundqvist 1981, Sjögren *et al.* 1990, Siqueira *et al.* 1999). However, inflexible instruments alter the original anatomy of the root canal that in turn has a negative impact on debridement and subsequent filling of the root canal system (Weine *et al.* 1975). In addition, significant anatomical alteration such as over-straightening may cause perforations and thus negatively influence the treatment outcome (Pettiette *et al.* 2001, Peters 2004, Bürklein & Schäfer 2013).

These limitations were partially addressed by flexible shape memory alloys (nickel titanium, NiTi) that were developed in the late 1950s and subsequently introduced in the field of endodontics in the 1980s (Wang *et al.* 1965, Walia *et al.* 1988). NiTi alloys are manufactured in different shapes, sizes, tapers and surface or structural, pre- or post-manufacturing treatments. However, not all NiTi instruments behave in the same manner when used in root canals of similar shape, size, length and curvature (Peters *et al.* 2001, Hata *et al.* 2002, Rödig *et al.* 2002, Yun & Kim 2003, Gergi *et al.* 2010, Bürklein *et al.* 2014). Furthermore, technological advances in metallurgy, cross-sectional instrument geometry designs and surface treatment may impact on their performance. Therefore, comparing new NiTi rotary files with the previous generation and analysing their intracanal behaviour, that is transportation and centring ability, may provide valuable information on their effectiveness during mechanical shaping and cleaning.

To establish the effectiveness of NiTi rotary instruments in respecting and maintaining the original anatomy of root canals and to measure the possible transportation produced, the use of micro-CT (μCT) imaging has been recommended (Rhodes *et al.* 1999, 2000, Moore *et al.* 2009). The three-dimensional images produced by μCT provide detailed information about the changes in the root canals postoperatively, which can be measured using programmed software and compared with the preoperative shapes to calculate the changes (Rhodes *et al.* 1999, Grande *et al.* 2012).

This study was designed to compare the centring ability and transportation of four different rotary instrumentation techniques using μCT to establish their efficacy in respecting and maintaining the root canal anatomy and creating fewer aberrations, thus enhancing shaping and cleaning of the root canal systems. The NiTi systems compared were ProTaper Universal (PTU, Dentsply Maillefer, Ballaigues, Switzerland), ProTaper Next (PTN, Dentsply Maillefer), Race 123 (FKG Dentaire SA, La Chaux-de-Fonds, Switzerland) and RevoS (Micro-Mega SA, Besançon, France). The instruments were chosen to compare the new generation of instruments with off-centre asymmetric rectangular cross-sectional design (PTN) and off-centre asymmetric triangular cross-sectional design (RevoS), which have been claimed to improve the flexibility and movement of the files inside root canals and reduce instrument fatigue (Basrani *et al.* 2011, Pereira *et al.* 2013), with the traditional symmetrical triangular designs of PTU and Race 123.

Materials and methods

Selection criteria and sample size

One hundred and eighty-four mandibular molars were collected from a pool of donated extracted teeth, anonymized for referring purposes and examined for inclusion. All teeth had been extracted for periodontal, orthodontic, endodontic or restorative reasons.

A strict selection criterion was implemented in order to obtain realistic, identical and comparable samples for the experiment as described by Stern *et al.* (2012).

The extracted human mandibular teeth had mature apices and intact, or partially intact but restorable, crowns in the mesial aspect. The teeth were inspected under a surgical operating microscope (G4, Global Surgical Corporation, St Louis, MO, USA), and teeth with fractured or cracked mesial roots were excluded.

Where necessary, necrotic pulp tissue was extirpated with barbed broaches (Mani, INC. Tochigi, Japan). Subsequently, patency was confirmed with size 08 stainless steel K-Flexofiles (Dentsply Maillefer). Teeth with large root canal diameters, where the 08 file was judged to be loose, were excluded.

Periapical (PA) radiographs using a beam aiming device were taken to assess root canal morphology. Only teeth with two separate mesial root canals with a curvature of 20–45° (Schneider 1971) were included.

As a result, 30 mandibular molars were selected, with two mesial root canals per molar tooth, giving rise to 60 root canals. Each root canal was divided virtually into three sections: coronal, middle and apical thirds. Two reproducible and equidistant points in each section were subsequently marked for transportation and centring measurements by micro-computed tomography (μCT). This arrangement provided 360 points for overall analysis.

Tooth preparation

HiDi 501 diamond burs (Dentsply Ash, Weybridge, UK) and Endo-Z burs (Dentsply Maillefer) were used for preliminary access cavity preparations.

Six small 'reference' grooves were made on the external surface of the roots using HiDi 520 and 720 round diamond burs (Dentsply Ash). These reproducible reference points had been marked at levels 2.0, 4.0, 6.0, 8.0, 10.0 and 12.0 mm from the apices of the roots to facilitate superimposition and analysis of the μCT images obtained before and after instrumentation.

Micro-CT scanning

Samples (teeth) were randomly distributed into four groups. Each sample was scanned (GE Locus SP μCT Scanner, GE Pre-clinical imaging, London, ON, Canada) prior to and following root canal preparation utilizing similar parameters as described by Stern *et al.* (2012). Each tooth was secured in the scanner with a fixture, which allowed reproducible placement and scanning of each sample. The reconstructed images were subsequently handled with ImageJ software (Image processing and analysis in Java, Bethesda, MD, USA, imagej.nih.gov) for measurements and analysis of transportation and centring ratio.

Root canal preparation

For root canal preparation, teeth were fixed with putty in a mandibular jaw model (ModuPro Endo, Acadental, Overland Park, KS, USA) on a phantom head and prepared under a surgical operating microscope (G4, Global Surgical Corporation) to reproduce a clinical situation.

The investigator was trained and calibrated on 40 root canals using all four NiTi systems. A pilot study was carried out in order to test the preparation set-up, data collection and scanning parameters and implement necessary changes, using the first eight samples, which were equally distributed between four groups ($n = 2$ per group). Adjustments were subsequently implemented in specimen assembly and measurement. These adjustments are outlined in the discussion.

The teeth were divided randomly between four groups and relevant data collected. The groups were as follows:

Group 1: ProTaper Universal PTU (Dentsply Maillefer) ($n = 8$).

Group 2: ProTaper Next PTN (Dentsply Maillefer) ($n = 9$).

Group 3: Race 123 (FKG Dentaire SA) ($n = 6$).

Group 4: RevoS (Micro-Mega SA) ($n = 7$).

All canals in each group were shaped using the manufacturer's guidelines. The 'F2' was the final file in group 1, 'X2' in group 2, 'T2' in group 3 and 'SU' in group 4. This led to an apical preparation size of 0.25 mm diameter for all roots in all groups and apical taper of 8% in group 1, 6% in groups 2 and 4 and 5% in group 3.

All root canals were irrigated in-between files with 0.5 mL of 1% sodium hypochlorite and recapitulated using size 10 hand stainless steel files.

The preparation sequences were as follows:

Group 1: PTU instruments were used in a crown-down manner at a speed of 300 rpm. S1 (size 17, apical taper 2%) at two-thirds of working length (WL), S1 at WL, S2 (size 20, apical taper 4%) at WL, F1 (size 20, apical taper 7%) at WL; F2 (size 25, apical taper 8%) at WL.

Group 2: PTN instruments were used in a crown-down fashion with brushing motion at a speed of 300 rpm. X1 (size 17, apical taper 4%) at WL, X2 (size 25, apical taper 6%) at WL.

Group 3: Race instruments were used in a gentle in-and-out motion with a light touch at a speed of 600 rpm. T1 (size 10, taper 6%) at half of WL, T1 to WL, T2 (size 25, taper 5%) at WL. The final file in the sequence (T3 size 35, taper 4%) was omitted to maintain the apical preparation size of 0.25 mm diameter for all roots in all groups.

Group 4: RevoS instruments were used in a gentle in-and-out motion using a crown-down approach at a speed of 300 rpm. SC1 (size 25, taper 6%) at two-thirds of WL, SC2 (size 25, taper 4%) at WL, SU (size 25, taper 6%) at WL.

Measurement of transportation and centring ratio

The reconstructed μCT images were rotated, where necessary, using ImageJ software to position the clinical crowns of the teeth parallel to the x-axis (horizontal) in order to measure canal transportation in the mesio-distal direction. The following formula, as described by Gambill *et al.* (1996), was used to determine transportation: $T = (M1 - M2) - (D1 - D2)$.

In this formula, M1 is the shortest distance from the mesial aspect of the root to the periphery of the uninstrumented canal. M2 is the shortest distance from the mesial aspect of the root to the periphery of the prepared canal. Similarly, D1 is the shortest distance from the distal aspect of the root to the periphery of the uninstrumented canal and the D2 is the shortest distance from the distal aspect of the root to the periphery of the prepared canal. Based on this formula, a $T = 0$ result indicates no transportation. A positive result ($T > 0$) indicates transportation towards the mesial (outer) aspect of the root. A negative ($T < 0$) indicates transportation towards the distal (furcal) aspect of the root.

Centring ability of different instruments was subsequently calculated using the following formula (Gambill *et al.* 1996):

$$C = (M1 - M2)/(D1 - D2) \text{ if } (D1 - D2) > (M1 - M2)$$

$$\text{or } C = (D1 - D2)/(M1 - M2) \text{ if } (M1/M2) > (D1 - D2)$$

A $C = 1$ result indicates perfect centring ability. However, the closer the result to zero, the worse the centring ability of the instrument.

Statistical analysis

Statistical analysis consisted of a general descriptive for continuous parameters (mean, standard deviation, range and median), which were differentiated by instrument system and position. Moreover, 95% confidence intervals were computed. Normality of involved response variables was tested by means of the Kolmogorov–Smirnov test ($P < 0.05$).

A generalized estimation equation model (GEE) was applied to evaluate differences by means of transportation (and centring ratio) by instrument system, canal number and measurement position. Wald's chi-square statistic was calculated for main effects and interactions, including a test of the hypothesis of no interaction, with multiple comparisons tests based on LSD criteria (least significance difference). The estimated model was selected for an unstructured correlation matrix that provided the best possible goodness-of-fit indicators (Akaike's criteria). The reference level of significance was set up to 5% ($\alpha = 0.05$). A test of the hypothesis of no interaction was carried out in the GEE model in order to demonstrate the dependence or independence of the results on the third of the canal in which measurements are undertaken.

Results

Canal transportation

The interaction between file system and position was significant (Wald's $\chi^2 = 20.7$, $P = 0.002$), indicating the dependence of the results in each third of the root canal.

In the coronal third, there was a significant difference in the mean degree of transportation between PTN and PTU files ($P < 0.05$), with PTN creating the smaller transportation. The mean difference in transportation between the other file systems was not significant. PTN and Race provided the closest means of transportation to zero (Figs 1 and 2).

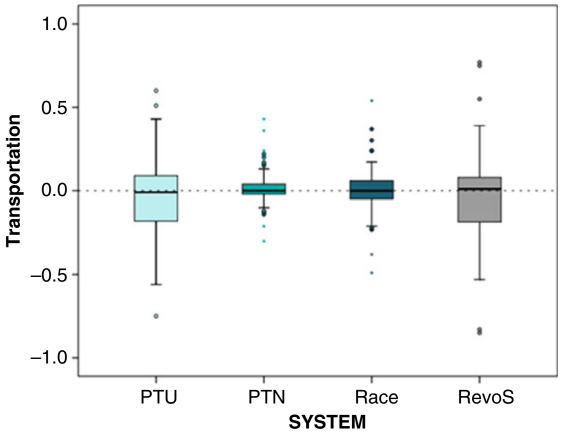

Figure 1 Box-and-whisker plot demonstrating the complete distribution of transportation values.

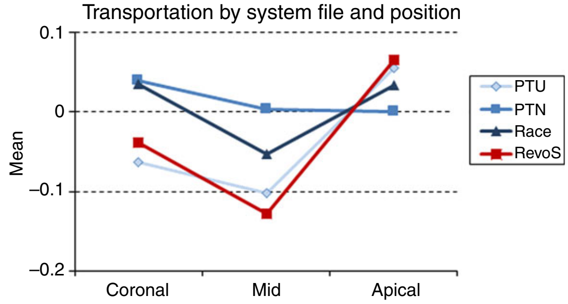

Figure 2 A line chart demonstrating the overall transportation by instrument system and position.

In the middle third, significant differences were observed between PTN and PTU files ($P < 0.05$), PTN and RevoS ($P < 0.05$), Race and PTU ($P < 0.05$) and Race and RevoS ($P < 0.05$) with the former file systems creating the smaller transportation. PTN provided the closest transportation to zero, but there was no significant difference between PTN and Race (Figs 1 and 2).

The mean difference in transportation between different file systems was not significant in the apical third. PTN provided the closest means to zero (Fig. 2).

Centring ratio

The interaction between file system and position was significant (Wald's $\chi^2 = 19.5$, $P = 0.003$). This result suggests the dependence of the results in each third of the root canal.

In the coronal third, PTN and Race provided significantly higher (closer to C = 1) centring ratios when compared with PTU and RevoS. The difference between the file systems PTN and PTU ($P < 0.001$), PTN and RevoS ($P < 0.001$), Race and PTU ($P < 0.01$) and Race and RevoS ($P < 0.01$) (Figs 3 and 4) was significant.

In the middle third, the only significant difference was observed when PTN and Race were compared with RevoS ($P < 0.01$ and $P < 0.05$, respectively) (Figs 3 and 4).

The difference in mean centring ratio in the apical third between PTN and other file systems [PTU ($P < 0.01$), Race ($P < 0.001$), RevoS ($P < 0.001$)] was significant. There was no significant difference between and within the PTU, Race and RevoS (Fig. 4).

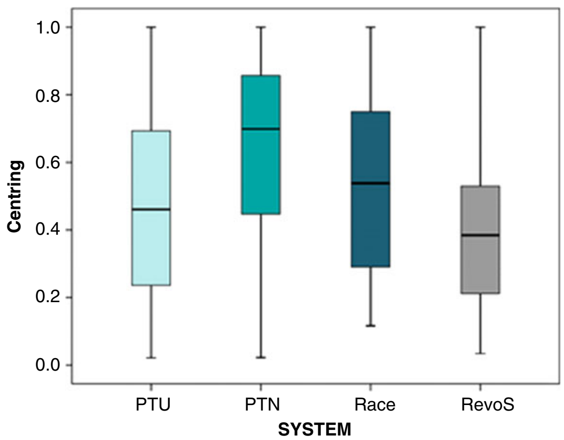

Figure 3 Box-and-whisker plot demonstrating the complete distribution of centring ratios.

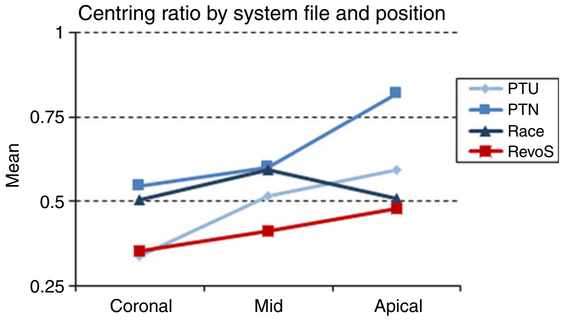

Figure 4 A line chart demonstrating the overall centring ratios by instrument system and position.

Discussion

The measurement of post-instrumentation root canal transportation and centring may reveal the efficacy of root canal instruments in maintaining the original root canal anatomy, reducing aberrations and ultimately facilitating the three-dimensional cleaning of the root canal walls. Clear visualization of root canal and root peripheries is essential for accurate analysis of these parameters. This could be achieved three-dimensionally with acceptable clarity using μCT (Rhodes *et al.* 2000, Hübscher *et al.* 2003, Peters *et al.* 2003, Stern *et al.* 2012). However, care must be taken to eliminate artefact-producing materials that can lead to beam hardening, scatter production and reduction in the accuracy of image reconstruction (Patel 2009).

In the present study, the specimens were mounted upside down so that the roots were not in contact with any fixatives or impression materials (Short *et al.* 1997, Peters *et al.* 2001, Capar *et al.* 2014). Furthermore, the addition of composite restorative material into the reference point grooves cut on the external root surface was identified to be unnecessary and therefore excluded (Stern *et al.* 2012, Alattar *et al.* 2015, Gergi *et al.* 2015). This set-up produced the most accurate and sharpest images of root peripheries when compared with other assemblies that were tested at the pilot phase of this project.

Root canal preparation for the analysis of transportation and centring *in vitro* and *ex vivo* should also resemble the clinical situation, in which the endodontic instruments will ultimately be used. This is especially crucial in terms of operator position in relation to the specimens, in order to provide meaningful results. Many bench-top, *in vitro* and *ex vivo* instrumentation studies either utilized mechanized jigs to standardize the preparations (Plotino *et al.* 2009) or were performed by operators under laboratory conditions with no clinical simulation (Hata *et al.* 2002). In addition, the instrumentation set-up, specimen assembly and operator position are rarely described. Although using jigs with plastic teeth or canals can standardize the endodontic hand-piece motion and instrument trajectory, which is beneficial in the analysis of endodontic instruments physical properties (Pedullá *et al.* 2013), it may not resemble a clinical situation in root canal morphology analysis such as transportation and centring. In the present study, all specimens were mounted in a mandibular jaw model of a phantom head and prepared using a surgical operating microscope to recreate the clinical setting.

Another factor that may influence transportation and centring results is the measurement of the root dentine thickness pre- and post-instrumentation. Gambill *et al.* (1996) described a formula for the analysis of transportation and centring ratio in the transverse (axial) plane, in which the direction of transportation was determined by measuring the shortest distance from the edge of the uninstrumented canal to the edge of the tooth in both mesial and distal directions and comparing it with the same measurements on the instrumented roots. These instructions were followed in the present study. However, during the pilot phase of the project it was observed that the direction of canal transportation did not always follow the description of the shortest distance from the canal wall to the mesial and distal periphery of the root as described by Gambill *et al.* (1996). This was particularly the case in 'oval' canals and in roots with curved mesial walls, where the root canals were transported across the minor axis of the oval (Figs 5 and 6). This was not always the shortest distance to the mesial and distal root periphery and was rarely perpendicular to the coronal (frontal) plane. This phenomenon is demonstrated in Figs 5 and 6 on axial μCT slices of middle third of mesial root of a mandibular first molar. The scan in Fig. 5 is illustrating the orientation of the middle third of the root, which is not perpendicular to the *x*-axis (coronal plane) in the lingual aspect (red oval and yellow arrow). The crown of this tooth and the coronal aspect of the root were parallel to the *x*-axis (coronal plane). The scan in Fig. 6 demonstrates the direction of transportation (yellow lines), which are not strictly perpendicular to the coronal plane and are not necessarily the shortest distance from the edges of the root canals to the root periphery.

This led to the proposal that root canal transportation in oval canals follows the direction of the minor axis of the canal mesially and distally, which may or may not be the shortest distance from the edge of the canal to the periphery of the root and may or may not be perpendicular to the coronal plane or the largest diameter of the root. The formula of Gambill *et al.* (1996) can still be used. However, the measurements should be adjusted to reflect the orientation of the minor axis of an oval canal.

The 'minor axis' theory was tested in all specimens, and the orientation of the transportation was always on the minor axis of the oval canals. This direction of transportation may be as a result of instrument shape, which engages the narrowest

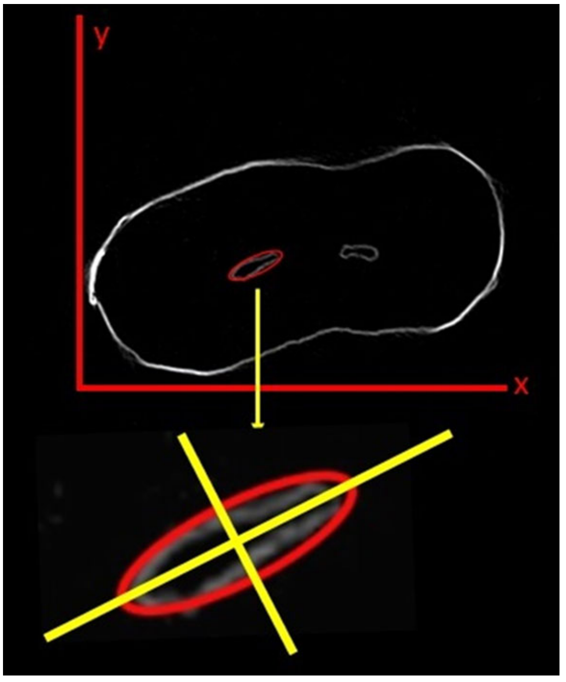

Figure 5 An axial μCT slice of middle third of mesial root of a mandibular first molar used as the first specimen in the pilot phase of the study. Image subtraction and edge identification have been utilized here using ImageJ software. Note the minor and major axes (yellow lines) in relation to the orientation of the lingual root canal and the overall orientation of the root. Compare the orientation of the lingual root canal (red oval) to the buccal root canal, which is parallel to the *x*-axis.

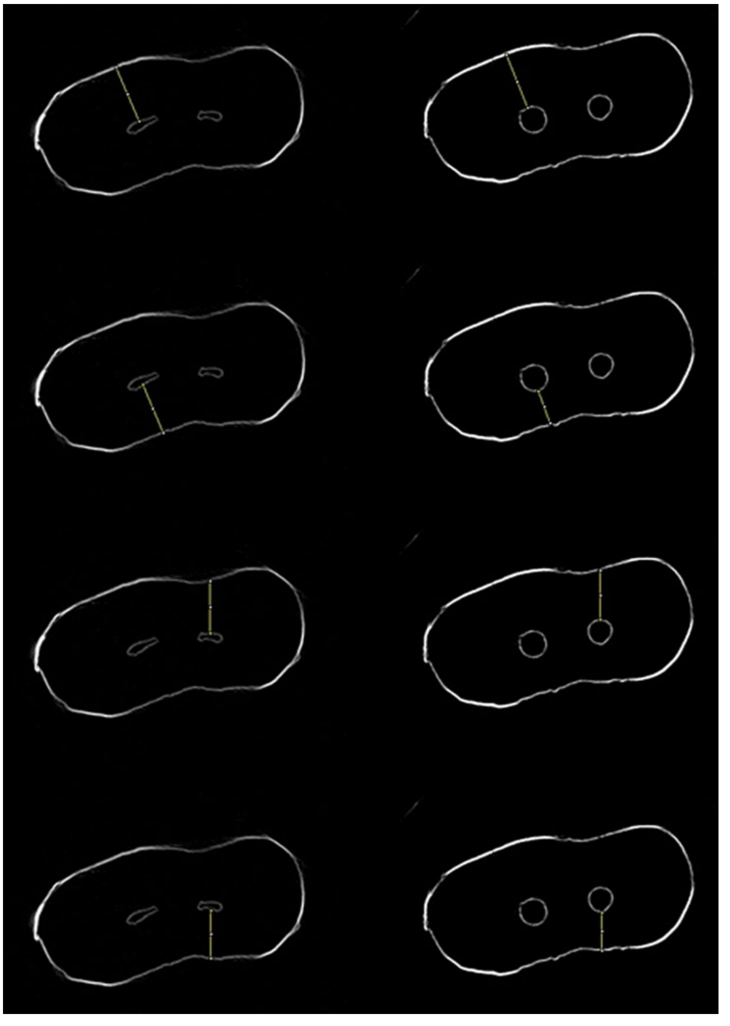

Figure 6 Axial μCT slice of the same tooth in Fig. 5, demonstrating the direction of transportation, which is on the minor axes of the lingual (left) and buccal (right) root canals. The axes of transportation have been marked by yellow lines.

point of the oval (minor axis), creating a pilot hole and guiding all subsequent larger instruments in the same direction.

This study compared the transportation and centring ability of four NiTi instrumentation techniques using μCT. The instruments were chosen to compare the new off-centre cross-sectional designs of PTN and RevoS with the traditional PTU and Race. The off-centre cross-sectional shape of the PTN and RevoS has been developed to reduce instrument fatigue and improve their cutting efficiency according to their respective manufacturers (Basrani *et al.* 2011, Pereira *et al.* 2013, Elnaghy 2014).

The comparison of transportation and centring ratios revealed that PTN respected the original root canal morphology more than the other files. ProTaper Next created more centred shapes with less canal straightening. This was closely followed by Race. RevoS straightened the root canals more than the other files. These results may be associated with the off-centre rectangular cross-sectional shape of the PTN, the variable taper of the files or a combination of these factors. In addition, specimen set-up, clinical preparation simulation and the use of 'minor axis theory' in the measurement of transportation may have contributed to the results.

The results are in agreement with observations made by other groups in terms of PTN transportation and centring when compared with PTU (Gagliardi *et al.* 2015, Wu *et al.* 2015).

Pasqualini *et al.* (2015) analysed canal centring ability and geometry modification of ProTaper Next and BioRace rotary instruments following rotary glide path preparation using μCT. They reported better preservation of root canal anatomy in the PTN group.

Bürklein *et al.* (2015) evaluated the transportation produced by PTN, PTU, BTRace and Mtwo rotary instruments using conventional radiographic films in curved canals prepared to a final apical size of 40. There were no significant differences between the file systems in terms of canal transportation. In a similar study using digital radiography, Saber *et al.* (2015) compared PTN, iRace and Hyflex CM and also found no significant difference in apical canal transportation between the files. In addition, Capar *et al.* (2014) also reported no significant difference when comparing CBCT images of root canal transportation caused by six different NiTi instrumentation techniques, PTN, PTU, WaveOne, Twisted File Adaptive, Reciproc and OneShape, to an apical size of 25. These studies may have demonstrated significant difference if more accurate imaging techniques had been utilized such as μCT scanning and evaluation. Furthermore, clinical simulation and the use of a phantom head assembly for the preparation of the specimens may have provided significant outcomes.

More transportation and centring studies using μCT for scanning and evaluation, minor axis for measurement and phantom head assembly for preparation of the teeth required with different NiTi file systems to streamline all previous studies in this field and make them directly comparable.

Conclusion

ProTaper Next prepared more centred root canal shapes when compared with Race, PTU and RevoS. In the coronal and middle third of the root canals, the differences in centring between PTN and PTU/RevoS were significant. PTN root canal preparations were more centred than those achieved with all other instruments in the apical third.

In terms of transportation, in the coronal third, PTN performed significantly better than PTU. However, there were no other significant differences between the other instruments. In the middle third, PTN and Race performed significantly better than PTU and RevoS. However, there were no other significant differences between other systems. There was no significant difference between the four systems in the apical third.

Specimen set-up, clinical simulation and accurate measurements may influence the analysis of transportation and centring. These parameters need to be carefully controlled in the future for meaningful data generation and system comparison.

Conflict of interest

Prof. Mannocci reports support from Dentsply Maillefer outside the submitted work. The other authors have stated explicitly that there are no conflict of interests in connection with this article.

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