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Shaping ability of ProTaper NEXT and BT-RaCe nickel–titanium instruments in severely curved root canals

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Abstract

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Aim To compare the shaping ability of four different nickel–titanium rotary instruments during the preparation of curved root canals in extracted teeth.

Methodology A total of 80 root canals with curvatures ranging between 25° and 39° were divided into four groups of 20 canals. Based on radiographs taken prior to instrumentation, the groups were balanced with respect to the angle and the radius of canal curvature. Canals were prepared to a final apical size of 40 using Mtwo, ProTaper Universal, ProTaper NEXT and BT-RaCe. Using pre- and post-instrumentation radiographs, straightening of the canal curvatures and canal transportation were determined with a computer image analysis programme. Preparation time and instrument failures were also recorded. The data were analysed statistically using ANOVA and Student–Newman–Keuls test.

Results The use of BT-RaCe files resulted in significantly more straightening during instrumentation compared to Mtwo ($P < 0.05$), whilst the differences between all other instruments were not significant ($P > 0.05$). No significant differences were obtained between all four instruments regarding canal transportation ($P = 0.429$). Instrumentation with ProTaper NEXT files was significantly faster than with all other instruments ($P < 0.05$). During the preparation of the curved canals, one BT2 instrument fractured, whilst no fracture occurred when using the other instruments ($P > 0.05$).

Conclusions Within the parameters of this study, all instruments maintained root canal curvature well and were safe. However, care should be taken when using the BT2 instrument due to its unique cylindrical design.

Keywords: canal curvature, canal straightening, Mtwo, M-wire, rotational speed.

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Introduction

The development of a modified nickel–titanium (NiTi) alloy, the M-wire NiTi, has led to the introduction of several innovative rotary NiTi instruments for root canal preparation [e.g. Reciproc (VDW, Munich, Germany), WaveOne and ProTaper NEXT (both Dentsply Maillefer, Ballaigues, Switzerland)] (Shen *et al.* 2013, Zhou *et al.* 2013). The M-wire alloy is a mixture of nearly equal amounts of R-phase (that is a pre-martensitic phase, thus an intermediate phase between austenitic and martensitic phase; Otsuka & Ren 2005) and austenite NiTi, whilst conventional superelastic NiTi has an austenite structure (Alapati *et al.* 2009, Gutmann & Gao 2012). M-wire NiTi contains substantial amounts of martensite that does not undergo phase transformation resulting in a metallurgical microstructure that exhibits alloy strengthening (Alapati *et al.* 2009). The metallurgical composition

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of M-wire is modified in comparison with austenite NiTi, as M-wire is a 508 NiTi alloy with a finer and homogenous alloy structure than austenite NiTi (Alapati *et al.* 2009, Zhou *et al.* 2013).

The recently introduced ProTaper NEXT instruments (Dentsply Maillefer) are made from M-wire. These instruments are characterized by an innovative off-centred rectangular cross section (Fig. 1) that is claimed to give the files a snake-like swaggering movement as it advances into the root canal (ProTaper Next: directions for use). The pitch length increases from the tip to the shaft (Fig. 2). This design feature may have an impact on the screwing effect, intraoperative torque values and the cleaning ability of the instruments (Paqué *et al.* 2005, Bürklein *et al.* 2011). ProTaper NEXT instruments are available in size 17, 0.04 taper; size 25, 0.06 taper; size 30, 0.07 taper; size 40, 0.06 taper; and size 50, 0.06 taper. However, it has to be taken into consideration that the given taper is not constant, but all files have a variable taper along their working part. The manufacturer recommends the creation of a glide path prior to canal preparation.

It is claimed that due to their specific design features, ProTaper NEXT instruments are best suited to prepare curved root canals. However, at the moment there is only limited information available regarding the shaping ability of this particular instrument.

Another recently introduced file, generated from conventional austenite NiTi, is the BT-RaCe instrument (FKG, La Chaux-de-Fonds, Switzerland). These files are characterized by a triangular cross section over the entire working part (Fig. 1) and the so-called 'booster tip' (BT-tip). This safety tip has six cutting edges and a reduced diameter (FKG: BT-RaCe, instructions for use). This design feature is claimed to facilitate progression of the instruments towards the apical part whilst maintaining the original canal curvature (FKG: BT-RaCe, instructions for use). BT-RaCe instruments are available in size 10, 0.06 taper; size 35, 0.00 taper; size 35, 0.04 taper; size 40, 0.04 taper; and size 50, 0.04 taper. The BT2 instrument has a unique design as this instrument with a tip size equivalent to ISO 35 is cylindrical; thus, this file is not tapered (Fig. 2). The instrument has a breaking point located 16 mm from the tip and is designed to allow preparation of the apical third of the canal. The manufacturer recommends the creation of a glide path up to at least size 15 with hand files prior to using BT-RaCe instruments. Up to now, there is limited information available regarding the shaping ability of BT-RaCe instruments.

The design features of Mtwo (VDW) and ProTaper Universal (Dentsply Maillefer) instruments, which were used as a control in this study, have been

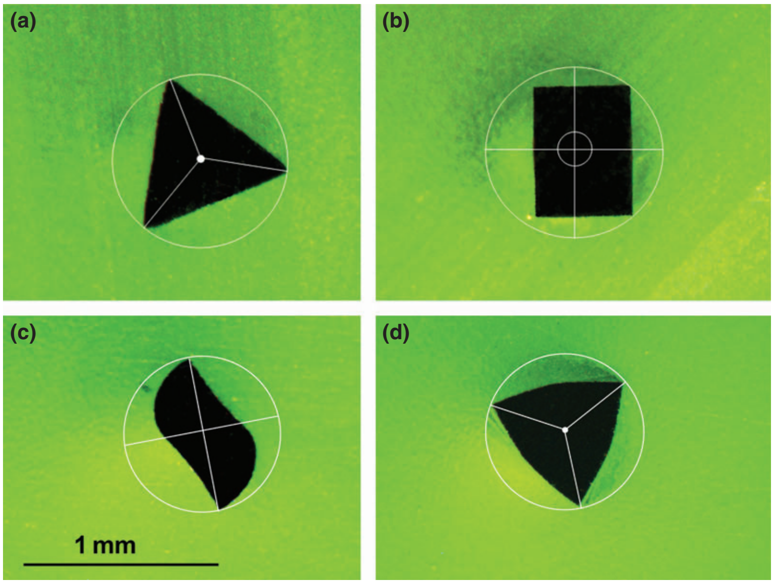

Figure 1 Cross sections of the tested instruments at the middle of the working part (original magnification ×60): (a) BT-RaCe; (b) ProTaper NEXT; (c) Mtwo; (d) ProTaper Universal.

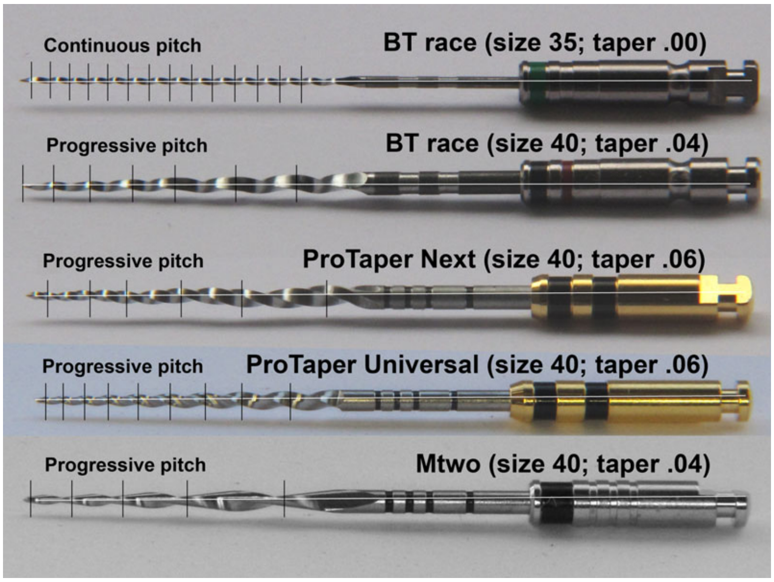

Figure 2 Comparison of the pitch lengths of the tested instruments (original magnification ×7). Whilst the BT2 instrument shows a constant pitch length, all other instruments are characterized by an increasing pitch length.

described in detail previously (Schäfer & Vlassis 2004, Paqué *et al.* 2005, Schäfer *et al.* 2006). In brief, Mtwo instruments are characterized by an S-shaped cross-sectional design with two cutting edges, and the pitch length increases from the tip to the shaft (Figs 1 and 2). ProTaper Universal instruments have a convex triangular crosssection (Fig. 1) and a flute design that combines multiple tapers within the shaft (Schäfer & Vlassis 2004, Paqué *et al.* 2005, Haapasalo & Shen 2013).

The null hypothesis tested was that there is no difference between the four rotary NiTi systems regarding canal straightening and canal transportation in severely curved root canals.

Materials and methods

Extracted teeth

A total of 80 extracted human teeth with at least one curved root and curved root canal were selected. Coronal access was achieved using diamond burs, and the canals were controlled for apical patency with a root canal instrument of size 10. Only teeth with intact root apices and whose root canal width near the terminus was approximately compatible with size 15 were included. This was checked with silver points sizes 15 and 20 (VDW).

Standardized radiographs were taken prior to instrumentation with the initial root canal instrument of size 15 inserted into the curved canal. The tooth was placed in a radiographic mount made of silicon-based impression material (Silaplast Futur; Detax, Ettlingen, Germany) to maintain a constant position. The radiographic mount compromised of a radiographic paralleling device embedded in acrylic resin. This device was attached to a Kodak Ultra-speed film (Kodak, Stuttgart, Germany) and was aligned so that the long axis of the root canal was parallel and as near as possible to the surface of the film. The X-ray tube, and thus the central X-ray beam, was aligned perpendicular to the root canal. The exposure time (0.12 s; 70 kV, 7 mA) was the same for all radiographs with a constant source-to-film distance of 50 cm and an object-to-film distance of 5 mm. The films were developed, fixed and dried in an automatic processor (Dürr-Dental XR 24 Nova; Dürr, Bietigheim-Bissingen, Germany).

The degree and the radius of canal curvature were determined using a computerized digital image processing system (Schäfer *et al.* 2002). Only teeth whose radii of curvature ranged between 4.0 and 9.0 mm and whose angles of curvature ranged between 25° and 39° were included (Table 1). On the basis of the degree and the radius of curvature, the

Table 1 Characteristics of curved root canals (n = 20 teeth per group)

Instrument	Curvature (°)			Radius (mm)			Distance apex-CEJ (mm)
	Mean ± SD	Min	Max	Mean ± SD	Min	Max	
Mtwo	32.2 ± 4.18	25	39	6.74 ± 1.22	4.0	9.0	13.3 ± 0.70
ProTaper Universal	32.0 ± 4.08	25	39	6.69 ± 1.21	4.1	8.7	13.2 ± 0.83
ProTaper NEXT	32.2 ± 4.10	25	39	6.70 ± 1.20	4.3	8.9	13.2 ± 1.01
BT-RaCe	32.1 ± 4.17	25	39	6.66 ± 1.25	4.7	9.0	13.2 ± 0.98
P-value (ANOVA)	0.913			0.837			0.903

teeth and the distance between the apex and the cemento-enamel junction were allocated into four similar groups of 20 teeth. The homogeneity of the four groups with respect to the aforementioned three parameters was assessed using analysis of variance (ANOVA) and *post hoc* Student–Newman–Keuls test (Table 1). At the end of canal preparation, the canal curvatures were redetermined on the basis of a radiograph with the final root canal instrument inserted into the canal using the same technique (Schäfer *et al.* 2002) to compare the initial curvatures with those after instrumentation. Only one canal was instrumented in each tooth.

A double-digital standardized radiographic technique was used to compare apical transportation between groups. Adobe Photoshop (Adobe Systems, San Jose, CA, USA) was used to superimpose post- and the corresponding pre-instrumentation image (Fig. 3). The central axes of the initial instrument of size 15 and the final instrument were superimposed. ImageJ software (National Institute of Health, public domain) was used to measure apical transportation at 0.5 mm short of the working length.

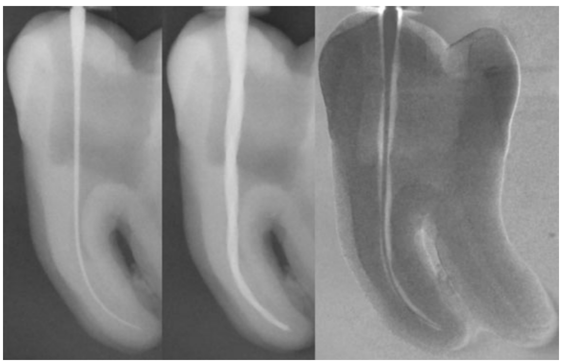

Figure 3 Representative preoperative, postoperative and superimposed pre- and postoperative images of curved root canals prepared with ProTaper NEXT.

Root canal instrumentation

The working length was obtained by measuring the length of a size 10 instrument at the major apical foramen minus 1 mm. During instrumentation the root canal was flushed with 2 mL of a 2.5% NaOCl solution after each instrument and at the end of instrumentation with 5 mL of NaCl using a plastic syringe with a 30-gauge needle (NaviTip; Ultradent, South Jordan, UT, USA). The needle was inserted as deep as possible into the root canal without binding. Apical patency was maintained using a size 10 K-file (VDW). Instrumentation was performed by a single operator experienced in the use of the tested instruments. All instruments were used in a gentle in-and-out pecking motion with an amplitude of <3 mm. The flutes of the instruments were cleaned after three in-and-out-movements (pecks).

All instruments were set into permanent rotation with a 6 : 1 contra-angle handpiece (Sirona, Bensheim, Germany) according to the manufacturers' instructions using the settings in the library of the electronic motor (VDW silver RECIPROC, VDW) or by programming the recommended torque and rotational speed settings manually. The preparation sequences were as follows:

Group A: All Mtwo instruments were used to the full length of the canals (single-length technique). The instrumentation sequence was as follows: size 10, 0.04 taper; size 15, 0.05 taper; size 20, 0.06 taper; size 25, 0.06 taper; size 30, 0.05 taper; size 35, 0.04 taper; and size 40, 0.04 taper instruments.

Group B: The ProTaper Universal instruments were used according to the crown-down approach. The instrumentation sequence was as follows: SX at two-third of working length (WL); S1 (size 17, taper 0.02–0.11) at WL – 1 mm; S2 (size 20, taper 0.04-0.115) at WL – 1 mm; F1 (size 20, taper 0.055–0.07) at WL; F2 (size 25, taper 0.055–0.08) at WL; F3 (size 30, taper 0.05–0.09) at WL; and F4 (size 40; taper 0.06) at WL.

Group C: All ProTaper NEXT instruments were used with a rotational speed of 300 rpm, and the torque was adjusted to 2.0 Ncm. All instruments were used to full working length. The instrumentation sequence was as follows: ×1 (size 17, 0.04 taper); ×2 (size 26, 0.06 taper); ×3 (size 30, 0.07 taper); and ×4 (size 40, 0.06 taper) instruments.

Group D: All BT-RaCe instruments were used with a rotational speed of 800 rpm, and the torque was adjusted to 1.5 Ncm. All instruments were used to full working length. The instrumentation sequence was as follows: BT1 (size 10, 0.06 taper); BT2 (size 36, 0.00 taper); BT3 (size 35, 0.04 taper); and BT4 (size 40, 0.04 taper) instruments.

In each of these four test groups, 20 canals were enlarged. Thus, a total of 80 canals were prepared. Instruments were used to instrument four canals only.

Evaluations

All root canal preparations were completed by one operator, whilst the assessments of the canal curvatures prior to and after instrumentation were carried out by a second examiner who was blind in respect of all experimental groups. The time for canal preparation was also recorded and included total active instrumentation, instrument changes within the sequence, cleaning of the flutes of the instruments and irrigation.

Analysis of variance (ANOVA) and *post hoc* Student–Newman–Keuls test were used for comparisons of the different groups regarding canal straightening, canal transportation and preparation time as these data were distributed normally (Kolmogorov–Smirnov test). The level of statistical significance was set at $P < 0.05$. The number of fractured instruments during enlargement was also recorded and statistically analysed using the chi-square test.

Results

During the preparation of the curved canals, one BT2 instrument fractured, whilst no fracture occurred when using the other instruments. This difference was not significant ($P > 0.05$). No deformation of instruments was noted.

The mean time taken to prepare the canals with the different instruments is shown in Table 2. Instrumentation with ProTaper NEXT files was significantly faster than with all other instruments ($P < 0.05$).

Table 2 Mean preparation time (s) and SD with the different instruments

Instrument	Mean	SD
Mtwo	188.6[b]	14.7
ProTaper Universal	178.3[b]	19.2
ProTaper NEXT	143.2[a]	9.2
BT-RaCe	171.3[b]	23.5

Values with the same superscript letters were not statistically different at $P = 0.05$.

All canals remained patent following instrumentation, and thus, none of the canals were blocked with dentine. With all instruments, no canal had overextension of preparation and loss of working length of about 1 mm was noted in two canals prepared with BT-RaCe ($P > 0.05$). Using BT-RaCe, three ledges were created, whilst Mtwo and ProTaper NEXT created one and ProTaper Universal two ledges. These differences were not statistically significant ($P > 0.05$).

The mean straightening of the curved canals and the mean canal transportation are shown in Tables 3 and 4. Mean canal straightening ranged between 1.08° (Mtwo) and 2.64° (BT-RaCe). The use of BT-RaCe files resulted in significantly more straightening during instrumentation compared to Mtwo

Table 3 Mean degree of straightening of curved canals (°) and SD after canal preparation with the different instruments ($n = 20$ canals in each group)

	Straightening (°)			
Instrument	Mean	SD	Min	Max
Mtwo	1.08[a]	0.98	0	5
ProTaper Universal	1.28	1.06	0	4
ProTaper NEXT	1.59	1.19	0	6
BT-RaCe	2.64[b]	2.01	0	8

Values with the same superscript letters were not statistically different at $P = 0.05$.

Table 4 Mean transportation of curved canals (mm) and SD after canal preparation with the different instruments ($n = 20$ canals in each group)

	Transportation (mm)			
Instrument	Mean	SD	Min	Max
Mtwo	0.07	0.04	0	0.22
ProTaper Universal	0.07	0.04	0	0.29
ProTaper NEXT	0.08	0.04	0	0.25
BT-RaCe	0.12	0.08	0	0.40

The means were not statistically different ($P = 0.429$).

($P < 0.05$), whilst the differences between all other instruments were not statistically significant ($P > 0.05$). Mean canal transportation ranged between 0.07 mm (Mtwo and ProTaper Universal) and 0.12 mm (BT-RaCe). No significant differences were obtained between all four instruments regarding canal transportation ($P = 0.429$).

Discussion

The aim of this study was to assess and compare the shaping ability of two novel rotary NiTi systems, ProTaper NEXT and BT-RaCe with the ProTaper Universal and Mtwo systems in severely curved root canals of extracted human molar teeth. ProTaper Universal and Mtwo were included in this study as a control to ensure reliability of the results. The results obtained for Mtwo and ProTaper Universal in the present investigation were comparable in terms of canal straightening and preparation time with those of previous studies conducted under similar experimental conditions (Schäfer & Vlassis 2004, Bürklein *et al.* 2011, 2012) and with previous studies using different experimental setups (Peters *et al.* 2003, Sonntag *et al.* 2007, Çelik *et al.* 2013).

Despite the variations in the morphology of natural teeth, attempts were made in the present study to ensure comparability of the experimental groups. Therefore, the teeth in all groups were balanced with respect to the apical diameter and the length (distance between apex and CEJ) of the root canal, and based on the initial radiograph, the teeth were also balanced with respect to the angle and the radius of canal curvature. The homogeneity of the four groups with respect to the defined constraints was examined using analysis of variance (ANOVA) and *post hoc* Student–Newman–Keuls test. According to the *P*-values obtained (Table 1), the groups were well balanced. The curvatures of all root canals ranged between 25° and 39° and the radii ranged between 4.0 and 9.0 mm (Table 1). These curvatures and radii were well in the range of the values report in previous studies, thereby ensuring reliable comparison with the results obtained in other investigations conducted under similar experimental conditions (Schäfer & Vlassis 2004, Bürklein *et al.* 2011, 2012, Saber *et al.* 2014).

The final apical preparation was set to size 40 in each group to ensure comparability between the groups. Prior to instrumentation of the curved canals, no glide path was created as all root canals had a canal diameter which was compatible with size 15. This was one inclusion criterion when selecting the teeth and was check with silver points sizes 15 and 20. Thus, the recommendation of the manufacturers that a glide path of at least size 15 should be established prior to rotary instrumentation was taken into consideration during this study.

Preparation time is dependent on the technique and the numbers of instruments used, the operator experience and on further details of the study design (Hülsmann *et al.* 2005). In the present study, the preparation time included active instrumentation as well as the time required for changing instruments, cleaning the flutes of the instruments and irrigation to allow comparison of the results with those of previous studies conducted with an identical experimental set-up (Bürklein & Schäfer 2006, Schäfer *et al.* 2006, Bürklein *et al.* 2012). ProTaper NEXT instruments were found to require significantly less time to prepare the canals compared with all other instruments (Table 2). This difference is mainly due to the fact that the Mtwo and the ProTaper Universal system, as used in this investigation, consisted of seven instruments to prepare the root canal to a size 40, whilst only four instruments were used for ProTaper NEXT. However, the BT-RaCe system, as used in this study, consisted also of four instruments, but required significantly more time to prepare the canals than ProTaper NEXT. It can be speculated that this may be due to the fact that the BT2 instrument is designed only for the enlargement of the apical third of the canal. Moreover, this instrument is cylindrical and should therefore be used in a very delicate and gentle pecking motion. Furthermore, it can be assumed that the cylindrical BT2 instrument possesses a lower buckling resistance than a tapered instrument of the same tip size, thus making progression of the instrument towards the apex more time-consuming. This aspect warrants further investigation. In summary, although significant differences regarding preparation time were obtained, from a clinical point of view these differences are of limited importance.

The results of the present study revealed that the use of Mtwo instruments resulted in significantly less canal straightening than the use of BT-RaCe ($P < 0.05$). However, regarding canal transportation, no significant difference between these two instruments was noted ($P > 0.05$). In general, all four instruments maintained the original canal curvature well, as no further significant differences in terms of canal straightening and canal transportation were obtained ($P > 0.05$). Thus, from a clinical point of view, the difference between Mtwo and BT-RaCe is of limited importance. Taking into account that severely curved canals were instrumented, the clinical relevance of a maximum difference in canal straightening of mere 1.56° caused by these two instruments remains questionable.

The results regarding canal straightening and canal transportation of ProTaper NEXT instruments were comparable to the results obtained with Mtwo and ProTaper Universal. The present findings corroborate those of a recent evaluation of mesial canals in extracted mandibular first molars (Saber *et al.* 2014). In the latter study, ProTaper NEXT instruments prepared 25°–39°-curved canals up to an apical size of 30 without significant shaping errors and no instrument fractured during this study (Saber *et al.* 2014). It is interesting to notice that in the present study equally curved canals were prepared even up to size 40 without an increased risk of canal straightening or canal transportation when comparing the results of Saber *et al.* (2014) with the present ones.

Regarding the shaping ability of BT-RaCe instruments, the present results cannot be compared with other published results as currently further studies on the preparation of curved canals with these instruments are not available. However, the results are well within the range of published data for precursor or similar systems of the same manufacturer such as RaCe (Schäfer & Vlassis 2004, Oliveira *et al.* 2009, Garcia *et al.* 2012, Leonardi *et al.* 2013, Ceyhanli *et al.* 2014), Bio-RaCe (Nabavizadeh *et al.* 2014), Bio-RaCe in combination with S-Apex (Bonaccorso *et al.* 2009) and iRaCe (Saber *et al.* 2014).

During the present study, no Mtwo, ProTaper Universal or ProTaper NEXT instrument fractured. All instruments were used to enlarge four curved canals (Bürklein & Schäfer 2006, Bürklein *et al.* 2011). However, one BT-RaCe instrument (BT2) fractured in the apical third of the curved canal. Thus, the pre-determined breaking point created by the manufacturer at 16 mm from the tip seems not to be a reliable safety feature to prevent instrument fracture in the apical part of root canals. This observation may be explained by the special design of this particular instrument. The BT2 file is not tapered as the working part is cylindrical, and it has a constant pitch length (Fig. 2). It is reasonable to assume that this cylindrical file possesses a lower resistance to buckling compared with tapered instrument of the same tip size. Instruments that have a low resistance to buckling may develop elastic or plastic deformation that impedes their apical progression (Lopes *et al.* 2012, 2014). As the BT-RaCe instruments are used with a comparatively high rotational speed of 800 rpm, the tip region of the instrument is prone to fracture when this part of the instrument is deformed inside the root canal. Furthermore, the deformation of the tip region of the file inside the root canal may explain another observation of this study. Of the three ledges created with BT-RaCe instruments, two were caused by the BT2 instrument. Thus, it can be speculated that the deformation of the tip region of the instruments hinders the file to progress apically, and this may initiated ledge formation at the outer aspect of the curved canal in the apical part. Certainly, these assumptions warrant further investigations.

Conclusions

According to the results of the present investigation, the null hypothesis was accepted as the use of the four NiTi instruments resulted in similar canal transportation and canal straightening.

Within the parameters of this study, all instruments maintained root canal curvature well and were safe. However, care should be taken when using the BT2 instrument due to its unique cylindrical design. Instrumentation with ProTaper NEXT files as used in the present study was significantly faster than with all other instruments.

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