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Effect of nickel-titanium alloys on root canal preparation and on mechanical properties of rotary instruments

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Abstract: The aim of this study was to evaluate the quality of curved root canal preparation, torsional fatigue, and cyclic fatigue of rotary systems manufactured with different NiTi alloys. Ninety single-rooted canals with curvatures of 15° to 30º were scanned and divided into three groups according to the rotary system used: BT-Race (BTR) – 10.06, 35.00, 35.04; SequenceRotaryFile (SRF) – 15.04, 25.06, 35.04; and ProDesignLogic (PDL) – 25.01, 25.06, 35.05. Each system was used on three specimens. The teeth were prepared, scanned, and analyzed to assess increase in volume, transportation, and centering ability of the root canal. Torsional fatigue of glide path instruments (BTR 10.06, SRF 15.04 and PDL 25.01) and cyclic fatigue of the finishing instrument (BTR 35.04, SRF 35.04 and PDL 35.05) were obtained by analyzing completely new instruments (n = 10) and instruments after they had been used three times (n = 10). After the torsional and cyclic fatigue tests, the fractured surface of the new and used instruments were examined by scanning electron microscopy. Increase in volume, canal transportation, and centering ability showed no significant differences among the groups ($p > 0.05$). The torsional test showed that SRF 15.04 produced the highest torque values for both new and used instruments, followed by PDL 25.01 and BTR 10.06 ($p < 0.05$). PDL 25.01, both new and used, exhibited higher values of angular deflection followed by SRF 15.04 and BTR 10.06 ($p < 0.05$). As regards cyclic fatigue, use of PDL 35.05, both new and used, required a longer time and larger number of cycles than did SRF 35.04 and BTR 35.04 ($p < 0.05$). Clinical use affected the torsional fatigue of BTR; however, cyclic fatigue was not significantly affected ($p < 0.05$). All rotary systems were able to prepare the curved canals satisfactorily and were used safely on the three specimens. Relative to torsional fatigue, SRF 15.04 exhibited a higher torque, and PDL 25.01, higher angular deflection. BTR 10.06 was the most affected by clinical use. PDL 35.05 showed greater resistance to cyclic fatigue.

Keywords: Endodontics; Dental Instruments; Root Canal Preparation; X-Ray Microtomography.

Introduction

In recent years, several modifications in alloys and in the design of nickel-titanium (NiTi) instruments have been made to improve their performance, with special reference to instruments used in curved canals. These modifications prevent canal transportation and instrument fractures, which could compromise the success of endodontic treatment.[1,2]

During root canal preparation, procedures are performed in successive steps, with the use of instruments for different purposes. One of these purposes is to create a glide path, a trajectory that leads from the canal entrance to the apical foramen.[3,4] Nowadays, several rotary systems have specific files for this step. However, because they are used at the beginning of the procedure, these instruments are more prone to torsional stresses.[4,5] Torsional stress occurs when the tip of the instrument becomes locked into the dentin wall as the shaft continues to rotate until fracture occurs.[6,7]

After glide path preparation, another important step in endodontic treatment begins: root canal enlargement. This step becomes even more challenging when the tooth has a curved canal, because at the maximum bending point of the instrument, it is subjected to tensile/compressive forces. If these forces, which are cumulative, exceed the maximum value the instrument can withstand, the instrument will fracture because of cyclic fatigue.[6,7] Considering the foregoing factors, several instruments have been introduced in the market, such as BT-RaCe (FKG Dentaire, La Chaux-de-Fonds, Switzerland). This is a rotary system with a new – booster tip – design which, according to the manufacturer, facilitates advancement of the instrument and reduces the risks of canal transportation, thereby improving centering ability. Furthermore, this system is made of a conventional NiTi alloy that has been subjected to electrochemical and thermal surface treatment. The BT-RaCe system has a glide path instrument with size 10.06 and two instruments for canal preparation with size 35.00 and size 35.04.[8-10]

Another rotary system, the Sequence Rotary File (MKLife, Porto Alegre, Brazil), has been recently introduced in the market, offering heat-treated instruments manufactured with Blue technology. With a cross section and an inactive guide, this system presents certain similarity to Vortex Blue. This system consists of a glide path with file size 15.04 and three shaping instruments with size 20.06, size 25.06, and size 35.04. Except for instrument 15.04, which has a quadrangular cross section, the other instruments have a convex triangular cross section. However, to the best of our our knowledge, there are no studies in the literature evaluating this system.

ProDesign Logic (Easy Dental Equipment, Belo Horizonte, MG, Brazil), a continuous rotary system, is manufactured of NiTi with controlled memory (CM). In the United States, the system is sold as Bassi Logic. This system has a glide path instrument with size 25.01, quadrangular section, and instruments for canal preparation with size 25.06 and size 35.05, with an S-shaped cross section.[11,12]

Several studies have investigated new instruments made available by different systems[1-5,7] without evaluating the interference of dentin, exposure to the irrigation solution, and steam sterilization procedures accomplished in an autoclave. In addition, the literature shows the possibility of reusing instruments,[13,14] however, the extent to which clinical use affects NiTi instruments and their mechanical properties is not known.

Cyclic fatigue is typically evaluated by testing smaller diameter instruments.[7] Nonetheless, the literature has shown improved characteristics of biomechanical preparation when wider enlargement of the root canals is performed.[15-17] Therefore, the aim of this study was based on the importance of elucidating which system would be safer for use in the instrumentation of curved canals. Specifically considering the scarcity of evidence on the above-mentioned aspect of safety, the aim was to evaluate the quality of preparation performed with SRF, BT-Race, and PDL systems, and the extent of cyclic fatigue of instruments with larger diameters. Consequently, the quality of the preparation of curved canals, torsional fatigue of glide path instruments, and cyclic fatigue of finishing instruments of continuous rotary systems with different types of NiTi alloys were assessed. The null hypotheses tested were as follows: a) there would be no difference in quality of preparation among the different systems, b) there would be no difference in torsional fatigue strength of the different glide path instruments, c) there would be no difference in cyclic fatigue strength among the finishing instruments of the tested systems, and d) there would be no influence of simulated clinical use on the mechanical properties of instruments.

Methodology

The present study was approved by the Human Research Ethics Committee (process number: 88418518.4.0000.5417).

The sample size was calculated using the G*Power v3.1 for Mac (Heinrich Heine, Universität Düsseldorf, Germany), and the data were statistically analyzed by the Wilcoxon-Mann Whitney test. The data obtained from a previous study of the cyclic and torsional tests[7] was used to establish the effect size of the present study (= 1.2). An alpha type error of 0.05, a beta power of 0.80, and a ratio N2/N1 of 1 were also stipulated. A total of eight samples per group were indicated as the ideal size required for finding significant differences. Nevertheless, 20% of the total number of instruments were added to compensate for possible atypical values that might lead to sample loss.

Tooth preparation

In total, 90 extracted human mandibular premolars, stored in a 0.1% thymol solution, were selected. The following inclusion criteria were used: type I canal configuration according to Vertucci's classification,[18] an angle of curvature between 15° and 30° according to Schneider's method,[19] without calcifications, root fractures or separated instruments, and complete apex formation.[20] Specimens with an anatomical diameter of 0.20 mm were selected according to measurements of mandibular premolar diameters investigated in previous studies.[21,22] The teeth were standardized and randomized to obtain the groups in terms of degree of curvature, assessed by digital radiography. The samples were then scanned by using computed microtomography (SkyScan 1174v2; Bruker-micro-CT, Ethiolles, Belgium). A silicone mold was made for each tooth to ensure that it would be scanned in the same position, so as not to interfere in the subsequent analysis. The parameters used were a 0.5-mm aluminum filter, 50 kV, 800 mA, and a voxel size of 19.6 µm, rotation angle of 0.7, and total rotation of 360º, thus producing images with a resolution of 1304 x 1024 pixels. Each scan resulted in images that were reconstructed using NRecon software v1.6.4.8 (Bruker-micro-CT). After the segmentation and binarization processes, three-dimensional models were reconstructed with CTAn v.1.12 software (Bruker-microCT Kontich, Belgium). CTVol v.2.2.1 and Data Viewer software programs (Bruker-micro CT Kontich, Belgium) were used for visualizing and evaluating the internal anatomy. The baseline volume of both the entire canal and the apical third were standardized based on micro-CT assessment.

After creating the endodontic access cavity, the canals of all teeth were explored with size 06, 08, and 10 K-files. The working length (WL), 1 mm short of the apical foramen, was established with a 10 K-file (Dentsply Sirona, Ballaigues, Switzerland) when its tip was visualized in the foramen under a stereo microscope (Stemi 2000C; Carl Zeiss, Jena, Germany). Subsequently, the teeth were subjected to biomechanical root canal preparation with the following rotary systems (n=30):

Group 1: BT-Race (BTR) – The canal was irrigated with 2 mL of 2.5% sodium hypochlorite (NaOCl) and then instrumented with the BTR system according to the sequence proposed by the manufacturer. BTR 10.06, 35.00, and 35.04 instruments were coupled to an endodontic electric motor (VDW GmbH, Munich, Germany) and used in continuous rotation at a speed of 800 rpm and torque of 1.5 N. For each instrument, three in-and-out movements were performed in the apical direction. After these movements, the instrument was cleaned with gauze and the canal was irrigated with 2.5% NaOCl. Instrumentation was performed repeatedly, as described earlier, until the WL was reached. During root canal preparation, the canals were irrigated with 20 mL of 2.5% NaOCl using the syringe-needle irrigation technique. In addition, a 30-G side-vented needle was used at a distance of 3 mm from the WL. After root canal shaping, the instruments were ultrasonically cleaned for 5 min and sterilized at 121° C, at a pressure of 30 psi, for 20 min. Each system was used on three teeth and the procedures were repeated.

Group 2: Sequence Rotary File (SRF) – The procedure was similar to that described earlier, but SRF 15.04, 25.06, and 35.04 instruments were used in continuous rotation, with the glide path 15.04 instrument at a speed of 350 rpm and torque of 1 N, and the shaping instruments 25.06 and 35.04, at a speed of 500 rpm and torque of 2 N, driven by a VDW endodontic electric motor in the Doctors mode, according to the manufacturer's instructions.

Group 3: ProDesign Logic (PDL) – A procedure similar to the previous two was performed using PDL instruments 25.01, 25.06, and 35.05 in continuous rotation, with glide path 25.01 instrument at a speed of 350 rpm and torque of 1 N and shaping instruments 25.06 and 35.05 at a speed of 950 rpm and torque of 4 N, driven by a VDW endodontic electric motor in the Doctors mode, according to the manufacturer's instructions.

Upon the completion of biomechanical root canal preparation, the canals were irrigated with 5 mL of 17% EDTA (Biodynamics, Ibiporã, Paraná, Brazil) for 3 min to remove the smear layer and then rinsed with 5 mL of saline solution, dried with #35 absorbent paper points, and subjected to computerized microtomography (micro-CT) using the same parameters used initially.

Volume measurement

The pre-instrumentation and post-instrumentation images were superimposed using the 3D recording function of DataViewer v.1.5.1 (Bruker micro-CT) software. The images recorded were processed in CTAN software v.1.14.4 (Bruker micro-CT) to calculate the apical volume, comprising the last four apical millimeters, and the total volume, which consisted of the volume of the canal that extended from the root apex to 10 mm in the cervical direction.

Evaluation of root canal transportation

For the analysis of root canal transportation, axial sections corresponding to distances of 1, 2, 3, and 4 mm from the apex, which indicated the region of the curvature, were selected. Transportation was calculated in millimeters using the formula ([X1-X2] - [Y1-Y2]) as described by Gambill et al.,[23] where X1 is the shortest distance between the inner wall of the root curvature and the lumen of the uninstrumented canal; X2 is the shortest distance between the inner wall of the root curvature and the lumen of the canal after being instrumented; Y1 is the shortest distance between the outer wall of the root curvature and the lumen of the uninstrumented canal; and Y2 is the shortest distance between the outer wall of the root curvature and the lumen of the canal after being instrumented (Figure 1). According to this formula, a result of 0 (zero) indicated no root canal transportation; a negative result indicated transportation to the outer region of the curvature; and a positive result indicated transportation to the inner region of the curvature.

Evaluation of centering ability

The measurements of X1, Y1, X2, and Y2 at the apical third were used to evaluate centering ability (Figure 1), according to the equation suggested by Gambill et al.[23]: (X1-X2)/(Y1-Y2) or (Y1-Y2)/(X1-X2). The lowest value was considered the numerator. A result of 1 indicated perfect centering ability.

Torsional fatigue test

During biomechanical preparation, the same system was used on three different teeth, and after being used three times, the glide path files were always subjected to a torsional fatigue test.

Torsion testing was based on ISO 3630-1 (1992) specification, for which a specific machine was used, as described in detail in other studies.[24,25] The test was performed only with the glide path files of the systems used in this study (BTR 10.06, SRF 15.04, and PDL 25.01), of both new instruments (n = 10) and those used three times for biomechanical preparation (n = 10). The test established the average torque and maximum angular deflection values before instrument fracture. The torque values were evaluated by measuring the force exerted on a small load cell by a lever arm connected to the axis of torsion. The angle of rotation was measured and controlled by a resistive angle transducer connected to a process controller. To perform the test, the instrument handle was removed at the point where it was attached to the shaft. The end of the shaft was attached to a mandrel connected to a reversible gear motor. Three millimeters of the instrument tip

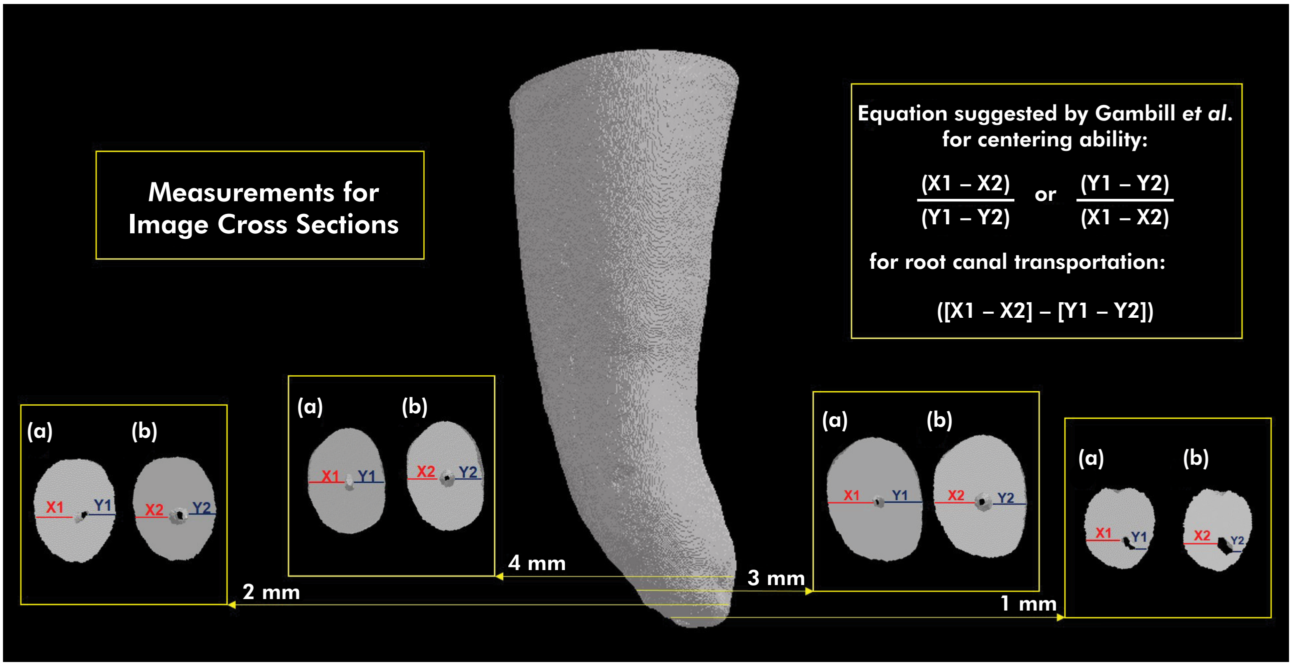

Figure 1. Representative images of the matching of axial reconstructions with the method used to detect root canal transportation in the last four millimeters of the apical portion: a) Axial sections indicating the thickness of the preoperative root canal dentin (X1 and Y1) and b) thickness of the dentin where root canal transportation (X2 and Y2) occurred in the postoperative period.

was attached to another mandrel with brass jaws to prevent slippage (Figure 2A).

The clockwise rotation speed was set to 2 rpm. The continuous recording of torque and angular rotation was monitored and the final torsional force and angular rotation (o) were provided by a specifically designed computer program (Analogica, Belo Horizonte, MG, Brazil) and recorded.[25]

Cyclic fatigue test

The cyclic fatigue test was conducted with the finishing instruments (BTR 35.04, SRF 35.04, and PDL 35.05) of each system used in the biomechanical preparation, and the methodology was based on that of the test described and used by Marks Duarte et al.[2] and Klymus et al.[26] An angle of 30° and a radius of 5 mm were used in the test (Figure 2B). The cyclic fatigue test was performed with brand-new instruments (n = 10) and also with the instruments that had been used three times in the biomechanical preparation (n = 10). Time (in seconds) until instrument fracture occurred was measured with a digital stopwatch. A video was recorded simultaneously to establish the exact moment when the fracture occurred. In addition, the number of cycles until instrument fracture was calculated.

SEM evaluation

After the torsional and cyclic fatigue tests, the instruments were ultrasonically cleaned and the fractured surfaces were examined by scanning electron microscopy (JSM-TLLOA; JEOL, Tokyo, Japan) to evaluate topographic features. The photomicrographs were taken at 50X, 200X, and 1000x magnification.

Statistical analysis

Statistical analysis was performed using GraphPad Prism 5 software (La Jolla, USA). The data were subjected to the D'Agostino-Pearson test to verify if they were normally distributed. For volume, canal transportation, and centering ability, the data were not normally distributed; thus, the non-parametric Kruskal-Wallis and Dunn's tests were used. For the torsional and cyclic fatigue tests, the data distribution was normal, and they were subjected to ANOVA and Tukey's parametric tests. A significance level of 5% was considered for all tests.

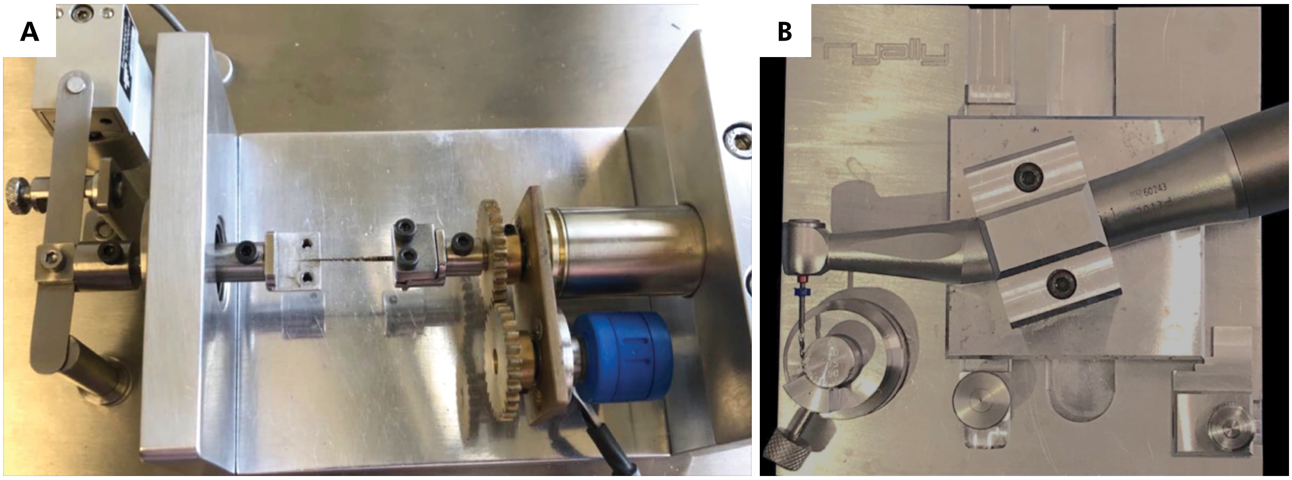

Figure 2. Experimental setup showing the (A) torsional fatigue test device and (B) cyclic fatigue test device.

Table 1. Median, minimum and maximum values for volume, in mm^3, and percent volume increase after the use of different rotary systems.

Region	Initial volume (mm^3)	Final volume (mm^3)	% volume increase
Apical			
BTR	0.19 (0.05/0.59)^{aA}	0.34 (0.23/0.64)^{B}	105.5 (18.0/370.0)^{a}
SRF	0.20 (0.12/0.57)^{aA}	0.50 (0.24/0.72)^{B}	107.4 (16.6/344.4)^{a}
PDL	0.30 (0.18/0.42)^{aA}	0.50 (0.35/0.64)^{B}	63.55 (27.9/154.6)^{a}
Total			
BTR	2.36 (1.05/4.22)^{aA}	3.38 (2.27/4.78)^{B}	46.0 (16.3/124.2)^{a}
SRF	3.32 (1.09/5.84)^{aA}	4.17 (3.02/6.48)^{B}	39.6 (16.9/176.3)^{a}
PDL	3.15 (1.33/4.51)^{aA}	4.20 (3.59/4.84)^{B}	29.35 (15.5/172.6)^{a}

Different lowercase letters in the same column indicate significant difference among groups ($p < 0.05$); Different uppercase letters in the same row indicate significant within-group difference ($p < 0.05$).

Results

The median, minima and maxima of baseline and final volume, and percent increase in volume are presented in Table 1. Baseline volume and percent increase in volume showed no significant difference in apical and total root canal volume ($p > 0.05$) among the groups. In the within-group comparison, however, there was a significant difference in all groups between baseline and final volume, both for apical and total volume ($p < 0.05$).

The median, minima and maxima of canal transportation, and centering ability are shown in Table 2. There was no significant difference among the groups for any of the analyses ($p > 0.05$). All groups exhibited little canal transportation and satisfactory centering ability.

The torsional strength (maximum load torque and angle of rotation) of the instruments is shown in Table 3. SRF 15.04, new, and used instruments had higher torsional strength than did PDL 25.01 and BTR 10.06, respectively ($p < 0.05$). In relation to the angle of rotation of both new and used instruments, PDL showed higher values, followed by SRF and BTR, respectively ($p < 0.05$). The within-group comparison between new and used instruments showed that BTR significantly reduced torque strength ($p < 0.05$), while SRF and PDL were not affected by clinical use ($p > 0.05$). In relation to the angle of rotation, all instruments were significantly affected by clinical use ($p < 0.05$).

Table 2. Mean, minimum and maximum values, in mm^3, for canal transportation and centering ability after the use of different rotary systems.

Region	Canal transportation			Centering ability		
	BTR	SRF	PDL	BTR	SRF	PDL
1 mm	-0.09[a] (-0.37/0.19)	-0.03[a] (-0.17/0.25)	-0.01[a] (-0.07/0.06)	0.31[a] (0.01/0.98)	0.40[a] (0.02/1)	0.50[a] (0.09/1)
2 mm	-0.08[a] (-0.29/0.33)	-0.03[a] (-0.18/0.04)	-0.03[a] (-0.38/0.13)	0.14[a] (0.01/0.99)	0.44[a] (0.13/0.96)	0.51[a] (0.10/0.95)
3 mm	0.11[a] (-0.14/0.21)	0.08[a] (-0.25/0.17)	-0.04[a] (-0.11/0.03)	0.25[a] (0.01/0.98)	0.33[a] (0.05/0.93)	0.55[a] (0.16/1)
4 mm	-0.07[a] (-0.15/0.10)	-0.05[a] (-0.14/0.06)	0.02[a] (-0.05/0.13)	0.39[a] (0.01/0.97)	0.49[a] (0.07/0.95)	0.66[a] (0.11/1)

In the analysis of canal transportation, positive values indicate wear on the inner wall of the curvature and negative indicate wear on the outer wall of the curvature. Different lowercase letters in the same row indicate significant difference among groups ($p < 0.05$).

Table 3. Mean values for torque (N.cm) and angle of rotation (°) of new instruments and used ones (after three uses).

Instruments	Torsional strength							
	New instruments				Used instruments			
	Torque (N.cm)		Angle (°)		Torque (N.cm)		Angle (°)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
BTR 10.06	0.2[aA]	0.04	363.4[aA]	12.7	0.1[aB]	0	303.1[aB]	13.7
SRF 15.04	0.4[bA]	0.09	462.1[bA]	16.1	0.4[bA]	0.06	367.2[bB]	14.1
PDL 25.01	0.2[aA]	0.04	952.7[cA]	11.3	0.2[cA]	0.03	810.9[cB]	27.6

SD, standard deviation. Different lowercase letters in the same column indicate statistical differences among groups ($p < 0.05$). Different uppercase letters in the same row indicate statistical differences between new and used instruments of the same group ($p < 0.05$).

Table 4. Mean values for time (in seconds) and number of cycles (NCF) of new instruments and used ones (after three uses).

Instruments	Cyclic fatigue							
	New instruments				Used instruments			
	Time (seconds)		Cycles (NCF)		Time (seconds)		Cycles (NCF)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
BTR 35.04	18.8[aA]	4.2	250.6[aA]	57.3	13.6[aA]	13.7	181.3[aA]	50.5
SRF 35.04	128.4[bA]	8.1	1070.0[bA]	67.9	126.8[bA]	22.1	1056.6[bA]	104.7
PDL 35.05	171.6[cA]	13.4	2717.0[cA]	171.1	164.9[cA]	23.9	2610.9[cA]	128.0

SD, standard deviation. Different lowercase letters in the same column indicate statistical differences among groups ($p < 0.05$); Different uppercase letters in the same row indicate statistical differences between new and used instruments of the same group ($p < 0.05$).

Cyclic fatigue resistance of the instruments is shown in Table 4. Among the new instruments, relative to both the time and the number of cycles until fracture, PDL 35.05 had the highest resistance to fatigue, followed by SRF 35.04 and BTR 35.04, respectively ($p < 0.05$). Among the used instruments, PDL and SRF exhibited a longer time to fracture than did BTR ($p < 0.05$). Nonetheless, when the number of cycles was analyzed, PDL had higher cyclic fatigue resistance than did SRF and BTR, respectively ($p < 0.05$). The within-group comparison between new and used instruments showed that no instrument was significantly affected by clinical use ($p > 0.05$).

Scanning electron microscopy of the fractured surface showed typical features of torsional failure for all brands (Figure 3) and typical features of cyclic

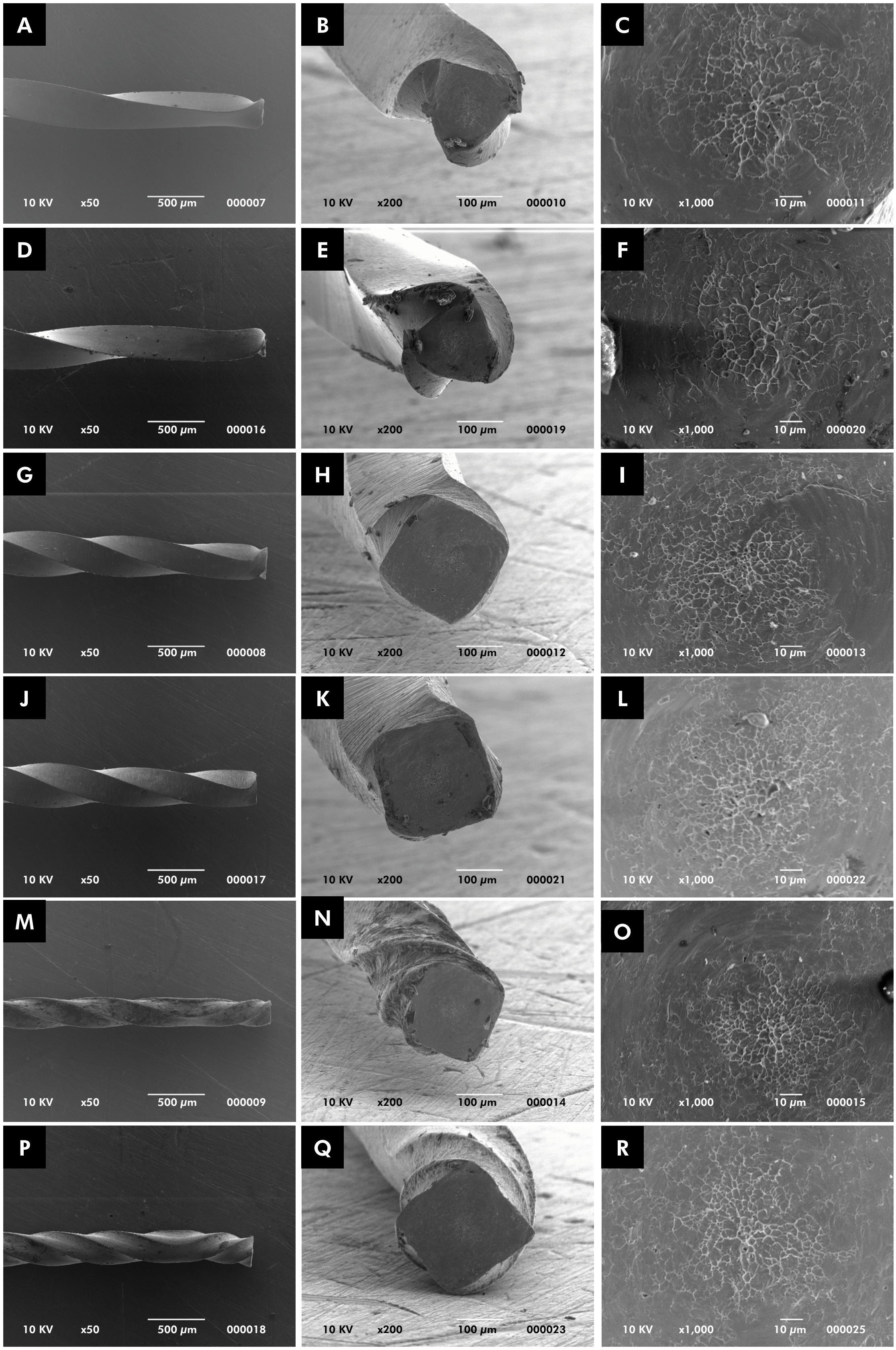

Figure 3. Scanning electron microscopy images of new (A, B, and C; G, H, and I; M, N, and O) and used (D, E, and F; J, K, and L; P, Q, and R) instruments of BT-Race, Sequence Rotary File, and ProDesign Logic systems, respectively, after torsional fatigue testing.

fatigue (Figure 4) for new and used instruments. In the side view (Figure 3), deformation of the spiral flutes of the instruments could be noted. The instruments had concentric abrasion and fibrous dimple marks at the center of rotation for torsional failure (Figure 3). In Figure 4, all the instruments displayed fractured surfaces with microvoids, which morphologically characterize ductile fractures.

Discussion

This study evaluated the quality of preparation of curved canals, torsional fatigue, and cyclic fatigue of new and used instruments of three rotary systems with different types of NiTi alloys. In view of the results obtained, the first null hypothesis was accepted, and the others rejected, given that there was no

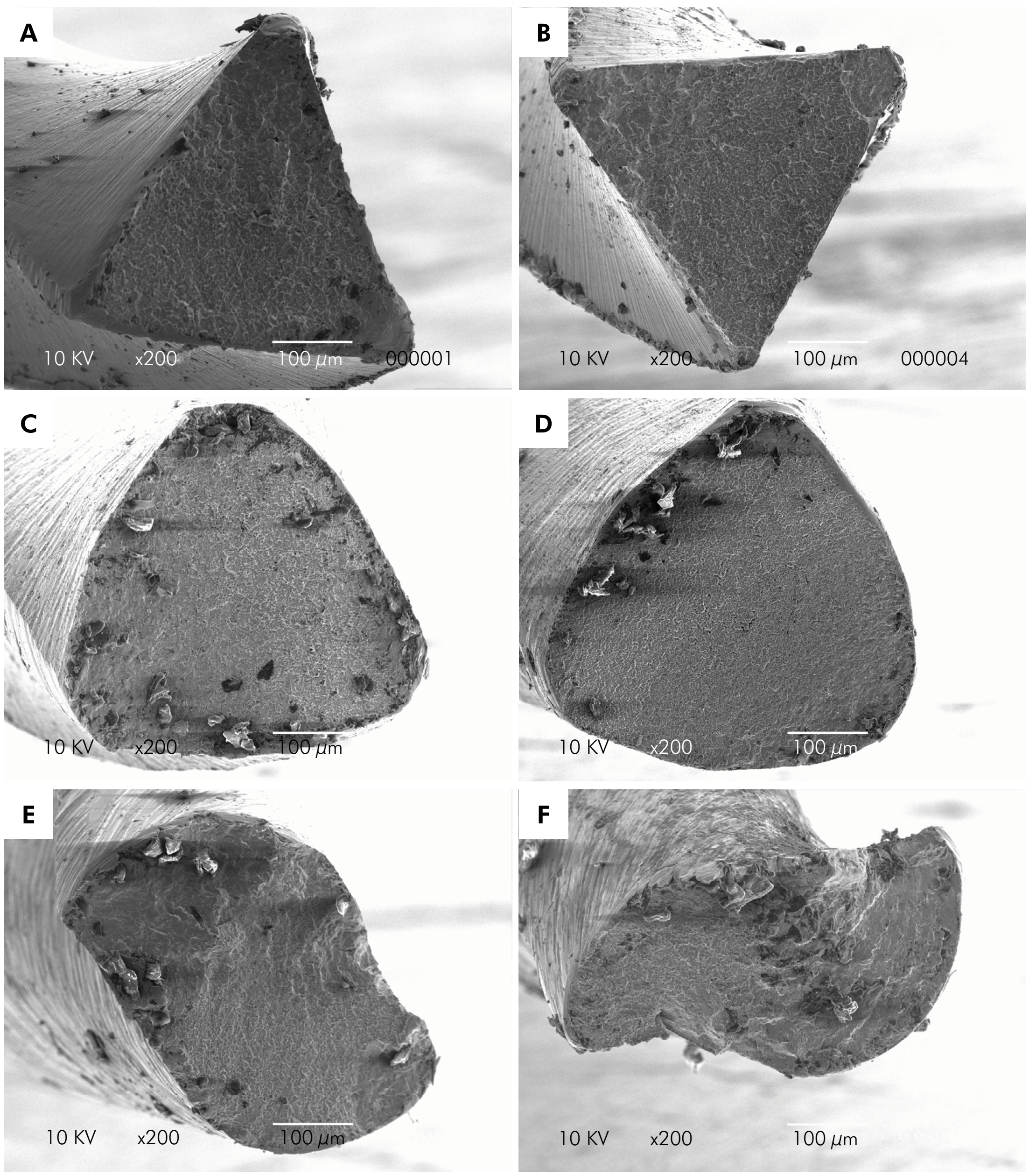

Figure 4. Scanning electron microscopy images of new (A, C, and E) and used (B, D, and F) instruments of BT-Race, Sequence Rotary File, and ProDesign Logic systems, respectively, after cyclic fatigue testing.

interference in the quality of the preparation between the systems; however, there were differences in the torsional and cyclic fatigue resistance tests, in addition to interference of the simulated clinical use in the properties of glide path instruments.

The study specimens consisted of single-rooted teeth with curvature between 15º and 30º. Despite the difficulty in pairing samples of natural teeth, they were standardized in terms of degree of curvature and assessed by digital radiography. The baseline volume of both the entire canal and the apical third were standardized by micro-CT.

Curved canals pose a great challenge during mechanical preparation because errors such as zipping, step, excessive wear, and instrument fractures can occur, worsening the prognosis of endodontic treatment.[27,28] In addition, there is still no consensus about the ideal diameter of apical preparation; however, several studies have demonstrated numerous benefits when this preparation was larger than that obtained with a #25 instrument.[16,17,29] Therefore, three rotary systems were investigated with the use of a size 35 finishing instrument. Probably, because of standardization of the final diameter and similar taper (BTR 0.04, SRF 0.04, and PDL 0.05), there was no significant difference among the groups regarding percent volume increase, even though the final instruments had different types of cross sections and were made of NiTi alloys (BTR – triangular section and conventional NiTi, SRF – triangular convex section and NiTi Blue, and PDL – S-shaped section and NiTi CM).

During biomechanical preparation of curved canals, preservation of their path is an important factor.[12,28] Therefore, we analyzed canal transportation and centering ability of the systems in the apical region (last 4 mm), which corresponds to the region of the curvature. Relative to canal transportation, the three groups exhibited values close to 0, i.e., lower than 0.3 – a threshold value that has no negative impact on the prognosis of endodontic treatment.[12] Regarding centering ability, based on the formula proposed by Gambill et al.,[23] it is known that the closer to 1, the better the centering ability. Although no significant differences were noted, PDL obtained values closer to 1, followed by SRF and BTR, respectively. This could be explained mainly by the types of alloys used in the systems. A CM alloy is used for PDL, and a Blue alloy is used for SRF. BTR is made of a conventional NiTi alloy, and several studies have demonstrated that heat-treated alloys have greater flexibility and better preservation of the canal path than do conventional alloys.[12,30,31]

Because these systems are relatively new in the market, few studies have analyzed the quality of preparation. The majority of these studies have revealed results for the behavior of BTR that were similar to those found in the present study.[8,9] Pinheiro et al.[12] observed that despite no statistical difference, PDL had better centering ability than that observed for different heat-treated rotary systems, which is in line with the results of this study.

During biomechanical preparation of curved canals, another important factor is creation of the glide path, as it can improve the quality of preparation and reduce the risk of fracture of shaping instruments.[4,5,32,33] Therefore, the majority of rotary systems have a specific instrument for this purpose. Generally, glide path instruments show high variability among systems in relation to tip diameter, taper, cross section, and type of NiTi alloy. These factors can contribute to different behaviors of the instruments.[4] In the present study, glide path instruments were used in three teeth with curved canals and then subjected to the torsional fatigue test in order to analyze maximum torque (N.cm) and maximum angular deflection (º). Concomitantly, brand-new instruments of exactly the same type were also subjected to the same test using a previously validated methodology.[7,33]

Analysis of maximum torque of the new and used instruments showed that SRF 15.04 produced higher values than did PDL 25.01 and BTR 10.06. These findings could be explained by the fact that SRF has a quadrangular cross section and a larger tip diameter than does BTR, which has a triangular cross section, with a smaller amount of metal mass in its initial millimeters. Analysis of maximum torque of the new and used instruments showed that SRF 15.04 produced higher values than did PDL 25.01 and BTR 10.06. These findings could be explained by the fact that SRF has a quadrangular cross section and a larger tip diameter than does BTR, which has a triangular

cross section, with a smaller amount of metal mass in its initial millimeters. The fact that torsional fatigue did not change in SRF and PDL after clinical use may be related to the heat treatment to which both were subjected. As the alloy used in the manufacture of BTR does not undergo heat treatment, its torsional fatigue resistance decreased, corroborating the findings of a previous study that analyzed instruments made of conventional NiTi alloys.[13]

In regards to angular deflection, in the evaluation of both new and used instruments, PDL 25.01 obtained significantly better results than did SRF 15.04 and BTR 10.06, respectively. This variable is directly related to the type of heat treatment and taper of this instrument, so the more flexible the instrument, the greater the angle of deflection.[4,36] There are no studies in the literature evaluating the torsional fatigue of BTR and SRF systems for comparison of the results obtained. Only one study evaluated PDL 25.01 and obtained results similar to those of the present study.[4] In addition, it should be noted that the angular deflection of the three instruments was affected by clinical use. This may have occurred because the instruments used in the preparation of the curved canals were not only subjected to torsional fatigue, but also to cyclic fatigue, reducing angular deflection.

After creating the glide path, the root canal is shaped by the instruments. When these instruments work in a curved canal, they undergo cyclic fatigue because of tensile and compressive forces at the maximum point of curvature.[2,37] The new and used finishing instruments (size 35) were subjected to the cyclic fatigue test in the present investigation to verify the extent of their safe use in canals with severe curvature. In the analysis of the time necessary until fracture of the instruments, both new and used, PDL 35.05 demanded significantly longer time than did SRF 35.04 and BTR 35.04, respectively. The same results were also observed for the number of cycles, as this varies according to the speed used. In the literature, there is a paucity of studies related to the mechanical properties of the systems tested. In the study of de Menezes et al.,[38] better behavior was also found for PDL, even when it was compared with heat-treated Gold instruments. These results might have been obtained owing to the instrument design (S-shaped cross section), but they were mainly attributable to CM heat treatment of PDL, which provided greater flexibility and resistance to cyclic fatigue.[7,25,38] With respect to the intermediate results obtained for SRF, which has a Blue heat treatment, an analogy can be made with the findings of Alcalde et al.[7] and Silva et al.,[37] in which the instrument with Blue heat treatment obtained good results; nevertheless, they were worse than those of the instrument with CM heat treatment. Concerning BTR, made of conventional NiTi alloy, several studies have shown this type of alloy has less resistance to cyclic fatigue than do NiTi instruments with some type of heat treatment.[39-41] Another factor that could influence cyclic fatigue resistance is the speed at which each instrument was used. However, one study revealed no influence of speed when the instrument design and type of alloy of which it was made were considered to be the most important factors.[39] Note that none of the finishing instruments tested in the present study were significantly affected by clinical use. This may have occurred because the test was performed with the finishing instrument, which does not undergo as much stress as the first type used for shaping.

Conclusion

Despite the limitations of this study, mainly with regard to obtaining a similar sample, it could be concluded that BTR, SRF, and PDL rotary instruments were safe and produced a similar quality of shaping in canals with moderate curvature. Yet, different behaviors were observed in the mechanical properties of the instruments. For torsional fatigue, SRF 15.04 exhibited the highest torque values, PDL 25.01 had the highest angular deflection values, and BTR 10.06 was the most frequently affected by simulated clinical use. PDL 35.05 showed higher resistance to cyclic fatigue, followed by SRF 35.04, and the finishing instruments were not affected by simulated clinical use.

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