Flexibility and resistance to cyclic fatigue of instruments manufactured by different methods

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ABSTRACT

Objective: This study compared the mechanical behavior of nickel-titanium instruments with similar geometry, but manufactured by different methods. **Material and Methods:** Twenty 25/0.06 RaCe files (FKG Dentaire, La Chaux-de-Fonds, Switzerland), 25 mm in length, manufactured with machined conventional NiTi wires; twenty 25/0.06 Twisted File endodontic instruments (TF) (SybronEndo, Orange, CA, USA), 27 mm in length, manufactured by twisting; and twenty 25/0.06 ProFile Vortex endodontic instruments (Dentsply Tulsa Dental, Tulsa, OK, USA), 25 mm in length, manufactured with M-Wire alloy were subjected to flexibility and cyclic fatigue tests. Each group comprised 10 instruments from each manufacturer. **Results:** Parametric ANOVA revealed significant difference between maximum load values in the following sequence: ProFile Vortex > RaCe > TF ($p < 0.01$). The rotating-bending test assessed the cyclic fatigue by measuring the time and number of cycles to fracture (NCF). Parametric ANOVA, with significance level set at 1%, revealed that RaCe files had significantly lower resistance than ProFile Vortex which, in turn, had lower values than TF, in terms of time and number of cycles ($p < 0.01$). **Conclusion:** TF instruments were more flexible than RaCe which, in turn, presented lower resistance than ProFile Vortex. Regarding the cyclic fatigue test, TF instruments had significantly better performance than the other two instruments tested, particularly in terms of time and NCF.

Keywords: Endodontics. Fatigue. Titanium. Nickel.

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Introduction

From a mechanical standpoint, mastering anatomy has always been a great challenge for root canal shaping.[1,2,3] In 1988, Walia et al[4] introduced nickel-titanium (NiTi) instruments to be used in Endodontics, which represented a breakthrough in root canal preparation thanks to two inherent features of NiTi alloys: shape memory effect (SME) and superelasticity (SE), in addition to high resistance to corrosion and biocompatibility.[5,6] According to Thompson,[6] SME and SE are associated with martensitic transformation (MT), a phase change of NiTi alloy in the solid state. MT may be induced by high pressure or low temperature and occurs between a phase of high-symmetry crystalline structure, austenite, and a phase of low-symmetry crystalline structure, martensite. Austenite is stable at high temperatures and low pressure. The phase change from austenite to martensite is key to explain SME and SE.[7]

This behavior allowed engine-driven NiTi endodontic instruments to be developed, which resulted in more efficient and safe root canal preparation with better preservation of the original canal shape.[8,9,10] Despite these favorable features, NiTi instruments are susceptible to fracture during use. This type of failure may occur unexpectedly, with no visual indication of plastic deformation on the instrument blade.[11,12]

More recently, Twisted File instruments (TF, SybronEndo, Orange, CA, USA), made of a crystallographic structure known as R-phase, were developed, thereby allowing instruments to be made of twisted NiTi wires.[13,14,15] Moreover, another generation of endodontic files has been manufactured with a new NiTi alloy known as M-Wire.[16,17] This alloy is produced by subjecting NiTi to a special thermomechanical process. These new manufacturing processes aim to reduce the occurrence of instrument fracture and improve the mechanical properties of endodontic files, in comparison to those produced by machined conventional NiTi alloy.[9,16,18]

Previous studies assessed some mechanical properties of TF, RaCe and Vortex instruments.[19,20] The aim of the present study was to extend these findings by assessing the mechanical behavior of three NiTi endodontic instruments with similar geometry, but produced by different manufacturing methods.

Material and methods

Sixty engine-driven NiTi endodontic instruments were used in the present study: twenty 25/0.06 RaCe files (FKG Dentaire, La Chaux-de-Fonds, Switzerland), 25 mm in length, made of machined conventional NiTi wires; twenty 25/0.06 Twisted File instruments (TF, SybronEndo, Orange, CA, USA), 27 mm in length, made of twisted special NiTi wires (R-phase); and twenty 25/0.06 ProFile Vortex files (Dentsply Tulsa Dental, Tulsa, OK, USA), 25 mm in length, made of M-Wire alloy.

Instrument geometry

In order to standardize the samples tested, ten instruments of each commercial brand were assessed based on the following parameters: diameter at D_0, taper, length of the working portion, total number of flutes, and number of flutes per millimeter. Data were collected with the aid of a Zeiss® optical microscope (Carl Zeiss do Brasil Ltda., Cambuci, SP, Brazil), a PixeLINK camera model PL-a662 (PixeLINK, Ottawa, Canada), and a Zeiss® 1500LCD light source. All dimensions were quantified under 6.5x magnification, except for taper which was calculated according to the methods described by Stenman and Spangberg.[21] AxioVision 4.4® imaging software (Carl Zeiss MicroImaging, New York, USA) was also used.

Flexibility

In order to determine flexibility, instruments were subjected to the cantilever bending resistance test at 45° below the horizontal plane and by means of a universal testing machine (Emic, DL10000, Paraná, Brazil), as described in previous studies.[4,19,20] A 20 N load was applied by means of a stainless steel wire measuring 30 cm in length and 0.3 mm in diameter, with one end attached to the cross head and the other end secured 3 mm from the instrument tip (load application point). The tips of the instruments tested were subjected to a 15 mm displacement, within the elastic limit of the alloy. Testing was conducted at a speed of 15 mm/min. Data were subjected to statistical analysis by means of parametric ANOVA with significance level set at 0.01%.

Rotating-bending assay

An artificial canal measuring 1.4 mm in diameter and 19 mm in total length was manufactured with a stainless steel tube. A 9-mm-long curved segment with 6 mm curvature radius (measured at the internal concave surface of the tube and corresponding to a 86° arc) was created between two straight segments that measured 7 mm and 3 mm (Fig 1).

The apparatus used for the rotating-bending assay was described in a previous study.[19] The instruments were positioned to rotate clockwise within the artificial canal, under constant 3 N torque and 310 rpm, until fracture was visually detected. The time when fracture occurred was recorded using a digital chronometer (Herweg). To determine the number of cycles to fracture (NCF), the time required for fracture was multiplied by the number of revolutions per minute. This test was conducted using ten instruments of each brand. The time and NCF values were subjected to statistical analysis by parametric ANOVA.

Results

Instrument geometry

The mean diameters at D_0, the taper, the length of the working portion, the total number of flutes, and the number of flutes per millimeter are shown in Table 1.

Flexibility

The mean maximum loads necessary to bend the engine-driven NiTi instruments in the cantilever bending test are listed in Table 2.

Parametric ANOVA revealed significant difference in the maximum bending load values among the instruments tested ($p < 0.01$).

Rotating-bending assay

Means and standard deviations (in seconds) for time to fracture and NCF are shown in Table 3.

Parametric ANOVA, with significance set at 1%, revealed that RaCe files had significantly lower values than ProFile Vortex which, in turn, had significantly lower values than TF regarding time and number of cycles to fracture ($p < 0.01$).

Discussion

The impact of thermal treatment and the different manufacturing methods of NiTi alloys have been the subject of discussion of several recent studies.[6,13,16,22-25]

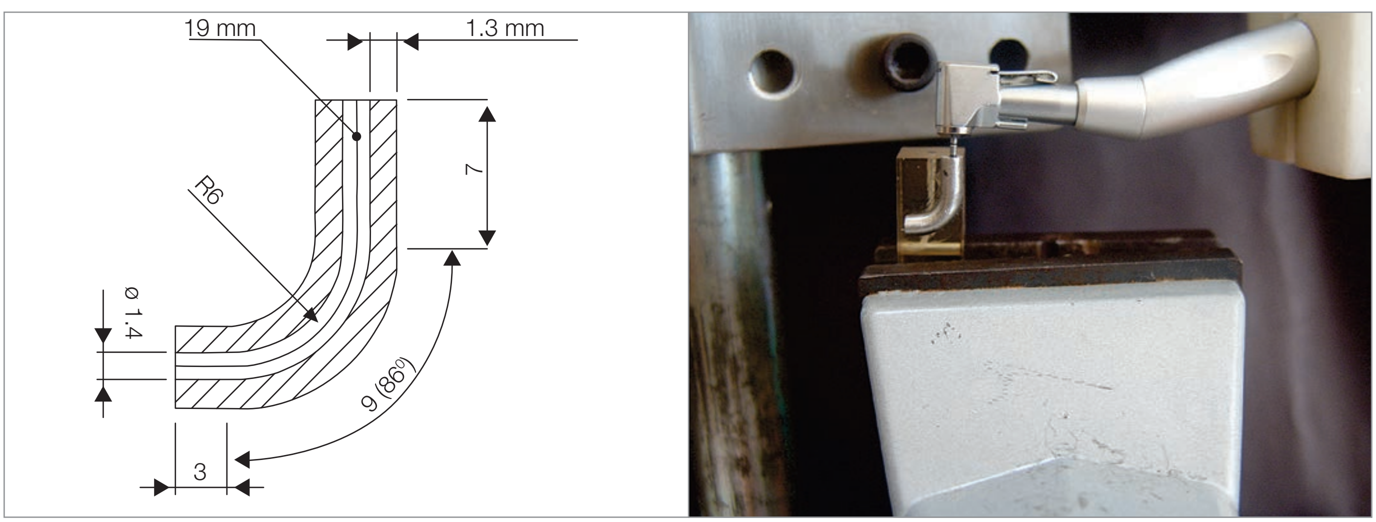

Figure 1. Schematic representation and photograph of the artificial canal used in the present study.

Table 1. Mean diameter at D_0, taper (T), length of the working portion, total number of flutes, and number of flutes per millimeter. (NF/mm).

Instrument	#	D_0	T	LWP	NF	NF /mm
RaCe	10	0.28	0.06	17.56	7	0.4
TF	10	0.23	0.06	15.53	11	0.7
ProFile Vortex	10	0.24	0.06	16.75	10	0.6

#, number of instruments; D_0, initial diameter T, taper; LWP, length of the working portion; NF, number of flutes; NF/mm, number of flutes per millimeter.

Table 2. Mean and standard deviation for the maximum bending load (gf) of RaCe, TF, and ProFile Vortex instruments.

Instrument	Number of instruments	Maximum load (gf)
RaCe	10	333.4 ± 16.5
TF	10	228.4 ± 15.18
ProFile Vortex	10	603.7 ± 29.3

Table 3. Mean and standard deviation for time and number of cycles to fracture (NCF) of RaCe, TF, and ProFile Vortex.

Instrument	Number of instruments	Time (s)	NCF
RaCe	10	26.8 ± 5.03	138.3 ± 25.95
TF	10	82.4 ± 4.33	423.64 ± 22.35
ProFile Vortex	10	37 ± 5.77	190.92 ± 29.79

The present work compared three different types of NiTi endodontic instruments: TF, manufactured by the twisting method and made of a special (R-phase) NiTi alloy; ProFile Vortex, produced by the machining method and made of M-Wire; and RaCe manufactured by the machining method and made of conventional NiTi alloy. In order to prevent discrepancies in instrument geometry, the instruments were assessed as described in previous studies.[20,21] The mean diameter at D_0, the length of the working portion, the total number of flutes, the number of flutes per millimeter, and the taper of all instruments presented compatible values for comparison. Moreover, all instruments had similar cross-sectional designs.

Several authors[6,22,26,27] report that the thermal treatment to which instruments are subjected during the manufacturing process may affect the mechanical properties of the alloy and significantly alter the resulting instrument flexibility. The results of the present study show that TF 25/0.06 instruments were significantly more resistant to cyclic fatigue than ProFile Vortex 25/0.06 which, in turn, were significantly more resistant than RaCe 25/0.06. ProFile Vortex files were less flexible than RaCe. Moreover, ProFile Vortex had higher NCF values than RaCe. The thermal treatment to which the alloy was subjected during the manufacturing process of M-Wire may have improved the instruments resistance to cyclic fatigue. This finding suggests that M-Wire performs better than conventional NiTi, corroborating results from previous studies.[16,22,24,25,26] It is important to mention that the TF instruments, in addition to being subjected to thermal treatment, are produced by twisting and are significantly more resistant to cyclic fatigue (time and NCF) than the other two instrument brands tested. This may be attributed to the presence of the R-phase during the thermal process and to the manufacturing method of twisting, which has proved to promote greater resistance to fatigue than other manufacturing methods.[13,15]

Another hypothesis to explain the better performance of TF instruments, in comparison to instruments made of M-Wire and conventional alloy, may be related to their cross-sectional design. Although all instruments tested had triangular cross-sections, ProFile Vortex files presents a convex triangle cross-sectional design, which increases the cross-sectional area, thereby decreasing flexibility. According to Schäfer and Tepel,[28] cross-sectional shape and area are the main parameters that influence the elastic properties of endodontic instruments. The cross-sectional area of a given file is inversely proportional to its flexibility.[29]

Flexibility and rotating-bending tests have been considered, by several authors, the best methods to assess the mechanical behavior of NiTi instruments and determine their resistance to fracture.[30-34] The rotating-bending assay allows the instrument to freely rotate within curved segments of the canal with no interference of torsional loads, which could also lead to fracture[5,15] This test generates continuous alternating traction and compression stresses at the point of greatest deflection within the canal, until instrument fracture occurs.[30,33,35] In the present study, comparison between the results from the flexibility and rotating-bending assays showed that TF required lighter loads to undergo elastic deflection in comparison to the other instruments tested. Since stress on TF surface is lighter, the generated stress, which could induce propagation and development of cracks, is also smaller. Consequently, the amount of time required for crack propagation in TF was significantly greater than that of RaCe and ProFile Vortex. These findings are justified by the principle that in material under fatigue, the relationship established between stress and the size of crack can be calculated by the following equation: $T = \sqrt{2E\gamma/\pi a}$; in which T is the stress at the far end of the crack, E is the elastic modulus, γ is the surface energy, and a is half of the crack length.

Conclusion

Based on the results of the present study, it is reasonable to conclude that TF instruments were more flexible than RaCe which, in turn, were less resistant to cantilever bending than ProFile Vortex. In the rotating-bending assay, TF had significantly better performance, in terms of time and number of cycles to fracture, when compared to the other two brands of instrument tested.

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