Comparison of the flexibility and torsional resistance of nickel-titanium rotary instruments

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ABSTRACT

Introduction: This study compared the flexibility and torsional resistance of two types of instruments manufactured with special NiTi alloys, and one with conventional NiTi. **Methods:** Twisted File (TF) instruments manufactured with the R-phase of NiTi (SybronEndo, Orange, CA), and ProFile Vortex instruments (Dentsply Tulsa Dental, Tulsa, OK, USA) made of M-Wire NiTi were compared with RaCe (FKG Dentaire, La Chaux-de-Fonds, Switzerland) instruments made of conventional NiTi. Flexibility and torsion assays were carried out using twenty 25/0.06 instruments from each manufacturer. Statistical analysis was performed by ANOVA. **Results:** The mechanical resistance of the instruments tested was significantly different. TF were the most flexible instruments, followed by RaCe and ProFile Vortex ($P < 0.01$). In the torsion assay, ProFile Vortex instruments endured the greatest maximum load and maximum torque values prior to fracture, followed by RaCe and TF ($P < 0.01$). The torsional resistance values of RaCe and TF were not significantly different ($P = 0.061$). **Conclusion:** We observed a relationship between flexibility and torsional resistance (maximum torque and maximum angular deflection in torsion). The most flexible instrument (TF) was the least resistant to torsion, while the least flexible (ProFile Vortex) was the most resistant to torsion. RaCe presented intermediate results for both flexibility and torsional resistance.

Keywords: Mechanical torsion. Nickel. Dental instruments. Titanium.

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Introduction

Since the introduction of NiTi in Endodontics by Walia et al,[1] the technological evolution for fabricating NiTi instruments has allowed the production of more flexible and resistant instruments,[2,3] revolutionizing the process of root canal shaping. The ability to widen the apical diameter of a curved canal, the availability of instruments with different tapers and cross-sections, the achievement of more centered preparations, and the reduction in the learning curve of endodontic systems are among the evidences of this paradigm shift.[4,5] The super elasticity and shape memory effect of NiTi alloys are recognized as properties that allowed this revolution to take place.[6]

More recently, advances in the development of endodontic instruments reflect improvements in the thermal treatment of NiTi, culminating in the emergence of two special Nitinol alloys: R-phase and M-Wire. Twisted Files (TF - SybronEndo, Orange, CA, USA) instruments are manufactured by twisting a super elastic R-phase NiTi wire, as opposed to grinding or machining.[7-9] ProFile Vortex instruments (Dentsply Tulsa Dental, Tulsa, OK, USA) represent the new generation of ProFile and are made of machined M-Wire, a NiTi alloy obtained by a proprietary process. In this manufacturing process, the alloy is subjected to a special thermomechanical treatment during the cooling and heating cycles.[8-11]

In previous studies, Rodrigues et al[12] and Lopes et al[13] assessed some mechanical properties of TF, RaCe and Vortex instruments. The purpose of the present study was to extend these findings by assessing the mechanical behavior, more specifically the bending and torsional resistance of two types of endodontic instrument fabricated with special NiTi alloys (TF and ProFile Vortex) and one instrument manufactured with conventional alloy (RaCe, FKG Dentaire, La Chaux-de-Fonds, Switzerland).

Material and Methods

Sixty rotary NiTi endodontic files were used in this study: Twenty 25/0.06 RaCe files (FKG Dentaire, La Chaux-de-Fonds, Switzerland), measuring 25 mm in nominal length; twenty 25/0.06 Twisted Files (TF) (SybronEndo, Orange, CA, USA), measuring 27 mm in nominal length; and twenty 25/0.06 ProFile Vortex (Dentsply Tulsa Dental, Tulsa, OK, USA), with nominal length of 25 mm.

Geometric characterization of instruments

Ten instruments of each brand were analyzed according to the following parameters: taper; length of the working portion; diameter at D0, D3, and D13; total number of flutes; and number of flutes per millimeter. These data were obtained with the aid of a Zeiss® optical microscope (Carl Zeiss do Brasil Ltda., Cambuci, SP, Brazil) to which a PixeLINK model PL-A662 camera (PixeLINK, Ottawa, Canada) was attached. All dimensions were obtained under 6.5X magnification except for the taper which was calculated according to the methodology described by Stenman & Spangberg.[14] The AxioVision 4.4® imaging software (Carl Zeiss MicroImaging, Thornwood, NY, USA) was also used to aid the measurements.

Flexibility assay

The bending resistance was assessed by the cantilever bending test using a universal testing machine (EMIC, DL10000) as described in previous studies,[15,16] with a downward incline of 45° in relation to the horizontal plane. 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 3 mm from the instrument tip (load application point). Testing was conducted at a speed of 15 mm/min.

Torsional assay

The instruments were subjected to clockwise rotation with no axial load by using an apparatus attached to the universal testing machine, as described in a previous study.[17] The apparatus monitored the rotation and the load applied to the instrument. The file was held by a vise placed at 3 mm from the instrument's tip, and the other end of the file was attached to a mandrel connected to the rotating shaft of the apparatus.

Torsion was achieved by twisting a braided nylon string measuring 0.3 in diameter around the rotating shaft which measured 8 mm in diameter. This nylon thread connected the rotating shaft to a 20 N load attached to the testing machine cross head, causing the shaft to rotate at 2 rpm. The load applied and the displacement of the nylon string until the instrument fractured were continuously monitored by a computer attached to the testing machine. The maximum angular deflection and maximum torque were assessed with the aid of the M Test 1.01 software (EMIC DL 10000).

The fractured surfaces were analyzed under SEM to determine the type of fracture and the presence of plastic deformation on the instrument shafts. The values obtained in the bending and torsional assays were subjected to ANOVA.

Results

Geometric characterization of instruments

The mean diameters at D0, D3, and D13, 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.

Bending assay

The mean and the standard deviation for the maximum load to bend each instrument are presented on Table 2. Statistically significant difference was observed between the values of the maximum load necessary to bend the instruments. TF were the most flexible among the instruments tested, followed by RaCe and ProFile Vortex (P < 0.01).

Torsional assay

The means and standard deviations for the maximum load and maximum torque necessary to fracture the instrument are shown in Table 3. Significant difference was observed between the three types of instruments. ProFile Vortex withstood greater values of maximum load and maximum torque, followed by RaCe and TF (P < 0.01).

Table 4 shows the means and standard deviations for the maximum angular deflection before torsional failure as well as the number of turns that are necessary to fracture the instrument. TF and RaCe instruments did not show significant differences among each other (P = 0.061), but both presented greater angular deflection values and number of turns than ProFile Vortex (P < 0.01).

In order to confirm the association between flexibility and maximum torsional torque, a graph presenting the relationship between these parameters was constructed (Fig 1). Another graph shows the relationship between the maximum angular deflection in torsion and flexibility (Fig 2). Finally, a third graph was constructed to show the association between the mean maximum angular deflection and the maximum torsional torque (Fig 4).

Table 1. Mean values for diameters at D0, D3, and D13; taper; length of the working portion; number of flutes; and number of flutes per millimeter.

Instruments	n	Diameter (mm)			T	WL	NF	F/mm
		D0	D3	D13				
RaCe	10	0.28	0.47	1.10	0.06	17.56	7	0.4
TF	10	0.23	0.41	0.97	0.06	15.53	11	0.7
ProFile Vortex	10	0.24	0.42	1.00	0.06	16.75	10	0.6

Table 2. Means ± standard deviation of the maximum loads (gf) necessary to bend the instruments tested.

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. Means ± standard deviation for the maximum loads and maximum torque at fracture of the instruments tested.

Instrument	Number of instruments	Maximum load (gf)	Maximum torque (gf-mm)
RaCe	10	184.5 ± 7.61	765.71 ± 31.59
TF	10	107.27 ± 8.50	445.19 ± 35.28
ProFile Vortex	10	250.93 ± 31.15	1041.39 ± 129.26

Table 4. Means ± standard deviation for the maximum angular deflection at torsional fracture and number of turns necessary to fracture the instrument in the torsional assay for the instruments tested

Instrument	Number of instruments	Maximum deflection (°)	Number of turns
RaCe	10	578.88 ± 50.96	1.61 ± 0.14
TF	10	688 ± 154.92	1.91 ± 0.43
ProFile Vortex	10	394.56 ± 72.0	1.10 ± 0.20

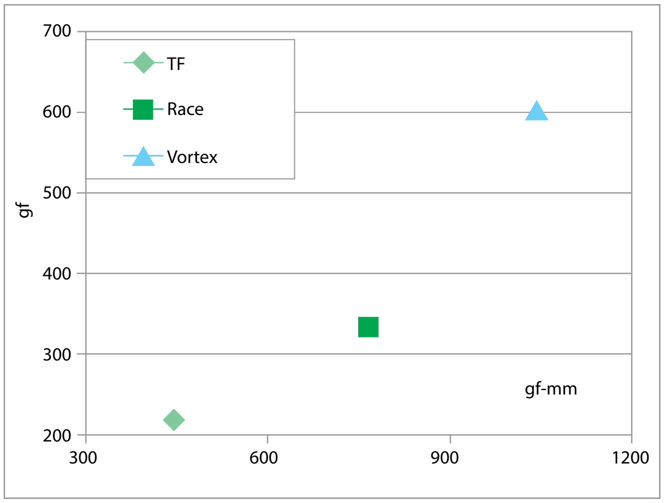

Figure 1. Graphic representation of the relationship between flexibility (gf) and maximum torque (gf-mm).

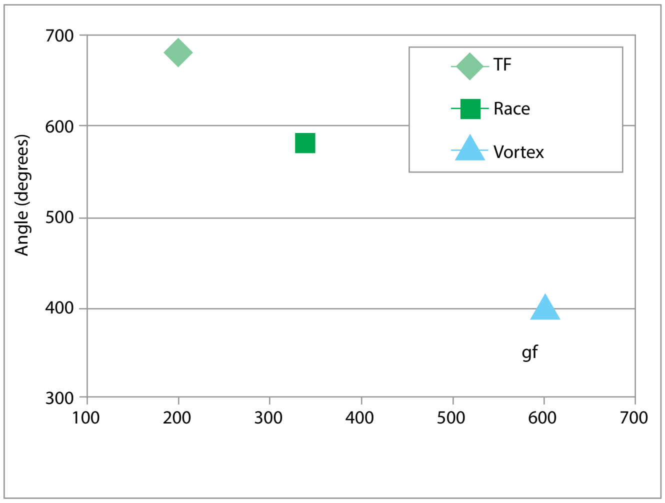

Figure 2. Graphic representation of the relationship between maximum angular deflection (degrees) and flexibility (gf).

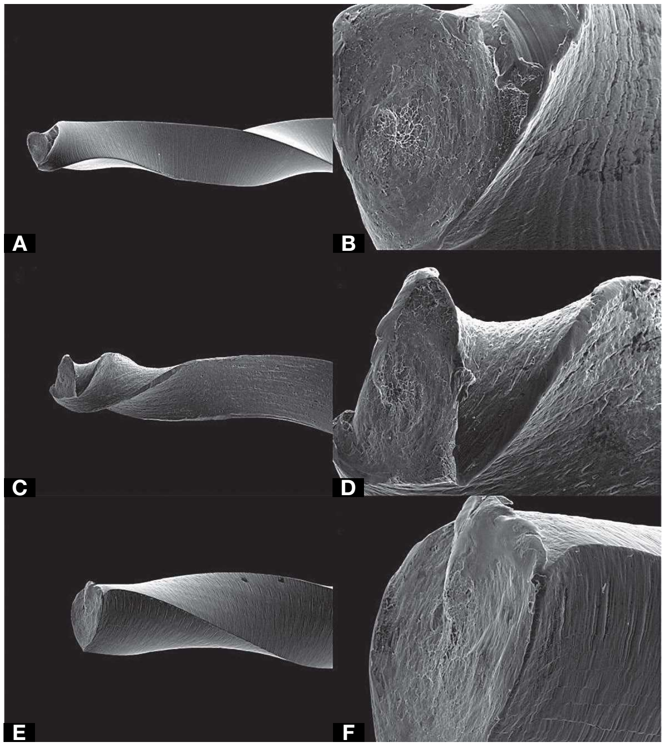

Figure 3. Appearance of the fractured surfaces, showing reversed flutes near the tip, where the instruments were held by the vise. Instruments: RaCe (**A** and **B**), TF (**C** and **D**), and ProFile Vortex (**E** and **F**). Presence of plastic deformation, grooves, and cracks of varying depths (**A**, **C**, and **E** under 100x magnification; **B**, **D**, and **F** under 500x magnification).

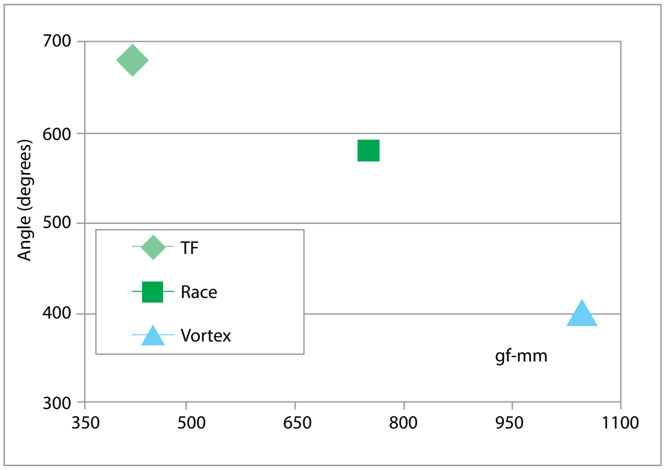

Figure 4. Graphic representation of the relationship between maximum angular deflection (degrees) and maximum torque (gf-mm).

SEM showed that all instruments tested displayed features of ductile mode fracture. Plastic deformation was observed in the helical shaft of all instruments (Fig 3).

Discussion

Although the instruments selected for the present study were made of different types of NiTi, all of them had similar cross-sectional designs (triangular), since this variable is known to influence the performance of instruments in mechanical assays.[18]

In the present study, TF instruments required the smallest load to deflect 45° below the horizontal plane. Clinically, the greater an instrument's flexibility, the less likely it is to produce apical deviation during root canal instrumentation.[19] Based on our results, we expect TF to present more satisfactory clinical performance.

The greater flexibility of TF may be due to the fact that these files are made of R-phase NiTi, which provides greater flexibility, lower elasticity modulus, and less rigidity in comparison with conventional austenite NiTi instruments.[20,21] Thus, instruments fabricated with this special alloy are able to withstand greater elastic and plastic deformation than conventional alloys, when subjected to similar torque. Our results corroborate previous studies.[7,22-24] Moreover, TF instruments are manufactured by twisting NiTi wires, which distinguishes these instruments from the two other groups manufactured by grinding. Twisted instruments present significantly less surface flaws than ground files.[7,9,23-26]

The results from the torsional assay demonstrated that ProFile Vortex instruments are able to withstand significantly greater maximum torque than RaCe and TF. Some factors may explain this difference:

- The cross-sections of TF and RaCe are equilateral triangles, while the cross-section of ProFile Vortex is a convex triangle.
- The resistance to torsional fracture of engine-driven NiTi instruments increases with the cross-sectional area and the moment of inertia. Profile Vortex files has larger cross-sectional areas.
- Previous studies have demonstrated a direct correlation between the diameter and the cross-sectional area.[24,25,27-32] However, these studies do not analyze the cross-sectional area, which depends on both instrument diameter and shape.
- The manufacturing process/thermomechanical treatment of the alloy may also have influenced the maximum torque values. Variations in the final thermomechanical state of the alloy (austenite, martensite, or R-phase) lead to different mechanical properties.

With regard to the maximum angular deflection before torsional failure, our results show significantly higher values for TF in comparison with ProFile Vortex. Conversely, no statistically significant difference was observed between TF and RaCe. Several authors suggest that resistance to torsion be assessed by angular deflection, not by the maximum torque.[28,33,34] This is justified by the fact that control of the torsional deflection (measured either in degrees or number of turns) may represent a safety factor when hand-operated instruments are used in clinical settings. In the event in which a hand-operated instrument may become lodged inside the canal, the clinician can apply torque within the torsional deflection limits, thus preventing instrument fracture caused by torsion. In engine-driven rotary instruments, however, it is not possible to control the angular deflection in torsion. Instead, these engines prevent instrument failure by controlling the maximum torque.[20,24,32,35]

Another important parameter that should be taken into account in order to explain the higher maximum angular deflection values of TF is related to the manufacturing process and the resulting surface finish of these instruments. Although TF instruments display the worst surface finishing, these manufacturing imperfections are longitudinal and perpendicular to the fracture plane. The nucleated cracks develop along the longitudinal imperfections, and do not contribute to form the fracture plane. After the torsion test, several cracks were observed on the surface of TF. In the remaining instruments, which present circumferential manufacturing imperfections, the cracks tend to develop more easily along these grooves, leading to instrument failure under smaller angular deflection (Fig 3).

The results obtained in the present study revealed a relationship between maximum torque, bending resistance, and maximum angular deflection until torsional failure. This may be explained by differences in instrument geometry, cross-sectional area, and moment of inertia. The cross-section shape plays an important role in the process of instrument fracture, since the maximum load (Lmax) is directly proportional to the radius (R) and to the maximum torque (Mt), and inversely proportional to the moment of inertia (I), as demonstrated by the following equation: $L_{max} = M_t R / I$.

The differences in torque resistance verified in the present study cannot be associated with the initial diameter at the instrument tips (standardized at 0.25 mm) or to the diameter at D3, (approximately the same for all instruments), nor to the taper (standardized at 0.06 mm). ProFile Vortex presented the greatest torsional resistance among the instruments tested. On the other hand, TF, the instrument with the lowest resistance to torsion, presented the greatest flexibility and the highest angular deflection before torsional failure. This result corroborates observations of other authors who reported that the cross-sectional area is inversely proportional to the flexibility of endodontic files.[6,18,20,30,36-39] It is important to mention that instruments with the same cross-sectional area may present different moments of inertia.

Based on the findings of the present study, it was possible to establish a relationship between flexibility and maximum torque, as well as between flexibility and maximum angular deflection for the instruments tested. The most flexible instrument (TF) was the least resistant to torsion, while the most resistant to torsion (ProFile Vortex) was the least flexible. TF, the most flexible, was also able to withstand the highest angular deflection until torsional failure, and ProFile Vortex, the least flexible, had the lowest angular deflection values. RaCe had intermediate results for both flexibility and angular deflection.

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