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Torsional fatigue resistance of pathfinding instruments manufactured from several nickel-titanium alloys

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Abstract

Alcalde MP, Duarte MAH, Bramante CM, Tanomaru-filho M, Vasconcelos BC, Só MVR, Vivan RR. Torsional fatigue resistance of pathfinding instruments manufactured from several nickel-titanium alloys. *International Endodontic Journal*.

Aim To evaluate the torsional properties of pathfinding nickel-titanium (NiTi) rotary instruments manufactured from several NiTi alloys, ProGlider (M-wire), Hyflex GPF (conventional NiTi Wire and controlled memory wire), Logic (conventional NiTi wire and controlled memory wire) and Mtwo (conventional NiTi wire).

Methodology A total of 56 NiTi instruments from Glidepath rotary systems ($n = 8$) were used: Logic (size 25, .01 taper), Logic CM (size 25, .01 taper), ProGlider (size 16, .02 taper), Hyflex GPF (size 15, .01 taper), Hyflex GPF CM (size 15, .02 taper; size 20, .02 taper) and Mtwo (size 10, .04 taper). The torsion tests were performed based on ISO 3630-1 (1992). Three millimetres of each instrument tip was clamped to a small load cell by a lever arm linked to the torsion axis. Data were analysed using a one-way analysis of variance (ANOVA) and Tukey test with a significance level at $a = 5\%$.

Results The Logic size 25, .01 taper had significantly higher torsional strength values ($P < 0.05$). The ProGlider was significantly different when compared with Hyflex GPF size 15, .01 taper and size 15, .02 taper ($P < 0.05$). The Logic CM size 25, .01 taper had significantly higher torsional strength than Hyflex GPF size 15, .01 taper and size 15, .02 taper ($P < 0.05$). No difference was found amongst Mtwo size 10, .04 taper and Hyflex GPF groups (size 15, .01 taper; size 15, .02 taper; size 20, .02 taper). In relation to the angle of rotation, Logic CM size 25, .01 taper and Hyflex GPF size 15, .01 taper had the highest angle values ($P < 0.05$). The ProGlider had the lowest angle values in comparison with all the groups ($P < 0.05$) followed by Mtwo size 10, .04 taper. The Logic size 25, .01 taper had significantly higher angle of rotation values than ProGlider and Mtwo size 10, .04 taper ($P < 0.05$).

Conclusion The Logic size 25, .01 taper instrument made of conventional NiTi alloy had the highest torsional strength of all instruments tested. In addition, the ProGlider instrument manufactured from M-Wire alloy had the lowest angle of rotation to fracture in comparison with the other instruments.

Keywords: Nickel-Titanium, pathfinding instruments, rotary instruments, thermal treatment.

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Introduction

Maintenance of the original root canal morphology is mandatory during root canal preparation (Patiño *et al.* 2005, De-Deus *et al.* 2016). Creation of a glide path is an important clinical procedure with the purpose of preshaping the root canal from its orifice to its apical foramen (West 2010, Ruddle *et al.* 2014) to prevent shaping errors (Patiño *et al.* 2005, Berutti *et al.* 2009, West 2010). This clinical step has been widely recommended to improve the safety of rotary nickel-titanium preparation by decreasing the incidence of instrument fracture (Pasqualini *et al.* 2012, D'Amario *et al.* 2013).

The glide path can be performed with conventional stainless steel hand files or with mechanical NiTi instruments with small tip sizes and smaller taper (Gambarini *et al.* 2015). At present, use of NiTi rotary instruments for glide path preparation has been recommended because it leads to a reduction in postoperative pain (Pasqualini *et al.* 2012); preservation of the original root canal morphology (D'Amario *et al.* 2013, Elnaghy & Elsaka 2014); prevention of instrument fracture (Berutti *et al.* 2009) and is simple to teach (West 2010).

The NiTi instruments used for glide path preparation are susceptible to torsional failure in constricted root canals because they are used at the beginning of the procedure (Arias *et al.* 2016, De-Deus *et al.* 2016). Torsional failure occurs when the tip of the instrument is locked in the canal whilst the shank continues to rotate (Sattapan *et al.* 2000). This can happen especially in the preparation of constricted canals when the file is susceptible to high torsional loads (Wycoff & Berzins 2012). Therefore, to minimize this drawback, the manufacturers have developed new instruments with various cross-sections, designs and thermomechanical treatments (Karataş *et al.* 2016).

Several NiTi rotary glide path files are manufactured as single-file or multiple-file systems. Examples of single-file glide path instruments include ProGlider (Dentsply Sirona, Ballaigues, Switzerland), Mtwo (VDW, Munich, Germany) and ProDesign Logic (Easy Equipamentos Odontológicos, Belo Horizonte, Brazil).

The ProGlider instrument is made of M-wire alloy (Dentsply Sirona) and has a square cross-section design. It has a size 16 tip and variable taper of between 2% and 8% along the shaft (De-Deus *et al.* 2016). The Mtwo rotary instrument has a size 10 tip and .04 taper, manufactured from conventional NiTi Wire and an S-shaped cross-sectional design with double cutting edges and noncutting tip (de Oliveira Alves *et al.* 2012). The Prodesign Logic size 25, .01 taper (Easy Equipamentos Odontológicos) is new glide path instrument that has a square cross-section. This instrument is made of both conventional NiTi Wire and CM-Wire.

The Hyflex GPF (Coltene-Whaledent, Altstätten, Switzerland) is an example of a multiple-rotary pathfinding system composed of three instruments: size 15, .01 taper, size 15, .02 taper, and size 20, .02 taper. The instrument size 15, .01 taper is manufactured of conventional NiTi Wire and a triangular cross-section; the other instruments are made of controlled memory wire (CM-Wire) and have a square cross-section (Capar *et al.* 2015).

The advantages of rotary techniques for glide path preparation are evident; however, unexpected instrument fracture can occur. The torsional properties of pathfinding instruments can vary according to the instrument's taper, tip size, cross-sectional design and the type of NiTi used during the manufacturing process (Elnaghy & Elsaka 2015, Arias *et al.* 2016, De-Deus *et al.* 2016). Thus, knowledge of the best torque recommendations of these instruments is of fundamental importance to provide a safe and effective clinical application. The torsion test provides the maximum torsional strength and angle of rotation supported by an instrument before fracture (Arias *et al.* 2016, Pedullà *et al.* 2016). This test attempts to simulate a standardized and extreme clinical situation with high torsional load (Kim *et al.* 2012, Elnaghy & Elsaka 2015, Arias *et al.* 2016) and has been previously described (Elnaghy & Elsaka 2015, Arias *et al.* 2016, Pedullà *et al.* 2016, Alcalde *et al.* 2017).

There is a lack of information comparing the torsional properties of these instruments, especially of the Proglider, GPF Hyflex, Logic size 25, .01 taper and Logic CM size 25, .01 taper systems. The aim of this study was to evaluate the torsional properties (maximum torsional strength and angle of rotation) of the Proglider, Hyflex GPF, Logic and Mtwo instruments. The null hypothesis was that there would be no difference in the torsional properties amongst the types of instruments.

Materials and methods

The sample calculation was performed using the G*Power v3.1 for Mac (Heinrich Heine University Düsseldorf (HHU) by selecting the Wilcoxon–Mann–Whitney test of the *t*-test family. The alpha-type error of 0.05, a beta power of 0.95, and a ratio N2/N1 of 1 were also stipulated. A total of six samples per group were indicated as the ideal size required for noting significant differences. Eight samples per group were used because an additional 20% was calculated to compensate for possible outlier values that might lead to sample loss.

A sample of 56 NiTi instruments (length, 25 mm) from seven different Glidepath rotary systems ($n = 8$ per system) were used, as follows: Logic (size 25, .01 taper), Logic CM (size 25, .01 taper), ProGlider (size 16, .02 taper), Hyflex GPF (size 15, .01 taper), Hyflex GPF CM (size 15, .02 taper; size 20, .02 taper) and Mtwo (size 10, .04 taper). Before testing, every instrument was inspected for defects or deformities under a stereomicroscope (Stemi 2000C; Carls Zeiss, Jena, Germany) at 16× magnification; none were discarded.

Torsional test

The torsion tests were performed, based on the International Organization for Standardisation ISO 3630-1 (1992) specification, using a torsion machine described in detail elsewhere (Bahia *et al.* 2006, Alcalde *et al.* 2017).

Before testing, each instrument handle was removed at the point where the handle was attached to the shaft. The shaft of each instrument was clamped in a chuck with brass jaws to prevent sliding and was connected to the reversible geared motor. The rotation speed of the motor was set at 2 rpm in a clockwise direction for all groups. Three millimetres of the instrument's tip was clamped into another chuck with brass jaws. The torque values were assessed by measuring the force exerted on a small load cell by a lever arm linked to the torsion axis. Measurement and control of the rotation angle were performed by a resistive angular transducer connected to a process controller. Continuous recording of torsional strength and angle of rotation were monitored, and the ultimate torque and angle before fracture (°) were provided by a specifically designed computer program (Analógica, Belo Horizonte, MG, Brazil) and were recorded.

SEM evaluation

After the torsional test, four instruments of each group were randomly selected and ultrasonically cleaned to remove debris. The instruments were examined by scanning electron microscopy (JEOL, JSM-TLLOA, Tokyo, Japan) to assess the topographic features of the fractured surface of the instruments. The photomicrographs were taken at 50× and 350× magnification. Furthermore, additional photomicrographs were taken at 1000× magnification in the centre of the fracture surface of the instruments to improve the analysis of the topographic features.

Statistical analysis

Preliminary analysis of data normality was performed with the Shapiro–Wilk test, showing that the data were normally distributed. The One-way analysis of variance (ANOVA) and Tukey tests were used for multiple and individual comparisons. The Prism 6.0 software (GraphPad Software Inc., La Jolla, CA, USA) was used as the analytical tool, and the level of significance was set at 5%.

Results

The mean and standard deviations of torsional fatigue resistance (torque maximum torsional strength and angle of rotation) for each instrument are presented in Table 1. The Logic size 25, .01 taper had significantly higher torsional strength values than all the other groups ($P < 0.05$). The ProGlider was significantly different only when compared with Hyflex GPF size 15, .01 taper and size 15, .02 taper ($P < 0.05$). The Logic CM size 25, .01 taper showed significantly higher torsional strength values than Hyflex GPF size 15, .01 taper and size 15, .02 taper ($P < 0.05$). No difference was found between the Mtwo size 10, .04 taper and Hyflex GPF groups (size 15, .01 taper; size 15, .02 taper; size 20, .02 taper). The Hyflex GPF CM size 20, .02 taper showed higher torsional strength values than GPF size 15, .01 taper and size 15, .02 taper ($P < 0.05$). No difference was found between Hyflex GPF size 15, .01 taper and size 15, .02 taper.

In relation to the angle of rotation, the ProGlider had the lowest values when compared with the other groups ($P < 0.05$) followed by Mtwo size 10, .04 taper. The Logic size 25, .01 taper had significantly higher angle of rotation values than ProGlider and Mtwo size 10, .04 taper ($P < 0.05$). The Logic CM size 25, .01 taper was not significantly different when compared with Hyflex GPF size 15, .01 taper ($P < 0.05$). No difference was found between the Hyflex GPF size 15, .01 taper and size 15, .02 taper. The Hyflex GPF CM size 20, .02 taper had a significantly lower angle of rotation than Hyflex GPF size 15, .01 taper and size 15, .02 taper ($P < 0.05$).

SEM evaluation

Scanning electron microscopy of the fracture surface revealed similar and typical features of torsional failure for all brands. All the instruments had concentric

Table 1 Torque (N cm) and angle of rotation (°) of instruments tested

	Instruments													
	Logic 25.01		Logic 25.01 (CM)		ProGlider 16.02		Mtwo 10.04		GPF 15.01		GPF 15.02		GPF 20.02	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Torque (N cm)	0.47[a]	0.057	0.29[b,d]	0.030	0.30[b]	0.079	0.25[b,d,e]	0.018	0.19[c,e,f]	0.010	0.19[c,e,f,g]	0.016	0.30[b,d,e]	0.010
Angle (°)	793.1[a]	58.50	1395[c]	67.41	388.2[b]	66.54	544.7[d]	41.07	1337[c,e]	131.0	1229[e,f]	41.24	1088[g]	34.34

SD, standard deviation. Different superscript letters in the same line indicate significant differences amongst groups ($P < 0.05$).

abrasion marks and fibrous dimple marks at the centre of rotation for torsional failure (Fig. 1). In addition, in the side view, it is possible to note the deformation of the spiral flutes of the instruments, mainly in those that had a higher angle of rotation value (Fig. 1).

Discussion

Glide path preparation reduces the possibility of operational errors (D'Amario *et al.* 2013, Elnaghy & Elsaka 2014) and the risk of instrument fracture (Berutti *et al.* 2009), particularly in constricted root canals, in which the instrument is susceptible to high torsional loads (Sattapan *et al.* 2000). If instrument fracture occurs at this stage and the fragment cannot be removed, the root canal cannot be cleaned, which could compromise the success of the treatment (Capar *et al.* 2015). Thus, it is important to know the torsional fatigue resistance of the pathfinding instruments for suitable clinical use. The results of this study revealed that there was a significant difference in relation to the maximum torsional strength and angle of rotation amongst the instruments tested. Thus, the null hypothesis was rejected.

In this study, the torsional fatigue resistance (maximum torsional strength and angle of rotation) to fracture was evaluated. The torsional tests were performed in accordance with the ISO Standard 3630-1 specification. In this study, 3 mm of the tip was fastened and rotation in a clockwise direction was set for all instruments. The 3 mm of the tip was chosen because at this point, the instrument is more susceptible to fracture than at 5 mm (Capar *et al.* 2015).

Several variables such as instrument tip size, taper, cross-sectional design and manufacturing techniques affect the clinical performance of endodontic files and their resistance to fracture by torsion (Pereira *et al.* 2012, Arias *et al.* 2016, De-Deus *et al.* 2016, Kaval *et al.* 2016, Magalhães *et al.* 2016, Acosta *et al.* 2017). The results revealed that Logic size 25, .01 taper had significantly higher torsional strength values when compared with all the groups ($P < 0.05$). However, the Logic CM size 25, .01 taper had significant differences only when compared with Hyflex GPF size 15, .01 taper and size 15, .02 taper ($P < 0.05$). Although the Logic size 25, .01 taper and Logic CM size 25, .01 taper have the same tip size, taper and cross-sectional design, the results revealed there was a significant difference between the groups

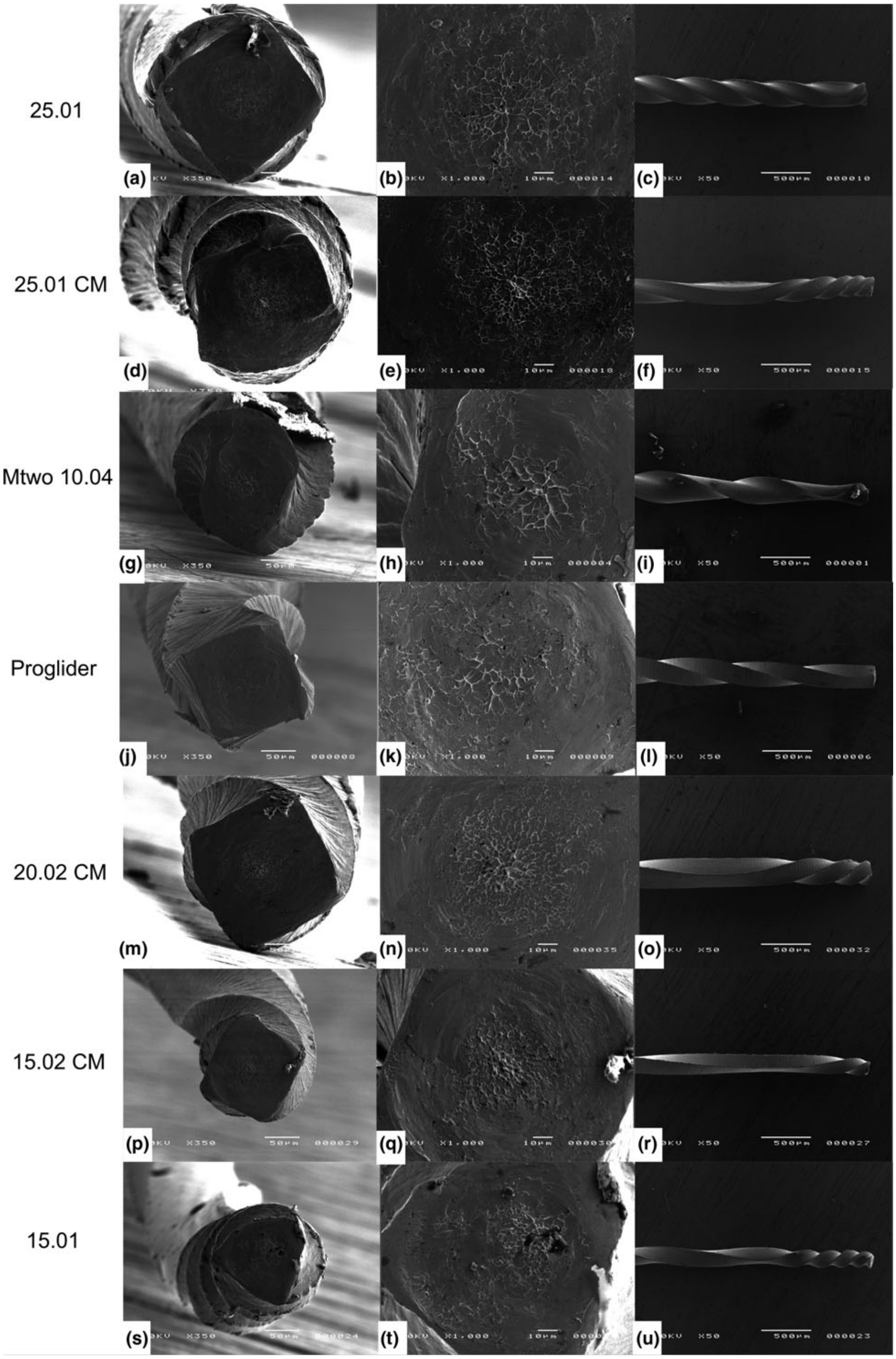

Figure 1 Scanning electron microscopy images of fractured surfaces of separated fragments of (a–c) Logic size 25, .01 taper, (d–f) Logic size 25, .01 taper CM, (g–i) Mtwo size 10, .04 taper, (j–l) ProGlider, (m–o) Hyflex GPF CM size 20, .02 taper, (p–r) Hyflex GPF CM size 15, .02 taper and (s–u) Hyflex GPF size 15, .01 taper after torsional fatigue testing. The first column shows the front-view images of the instruments at 350× magnification; the second column shows the concentric abrasion mark at 1000× magnification; the skewed dimples near the centre of rotation are typical features of torsional failure; the third column represents the side view of the instruments at 50× magnification, showing the plastic deformation of the spiral flutes.

($P < 0.05$). This could be explained because of the different NiTi alloys used during the manufacturing process. Previous studies have shown that controlled memory wire has greater flexibility and lower torsional load than conventional NiTi Wire (Pereira *et al.* 2012, Shen *et al.* 2013, Kaval *et al.* 2016, Kwak *et al.* 2016, Pedullà *et al.* 2016, Acosta *et al.* 2017).

There was no significant difference ($P < 0.05$) relative to the torsional strength amongst Logic CM size 25, .01 taper, Proglider, Mtwo size 10, .04 taper and GPF CM size 20, .02 taper groups. These results are probably related to their different cross-sectional design, type of NiTi alloy, tip size and taper, which affected the torsional properties of NiTi instruments (Ninan & Berzins 2013, Shen *et al.* 2013, Kaval *et al.* 2016, Pedullà *et al.* 2016, Silva *et al.* 2016, Acosta *et al.* 2017). The Hyflex GPF size 15, .01 taper and size 15, .02 taper had the lowest torsional strength values when compared with the other groups ($P < 0.05$). Previous reports have indicated that instruments with lower metal mass (diameter of core, tip size and taper) generally have lower torsional strength (Baek *et al.* 2011, Zhang *et al.* 2011, Kim *et al.* 2012, Kwak *et al.* 2016, Pedullà *et al.* 2016).

However, it was difficult to make comparisons amongst the different instruments, because of differences in the type of alloy, cross-section, tip size and taper. In a supplementary examination, the cross-sectional configuration of the instruments was captured at D3 by SEM and the area measured by means of software (AutoCAD; Autodesk Inc, San Rafael, CA, USA; Pedullà *et al.* 2016). The Hyflex GPF size 15, .01 taper and Hyflex GPF CM size 15, .02 taper had the smallest area (14.491 and 24.699 μm^2, respectively) followed by ProGlider (30.823 μm^2), Hyflex GPF size 20, .02 taper (33.311 μm^2), Mtwo size 10, .04 taper (36.890 μm^2), Logic size 25, .01 taper and Logic CM size 25, .01 taper (42.469 and 42.472 μm^2). The Hyflex GPF size 15, .01 taper and size 15, .02 taper had lower torsional strength values until fracture and also the smallest cross-sectional areas. Previous reports have stated that instruments with small cross-sectional areas generally have lower torsional strength (Turpin *et al.* 2000, Baek *et al.* 2011, Kim *et al.* 2012, Ninan & Berzins 2013, Pedullà *et al.* 2016). Moreover, the cross-sectional design modified the stress distribution under torsion, which affected the torsional strength and susceptibility to fracture (Turpin *et al.* 2000, Zhang *et al.* 2011, El-Anwar *et al.* 2016).

In relation to the angle of rotation, the Logic CM size 25, .01 taper had the highest deformation capacity when compared with the other groups ($P < 0.05$) followed by GPF size 15, .01 taper, Hyflex GPF CM size 15, .02 taper, Hyflex GPF CM size 20, .02 taper, and Logic size 25, .01 taper. The ProGlider and Mtwo size 10, .04 taper had significantly lower values than the other groups ($P < 0.05$). Additionally, the ProGlider had a significantly lower angle of rotation values than Mtwo size 10, .04 taper. It is important to note that the instruments with smaller taper diameters had the highest angles of rotation to fracture. The results were in agreement with the studies of De-Deus *et al.* (2016) and Arias *et al.* (2016) that revealed that instruments with a larger taper are more susceptible to fracture.

The higher angle of rotation of Logic CM size 25, .01 taper, Hyflex GPF size 15, .02 taper and size 20, .02 taper could be influenced by the special thermal treatment of the NiTi used in manufacturing process, which increased the flexibility and deformation capacity of controlled memory instruments (Pereira *et al.* 2012, Peters *et al.* 2012, Shen *et al.* 2013, Kaval *et al.* 2016, Kwak *et al.* 2016, Pedullà *et al.* 2016, Acosta *et al.* 2017). However, CM of NiTi is not always superior to the conventional NiTi Wire or M-Wire, because other factors, such as cross-sectional design, core mass, taper and tip size (Ninan & Berzins 2013, Shen *et al.* 2013), need to be taken in account, which could explain the high angle of rotation values of Hyflex GPF size 15, .01 taper.

The scanning electron microscopy analysis revealed the typical fractographic appearance of torsional fractures that were similar amongst all brands (Fig. 1). After the torsional test, the fragments demonstrated the typical features of shear failure, including concentric abrasion marks and fibrous microscopic dimples at the centre of rotation (Kim *et al.* 2012, Pedullà *et al.* 2016). In addition, in the side view, it was possible to note the deformation of the spiral flutes of the instruments, particularly in those that had a higher angle of rotation before fracture (Fig. 1).

The torsional test was performed in accordance with the ISO Standard 3630-1 methods for root canal instruments as previously described (Elnaghy & Elsaka 2015, Arias *et al.* 2016, Pedullà *et al.* 2016, Alcalde *et al.* 2017). This test provides accurate information regarding the maximum torsional strength and angle of rotation supported by each instrument before fracture, ensuring precise torque values for their safe and effective clinical use (Bahia *et al.* 2006, Arias *et al.*

2016). In this study, the test did not simulate the clinical use of instruments. However, it provided precise and standardized conditions of high torsional loads for all groups (Kim *et al.* 2012, Pedullà *et al.* 2016). Furthermore, during the glide path procedure, a pecking motion is recommended to prevent the instrument tip locking in the root canal (Berutti *et al.* 2009, De-Deus *et al.* 2016). However, in this study, the static model was used to allow a precise condition for all instruments with the objective of decreasing several variables, such as, the amplitude motion of the file and the amount of force applied in the axial direction, which are completely subjective in a clinical situation (Kim *et al.* 2012, Lopes *et al.* 2013). In addition, the standardisation of the force and the direction is fundamental to ensure accurate results for the torsional tests (Bahia *et al.* 2006, Lopes *et al.* 2013).

Conclusions

The Logic size 25, .01 taper instrument made of conventional NiTi alloy had the highest torsional strength of all instruments tested. In addition, the ProGlider instrument manufactured from M-Wire alloy had the lowest angle of rotation to fracture in comparison with the other instruments.

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Conflict of interest

The authors have stated explicitly that there are no conflicts of interests in connection with this article.

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