CYCLIC AND TORSIONAL FATIGUE RESISTANCE OF THREE DIFFERENT THERMALLY TREATED NICKEL-TITANIUM ROTARY INSTRUMENTS

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ABSTRACT

Background: The aim of this study was to evaluate the cyclic fatigue and torsional fatigue resistance of three thermally treated rotary instruments, such as: Logic 2 25.05 (LOG 25.05), Edge Taper Platinum 25.06 (EDT 25.06) and ProTaper Gold 25.08 (PTG 25.08).
Methods: A total of 60 rotary instruments of LOG 25.05, EDT 25.06 and PTG 25.08 were used (n=20). Cyclic fatigue tests were performed at 36°C using an artificial stainless steel canal with a 60º angle and a 5-mm radius of curvature. The time (in seconds) and number of cycles to fracture (NCF) was recorded. The torsional test evaluated the torque and angle of rotation to failure at 3 mm from the tip according to ISO 3630-1. The fractured surface of each fragment was observed by using scanning electron microscopy (SEM). Data were analyzed using one-way ANOVA and Holm-Sidak's tests for multiple comparison, the level of significance was set at 5%.
Results: EDT 25.06 had highest cyclic fatigue resistance (time and NFC), followed by LOG 25.05 and PTG 25.08 ($P<0.05$). There were no significantly difference between LOG 25.05 and ETP 25.06 regarding the NCF ($P>0.05$). In relation the torsional test, the LOG 25.05 and ETP 25.06 presented similar torque ($P>0.05$). The PTG presented greater torque than the other groups ($P<0.05$). The PTG 25.08 presented the lowest angular rotation to fracture than the other groups ($P<0.05$). The SEM images demonstrated typical features of cyclic and torsional fracture.
Conclusion: In conclusion, the LOG 25.05 and ETP 25.06 presented similar cyclic and torsional properties. The PTG 25.08 showed greater torsional strength.
KEYWORDS: Endodontics. Nickel-Titanium. Endodontic instruments.

INTRODUCTION

The introduction of nickel-titanium (NiTi) rotary instruments in endodontics provided several advantages: faster preparation, safer procedures, and greater canal centering ability than stainless steel instruments[1,2]. However, these instruments continue to be susceptible to separation caused by cyclic or torsional fatigue[3].

Instrument separation is strongly affected by instrument features (cross-section, taper, core diameter, and type of NiTi)[4]. The manufacturers have proposed several modifications to the instrument's design and the thermal treatment of the NiTi to improve the flexibility and resistance to fatigue during root canal preparation[5]. Also, it is important to emphasize that the clinician should know the mechanical properties of the instruments to ensure safe clinical use according to the root canal anatomy [6,7].

The ProTaper Gold (Dentsply-Sirona, Baillagues, Switzerland) is the new generation of ProTaper Universal (Dentsply-Sirona, Baillagues, Switzerland), which use the same sequence and design but with different type of NiTi alloy[7]. One of the main features of all generation ProTaper instruments is the variable taper along the spiral flutes, reducing the metal mass volume and higher flexibility[7,8].

The EdgeTaper Platinum (EdgeEndo, Albuquerque, NM) is a heat-treated rotary system that presents convex triangular cross-section and the technique preparation of ProTaper Gold system[9,10]. Accordingly with the manufacturers, the Fire Wire™ thermal treatment and a progressive changing taper design along the instrument favor high flexibility. Previous studies reported that Edge Taper platinum 25.06 presented greater cyclic fatigue resistance and lower torsional resistance than ProTaper Gold 25.08 [9,10].

Recently, a novel heat-treated NiTi rotary system was introduced in the market, Logic 2 Rotary system (Easy Equipamentos Odontológicos, Brazil). This system has an S-Shaped cross-section and is manufactured by controlled memory technology. In this second generation, the manufacturer reduced the 0.06 taper to 0.05 mm/mm of the instrument #25. Also, the when the diameter of the instruments reaches 1.0mm of diameter on the spiral flutes, the wire becomes a cylinder, that is, without taper. According with the manufacturer, these modifications promoted the volume reduction of metal mass along of the spiral flutes, favoring greater preservation of dentin during canal shaping and flexibility.

To date, there is no reporting available the cyclic and torsional fatigue resistance of the new Logic 2 rotary system. Therefore, the aim of this study to investigate the cyclic and torsional fatigue resistance of the Logic 2 25.05, EdgeTaper Platinum and compare it with the ProTaper Gold instruments. The null hypotheses tested were as fallow:

(1) There would be no difference in cyclic fatigue resistance among the instruments;
(2) There would be no difference in the torsional properties (maximum torque and angular rotation) among the instruments.

MATERIALS AND METHODS

The sample size calculation was performed based on a pilot study using G*Power v3.1 for Mac (Heinrich Heine, University of Düsseldorf, Düsseldorf, Germany) by selecting the ANOVA: Fixed effect, omnibus, one-way of the F family. An alpha-type errorof 0.05, a beta power of 0.095, and an effecti size of 0.08 were used. A total of eigh instruments per group were indicated as the ideal size required for noting significant differences. Ten instruments were used because of an additional 20% was calculated to compensate for possible outlier values that might lead to samples loss.

A total of 60 NiTi instruments (25 mm) were used for this study. The samples were divided into three groups (n=20), as follows: LOG 25.05, EDT 25.06 and PTG 25.08 systems. Previously to the mechanical tests, all instruments were inspected under a stereomicroscope (Carls Zeiss, LLC, EUA) at 16x magnification to detect possible defects or deformities; none were discarded.

Cyclic fatigue Test

The cyclic fatigue test was performed using a custom-made device that simulated an artificial canal made of stainlless-steel, with a 60^0 angle of curvature and a 5-mm radius of curvature, as previously described[9,13]. The cyclic fatigue tests were performed at body temperature (36° ± 1°C) using a histology water bath equipement (Leica HI 1210), which allowed to control the temperature [11, 12]. A total of 600 mL of water was used to fill the the equipement container to the desired level, allowing that the simulated canal was totally submerged on the water. The temperature was controlled using a digital thermometer of the equipement and infrared thermometer during all the test.

A total of 10 instruments for each system were used, coupled to a VDW Silver Motor (VDW, Munich, Germany) connected to the cyclic fatigue device. Instruments were activated according to the manufacturers recomendations, as follow: LOG 25.05 (950 RPM and 4N.cm), ETP (300 RPM and 3 N.cm), and PTG (300 RPM and 3 N.cm). The time to failure was recorded using a digital chronometer and video recording was made simultaneously to ensure the exact time of instrument fracture. The number of cycles to failure (NCF) was calculated using the following formula: time to failure (in seconds) X RPM/ 60.

Torsional fatigue Test

The torsional tests were performed, based on ISO 3630-1 (1992), as previously reported[9,13]. A total of 10 instruments of each rotary system were used. The test was performed to measure the maximum torque and angular rotation until instrument failure using a specific program and torsion machine (MicroTorque; Analógica, Belo Horizonte, MG, Brazil). The three millimeters of the instrument tips were clamped into a mandrel connected to a geared motor. The geared motor operated in clockwise rotation, at speed set to 2 rpm for all the groups.

SEM Evaluation

The instruments were assessed by SEM evaluation (JEOL, JSM-TLLOA, Tokyo, Japan) to determine the topographic features of the fragments. The instruments were cleaned in an ultrasonic cleaning device (Gnatus, Ribeirão Preto, São Paulo, Brazil) in distilled water during 3 minutes before SEM evaluation. All the fractured surfaces of the instruments were examined at 200x and 1000x magnification in the center of the surface.

RESULTS

The mean and standard deviatons of time and NCF of the cyclic fatigue test are shown in **Table 1**. The EDT 25.06 had a significant higher time to fracutre, followed by the LOG 25.05 and PTG 25.08 (P<0.05). Regarding the NCF, there was no signifincatly difference between LOG 25.05 and EDT 25.06 (P>0.05). PTG 25.08 presented the lowest values of NCF (P<0.05).

The mean and standard deviations of torque (maximum torsional strength - N.cm) and angular rotation (°) to fracture are show in **Table 1**. There was no significant difference between LOG 25.05 and EDT 25.06 regarding the maximum torsional strength (P>0.05). The PTG 25.08 presented the highest torsional strength values (P<0.05). In relation of the angular rotation, the LOG 25.05 and EDT 25.06 presented similar angular values to fracture (P>0.05). The PTG 25.08 presented the lowest angular values than the other groups (P<0.05).

Table 1. Mean values of time (in seconds), number of cycles (NCF), Torque (N.cm) and angular rotation (°) of instruments tested.

Instruments	Cyclic Fatigue				Torsional Fatigue			
	Time (seconds)		Cycles (NCF)		Torque (N.cm)		Angles (°)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
LOG 25.05	244.7^{a}	50.11	1427^{a}	92.20	1.13^{a}	0.121	705.3^{a}	109.10
EDT 25.06	290.6^{b}	08.55	1453^{a}	42.76	1.08^{a}	0.112	625.3^{a}	34.28
PTG 25.08	146.5^{c}	12.27	732.7^{c}	61.32	1.52^{b}	0.097	444.1^{b}	30.64

SD, standard deviation.

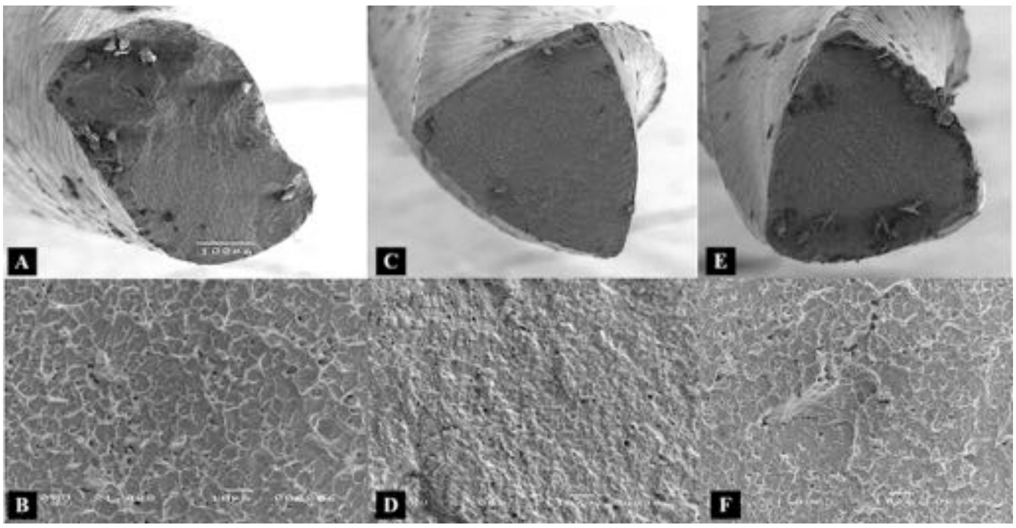
Different superscript letters in the same column indicate statistical differences among groups (P < .05).

The SEM evaluation of the fractured surface revealed similar and typical features of cyclic and torsional behavior. The cyclic fatigue test crack caused crack initiation area and microscopic dimples (**Fig. 1**). The torsional test generated a concentric abrasion marks, with a dimple surface with micro-voids at the center (**Fig. 2**).

DISCUSSION

The instrument separation during root canal preparation might occur due to cyclic and torsional fatigue [14,3]. The evaluation of mechanical properties of engine-driven NiTi instruments can be valid information for the clinicians, helping them to choose the suitable instrument for constricted or curved canals[4,9,13]. Therefore, the laboratory studies of cyclic and torsional fatigue can provide information of their mechanical properties, which could be extrapolated to their resistance to fatigue during canal preparation[9,15]. During a literature review, there was no study evaluating the mechanical properties fatigue resistance of Logic 2 25.05 rotary instrument. For this reason, the aim of this study aimed to evaluate the cyclic and torsional

Figure 1: SEM images of fractured surfaces of separated fragments of Logic 2 25.05 (A,B), Edge Taper Platinum (C, D) and ProTaper Gold (E, F) instruments after cyclic fatigue testing. The images show numerous dimples, a feature of ductile fracture.



fatigue resistance of Logic 2 25.05 and to compare with ProTaper Gold 25.08 and EdgeTaper Platinum 25.06.

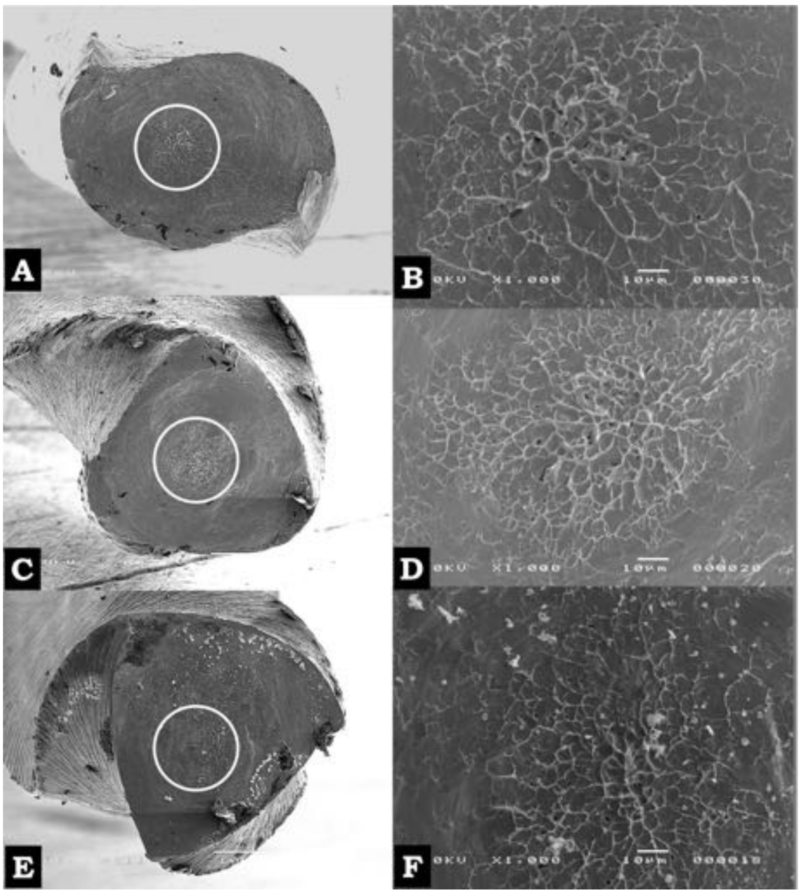
The methodology used in this study was already validated and previously published in peer-reviewed journals[11-13]. It is important to high light that there are no specification or international standards for cyclic fatigue methodology of NiTi instruments. Plotino et al.[16] affirmed that the artificial canal should reproduce the instrument size and taper of the instruments tested to ensure a accurate canal trajectory in terms of radius and angle of curvature. However, this is not possible in the current study because the taper of the instruments differed among them. Therefore, the testing condition was standardized using same tapered artificial canal for all the groups (0.40 mm diameter at most apical portion, and 0.08 mm of fixed taper).

Another methodological point that needs to be addressed is the static cyclic fatigue model used in this study, as previously reported[8,9,13,15]. It has been a huge discussion on literature regarding the use of static model to evaluate cyclic fatigue resistance. Some authors, stated that static model induces higher localized stress, reducing the time and number of cycles to fatigue and not reproduces the clinical use of the instruments[17,18]. On the other hand, Dederich and Zakariasen[19] stated that the dynamic model could create a torsional stress depending on the design of the tube or artificial groove, which could modify the results. Therefore, it would be necessary the use of axial motion without any lateral movement during the tests, which is complicated, as reported by Hullsman et al.[17]. For this reason, this study used the static test because the dynamic analysis seems to be a more sensitive method and could create other variables beyond the type of the instrument.

The first results of the present study demonstrated significant differences in the cyclic fatigue resistance among the instruments. The EDT 25.06 presented highest time to fatigue followed by LOG 25.05 ($P<0.05$). There was no significant difference regarding the NCF between EDT 25.06 and LOG 25.05 ($P>0.05$). PTG 25.08 presented the lowest time and NCF to fatigue ($P<0.05$). Therefore, the first null hypothesis was rejected. Although all tested instruments have the same tip size (0.25mm), it has different taper values, cross-section design, and type of NiTi among then. PTG 25.08 and EDT 25.06 present convex triangular cross-section, and LOG 25.05, an S-shaped cross-section. Also, the PTG and EDT present fixed taper along the first three millimeters of the tip, while LOG has a fixed taper along with the spiral flutes. Previous studies have shown that cross-section design and taper values can provide large metal mass volume of the instruments, reducing the flexibility and the cyclic fatigue resistance [4,13,15]. Therefore, it could be speculate that PTG presented higher metal mass volume at the maximum point of stress during the cyclic fatigue test, explaining the results.

Other points that need to be discussed are the different thermal treatments of the instruments and the rotation speed used during the tests. The thermal treatments of the NiTi alloys can induce a higher percentage of the martensitic phase, which has a key role effect on the instrument's flexibility[2,5,20]. Previous reports have indicated that instruments with a greater amount of martensitic phase tend to present more flexibility and

Figure 2: SEM images of fractured surfaces of separated fragments of Logic 2 25.05 (A,B), Edge Taper Platinum (C, D) and ProTaper Gold (E, F) instruments after torsional test, with the circular box indicating the concentric abrasion mark at 200X magnification ; the right column shows the concentric abrasion mark at 1000x magnification, the skewed dimples near the center of rotation are typical features of torsional failure.



higher cyclic fatigue resistance [5,20]. Our results demonstrated that EDT 25.06 and LOG 2 25.06 showed greater cyclic fatigue resistance between PTG 25.08. Probably, the type of thermal treatment of Protaper Gold favors less martensitic phase and, an association of the design of the instruments, less flexible instruments. The results of this study are in agreement with previous studies that stated that EDT 25.06 is more cyclic fatigue resistant than PTG 25.08 [9,10] and that control memory technology used in LOG 2 25.06 favor greater flexibility than Gold instruments [13,21]. Future studies should be conducted by differential calorimetry to complete our results.

Despite controversial literature regarding the influence on the rotational speed in the instrument's cyclic fatigue, these instruments were tested following the manufacturer's recommendations. It could be speculated that instruments with higher rotation speed should more stressed [22,23]. It would be expected that LOG 25.05 should present less time and NCF to fatigue, which did not occur. Therefore, the other points previous discussed had more influence on these results.

The methodology used in the torsional test was also reported and validated in previous studies [11,13]. This test aims to evaluate the maximum torsional strength and angular rotation to fracture, submitting then to a higher level of torsional stress[13,24]. The results of this study pointed out to significant differences among the tested instruments. Therefore, the second null hypothesis was also rejected. PTG 25.08 presented significant higher torsional strength and lower angular rotation to fracture than EDT 25.06 and LOG 2 25.05 ($P<0.05$); no significant difference was found between EDT 25.06 and LOG 2 25.05 ($P>0.05$). The possible explanation of our results could be related with the different design (cross-section, taper) and thermal treatments of the NiTi, as previous discussed. Previous studies have shown that NiTi instruments with greater metal mass volume tend to present higher torsional load [4,9]. Also, previous studies showed that the thermal treatment of PTG favor less flexibility than FireWire™ and CM-Wire treatment of EDT and LOG, respectively[9,10]. Probably, the PTG 25.08 probably present higher metal mass volume at the first 3 mm of the tip of the instruments and a less % martensitic phase on the NiTi, which could explain our results. It is important to emphasize that all values of torque to fracture were lower than those indicated by the manufacturers, which is a significant data to the clinician, suggesting that the torque values could be reduced during the use.

The SEM analysis showed the typical features of cyclic and torsional fatigue for the three tested reciprocating files. After the cyclic fatigue test, all of the instruments evaluated showed crack initiation areas and overload zones, with numerous dimples spread on the fractured surfaces. After the torsional test, the fragments showed concentric abrasion marks and fibrous dimples at the center of rotation.

CONCLUSION

In conclusion, with limitation of this study, the LOG 25.05 and ETP 25.06 presented similar cyclic and torsional fatigue resistance. The PTG 25.08 showed greater torsional strength.

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