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Evaluation of the Cyclic and Torsional Fatigue Resistance of Thermally Treated Hyflex CM *versus* Aurum Blue Nickel-titanium Rotary Instruments

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ABSTRACT

Introduction: We aim to evaluate the cyclic and torsional fatigue resistance of two rotary instruments, Hyflex CM 25/0.06 (HCM) (Coletene-Whaledent, Allstetten, Switzerland) and Aurum Blue (AB) 25/0.06 (Meta-Biomed, Republic of Korea). **Methods and Materials:** Forty rotary instruments, HCM 25/0.06 and AB 25/0.06 (*n*=20 each) were used. The instruments were rotated in an artificial stainless steel canal with a 60° angle and a 5-mm radius of curvature (*n*=10) at body temperature (35°±1°C). The torsional test evaluated the torque and angle of rotation at failure of new instruments (*n*=10) in the portion 3 mm from the tip according to ISO 3630-1. The fractured surface of each fragment was observed by scanning electron microscopy. The data were analyzed using unpaired student's *t*- test, and the level of significance was set at 5%. **Results**: AB 25/0.06 had significantly greater number of cycles to failure than HCM 25/0.06 ($P<0.05$). The torsional test showed there were no significant differences in the torsional strength and angular rotation to fracture between the groups ($P>0.05$). **Conclusion:** Based on this *in vitro* study, AB 25/0.06 instrument was more resistant to cyclic fatigue than the HCM 25/0.06 instrument, suggested that these instruments are safer than HCM 25/0.06 for the preparation of severely curved canals. However; there was no significant difference in the torsional properties of the two instruments then appear to have similar performance during constricted canal preparation.

Keywords: Cyclic Fatigue; Instrumentation; Nickel-titanium; Rotary System

Introduction

Nickel-titanium (NiTi) engine-driven instruments are widely used in shaping root canals because of their high flexibility, which favors safe root canal preparation and provides suitable centering ability [1, 2]. However, instrument fracture continues to be a concern during root canal procedures.

The most common causes of instrument fracture are cyclic stress and torsional stress [1, 2]. Cyclic fatigue fractures occur when the file is exposed to repetitive compaction and tension forces at the maximum point of flexure while rotating in a curved canal [3]. Torsional fracture occurs when the tip of the file becomes lodged in the root canal while its coronal segment continues to rotate [4].

The manufacturers have proposed several modifications of the instruments' design (spiral flutes, core diameter, and taper) and various thermal treatments of NiTi to improve their mechanical properties and resistance to fatigue [3-6]. The thermal treatment controls the transition temperature of the NiTi alloy by favoring better arrangement of the crystal structure [7-9]. Certain types of thermal treatment can induce a higher percentage of martensite or R-phase of crystalline structure, favoring higher flexibility and less the risk of instrument fracture [10-12].

Several previous studies showed that Hyflex CM (HCM) (Coletene-Whaledent, Allstetten, Switzerland) presents high flexibility and cyclic fatigue resistance [12-15] The "Controlled Memory Wire" (CM-Wire) technology provides high flexibility and higher cyclic fatigue resistance than other thermal treatments [13, 16-19]. Also, CM-Wire technology tends to reduce their torsional strength and increases the angular deflection to fatigue [2, 19].

Recently, a new rotary instrument, the Aurum Blue System (AB) (Meta-Biomed, Cheongju Korea) was introduced. These instruments are manufactured using a special thermal treatment that results in a distinctive blue color due to a visible titanium oxide layer, similar to the "Blue treatment" [3, 4]. According to the manufacturer, this thermal treatment favors a high percentage of the martensite phase, which makes the instruments extremely flexible and resistant to fatigue. In addition, the instruments are subjected to an electro polishing process that removes surface imperfections. There is no data on the literature regarding the cyclic and torsional properties of this rotary system.

Although the HCM and AB instruments present several different features in the manufacturing process, it would be suitable to compare the mechanical properties between them because HCM could be considered a gold standard instruments due to their excellent mechanical properties [12-14]. Therefore, the aim of this study was to evaluate the cyclic and torsional fatigue resistance of the HCM 25/0.06 and AB 25/0.06 instruments. The null hypotheses tested were as follows: (1) there would be no difference in the cyclic fatigue resistance of the instruments and (2) there would be no difference in the torsional resistance of the instruments.

Materials and Methods

This study did not use extracted teeth or patients, no ethics committee approval was necessary. The sample calculation was performed using G*Power v3.1 for Mac (Heinrich Heine, University of Düsseldorf, Germany) and selecting the Wilcoxon–Mann-Whitney test of the *t*-test family, as previous studies [19, 20]. An alpha-type error of 0.05, a beta power of 0.95, and an N2/N1 ratio of 1 were also stipulated. A total of 10 instruments per group were indicated as the ideal size required for each mechanical test. Therefore, 40 NiTi instruments (25mm long) representing the two rotary systems (n=20 per system) were used in this study, as follows: HCM 25/0.06 (HCM, Coletene-Whaledent, Allstetten, Switzerland) and AB 25/0.06 (AB, Meta-Biomed, Republic of Korea).

Before the cyclic and torsional fatigue tests, each instrument was inspected for defects or deformities before being tested under a stereomicroscope (Carls Zeiss, LLC, NY, USA) at 16× magnification; none were discarded.

Cyclic fatigue test

The cyclic fatigue tests were performed using a custom-made device that simulates an artificial curved canal with a 60° angle of curvature and a 5-mm radius of curvature, as in previous studies [19, 20]. The artificial canal had 0.40 mm diameter at the most apical portion and 0.06 mm taper, which ensured the instruments to rotate freely. The test was performed at body temperature (35°±1° C) by submerging the cyclic fatigue device in a plastic container filled with heated deionezed water. The temperature was adjusted to 35°±1° C using a thermostat (Hopar, Guangdong, China) and measured during all tests using a digital thermometer (Aleas, Guangdong, China), as previously reported [20].

Ten instruments of each rotary system were activated using a 6:1 reduction handpiece (Sirona Dental Systems GmbH, Bensheim, Germany) powered by a torque-controlled motor (Silver Reciproc, VDW, Munich, Germany) in accordance with the manufacturers' instructions. HCM 25/0.06 and AB 25/0.06 were used at 500 rpm and 2 N/cm. The artificial canal was lubricated with synthetic oil (Super Oil; Singer Co., Elizabethport, NJ, USA) during the test.

The time required to the instruments failure was recorded using a digital chronometer. In addition, video recording was performed to ensure accurate timing of instrument failure. Then, the number of cycles to instruments failure was obtained using following formula: number of rotations per min (RPM)/60 (number of rotations per sec).

Torsional fatigue test

The torsion tests were performed based on the "International Organization for Standardization" (ISO) 3630-1 (1992) specification using a torsion machine as previously described [19]. All instruments used were 25 mm long, and 10 instruments of each system were used to test the torsion to establish maximum torque load and distortion angle to failure.

The torque and distortion angle values were provided by a torsion machine (Analógica, Belo Horizonte, MG, Brazil) connected to a computer. A three-millimeter length of the instrument tip was clamped into a mandrel connected to a geared motor. The torque values were assessed by measuring the force exerted on a small load cell by a lever arm linked to the torsion axis. The geared motor operated in the clockwise direction at a speed set to 2 rpm. All data were recorded by a specific program of the machine (MicroTorque; Analógica, Belo Horizonte, MG, Brazil).

Scanning electron microscopy evaluation

The fractured surfaces of all the instruments were examined by scanning electron microscopy (SEM) (JEOL, JSM-TLLOA, Tokyo, Japan) to determine the topographic features of the fragments after the cyclic and torsional fatigue tests. Before SEM evaluation, the instruments were ultrasonically cleaned to remove debris. The fractured surfaces of the instruments

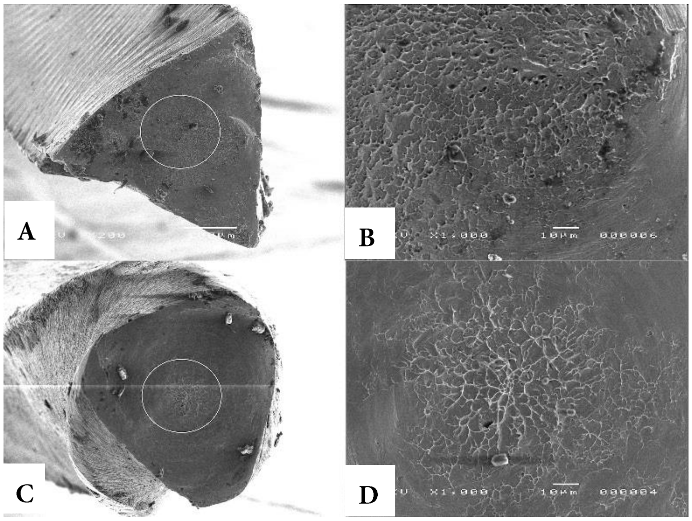

Figure 1. SEM images showing fractured surfaces of separated fragments *A, B*) HCM 25.06 and *C, D*) AB 25.06 after cyclic fatigue testing. The images show numerous dimples, a feature of ductile fracture

subjected to cyclic fatigue testing were assessed under 150-200× magnification. Furthermore, images of the centers of the surfaces of the instruments submitted to both tests were obtained at 1000× magnification.

In a supplementary examination, we captured the cross-sectional configuration of each instrument at D5 by and measure the cross-section area using software (AutoCAD; Autodesk Inc., San Rafael, CA, USA) [19] with the aim of making a correlation with the maximum flexion point of the instruments in the cyclic fatigue test.

Statistical analysis

The data were first examined using the Koromonov-Smirnov test for analyze the normality of distribution. The results were analyzed using unpaired Student t-test, and the level of significance was set at 5%. The Prism 6.0 software (GraphPad Software Inc., La Jolla, CA, USA) was used as the analytical tool.

Results

Cyclic and torsional fatigue tests

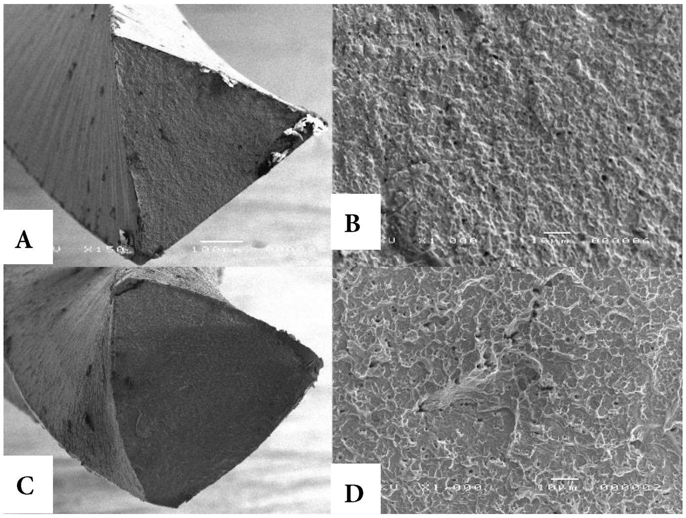

Figure 2. SEM images of fractures fragments; *A, B*) HCM 25.06 and (*C, D*) AB 25.06 after torsional fatigue testing. The first column show the front-view images of the instruments 200× magnification; The second column shows the concentric abrasion mark at 1000× magnification, showing the skewed dimples near the centre of rotation, typical feature of torsional failure

The means and standard deviations of the values obtained in the cyclic and torsional fatigue tests (torque maximum load and angle of rotation) are presented in Table 1. AB 25.06 had longer time and a greater number of cycles to fracture than HCM 25/0.06 (P<0.05).

The maximum torsional strength and angular rotation values are presented in Table 1. The results show there are no significant differences between AB 25/0.06 and HCM 25/0.06 in torsional strength or angular rotation to fracture.

SEM evaluation

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

The supplementary evaluation demonstrated no significant difference between the cross-section area of HCM 25/0.06 and AB 25/0.06 (P>0.05). HCM 25/0.06 and AB 25/0.06 presented 109.145 μm^2 and 112.200 μm^2 values.

Table 1. Mean (SD) of time (in seconds), number of cycles to failure (NCF), Torque (N.cm) and Distortion Angle (°) of instruments tested

Instruments	**Cyclic Fatigue**		**Torsional Fatigue**	
	Time (Seconds)	**Cycles (Number)**	**Torque (N.cm)**	**Angles (°)**
AB 25.06	323.3^{a} (21.87)	2.694^{a} (268.2)	0.60^{a} (0.13)	659.1^{a} (90.38)
HCM 25.06	223.8^{b} (31.97)	1.865^{b} (219.1)	054^{a} (0.19)	662.5^{a} (88.28)
P-value	P<0.001	(P<0.001)	(P>0.0852)	(P>0.0639)

Different superscript letter in the same column indicate significant statistic differences among the groups

Discussion

The development of new thermal treatments improve the flexibility of the NiTi instruments and their resistance to fatigue [11]. In the present study, instruments with different manufacturing process and similar cross-section, tip and taper size were chosen to evaluate the cyclic and torsional fatigue resistance. There is no data on the literature regarding the mechanical properties of the AB 25/0.06 rotary instruments. Therefore, this study opted to compare AB 25/0.06 with HCM 25/0.06, because of its excellent mechanical properties, as demonstrated by previous studies [13-16] .

Cyclic fatigue was tested in an artificial canal with 60° curvature and a 5-mm radius of curvature, as used in previous studies [19, 20]. In this study, the static cyclic fatigue test was used to ensure suitable standardization and minimize possible bias, such as bias due to the amplitude of axial motion and the speed, which are subjective in a clinical situation because their reproduction is manually controlled [21]. In addition, it is important to emphasize that the cyclic fatigue test was performed at body temperature (35±1°C) to mimic clinical conditions [20].

The results showed that AB 25.06 had significantly greater number of cycles to failure (NCF) than HCM 25/0.06. Therefore, our first null hypothesis was rejected. Although the two instruments have the same tip size (0.25 mm) and taper (0.06 mm/mm), our results showed that the instruments had different cyclic fatigue resistances. Thus, other variables such as cross-sectional design, thermal treatments and electro polishing of the surface should be taken into consideration for the outcome.

It has been reported that the cross-section design, taper and core diameter can affect the metal mass volume of the instruments and, consequently, the flexural and torsional properties of the NiTi engine-drive instruments [11, 22, 23]. The supplementary evaluation by SEM demonstrated that there was no significant difference of cross-section area between HCM 25/0.06 and AB 25/0.06. NiTi instruments with larger cross-sectional areas tend to present lower cyclic fatigue resistance [20, 24, 25] . The results of these studies did not corroborate with our results. Therefore, the different thermal treatments explain the results.

The thermal treatments of HCM 25/0.06 and AB 25/0.06 are different, and this contributed to the results obtained in this study. Although some previous studies reported that HCM 25/0.06 had greater cyclic fatigue resistance than rotary instruments manufactured using the Blue treatment [26, 27], our results showed that AB 25/0.06 was more cyclic fatigue-resistant than HCM 25/0.06. It is likely that the thermal treatment and electro polishing of AB 25/0.06 cause the energy required for crack formation and propagation during cyclic fatigue testing to dissipate differently [21]. The electropolishing process removes surface defects that might remain after the machining process and tends to increase the cyclic fatigue resistance of NiTi instruments [28].

The torsional test was performed in ambient temperature, as previously reported by several authors [3, 19, 23]. Silva *et al.* [29] demonstrated that the body temperature did not affect the torsional properties of thermally treatment and conventional NiTi instruments, which justify the use of traditional methodology of torsional test. The torsional fatigue results showed that there was no significant difference in torsional strength or angular rotation to fracture between the groups. Therefore, our second null hypothesis was accepted.

According to our results, the different cross-sectional designs, thermal treatments and electro polishing surface treatments did not result in significant differences in the torsional strength or angular rotation to fracture. The torsional resistance is an important feature when constricted and narrow canals are prepared because the instruments are subjected to high torsional loads that can twist their spiral flutes [30]. It was previously reported that thermal treatment mainly increases cyclic fatigue resistance without affecting the torsional properties of the instrument [30, 31]; this is consistent with the results of this study.

The scanning electron microscopic analysis revealed the typical fractographic appearance of torsional fractures that were similar between the two instruments. After the torsional test, the fragments showed the typical features of shear failure, including concentric abrasion marks and fibrous microscopic dimples at the center of rotation [20, 32].

Despite the fact that it is difficult to correlate the results of laboratory tests with a clinical situation due to the number of variables that act together to result in instrument failure, it is important to evaluate the mechanical properties of endodontic instruments to present important information for the clinician [7].

Conclusion

Our *in vitro* study indicates that AB 25/0.06 showed longer time and a greater number of cycles to fatigue than HCM 25/0.06. It can be suggested that these instruments are safer than HCM 25/0.06 for the preparation of severely curved canals; however *in vivo* studies may be required. The two instruments showed similar torsional resistance to fracture and appear to have similar performance during constricted canal preparation.

Conflict of Interest: 'None declared'.

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