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Extended cyclic fatigue life of F2 ProTaper instruments used in reciprocating movement

G. De-Deus[1], **E. J. L. Moreira**[2], **H. P. Lopes**[3] **& C. N. Elias**[4]

[1]Veiga de Almeida University, Rio de Janeiro; [2]UNIGRANRIO School of Dentistry, Rio de Janeiro; [3]ABE/RJ and UNESA, Rio de Janeiro; and [4]Military Institute of Engineering, Biomaterials Laboratory, Rio de Janeiro, RJ, Brazil

Abstract

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Aim To evaluate the cyclic fatigue fracture resistance of engine-driven F2 ProTaper instruments under reciprocating movement.

Methodology A sample of 30 NiTi ProTaper F2 instruments was used. An artificial canal was made from a stainless steel tube, allowing the instruments to rotate freely. During mechanical testing, different movement kinematics and speeds were used, which resulted in three experimental groups ($n = 10$). The instruments from the first group (G1) were rotated at a nominal speed of 250 rpm until fracture, whilst the instruments from the second group (G2) were rotated at 400 rpm. In the third instrument group (G3), the files were driven under reciprocating movement. The time of fracture for each instrument was measured, and statistical analysis was performed using parametric methods.

Results Reciprocating movement resulted in a significantly longer cyclic fatigue life ($P < 0.05$). Moreover, operating rpm was a significant factor affecting cyclic fatigue life ($P < 0.05$); instruments used at a rotational speed of 400 rpm (approximately 95 s) failed more rapidly than those used at 250 rpm (approximately 25 s).

Conclusions Movement kinematics is amongst the factors determining the resistance of rotary NiTi instruments to cyclic fracture. Moreover, the reciprocating movement promoted an extended cyclic fatigue life of the F2 ProTaper instrument in comparison with conventional rotation.

Keywords: cyclic fatigue, instruments, ProTaper, reciprocating movement.

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Introduction

Endodontic NiTi instruments have the shape memory effect and superelasticity of NiTi alloy that make them suitable for the enlargement of curved root canals. NiTi rotary instruments with varying cross-sectional designs and tapers have been developed and marketed in the past two decades. However, despite their clear advantages, NiTi instruments may undergo premature failure by fatigue (Grande *et al.* 2006, Inan *et al.* 2007, Lopes *et al.* 2007, Ounsi *et al.* 2007, Whipple *et al.* 2009), which is the life-limiting factor for its clinical use. As a consequence, the performance of NiTi rotary systems is under constant evaluation (Peters 2004, De-Deus & Garcia-Filho 2009).

Recently, a new approach to the use of the ProTaper F2 instrument in a reciprocating movement was reported (Yared 2008). The concept of using a single NiTi instrument to prepare the entire root canal is interesting; the learning curve is reduced considerably as the technique is simplified. Moreover, the use of only one NiTi instrument is more cost-effective than the conventional multi-file NiTi rotary systems.

Although the first clinical impressions of the single-file NiTi technique appear promising, other important parameters remain to be assessed by both laboratory and clinical studies. The fracture of an endodontic instrument happens as a result of torsional or bending

Correspondence: Gustavo De-Deus, Av. Henrique Dodsworth, 85 ap. 808, Lagoa, 22061-030 Rio de Janeiro, RJ, Brazil (e-mail: endogus@gmail.com).

fatigue (Sattapan *et al.* 2000, Guilford *et al.* 2005, Xu & Zheng 2006, Inan *et al.* 2007, Ounsi *et al.* 2007) and is a complex event. Thus, a drastic change in the movement kinematics, as proposed by Yared (2008), needs to be assessed in terms of cyclic facture resistance. The hope of better fracture resistance with a new movement kinematic requires systematic evaluation.

The purpose of this study was to evaluate the cyclic fatigue life of the F2 ProTaper instrument, engine-driven under reciprocating movement. The conventional rotary movement (continuous rotation) was used as a reference for comparison. The null hypothesis tested was that there are no differences in the fatigue fracture resistance between the two movements. The instrument surface fracture morphology and the helical shaft of the instruments were made to determine the fracture patterns of the instruments.

Materials and methods

A sample of 30 NiTi ProTaper F2 instruments (25 mm in length; Maillefer SA, Ballaigues, Switzerland) from six different lots was used. During mechanical testing, different movement kinematics and speed settings were used, which resulted in three experimental groups ($n = 10$). The instruments were randomly distributed with the aid of a free computer algorithm (http://www.random.org).

One artificial canal was made from stainless steel tube with an inner diameter of 1.04 mm, a total length of 20.0 mm, and arcs on the tips with a curvature radius of 6.0 mm. The arc of the tube measured 9.4 mm and the straight portion 10.6 mm, whereas the curvature radius was approximately 90° and was measured taking into consideration the concave surface of the interior of the tube (Figure 1a and 1b).

A stainless steel apparatus was fabricated with a square base and a vertical axis (Lopes *et al.* 2009). The vertical axis contained a structure that allowed for the fixture and movement of a micromotor/contra-angle headpiece; a bench vice held the stainless steel tubes. A gap at the base of the apparatus allowed for the movement of the bench vice in a horizontal direction, allowing for a connection between the axis of the instrument and the straight part of the stainless steel canal (Sattapan *et al.* 2000). The lengths of the instruments were measured using a digital vernier calliper (Mitutoyo Sul-Americana Ltd., Suzano, SP, Brazil). The lengths of the metallic handles (*L*) of the instruments were computed by subtracting the blade length from the total length.

The instruments rotated freely within the stainless tube, which was filled with glycerin to reduce friction and heat production. Each instrument was positioned in a contra-angle handpiece and introduced into the canal until the tip touched a shield positioned at the other extremity. This shield was subsequently removed, as it was used to standardize the instrument penetration into the canal.

Three NiTi file groups were tested. The instruments from the first group (G1) were rotated at a nominal speed of 250 rpm until fracture, whilst the instruments from the second group (G2) were rotated at 400 rpm. The instruments from groups G1 and G2 were driven in right-hand rotation by an electric motor (X-Smart

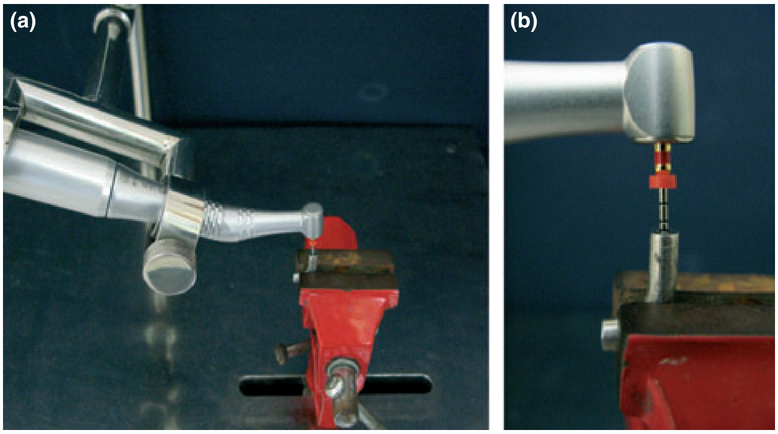

Figure 1 (a) An overview of the stainless steel apparatus used. The structure at the vertical axis allowed for the fixture and movement of the micromotor/contra-angle. (b) Closer view of the artificial root canal (stainless steel tube) used.

model; Tulsa/Dentsply, Tulsa, OK, USA) using a 1 : 20 reduction contra-angle handpiece. For both G1 and G2, the instruments were driven following the manufacturer's instructions.

For the third instrument group (G3), the files were used following the method of Yared (2008); the nominal speed was set at 400 rpm and the instruments were driven with an ATR Teknica electric micromotor (Pistoia, Tuscany, Italy) using reciprocating movement.

The time of fracture of each instrument was measured by the same operator for all groups, using a digital chronometer. The instance of fracture was based on visual observation of the fracture occurring in the instrument. An analysis for each fractured instrument was performed under SEM (JEOL JSM 5800; JEOL, Mitaka, Tokyo, Japan) to determine the mode of fracture.

As the preliminary analysis of the raw pooled data revealed a bell-shaped distribution (D'Agostino & Person omnibus normality test), the statistical analysis was performed using parametric methods: one-way analysis of variance. Post hoc pair-wise comparisons were performed using Tukey test for multiple comparisons. The alpha-type error was set at 0.05. SPSS 11.0 (SPSS Inc., Chicago, IL, USA) and Origin 6.0 (Microcal Software, Inc., Northampton, MA, USA) were used as analytical tools.

Results

The average length of the Pro Taper F2 instruments was 25 mm.

SEM evaluation demonstrated that fractured surfaces had ductile morphological characteristics (Fig. 3a,c). Dimples with varied forms were identified. In all the samples, although there were small increases in length, plastic deformation in the helical shaft of the fractured instruments was not observed (Fig. 3b).

The number of cycles until fracture was a function of the movement kinematics (reciprocate and continuous rotation). Under continuous rotation, instrument fracture occurred after an average of 160 cycles at 250 rpm and 120 cycles at 400 rpm. Under the reciprocating movement, fracture occurred after an average of 126 completed rotations at 400 rpm, which results in 630 cycles.

The average, the minimal and the maximal values, as well as the standard deviation, of the time until the fracture are shown in Fig. 2. Based on the statistical analysis, the instruments used in the reciprocating movement revealed a significantly longer cyclic fatigue life ($P < 0.05$). Moreover, speed of rotation had a significant effect on the cyclic fatigue life in the two rotary movement groups ($P < 0.05$).

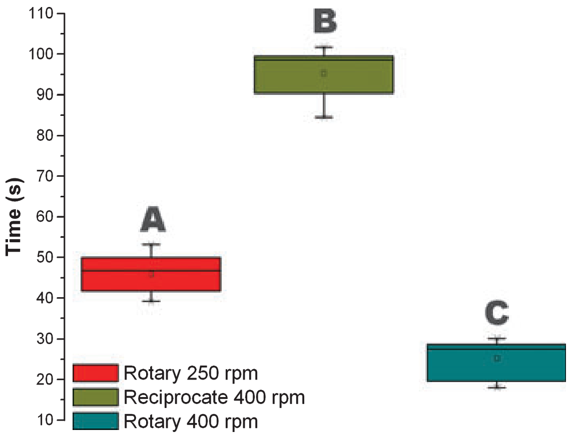

Figure 2 Box-plot showing the average, median, the minimal and maximal values, as well as the standard deviation, of the time until instrument fracture occurred. Different letters indicate significant statistical differences between groups; $P < 0.05$.

Figure 3a,b,c shows representative SEM micrographs illustrating the surface morphology of the fractured instruments.

Discussion

The results demonstrated that movement kinematics had a significant influence on the cyclic fatigue life of F2 ProTaper instruments. Therefore, the null hypothesis can be rejected.

From a mechanical viewpoint, stress fracture in rotary endodontic instruments results from continued repetitive loading (cyclic fatigue). Research has shown that fatigue failure occurs by the formation of microcracks, usually at the surface of a file, with the growth of this crack increasing by small increments during each loading cycle (Christ 2008). This behavior is commonly observed in any material submitted to fatigue loading. In clinical conditions, tensile stress induces a crack nucleation and propagation in instrument surface irregularities, which present a region of concentrated stress (Ounsi *et al.* 2007, Wei *et al.* 2007). All new endodontic instruments show irregularities on the surface (Anderson *et al.* 2007, Wei *et al.* 2007). Experimental data has shown that there are

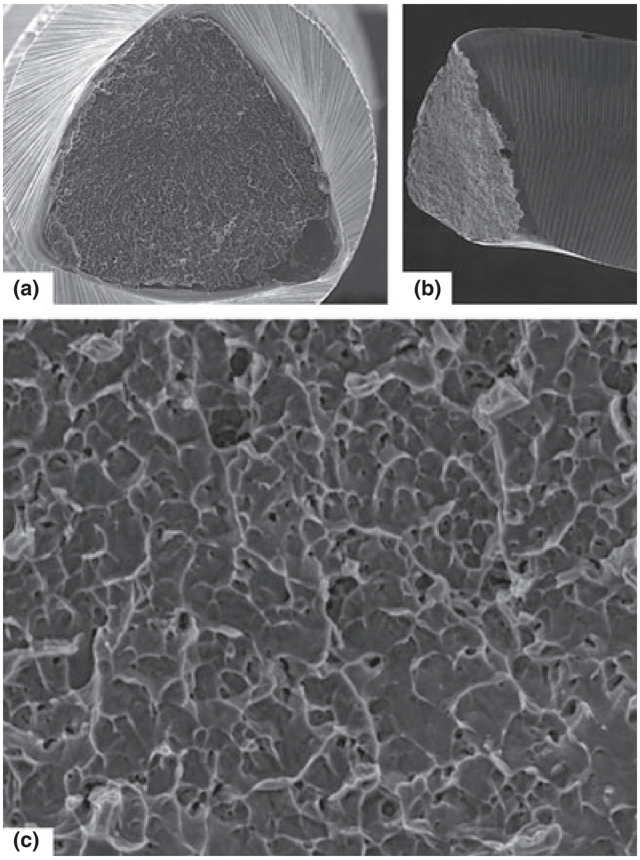

Figure 3 (a) Ductile surface fracture morphology. It is possible to observe dimples. (b) Surface fracture in the helical shaft of the fractured instrument with an absence of plastic deformation. (c) Ductile surface fracture morphology. It is possible to observe dimples.

large variances in fracture strength of endodontic instruments resulting from a distribution of pre-existing defects on the surface (Anderson *et al.* 2007, Wei *et al.* 2007). Consequently, the instrument fatigue life can be regarded as a function of the tensile value, irregularities and the size of cracks on the surface.

The fatigue behavior of endodontic instruments and stress analysis during canal treatment is illustrated in Fig. 4. At point 1, the concave part of the instrument is submitted to tensile stress and the crack is opened. At point 3, the convex part of the instrument is under compressive stress and the crack is closed. When the part of the instrument at point 1 turns 180 degrees, the position changes to point 3 and the material is submitted to a compressive stress and the crack closes. On the other hand, when point 3 turns 180 degrees, it undergoes tensile stress at point 1. At each cycle, the maximum tensile stress occurs at point 1 and maximum compressive stress occurs at point 3. The instrument fails after ''*N*'' cycles, which is the instrument's fatigue life. When the rotation speed increases, the instruments' average time of fracture decreases, but the number of cycles does not change. Figure 2 shows that the fatigue life reduced when the rotation speed increased from 250 to 400 rpm. This can be viewed as a further finding of this study. Several reports have noted the effect of the rotational speed on NiTi instrument fracture, with these results being in line with the present findings, which indicate that instruments rotated at higher speeds are more susceptible to fracture than when used at lower rotational speeds (Gambarini 2001, Zelada *et al.* 2002).

Figure 4b also shows that when the instrument is submitted to a reciprocating movement, the average time until fracture increases. It is well known that greater bending deflection of the instrument in each cycle results in a reduction in the number of cycles needed to break the file (Xu & Zheng 2006). Many

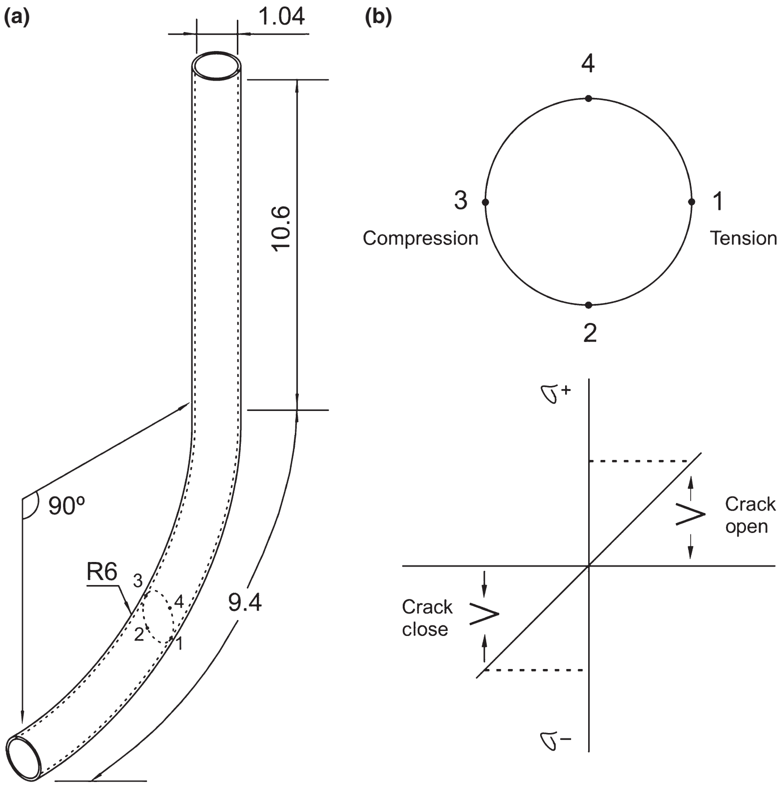

Figure 4 (a) Schematic drawing of the root canals used in the study; Angle 90 degrees and arc 9.4 mm. (b) Schematic drawing showing that when the instrument is submitted to a reciprocating movement, the average time of fracture increases.

cycles would be required for fracture if the root canal constraint was able to produce only elastic deformation. During just one reciprocating movement (Yared 2008), the instrument turns clockwise 0.4 of the cycle (144 degrees) and returns 0.2 part of the cycle (72 degrees), which means that after five reciprocating movements, the instrument completes one entire rotation (360 degrees). The fatigue life is measured by the number of times that the crack closes and opens. During one cycle, the crack opens and closes once. This movement rationale acts to extend the fatigue life of F2 ProTaper instruments.

There are no previous reports on the effect of reciprocating movement on the cyclic fatigue life of the F2 ProTaper instrument, and further studies are needed to confirm the extended fatigue life of the F2 ProTaper instrument driven with reciprocating movement.

The present results indicate that movement kinematics is included amongst the factors determining the resistance of rotary NiTi instruments to cyclic fracture resistance. Under the present experimental framework, reciprocating movement extends the cyclic fatigue life of F2 ProTaper instruments when compared to the conventional rotary movement. In addition, the influence of speed on the fatigue life is confirmed when the F2 instrument was driven under rotary movement. Further clinical studies are required to determine the relationship of the present experimental data with the efficacy of the F2 ProTaper file used in reciprocating movement in vivo.

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