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Cyclic Fatigue Resistance of Rotary NiTi Instruments after Simulated Clinical Use in Curved Root Canals

Oscar Faciola Pessoa[1], Juliana Melo da Silva[1], Giulio Gavini[2]

[1]Discipline of Endodontics, Dental School, UFPA - Federal University of Pará, Belém, PA, Brazil
[2]Discipline of Endodontics, Department of Esthetic Dentistry, Dental School, USP - University of São Paulo, São Paulo, SP, Brazil

Correspondence: Prof. Dr. Oscar Faciola Pessoa, Avenida Gentil Bittencourt, 1206, 66040-000 Belém, PA, Brasil. Tel: +55-91-8500-2827. e-mail: ofpessoa@ufpa.br; ofpessoa@cesupa.br

The aim of this study was to assess cyclic fatigue resistance in rotary nickel-titanium instruments after simulated clinical use in curved root canals (40-degree, 5-mm radius curve). Thirty-six RaCe rotary NiTi files, size #5, taper 0.04, were divided into 3 groups: Groups A, B and C with one, three and five cycles of use, respectively. Time to failure was recorded with a stopwatch in seconds and subsequently converted to number of cycles to fracture. The data were analyzed statistically by ANOVA and Tukey's test (α=0.05). Five sets of clinically used files (group C) reached significantly lower cycle-numbers before fracture (mean=197.5 cycles) when compared with one set of clinically used files (mean=309.2) and three sets (mean=287.5). Results showed that the number of simulated clinical uses of RaCe instruments for shaping curved canals affects adversely the fatigue resistance of these instruments after five uses.

Key Words: cyclic fatigue, Endodontics, nickel-titanium, root canal, rotary files.

Introduction

The advent of rotary nickel-titanium (NiTi) instruments has aided endodontists in the cleaning and shaping of root canals. Since then, several file designs have been tested and introduced with variations in rake angle, radial lands design, helical pitch or thickness of the core. Some designs are highly aggressive and some are more flexible, whereas others offer safe tips or an interrupted helical angle (1).

The RaCe (reamers with alternating cutting edges) file has a safety tip and triangular cross-section. This file possesses an alternating spiral and has a cutting shank of 8 mm, providing variable helical angles and a variable pitch. Alternating cutting edges avoid the threading/blocking effect and have the advantage of an extremely low operating torque. This enhances the file's "anti-screwing-in" characteristic (2). Electrochemical treatment of RaCe files improves resistance to torsion and metal fatigue, and facilitates cleaning and sterilization (3). Reports suggest the instrument design is able to produce more centered canal shapes and can effectively clean and shape canals (4).

During instrumentation, the file is subjected to different forces, such as flexion, torsion, traction and apical pressure, which require a satisfactory resistance from the instrument in order to avoid its fracture (5). The unexpected failure of nickel–titanium (Ni–Ti) rotary instruments inside the root canal during root canal treatment is a matter of serious concern, as these instruments may fracture within their elastic limit without any visible sign of previous permanent deformation (5,6). Fracture of instruments used in rotary motion occurs in two different ways: torsional and flexural or fatigue (6). Fracture due to torsion occurs when the tip or another part of the instrument binds in a canal whilst the shank continues to rotate (7). Fracture due to flexural fatigue occurs when the instrument does not bind, but rotates freely in a curvature, generating tension/compression cycles at the point of maximum flexure until fracture occurs. Such aspects can be aggravated when the professional suddenly finds unfavorable anatomic conditions, such as a canal with enhanced curvature (8). The prolonged use of rotary NiTi instruments decrease significantly their resistance to cyclic fatigue. However, there is no agreement about the exact number of uses that an instrument can be submitted to before failure (9). In some cases, the instruments should be discarded after a single use in very complex, calcified, and curved canals (10) or selectively discarded to increase safety in clinical practice (11). Therefore, the objective of this study was to evaluate the cyclic fatigue resistance in NiTi rotary endodontic instruments, using a custom-made cyclic fatigue testing apparatus.

Material and Methods

One hundred and eight simulated canals were constructed using size 15 silver points as templates. The annealed silver points were pre-curved to create artificial canals with an angle of curvature of 40º, 5 mm radius curvature and 21 mm long, and the beginning of the curve was positioned 14 mm from the canal orifice. These simulated canals were constructed using self-curing epoxy resin (Araldite LY 1316; Ciba, São Paulo, SP, Brazil) at the ratio of 100 g of resin to 13 g of catalyst (HY 1208; Ciba). To prevent the formation of bubbles, mixing of the resin with the catalyst was carried out by the vacuum spatulation (Model A 300; Polidental, São Paulo, SP, Brazil).

Fatigue testing of instruments was performed in the artificial resin canals (n= 108). A total of 36 RaCe files (size #25, taper 0.04; FKG Dentaire SA, La Chaux-de-Fonds, Switzerland) were submitted to the cyclic fatigue test, distributed in the following groups: Group A, with one cycle of use; Group B, with three cycles of use and group C, with five cycles of use.Prior to the fatigue testing, the artificial canals were designed to accommodate each instrument in terms of size and taper, preparing the cervical third with #25 files taper .10 (Flare Quantec, Mexico), enlarged 8 mm deep, and also producing a little apical enlargement with #20 instrument taper .02 (FKG Dentaire SA).

Cyclic fatigue testing was performed with a custom-made cyclic fatigue testing apparatus (12), specifically designed to allow dynamic testing and made essentially of aluminum (Fig. 1). The device consisted of a horizontal rectangular base and platforms. A ring allowed the micromotor/contra-angle handpiece displacement, both in lateral and anteroposterior direction. A cylinder base, attached to a diameter compatible concave base, allowed the tested instrument to remain curved and free to rotate. An electric motor handpiece (Driller, São Paulo, SP, Brazil) was used with a contra-angle of 16:1 (NSK, Kanuma, Japan). First, the micromotor/contra-angle handpiece was secured to the support arm in a parallel position to the apparatus base. Then, the file was secured to the contra-angle handpiece, ensuring correct locking. The electric motor was calibrated to run at a speed of 300 rpm and a torque of 2 N.cm according to manufacturer's instructions.

Platforms were moved using the grading rings until reaching a position that allowed the file to remain curved and free to rotate between the cylinder and the steel jig, thus simulating rotary instrumentation of a canal with a 40-degree, 5-mm radius curvature. Care was taken to ensure that the instrument was well positioned in the cylinder groove, to avoid file displacement. The instrument tip remained visible throughout the experiment (Fig. 2). With the instrument positioned adequately, the electric motor was turned on. Testing time was registered with a digital stopwatch manually operated, started at the moment the motor was turned on and stopped at fracture detection. This procedure was sequentially repeated for all instruments in both groups. All fatigue tests were performed by the same operator. After completion of all tests, the mean time to failure observed in each group was recorded in seconds and subsequently converted to number of cycles to fracture.

Data were statistically analyzed by ANOVA and Tukey's test using the SPSS software 15.0 (SPSS Inc., Chicago, IL,

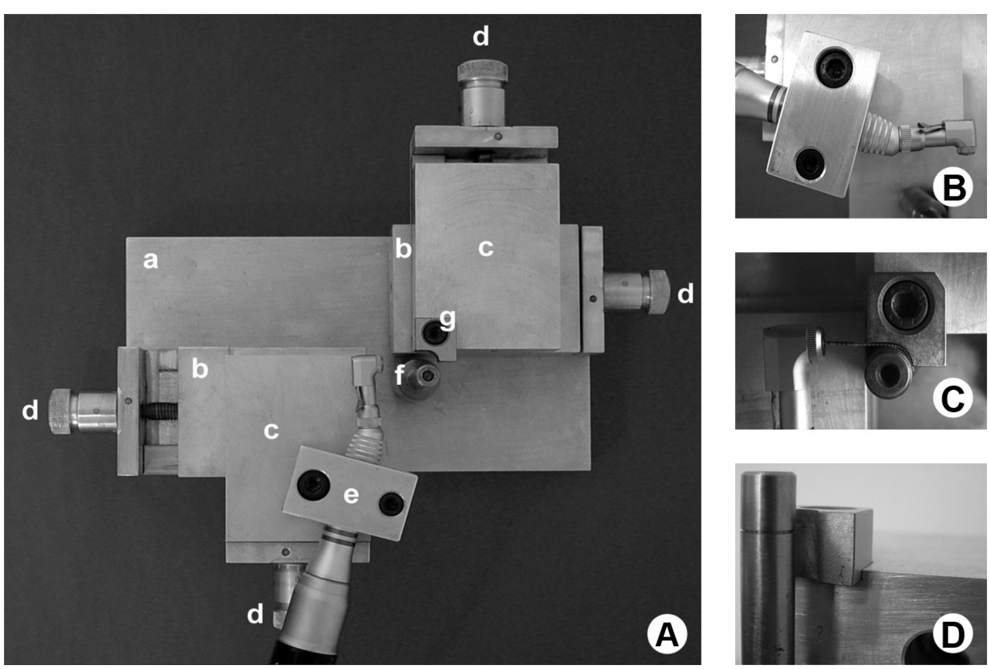

Figure 1. A: Cyclic fatigue testing apparatus (upper view): a) horizontal, rectangular base; b) two lower platforms allowing movement from left to right and vice versa; c) two upper platforms, each one connected to a lower platform and stabilized by means of a swallow-tail structure, allowing back-and-forth movements; d) four grading rings allowing measurements accurate to 0.1 mm; e) support arm with locking ring, allowing to secure the micromotor/contra-angle assembly to the left upper platform with two retaining screws, one to control locking-ring opening and closure while adjusting the micromotor, and the other to allow rotary movements to the support arm and different micromotor positions; f) 10-cm long, 5-mm radius cylinder, secured to the base, containing a 1-mm deep groove located 3.5 cm from the upper end, designed to hold the file; g) hardened steel jig (jig and cylinder allow the instrument to remain at the same time curved and free to rotate). B: Locking ring at the micromotor/contra-angle assembly. C: Upper view of the RaCe files size # 25, taper 0.04 in relation to the cylinder. D: Side view of the cylinder and groove.

USA). The significance level was set at 5%.

Results

Figure 3 shows the average and the standard deviation obtained within each group. Five sets of clinically used files (group C) reached a significantly lower number of cycles before fracture (mean=197.5 cycles) compared with the one set of clinically used files (mean=309.2) and three sets (mean=287.5). No statistically significant difference was observed between groups A and B (p>0.05).

Discussion

Fractured rotary NiTi instruments have been classified into those that fail as a result of cyclic flexural fatigue or torsional failure or a combination of both. Clinically, NiTi rotary instruments are subjected to both torsional load and cyclic fatigue (13).

Sattapan et al. (6) reported that torsional fracture occurred in 55.7% of all fractured files, whereas flexural fatigue occurred in 44.3%. These results indicated that torsional failure, which may be caused by using excessive apical force during instrumentation or by other contributing factors, such as the pre-existing size of the canal, occurred more frequently than flexural fatigue, which may result from use in curved canals.

An aggravating factor is that, unlike torsion fracture, flexional fracture does not present previous deformation, which is a criterion used by many professionals in order to throw away the instruments. Thus, there is too much doubt about the main factors responsible for the flexional fracture to establish the correct protocol to prevent its occurrence.

The sequential cycles of traction and compression forces in the curvature area of the canal are the most destructive way of cyclic carrying and following fracture (5). The fractured surface of stainless steel instruments presents the characteristics of a fragile fracture, while the NiTi ones present characteristics of a ductile fracture (14).

On the other hand, in the present study, in contrast to instruments that were submitted to torsion trials, the instruments submitted to cyclic fatigue showed resistance to fracture, which is inversely proportional to the diameter and taper, indicating that files with greater diameter are at higher risk on curvature areas. In this way, the stress on the external surface of the maximum curvature region with the same radius is bigger than more calibrated instruments.

The file design of RaCe may act to concentrate stress at specific points, rather than distribute it along the entire file length (15). Subramaniam et al. (16) showed that instrument design plays a role in enhancing its fracture resistance.

The instrument tested in the present study was a #25/.04 because it is a different standard ISO taper, and has compatible tip diameter to work in the apical third, being adequate for shaping curved canals, but critical in the process of cyclic fatigue.

A review on rotary NiTi instrument fracture and its consequences concluded that along with the prevalence and relation of metallurgy and fracture, other factors like the manufacturing process can also alter the fracture resistance and cutting efficiency of NiTi files (17). For this reason, electropolishing of RaCe NiTi instruments has been introduced to improve the surface profile and reduce the number and extent of surface defects. Electropolished instruments survive a higher number of cycles before fracture than non-electropolished instruments (18).

Another way to prevent the file's excessive engagement in the canal walls is to alternate the cutting blades. Alternating cutting edges in RaCe rotary file design constantly switches the helix angles of the blades as they rotate inside the canal (19). Increase in the angle and decrease in the radius of curvature can decrease the cyclic fatigue resistance of RaCe file systems. Torsional failure is the predominant mode of fracture for the RaCe instruments (20).

The technological advances experienced in the last years led to the fabrication of endodontic instruments

Figure 2. Detail of instrument set for testing and visible instrument tip.

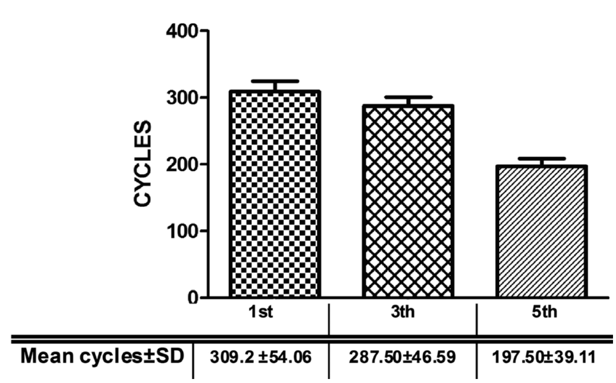

Figure 3. Mean cycles to failure and standard deviations.

with metallic alloys of better quality, such as NiTi alloy, and determined other modifications, including helicoidally cross-section design, instrument tip design, helix angle and dimensions of the instrument center. Changes in the tip taper and diameter of endodontic instruments have also been proposed (21). The risk of instrument fracture represents a dilemma in rotary root canal preparation. Instruments tend to deform before fracture occurs, which could be avoided by constantly monitoring the spirals (22). More researches are required to determine how many times the NiTi file could be used safely in root-curved canals.

Other studies have proposed a new fatigue testing method for NiTi rotary instruments in which the number of fatigue cycles to failure is determined under controlled loading conditions (12,23). Unlike common fatigue tests that impose the flexure in artificial canal shapes (24), cyclic fatigue apparatus test allows a precise control over how a file is loaded during the test. This precise control can help standardizing fatigue performance testing, and predicting the fatigue lifetime of NiTi rotary instruments (23).

It is important to provide to clinicians the required knowledge for evidence-based practices, maximizing the benefits of the selection and application of NiTi rotary instruments for root canal treatment (25).

The results of the present study showed no significant difference between the instruments submitted to only one cycle of usage when they were compared with instruments used three times. On the other hand, instruments used for five cycles presented significantly lower resistance to cyclic fatigue than the other tested groups. The number of simulated clinical use of Race files for shaping curved artificial canals affected adversely the fatigue resistance of these rotary nickel-titanium instruments.

Resumo

O objetivo deste estudo foi avaliar a resistência à fadiga cíclica de instrumentos rotatórios de níquel-titânio após simulação de uso clinico em canais curvos (curvatura de 40° e raio de 5 mm). Trinta e seis instrumentos, calibre nº 25 conicidade 0,04, foram divididos em três grupos: o Grupo A com um ciclo de uso; Grupo B, três ciclos de uso e grupo C, cinco ciclos de uso. Um cronômetro digital aferiu em segundos o tempo até a fratura do instrumento que, posteriormente, foi convertido em número de ciclos para fratura. Os dados foram analisados por ANOVA e teste de Tukey (p<0,05). O grupo que utilizou o instrumento por cinco ciclos (grupo C) atingiu significativamente menores números de ciclos antes da fratura (média = 197,5 ciclos) quando comparado com os instrumentos utilizados em um ciclo (média = 309,2) e três ciclos (média = 287,5). Os resultados mostraram que o número de uso de instrumentos RaCe para modelar canais curvos afeta negativamente a resistência à fadiga cíclica dos instrumentos após cinco usos.

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