ORIGINAL ARTICLE

Cyclic fatigue resistance of three reciprocating nickel-titanium instruments with heat treatment at intrachannel temperature[1]

Resistencia a la fatiga cíclica de tres instrumentos alternativos de níquel-titanio con tratamiento térmico a temperatura intracanal[1]

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ABSTRACT

Introduction: *the in vitro study compared the dynamic cyclic fatigue resistance of 3 reciprocating NiTi files with heat treatment.* ***Methods:*** *we distributed 30 new endodontic files in three groups. The endodontic files selected for this experiment were: AF Blue R3 25/06 (AFB) (Fanta Dental, Shanghai, China), X1 Blue File 25/06 (X1B) (MK Life, Porto Alegre, RS, Brazil), and Reciproc Blue 08/25 (RB) (VDW, Munich, Germany. We measured the time to file fractureand the length of the fractured fragment. ANOVA analysis was used, followed by the Tukey test for multiple comparisons, with a significance level of 5% (P < 0,05).* ***Results:*** *the mean time in seconds until the file fractured was 170.7 ±15,1 for AFB files, 110,4 ±26,8 for X1B, and 163,3 ±22,9 for RB files. This difference was statistically significant when comparing X1B to AFB (p: 0,000) and X1B to RB (p: 0,000). However, there are no statistically significant differences between RB and AFB (p:0,739).* ***Conclussions:*** *this study found that RB and AFB files exhibit similar resistance to cyclic fatigue.*

Keywords: *dental instruments, shape memory alloys, flexural strength.*

Resumen

Introducción: *el estudio in vitro comparó la resistencia a la fatiga cíclica dinámica de 3 limas NiTi recíprocas con tratamiento térmico.* ***Métodos:*** *distribuimos 30 limas endodónticas nuevas en tres grupos. Las limas endodónticas seleccionadas para este experimento fueron: AF Blue R3 25/06 (AFB) (Fanta Dental, Shanghai, China), X1 Blue File 25/06 (X1B) (MK Life, Porto Alegre, RS, Brasil), y Reciproc Blue 08/25 (RB) (VDW, Munich, Alemania. Se midió el tiempo transcurrido hasta la fractura de la lima y la longitud del fragmento fracturado. Se utilizó el análisis ANOVA, seguido de la prueba de Tukey para comparaciones múltiples, con un nivel de significación del 5% (P < 0.05).* ***Resultados:*** *el tiempo medio en segundos hasta la fractura de la lima fue de 170.7 ±15.1 para las limas AFB, 110.4 ±26.8 para las X1B y 163.3 ±22.9 para las RB. Esta diferencia fue estadísticamente significativa al comparar X1B con AFB (p: 0.000) y X1B con RB (p: 0.000). Sin embargo, no hay diferencias estadísticamente significativas entre RB y AFB (p:0.739).* ***Conclusiones:*** *en este estudio se ha comprobado que las limas RB y AFB presentan una resistencia similar a la fatiga cíclica.*

Palabras clave: *instrumentos dentales, aleaciones con memoria de forma, resistencia flexional.*

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INTRODUCTION

Despite the superior quality of the NiTi alloy compared to traditional stainless steel instruments, used in rotational or reciprocating movements in the root canals with significant curvature, they present a great risk of fracture, which could compromise the success of endodontic treatment[1–6].

The shaping and decontamination of root canals cause superficial defects in NiTi instruments observed through Scanning Electron Microscopy (SEM). Longitudinal microcracks can be observed along the axis of the file, and distortion can be observed in machined grooves when subjected to torsional loads[7]. The improvement in the fatigue resistance of endodontic instruments is achieved thanks to the optimization of the microstructure of its alloy; this is achieved by thermomechanical processing[8].

Another critical factor in preventing instrument fractures is to prevent them from going beyond the elastic limit of the metal alloy, which is why it has been proposed to work with new movements during instrumentation, such as reciprocal movement. It is claimed that using of reciprocating motion for a nickel-titanium file increasesfatigue strength compared to continuous rotation[9].

Among the reciprocating systems that are manufactured by changing the molecular structure through a new heat treatment to increase the resistance to cyclic fatigue, and this new heat treatment gives the files their blue color, as Reciproc Blue files (VDW, Munich, Germany) which has an S-shaped cross-section, two cutting edges and a non-cut tip, variable taper 0,08[10], the AF Blue R3 files (Fanta Dental, Shanghai, China) have a square cross-section and a fixed taper of 0.06 and the X1 Blue File file (MK Life, Porto Alegre, RS, Brazil) which has an inactive tip and a triangular cross-section and a fixed 0,06 taper.

Fracture strength studies of various rotary systems are essential. The aim of this *in vitro* study was to compare the dynamic cyclic fatigue strength of 3 reciprocating NiTi files with heat treatment Reciproc Blue (25/08), AF Blue R3 (25/06), and X1 Blue File (25/06).

METHODS

A total of 30 new endodontic files, AF Blue R3 Blue 25/06 (Fanta Dental, Shanghai, China), X1 Blue File 25/06 (MK Life, Porto Alegre, RS, Brazil), Reciproc Blue 25/08 (VDW, Munich, Germany), were selected for this experiment. They were from two different production lots. Each file was examined using an operating microscope (Alliance, São Carlos, São Paulo, Brazil) with a magnification of 24 to verify that it does not have defects and deformities.

The sample size calculation was carried out with the EPIDAT program with the following data: significance level 5%, power of 90%, mean differences of 20 (standard deviations of 15,3 and 11,2). The sample size calculation indicates the need for the present study to have 10 files in each group.

For dynamic cyclic fatigue resistance tests, a groove was made simulating an artificial root canal in a stainless steel plate (Figure 1), according to criteria established in previous studies[11,12]. The curved metal artificial root canal had an angle of 69° and a radius of 2,5 mm. The straight part of the cervical canal up to the limit preceding the beginning of the curvature was 13,35 mm long, the length of the curvature was 2,15 mm, and that of the straight part of the posterior canal at the end of the curvature to the apex it had a length of 7,5 mm. The width of the canal of the cervical part was 2 mm, at the limit before the curvature of 1.52 mm, at the final limit of the curvature was 1.49 mm, and the apical width was 1.00 mm. The purpose of these dimensions was to allow the freely rotation of the file within the canal. An acrylic plate was fixed on the stainless-steel plate so there was no loss of the separated fragment, and the file was contained within the simulated canal during the experiment.

Figure 1. Artificial canal used for the cyclic fatigue test

Source: by the authors

The instruments were coupled to the 6:1 contra-angle (Sirona Dental Systems GmbH, Benshein, Germany), of a silver VDW engine (Dentisply Industria e Comércio Ltda; VDW GmbHMunich - Germany) the files were activated using the programming "RECIPROC ALL." To reproduce the axial movements of the instruments that occur during a clinical procedure, the reducing contra-angle was coupled to a mechanical system of vertical movement to avoidvariations in position and angulation. The tests were performed dynamically, where the mechanical system of vertical movement was driven by a SAVOX SC-12 56T69 engine (Savox All Rights Reserved, Taichung, Taiwan) which makes the mechanical system penetrate and traction what is done through a linear guide, with servo movement controlled by an electronic processor that controls the speed and amplitude of penetration and traction.

With the endodontic contra-angle disabled, the files were inserted 22 mm in the artificial canal and activated in a reciprocating movement to the left and underwent a penetration and axial traction movement with an amplitude of 3 mm in penetration movement and 3 mm in the direction of traction, the penetration and traction movement starts simultaneously with the triggering of the reciprocating movement of the file within the canal.

During the experiment, the artificial root canal was filled with lubricating oil (Synger, La Vergne, Tennessee, USA) using a 24G 3/4 (0,55 x 20 mm) hypodermic needle (Shandong Weigao Group Medical Polymer, Shandong Province, China). The endodontic motor was activated, thus initiating the dynamic cyclic fatigue test, immediately the linear guidance device exerted the penetration movement of 3 mm and then performed the traction movement of 3 mm, with a speed of 3 mm / s for both movements[13], standardized and until the file fractures.

During axial penetration and traction movement so, that the files never changed the range of motion and always remained with their active part within the length of the curvature, an amplitude of 3 mm in each direction was used to simulate the pecking movement used in an actual clinical situation.

The stainless steel plate with the simulated channel was placed on a heated plate of a magnetic stirrer at a controlled temperature of 35oC ± 1oC better simulate the intrachannel temperature conditions[14], and confirmation of this temperature was performed by a digital infrared thermometer (G-Tech) before starting the test each.

Video recording was carried out simultaneously, from the beginning of the file activation until its fracture, with a digital cell phone camera (Huawei p30, Shenzhen, Guangzhou, China) to avoid possible errors and allow checking the time until the fracture occurs. The video was transferred to a computer and using Windows Media Player software (Microsoft Windows, Redmond, Washington, USA) which allowed us to analyze the exact moment when the file is activated within the simulated canal until the moment of fracture, considered a time for fracture of each file[6,15].

All fractured fragments of the samples underwent a cleaning phase in an ultrasonic vat and dried in an oven at 37oC for 24 hours, placed in plastic tubes identified with the name and number of the instrument. They were then analyzed using a scanning electron microscope (SEM; EVO 15; ZEISS, Cambridge, UK), where the separate file fragment was photographed horizontally and transversely.

Fractured file fragments were measured with a 150 mm digital gauge, precision ± 0,03 mm / 0,001 (hardened stainless steel, model MTX 316119). And the following were analyzed: the pattern in the fracture length of the files in each group and the location of the maximum tension point in the artificial test canal.

Statistical analysis

Statistical analysis was performed using the Stata 15,0 Software. The Shapiro-Wilk test was applied to analyze normality for both the time variable and mm variables. Considering a significance level of 5%, all variables were normally distributed. The ANOVA test was applied for theanalysis of multiple groups. Tukey's test was then used for intergroup analysis.

RESULTS

Each of the groups consisted of 10 and 25 mm files. The procedure was performed at controlled temperatures (Table 1). The onset temperature was 34,9 ±0,3 in the AFB group. The temperature during the process was 35,6 ±1,3 in the AFB group. The mm of the fragment fracture was 6,5 ±0,5 in the AFB group.

Table 1. Characteristics of the procedure in terms of temperature and mm of the fracture. n:30

	Start temperature	Temperature during the procedure	Fracture Fragment mm
X1B	35,1 ±0,3	35,1 ±0,3	7,1 ±0,5
AFB	34,9 ±0,3	35,6 ±1,3	6,5 ±0,5
RB	35,1 ±0,3	35,2 ±0,4	6,5 ±0,6

Source: by the authors

The mean time in seconds until the file fractured was 170,7 ±15,1 in the AFB group. This difference was statistically significant (p: 0,000) compared to the X1B and RB group with the ANOVA test (Table 2). Subsequently, with the tukey test, it was demonstrated that these differences are presented by comparing X1B with AFB (p: 0,000) and X1B with RB (p: 0,000). However, there are no statistically significant differences between RB and AFB (p:0,739).

Table 2. Mean values of the time in seconds for the three study groups. n: 30

Tempo	Mean	SD	min-max	*p*-value
X1B	110,4[b]	26,8 [b]	55-148 [b]	0,0000
AFB	170,7a	15,1 a	149-197 a	
RB	163,3a	22,9 a	122-195 a	

[b]statistical difference
Source: by the authors

Crack initiation areas and overload rapid fracture zones were also observed without morphological differences in the fracture surfaces of all evaluated instruments. The micro-cavities observed on the instrument surfaces evolve from the first test cycles, producing micro-cracks in AFB, X1B, and RB files, respectively (Figure 2). Often, these microcracks come together to create cracks, usually in the axial direction. However, the failure only occurs when this defect grows in or near the file.

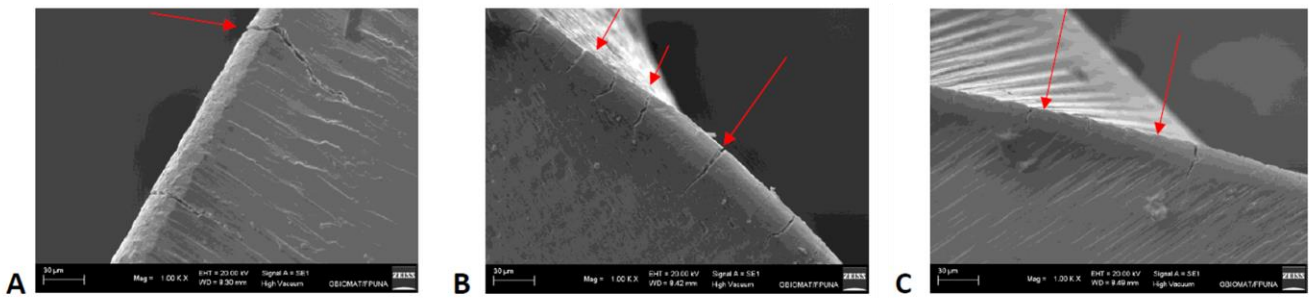

Figure 2. The micro-cavities observed on the instrument surfaces evolve from the first test cycles, producing micro-cracks. A. AFB, B. X1B, C. RB. Often these microcracks come together to produce cracks, usually in the axial direction. However, the failure only occurs when this type of defect grows in or near the file. At this point, the voltage concentration 15 particularly high.

Source: by the authors

The Scanning electron microscopy images (SEM) analysis of the instruments submitted to the cyclic fatigue resistance test showed typical characteristics of cyclic fatigue fracture, that is, morphological characteristics of the ductile type with numerous dimples in AFB, X1B, and RB files, respectively (Figure 3). The images show multiple grooves scattered across the fractured surfaces, which are a typical feature of ductile fracture.

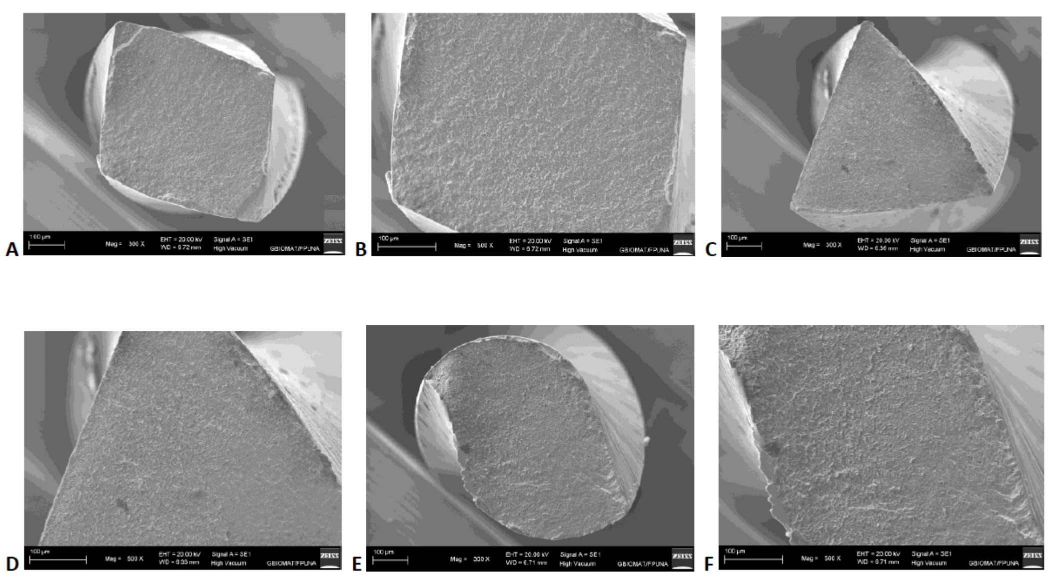

Figure 3. Scanning electron microscopy images of the surface of fractured fragments from AFB 25,06. A, B. X1B 25,06. C, D. RB 25,08. E, F. After the cyclic fatigue test. The images show numerous grooves scattered across the fractured surfaces, which are a typical feature of ductile fracture.

Source: by the authors

DISCUSSION

In this studio, 30 new files from the RB, AFB, and X1B brands were tested because the files are manufactured from the same NiTi alloy and have the same surface heat treatment. The instrument sizes of 10 and 25 mm was tested because these sizes are commonly used during instrumentation.

The additional heat that NiTi instruments are subjected to during autoclave sterilization may vary their CF resistance. This was shown in a study that found that fatigue resistanceis higher in new files[16]. In this study, all files used were new.

The methodology used in this study allowed the evaluation of dynamic cyclic fatigue resistance at intracanal temperature 35°C ±1°C. This temperature was observed in other studies[6,14] because it reproduces more accuratly what happens inside the canal during instrumentation.

The curved metallic artificial channel used in this studio had an angle of 69° and a 2,5mm radius to ensure standardization of the experimental conditions and minimize any factors that might affect the results[17–19].

In addition, in the present study, a dynamic model was used to simulate better systems`s clinical use of the, in which the axial movement was fixed at 3 mm[20].

This study found differences in time in seconds until file fractures and NCF between X1B compared to AFB and RB. However, there are no differences between AFB and RB.

The cross-section is not the only parameter influencing the fatigue resistance between AFB, X1B, and RB files. Also, the diameter of RB is diferente than others. Therefore, an explanation for the longer service life of the RB and AFB of the X1B could be related to the different cross-sections of the two instruments. RB has an S-shaped cross-section, while X1B has a triangular cross-section. A triangular cross-section design with three cutting edgescould increase the file`s torsional stress on the by decreasing its cyclic fatigue resistance[21]. The S-shaped cross section can also be advantageous in reducing torsional stresses due to the smaller surface area in contact with the channel walls. In addition, the S-shaped cross-section design exhibits less blade interaction thanto the convex triangular cross-section and can influence the cyclic fatigue resistance of the instrument[3]. The thermomechanical CM treatment gives greater resistance to cyclic fatigue[23]. In addition, CM wire instruments have greater flexibility than conventional M-Wire and NiTi instruments[23-27].

Crack initiation areas and overload rapid fracture zones without morphological differences in the fracture surfaces of all evaluated instruments were also observed. The SEM analysis of the instruments submitted to the cyclic fatigue resistance test showed typical characteristics of cyclic fatigue fracture, that is, morphological characteristics of the ductile type with numerous dimples.

Regarding length of the broken segment of the file not diferente on our study, diferente of another study that showed significant difference in length of fractured fragments of four instruments (Reciproc R25, One Curve, Fanta-one, and Fanta R3- Reciproc). The one curve systems showed the shortest length of fractured fragments, probably because of the differences of the cross section along the file length. Fracture of the instruments occurred at the center or below the curvature which affirms the importance of the positioning of the files in the artificial root canal[28].

Regarding the limitations of the in vitro study, it was conducted under strictly controlled conditions without giving advantage to any study group. The curved simulated flute dynamic model standardizes variables affecting cyclic fatigue resistance, such as flute diameter, canal wall, and canal inlet length so that the file would rotate freely within the canal. Fanta Dental and the the X1 Blue files are made with the same NiTi and heat treatment. difference between these two files is the cross sections. It is well known that the cyclic fatigue resistance is more significant when the core is smaller. All things equal, a triangular cross-section will result in less time to fracture compared to a quadrangular cross-section. Even thoungh we calculated the number of cycles to fracture; it was not valid for reciprocating movements. Therefore, those data were not valid and were removed. As a limitation, it can be mentioned that different brands are not compared, so the need to carry out other studies arises. As a strength, a sample size calculation was performed to boost the study.

Very few studies were found comparing the strength of AFB against other files. Further experimental research or randomized clinical trials with a significant number of samples are recommended to find more conclusive results, considering the cost of AFB, which is much more affordable than RB.

CONCLUSION

AFB and RB files do not present differences in cyclic fatigue resistance.

CONFLICTS OF INTEREST

The authors declare that they have no conflict of interest.

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