Alcalde MP. Cyclic and torcional fatigue resistance of W File and X1 Blue file reciprocating instruments

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DOI: https://doi.org/10.14436/2358-2545.10.2.060-066.oar

ABSTRACT

Introduction: The aim of this study was to evaluate the cyclic and torsional fatigue resistance of reciprocating single-file systems W File 25.07 (WF, TDKaFile, Mexico City, Mexico) and X1 Blue File 25.06 (X1 BF, MK Life, Porto Alegre, Brazil) at body temperature. **Materials and Methods:** Forty reciprocating instruments of the W File 25.07 (WF 25.07) and X1 BF 25.06 (n=20) were used. Cyclic fatigue tests were performed at body temperature (36° ± 1°C). The instruments were reciprocated until fracture occurred in an artificial stainless steel canal with a 60^0 angle and a 5-mm radius of curvature (n=10). 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 using scanning electron microscopy (SEM). Data were analyzed using one-way ANOVA and Tukey tests, and the level of significance was set at 5%. **Results:** X1 BF 25.06 had significantly higher time and NCF to failure than WF 25.07 ($P<0.05$). The torsional test showed that WF 25.07 had significantly greater torsional strength ($p<0.05$). In relation to angular rotation, the X1 BF 25.06 showed higher angular rotation values to failure than WF 25.07 ($p<0.05$). **Conclusion:** The X1 BF 25.06 had the highest cyclic fatigue resistance and highest angular rotation values to fracture in comparison with WF 25.07. However, WF 25.07 showed higher torsional resistance to fracture than X1 BF 25.06.

Keywords: Endodontics. Dental Instruments. Nickel. Titanium Metallicum.

How to cite: Calefi PHS, Osaki RB, Evedove NFD, Cruz VM, Andrade FB, Alcalde MP. Cyclic and torcional fatigue resistance of W File and X1 Blue file reciprocating instruments. Dental Press Endod. 2020 May-Aug;10(2):60-6.
DOI: https://doi.org/10.14436/2358-2545.10.2.060-066.oar

» The authors report no commercial, proprietary or financial interest in the products or companies described in this article.

Submitted: January 08, 2019. Revised and accepted: February 11, 2019.

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Introduction

The mechanized Nickel-Titanium instruments (NiTi) have been widely used to prepare curved canals because of their high flexibility, which provides safe root canal preparation and low risk of shaping errors.[1,2] However, instrument's fracture continues to be a concernment for clinicians. The mechanized NiTi instruments can fracture due to cyclic and torsional fatigue.[3,4] Cyclic fatigue occurs when the instrument is rotating in a curved canal and is submitted to tension-compression stress occurs at the point of maximum flexure.[3,4] Torsional fatigue occrus when the instrument's tip is locked on the dentin walls and the instrument continues to rotate, which can induce a plastic deformation or fracture.[3,4]

During the last decades, the manufacturers have developed several modifications on the NiTi instruments with the aim to improve their mechanical properties, such as new instruments designs, manufacturing processes, new kinematics and new thermal treatment of the NiTi.[1,2,4-7] The thermal treatments promote an a better arrangement on the crystalline of the NiTi alloy, which can favor a certain amount of R-Phase and Martensite phase.[1,2,7] Generally, the thermal treatments of the NiTi induce greater flexibility, increases the cyclic resistance and the angular deformation capacity when compared with the conventional NiTi Wire (SE-Wire).[2,7]

Reciprocating kinematics has been shown to be safer than rotary motion during root preparation of curved and constricted root canals due to the reduction of cyclic and torsional stress.[4,6,8,9] Currently, there are several reciprocating NiTi instruments and all of them are thermally treated. The Reciproc Blue (RB, VDW, Munich, Germany) and Wave-One Gold (WOG, Dentsply Sirona, Ballaigues, Switzerland) are the most well known reciprocating instruments and have been widely used and several previous studies evaluated their cyclic and torsional fatigue resitance.[10-13] However, two new reciprocating instruments were recently introduced on the Brazilian market; the X1 Blue File (MK Life, Porto Alegre, Brazil) and WA1 File (TDKaFile, Mexico City, Mexico) and there is lack of information regarding the mechanical properties of these instruments.

The X1 Blue file (X1 BF) reciprocating system has three instruments with #20, #25 and #40 tip sizes and 0.06 taper, presents a convex triangular cross-section, and is manufactured with heat treatment similar to that of Blue technology.[12] Klymus et al.[12] showed that X1 BF 25.06 present similar cyclic fatigue resistance in comparison with RB 25.08 and WOG 25.07 at body temperature. However, there are no data regarding the torsional fatigue resistance of this instrument.

The W File is a Mexican reciprocating system that is imported by a Brazilian company (Eurodonto, Curitiba, Brazil). This system present instruments with similar tip size, taper and cross-sectional design than WOG system. This system has instruments with #20, #25, #35 and #45 tip size and taper 0.07, 0.07, 0.06 and 0.05, respectively, and present a parallelogram cross-sectional design. According to the manufacturer's, the instruments are thermally treated by a special process that induces an oxide layer on the instrument's surface, making them with a golden color. There are no data of the cyclic and torsional fatigue resistance of this system.

Previous studies reported that body temperature drastically affects the flexural resistance of NiTi instruments because it is capable of modifying the transformation temperatures of the NiTi.[14-16] Therefore, the cyclic fatigue test the NiTi instruments should be always performed close to body temperature to ensure relevant results and simulate the flexural behaviour at temperatures inside the root canal.[12,14-16]

The knowledge of the cyclic fatigue and torsional fatigue resistance of the NiTi instruments is of fundamental importance to provide a safe and effective clinical application. Therefore, it is important the mechanical properties of these new reciprocating system. The aim of this study was to evaluate the cyclic and torsional fatigue (maximum torque load and angular rotation) of the X1 BF 25.06 and WF 25.07 instruments at body temperature. The null hypotheses tested were as follows: (1) there are no differences in the cyclic fatigue resistance between the instruments and (2) there are no differences in the torsional resistance between the instruments.

Materials and Methods

The sample calculation was performed before the mechanical test by using the G*Power v3.1 for Mac (Heinrich Heine, University of Düsseldorf) and by selecting the Wilcoxon- Mann-Whitney test of the t-test family. The alpha-type error of 0.05, a beta power of 0.95, and a ratio N2/N1 of 1 were also stipulated. The test showed a total of 10 samples for each group as the ideal size for noting significant differences.

A total of 40 NiTi instruments (length, 25 mm) were used for this study. The samples were divided into three groups (n = 20 per system), as follows: X1 BF 25.06 and WF 25.07. Before the mechanical test, all instruments were inspected under a stereomicroscope (Carls Zeiss, LLC, USA) at 16x magnification to detect possible defects or deformities before the mechanical test, none were discarded.

Cyclic fatigue Test

The static cyclic fatigue test was performed in 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.[12,17] The cyclic fatigue tests were performed at body (36°± 1°C) temperature using a water bath, as in a previous study.[12] The cyclic fatigue device was submerged in a plastic container filled with 400 ml of deionized water and an aquarium thermostat (Hopar, Guangdong, China) was submerged in the water a few minutes before starting the testing of each file to achieve the desired temperature (36°± 1°C). During all tests, the temperature was monitored by an aquarium digital thermometer.

All the instruments were activated until fracture occurred, and the time to failure was recorded using a digital chronometer. Throughout the test, a video recording was made simultaneously, and the videos were observed to ensure the exact time of instrument fracture. In addition, the number of cycles to failure (NCF) was calculated using the following formula: time to failure (in seconds) X 350 RPM ("Wave One ALL")/ 60.

A total of 10 instruments for each reciprocating system were used, coupled to a VDW Silver Motor (VDW, Munich, Germany) connected to the cyclic fatigue device. The preset programs were selected according to manufactures recommendations. The X1 BF 25.06 and the WF 25.07 was used with the "WaveOne ALL" program.

Torsional fatigue Test

The torsional tests were performed, based on the International Organization for Standardization ISO 3630-1 (1992), using a torsion machine as previously described by other studies.[10,18] A total of 10 instruments, 25-mm long, of each reciprocating system were used. The test was performed to measure the maximum torque and angular rotation until instrument failure.

All the data were recorded by a specific program of the torsion machine (MicroTorque, Analógica, Belo Horizonte, MG, Brazil). Before testing, the handles of all the instruments were removed at the point where they were attached to the torsion shaft. The three millimeters of the instrument tips were clamped into a mandrel connected to a geared motor. The geared motor operated in counter-clockwise rotation, at speed set to 2 rpm for all the groups.

SEM Evaluation

After the cyclic and torsional test, all the instruments were assessed by SEM evaluation (JEOL, JSM-TLLOA, Tokyo, Japan) to determine the topographic features of the fragments after the cyclic and torsional fatigue tests. 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 150x and 350 x magnification after the cyclic fatigue test. In addition, the fractured surface of the instruments submitted to the torsional test was examined at 200x and 1000x magnification in the center of the surface. In addition, the SEM images were used to measure the cross-sectional area of the instruments using the software AutoCAD (Autodesk Inc, San Rafael, CA, USA), as previously reported.[10,18]

Statistical analysis

The Shapiro-Wilk test showed that the data were normally distributed. Then, The One-way analysis of variance (ANOVA) and Tukey tests were used for multiple and individual comparisons. The Prism 6.0 software (GraphPad Software Inc., La Jolla, CA, USA) was used as the analytical tool, and the level of significance was set at 5%.

Results

The mean and standard deviations of the cyclic (time and NFC) and torsional fatigue tests (torque maximum load and angle of rotation) are shown in Table 1. The X1 25.06 had the highest time and NCF to failure than WF 25.07 ($p<0.05$). The maximum torsional strength and angular rotation values are shown in Table 1. The X1 BF

25.06 had significantly lower torsional strength than WF 25.07 ($p<0.05$). In relation to the angular rotation, X1 BF 25.06 had significantly higher values when compared with WF 25.07 ($P<0.05$).

The mean and standard deviations of cross-sectional area at 3 and 5 mm from the tip are shown in Table 2. The X1 BF showed significantly lower cross-sectional area at both points analyzed than WF 25.07 ($P<0.05$).

The SEM evaluation of the fracture surface revealed similar and typical features of cyclic and torsional failure for both brands. After the cyclic fatigue test, all of the fractured instrument surfaces showed microvoids, which are morphologic characteristics of ductile fractures (Fig 1). Following the torsional test, all of the instruments had concentric abrasion marks and fibrous dimple marks at the center of rotation for torsional failure (Fig 2).

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

Instruments	Cyclic Fatigue				Torsional Fatigue			
	Time (seconds)		Cycles (NCF)		Torque (N.cm)		Angles (°)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
W File 25.07	118.3^b	95.18	690.0^b	219.1	1.34^a	0.13	237.1^b	13.38
X1 Blue File 25.06	227.3^a	137.8	1616.0^a	27.17	1.09^b	0.09	291.0^a	8.28

SD, standard deviation. Different superscript letters in the same column indicate statistical differences among groups ($P < .05$).

Table 2. Mean of the cross-sectional area at 3 and 5 mm from the tip (μm^2).

Instruments	Cross-sectional area (3mm)		Cross-sectional area (5mm)	
	Mean	SD	Mean	SD
X1 Blue File 25.06	104.957^a	0.128	226.680^a	0.313
W File 25.07	139.768^b	0.169	295.826^b	0.681

SD, standard deviation. Different superscript letters in the same column indicate statistical differences among groups ($P< .05$).

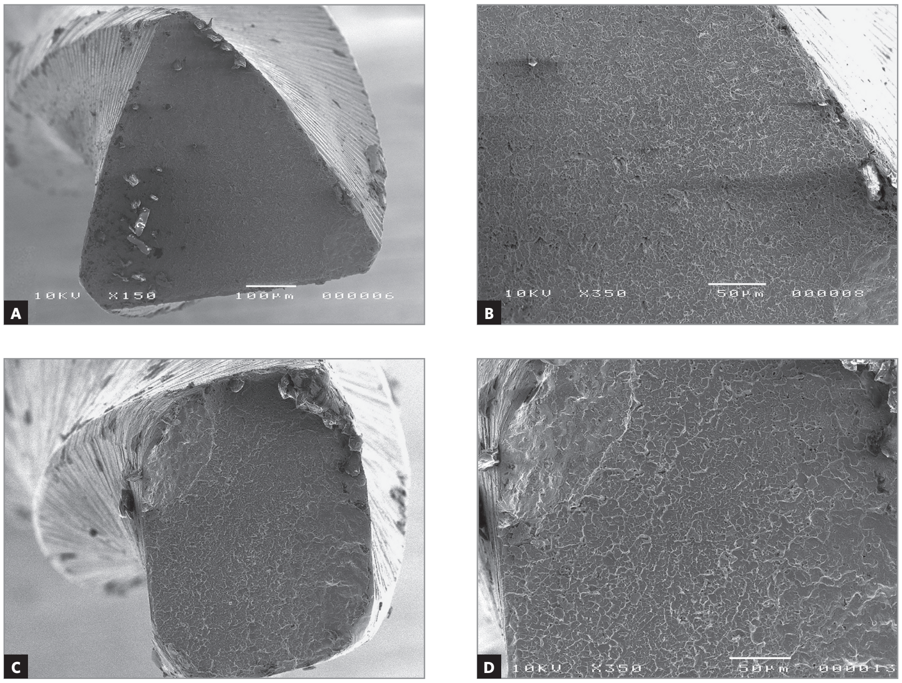

Figure 1. Scanning electron microscopy images of the fractured surfaces of separated fragments of X1 BF 25.06 (**A** and **B**) and WF 25.07 (**C** and **D**) after cyclic fatigue testing. The images show numerous dimples spread on the fractured surfaces, which constitute a typical feature of ductile fracture.

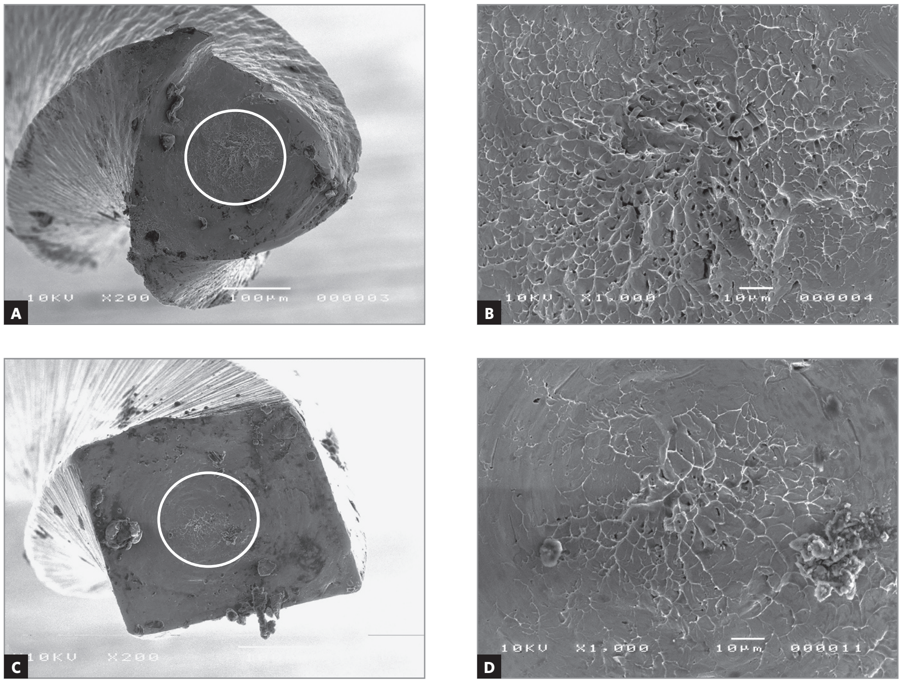

Figure 2. Scanning electron microscopy images of the fractured surfaces of X1 BF 25.06 (**A** and **B**) and WF 25.07 (**C** and **D**) after torsional testing. The left column shows images with the circular boxes indicating concentric abrasion marks at 200x magnification; the right column shows concentric abrasion marks at 1000x magnification; and the skewed dimples near the center of rotation are typical features of torsional failure.

Discussion

The reciprocating kinematics reduces the cyclic and torsional stress of the NiTi instruments during root canal preparation of curved or constricted canal.[4,6,8,9] Several factors can affect the mechanical properties of the NiTi instruments such as tip size, taper, cross-sectional design core diameter, type of NiTi alloy and the temperature of the root canal[1,2,4-7,12]. Thus, the manufacturers have proposed several modifications to improve the safety and effectiveness of the NiTi instruments during root canal preparation and new instruments have been developed.[1,2,4,7]

Recently, some authors demonstrated that the body temperature can reduce the cyclic fatigue resistance of NiTi instruments.[12,14-16] Therefore, the cyclic fatigue of mechanized NiTi instruments should be always evaluated at body temperature, which could speculate the mechanical behavior of them during root canal preparation[12,15]. Klymus et al.[12] reported that X1 BF 25.06 presented similar cyclic fatigue resistance of RB 25.08 and WOG 25.07 at body temperature. However, there is no report of the torsional fatigue resistance of the X1 BF 25.06. In addition, there is no data on the mechanical properties of WF 25.07. Therefore, the aim of this study was to evaluate the cyclic fatigue at body temperature and the torsional fatigue resistance of the X1 BF 25.06 and WF 25.07.

The methodology used in this study was similar than published Klymus et al.[12] The static cyclic fatigue test was performed was used because the cyclic fatigue device was submerged on the water bath. In addition, the static model reduces some variables, such as the amplitude of axial and speed motion, which are subjective because can be performed by different forms by the clinicians.[19,20] However, the type of model chosen for the cyclic fatigue test in this study was simulated artificial canals in a stainless steel block, as previously reported.[10,12,17] In this study, the torsional test was performed in accordance with the ISO 3630/1 specification, as in previous studies.[10,18] The 3 mm of the tip was chosen because it is the point most susceptible to fracture during constricted root canal preparation.[20] In addition, counter-clockwise rotation was used for all instruments because it is the direction of their spiraling flutes.[10,18]

The first results of this study showed that X1 BF 25.06 presented significantly time and NCF values than WF 25.07 ($P<0.05$). Thus, the first null hypothesis was rejected. The instruments used in this study had the same tip sizes (#25). However, the X1 BF has a nominal taper 0.06 mm/mm and WF 0.07 mm/mm. It was previously reported that less tapered instruments are more flexible and present greater cyclic fatigue resistance.[1,4,20] The results of this study are in accordance with these above-mentioned studies. However, other instrument's features, such as cross-sectional design, core diameter and thermal treatment, should be considered.

The cross-sectional design and the core diameter can induce a greater metal mass volume of the NiTi instruments, which can affect the flexibility and the cyclic fatigue resistance.[1,4,19,20] The X1 BF 25.06 has triangular cross-sections and the WF 25.07, a parallelogram-shaped. Therefore, the cross-sectional configuration of the instruments at 5 mm from the tip was captured by SEM and measured the area by means of software (AutoCAD; Autodesk Inc, San Rafael, CA).[10,18] The X1 BF presented the smallest cross-sectional area (226.680μm^2) than WF 25.07 (295.826 μm^2). Previous studies reported that the greater metal mass volume at the maximum point of the stress of the NiTi instruments can affect the cyclic fatigue resitance,[1,4,10] which contribute with the difference in the cyclic fatigue resistance between the instruments in this study.

The thermal treatments of NiTi alloys have strong influences on the martensitic/austenitic transformation behaviour.[1,7] The presence of a higher percentage of martensitic phase in the NiTi alloy promoted more flexibility and greater fatigue resistance.[1,2,7] The X1 BF and WF 25.07 are manufactured by similar thermal process than Blue and Gold technology, respectively. Klymus et al.[12] reported that the instruments manufactured with Blue and Gold technology present similar cyclic fatigue resistance at body temperature. However, the results of this study showed that WF 25.07 presented the lowest cyclic fatigue resistance compared with X1 BF 25.06 at body temperature ($P<0.05$). The possible explanation of the different results of this study can be related to the thermal treatment of the WF 25.07. Despite been similar than the thermal treatment of WOG 25.07, the thermal process used to manufacturer the WF can induce different arrangement the crystalline structure of the NiTi than Gold treatment used in the WOG, which probably favored different lower percentage of martensitic phase and lower flexibility. In addition, lower flexible NiTi instruments can affect the dissipation of the energy required for crack formation and/or propagation during cyclic fatigue testing.[1,2,7]

In this study, the torsional test evaluated the maximum torsional load and angular rotation to fracture while the instruments were rotating in a counterclock wise direction. The torsional test evaluated the torsional behavoir of the instrument when undergoing a high level of torsional stress.[4,10] The second result of this study showed that X1 BF 25.06 presented the lowest torsional strength when compared with WF 25.07 ($P<0.05$). In addition, the X1 BF 25.06 supported greater angular rotation to fracture than the WF 25.07 ($P<0.05$); Therefore, the second null hypothesis was rejected. The results of this study were probably related to the different cross-sectional designs, taper and thermal treatments of the NiTi Alloy.

In a supplementary evaluation, the cross-sectional configuration of the instruments was captured in D3 by SEM and the cross-sectional area was measured by means of a software (AutoCAD; Autodesk Inc, San Rafael, CA) before the torsional test.[10,18] The X1 BF 25.06 showed the smallest area (104.957μm^2) than WF 25.07 (139.768 μm^2). Previous studies have shown that instruments with larger cross-sectional areastend to present higher torsional strength to fracture.[1,10,21,22,28] The cross-sectional area can be affected by the design, core diameter and taper if the instruments.[1,20-22] In addition, instruments manufactured with Blue and Gold technology tends to present similar torsional strength to fracture; however the Blue technology favors greater angular rotation.[10] The results of this study are probably related due to the association of the thermal treatment, a larger cross-sectional area and taper of WF 25.07, which induced less flexible instruments than X1 BF 25.06.

The SEM analysis showed the typical features of cyclic and torsional fatigue for both instruments tested. After the cyclic fatigue test, all instruments evaluated showed crack initiation areas and overload zones, with numerous dimples spread on the fractured surface. After the torsional test, the fragments showed concentric abrasion marks and fibrous dimples at the center of rotation.[4,9,10,18]

Despite reciprocating kinematics promotes a significant reduction in cyclic and torsional fatigue resistance,[8,9] clinicians should know about the mechanical properties of NiTi reciprocating instruments to use them safely in curved and/or constricted canals. The cyclic fatigue resistance of the X1 BF 25.06 probably would ensure safe root canal preparation of curved canals than WF 25.07. However, the higher torsional load of WF 25.07 indicated that they could be safer to use in a constricted canal preparation than X1 BF 25.06.

Conclusion

In conclusion, within the limitations of this study, the cross-sectional design and the thermal treatments had a significant influence on the mechanical properties of the NiTi instruments. The X1 BF 25.06 had the highest cyclic fatigue resistance and highest angular rotation values to fracture in comparison with WF 25.07. However, WF 25.07 showed higher torsional resistance to fracture than X1 BF 25.06.

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