

Cyclic fatigue resistance of novel Genius and Edgefile nickel-titanium reciprocating instruments

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Abstract: This study aimed to assess the cyclic fatigue resistance of Genius and EdgeFile X1 reciprocating instruments compared with WaveOne Gold Primary. Twenty Genius (Ultradent) 25.04, 20 Genius 30.04, 20 EdgeFile X1 (EdgeEndo) and 20 WaveOne Gold Primary (Dentsply Maillefer) instruments were included in this study and tested in a static cyclic fatigue testing device, which has an artificial stainless steel canal with a 60° angle of curvature and a 5-mm radius of curvature. All instruments were operated in reciprocation mode until fracture occurred. The number of cycles to failure (NCF) was calculated and time to fracture (TF) was recorded in seconds using a digital chronometer. The mean and standard deviations of NCF and TF were calculated for each reciprocating system and the data were subjected to Kruskal-Wallis one-way analysis of variance and to Dunn's test ($p < .05$) using SigmaPlot software (Systat software, CA, USA). The fractured surfaces of five instruments from each brand were randomly examined and microphotographed by a low-vacuum environmental scanning electron microscopy - SEM (Tabletop Microscope TM3030, Hitachi, Japan) to confirm the cyclic fatigue fracture. EdgeFile exhibited the highest cyclic fatigue resistance, followed by both Genius files ($p < .05$). Within the limitations of this *in vitro* study, EdgeFile X1 instruments had significantly higher cyclic fatigue resistance than did Genius and WaveOne Gold Primary instruments. The cyclic fatigue resistance of both Genius files was higher than that of WaveOne Gold Primary.

Keywords: Dental Instruments; Endodontics; Root Canal Preparation.

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Introduction

Endodontic instruments manufactured with nickel-titanium (NiTi) were introduced by Walia et al.¹ to improve the instrumentation of curved canals, once NiTi instruments are more flexible and have superior resistance to torsional fracture compared with the rigidity of stainless steel instruments, reducing canal transportation.^{2,3} In addition, operator fatigue, procedural errors, and length of root canal treatment⁴ are reduced, improving the quality of endodontic therapy for both the professional and the patient.

Despite the advantages of NiTi, fracture incidence is the most common failure that occurs during its use⁵ as a result of flexural or torsional strength,

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or even a combination of both,⁶ without any visible indication of plastic deformation.⁷ Therefore, the manufacturers recommend limited or even single-time use of NiTi instruments, especially in curved canals.

The metal fatigue caused by repetitive stressing cycling is an important failure mechanism.⁸ In this fracture type, also known as cyclic fatigue, NiTi instruments undergo tension and compression forces in the area of maximum canal curvature, until fracture.⁹ Several studies have shown that reciprocating motion enhances cyclic fatigue resistance compared to rotation motion,^{10,11,12} making reciprocating instruments safer than rotary ones for root canal shaping.

WaveOne Gold (Dentsply Maillefer, USA) is available in the market as a single-file technique, with Small (20.07), Primary (25.07), Medium (35.06), and Large (45.05) instruments as recent versions of WaveOne (Dentsply Maillefer). It is manufactured with a gold heat treatment procedure, which is performed by heating the file and then cooling it slowly, in contrast to the pre-manufacturing heat treatment of M-Wire technology. The reciprocating motion of WaveOne was maintained, with a cutting action at 150° CCW and disengagement at 30° in the CW direction, but the file dimensions and geometry differ from the original WaveOne, featuring an off-center design with cutting edges and alternate 1-point contact in a parallelogram design. Also, Wave One Gold instruments have a different taper in the same instrument, as WOG Primary starts with a 25.07 tip, decreasing to .06 after 4 mm and to .03 after another 4 mm.^{13,14}

The Genius system (Ultradent, South Jordan, UT) has been recently developed to associate rotary and reciprocating techniques, with thermally treated NiTi alloy and a .04 taper, improving resistance and flexibility, as announced by the manufacturer. Rotary motion is indicated to enlarge the cervical third, and two reciprocating files are used to prepare the root canal, with 90° of cutting action (CW) and 30° of release (CCW). The instrumentation finishes with a 360° rotation, removing the debris from the canal. The files have an S-shaped cross-section design with double right positive cutting action and, according to the manufacturer, the progressive pitch of the file during instrumentation prevents the “screw-in” effect.¹⁵

The EdgeEndo company (Albuquerque, USA) has launched several automated instruments such as reciprocating (X1), rotary (X3, X5 and X7), or retreatment (XR) endodontic files. EdgeFile X1 (EdgeEndo) features a constant .06 tapered reciprocating instrument with a triangular cross-section and annealed heat-treated nickel-titanium alloy (Fire-Wire™), which according to manufacturer, increases flexural strength, enhancing durability and flexibility. The files must be used in the WaveOne® motor setting, therefore with the same motion of 150° (CCW) cutting action and 30° (CW) release, as recommended by the manufacturer.¹⁶

To date, there have been no studies on the cyclic fatigue resistance of reciprocating Genius and EdgeFile systems in curved canals. Therefore, the present study aimed to compare the cyclic fatigue resistance of Genius and EdgeFile reciprocating files with WaveOne Gold Primary instruments. The null hypothesis was that there would be no significant difference in the cyclic fatigue resistance of the instruments.

Methodology

In this study, 80 files were selected (n=20), as previously used for cyclic fatigue tests,^{17,18,19,20} as follows: 20 Genius (25.04), 20 Genius (30.04), 20 WaveOne Gold Primary (25.07), and 20 EdgeFile X1 (20.06) files. To measure the cyclic fatigue resistance of the files, an artificial canal, made of stainless steel with an inner diameter of 1.5 mm, a 60° angle of curvature, and a curvature radius of 5 mm, was used. The curvature of the artificial canal was located at the 5-mm coronal end of the canal.^{21,22} To reduce the friction of the files as they contacted the artificial walls of the canal, a synthetic oil (WD-40 Company, Milton Keynes, UK) was used for lubrication.²² All cyclic tests were performed at room temperature (20° ± 1°C).

The files were divided into four experimental groups (n = 20) and underwent the following procedures:

- a. Group 1: Genius 25.04: The files were used with the Genius reciprocating & rotary motor (Ultradent Products, Inc, South Jordan, USA) connected to a cyclic fatigue testing instrument and operated at 350 rpm, set to the genius files in reciprocation mode, with 90° of cutting action (CW) and 30° of release (CCW), until they fractured.

- b. Group 2: Genius 30.04: The files were used with the Genius reciprocating & rotary motor (Ultradent Products, Inc, South Jordan, USA) connected to a cyclic fatigue testing instrument and operated at 350 rpm, set to the genius files in reciprocation mode, with 90° of cutting action (CW) and 30° of release (CCW), until they fractured.
- c. Group 3: WaveOne Gold Primary: The files were used with the E3 Torque Control Motor (Dentsply Tulsa Dental Specialties, USA) connected to the cyclic fatigue testing instrument and operated at 350 rpm with the "WaveOne ALL" program until they fractured.
- d. Group 4: EdgeFile X1: The files were used with the E3 Torque Control Motor (Dentsply Tulsa Dental Specialties, USA) connected to the cyclic fatigue testing instrument and operated at 350 rpm with the "WaveOne ALL" program, as recommended by the manufacturer, until they fractured.

All the instruments were reciprocating and time from motor activation was recorded and stopped as soon as a fracture was detected visually and/or audibly on a digital chronometer. The number of cycles to failure (NCF) of each file was then calculated using the following formula: $NCF = \text{revolution per minute (rpm)} \times \text{time (seconds)} / 60$. The lengths of the fractured segments were measured by a digital caliper (Mitutoyo, Absolute Digimatic, Japan).

The fractured surfaces of five instruments from each brand, randomly selected after the cyclic fatigue test, were examined by a low-vacuum environmental scanning electron microscopy - SEM (Tabletop Microscope TM3030, Hitachi, Japan), in order to confirm that the files fractured because of the cyclic fatigue,^{17,21} and photomicrographs of the fractured surfaces were taken, as shown in Figure 1. Before SEM evaluation, the instruments were ultrasonically cleaned to remove any debris.²²

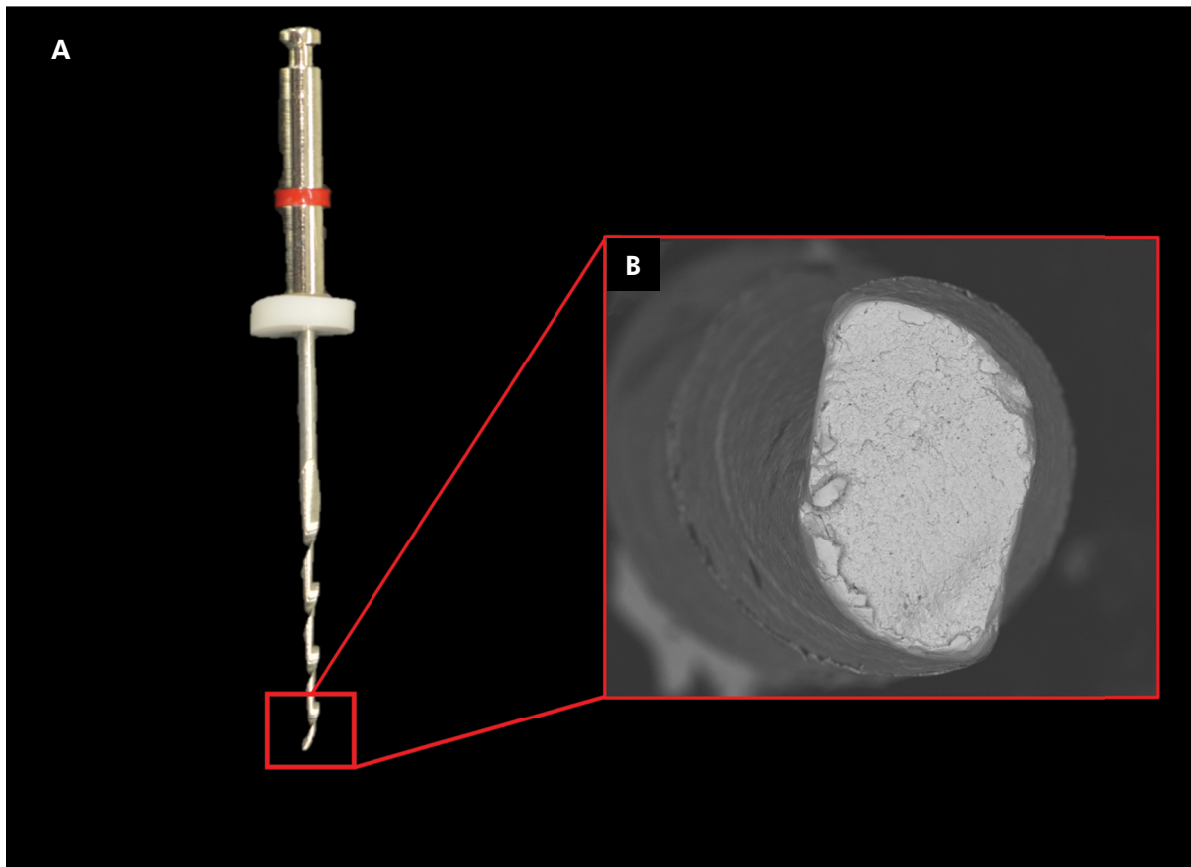


Figure 1. Illustrative example of a Genius 25.04 broken file after reciprocation inside the simulated canal, evidencing the area of analysis (A) and a SEM image (B), showing the analyzed inspection area of a cyclic fatigue ductile fracture.

Statistical analyses

The data were first analyzed using the Shapiro-Wilk test to verify the assumption of normality. The Kruskal-Wallis and Dunn's tests were performed using SigmaPlot software (Systat Software, San Jose, USA) to statistically analyze the data. The statistical significance level was set at $p < .05$.

Results

The means and standard deviations of the NCF, time to fracture, and the lengths of fractured segments are shown in Table. EdgeFile X1 had the highest fatigue resistance (NCF: 6175.74 ± 1608.99 ; TF: 1058.7 ± 275.82) while Wave One Gold Primary had the lowest fatigue resistance (NCF: 881.7 ± 108.04 ; TF: 151.15 ± 18.52) with a statistical difference ($p < .05$). The fatigue resistance of both Genius 25.04 (NCF: 1217.12 ± 230.36 ; TF: 208.65 ± 39.49) and 30.04 (NCF: 1365.58 ± 224.81 ; TF: 234.10 ± 38.56) was statistically higher than that of Wave One Gold Primary (881.7 ± 108.04) ($p < 0.05$), but presented no significant difference between the Genius instruments ($p > 0.05$).

The mean lengths of fractured segments were recorded in order to evaluate the correct positioning of the tested files inside the canal curvature, since each group maintained the approximate segment length. There was a statistically significant difference ($p < .05$) in the mean length of the fractured fragments among all instruments, except for Genius 25.04 and EdgeFile X1 (Table).

SEM evaluation

Scanning electron microscopy images of the fractured surface showed typical features of cyclic fatigue failure for all instruments. All the

instruments presented fractured surfaces with microvoids, a mechanical characteristic of ductile fracture (Figure 2).

Discussion

Since the introduction of NiTi instruments in endodontics by Walia et al.¹ in the 1980s, manufacturers have been improving the manufacturing process, aiming to enhance the mechanical properties of the alloy and decreasing the failures (broken files) observed during the endodontic treatment.²³ Nowadays, NiTi endodontic files are classified into instruments containing mainly the austenite phase, such as conventional NiTi, M-Wire, or R-Phase, and those containing mainly the martensite phase, such as CM Wire, Gold, and Blue (thermally treated). The instruments in the austenite phase show superelastic properties and high torque values, indicated for shaping straight or slightly curved canals or even as pathfinding instruments because of the smaller diameter. Martensitic instruments are more flexible, used in root canals with severe or double curvature, in addition to being prebendable.²⁴

However, several factors can affect the resistance of NiTi endodontic instruments, such as the manufacturing process, metallurgical design, instrument size, taper, helix angle, cross-sectional design, core diameter, file kinematics, heat treatment applied to the file,^{25,26,27} or even the temperature to which the instrument is subjected.^{20,28,29}

Many cyclic fatigue test devices may be used with static or dynamic test models. In this study, the model used for the cyclic fatigue test was static, in which an instrument-fixed working length is bended and then rotated until fracture occurs with no axial movement,

Table. Mean and standard deviations of the number of cycles to failure (NCF), time to fracture (seconds) and the length of the fractured fragment (mm) of the tested files

Group	NFC	TF (s)	Fractured Length (mm)
Genius 25.04	1217.12 ± 230.36^a	208.65 ± 39.49^a	3.14 ± 0.18^a
Genius 30.04	1365.58 ± 224.81^a	234.10 ± 38.56^a	3.86 ± 0.54^b
Wave One Gold Primary	881.7 ± 108.04^b	151.15 ± 18.52^b	2.37 ± 0.50^c
EdgeFile X1	6175.74 ± 1608.99^c	1058.7 ± 275.82^c	3.02 ± 0.45^c

Different superscript letters indicate statistical significance ($p < .05$).

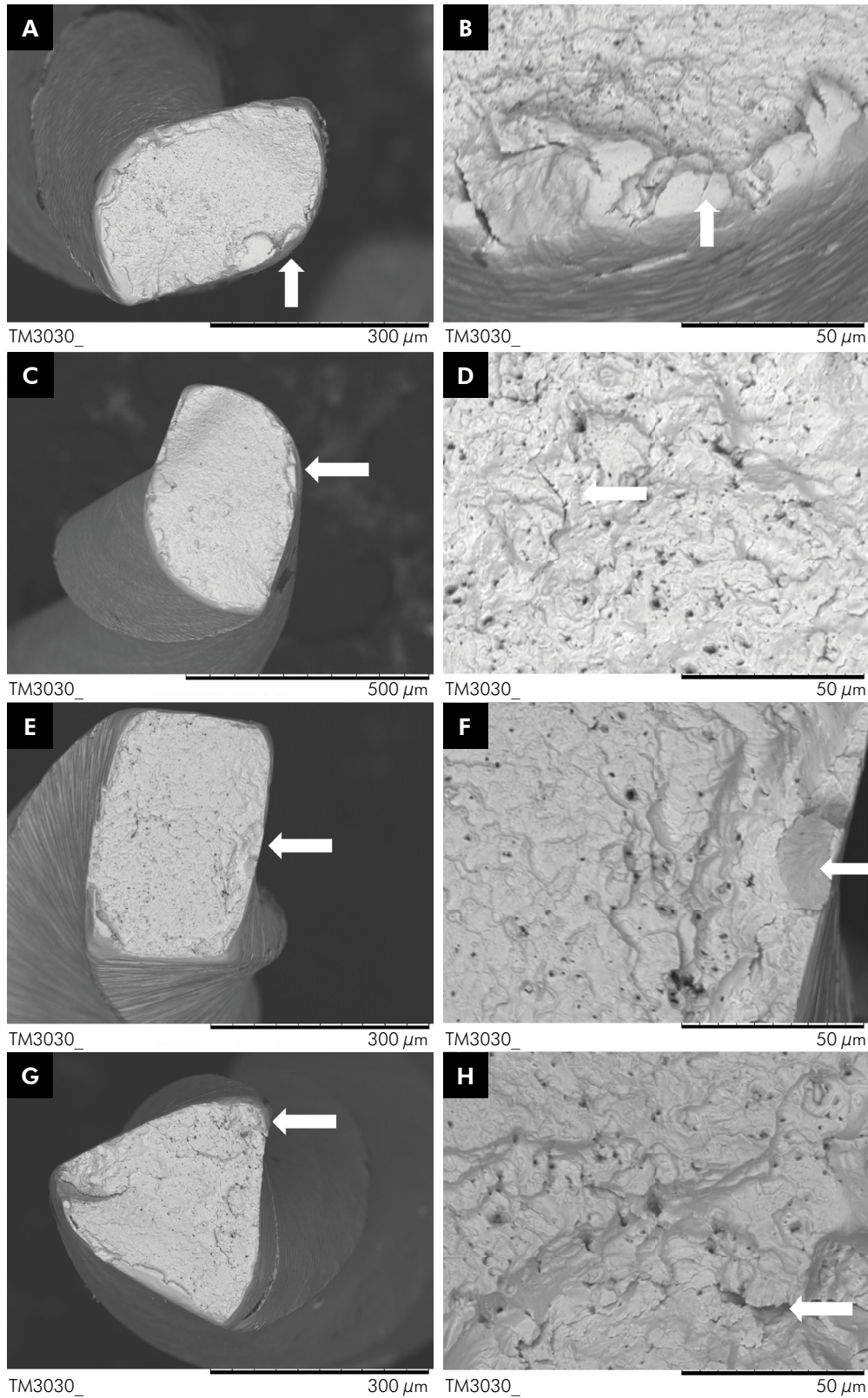


Figure 2. SEM Images after the fatigue cyclic test of Genius, WaveOne Gold Primary, and EdgeFile X1 instruments. General view of (A) Genius 25.04, (C) Genius 30.04, (E) WaveOne Gold Primary, and (G) EdgeFile X1 and high-magnification view of (B) Genius 25.04, (D) Genius 30.04, (F) WaveOne Gold Primary, and (H) EdgeFile X1 instruments, showing numerous dimples and fatigue striations, typical features of cyclic fatigue (white arrows).

allowing for a precise trajectory in the simulated artificial canal in a stainless steel block, as used in previous studies.^{10,17,22,30,31} The advantages of the static model consist mainly in reducing variables, such as the amplitude of axial movements.^{10,20,31}

With respect to the temperature of the *in vitro* test, the room temperature ($20^{\circ} \pm 1^{\circ} \text{C}$) was previously used to perform the cyclic fatigue test.^{19,21,32,33} However, recent findings have shown that NiTi martensite instruments operating at body temperature (37°C) show a significant decrease in flexural resistance and consequently in NCF, since heating may induce a transition to a stiffer austenite phase, which is more susceptible to fatigue failure.^{20,28,29,34}

The present study compared the cyclic fatigue resistance of the reciprocating Genius File and EdgeFile with WaveOne Gold. According to our results, the cyclic fatigue resistance of both Genius and EdgeFile systems was higher than that of WaveOne Gold, evidencing the highest fatigue resistance for EdgeFile. Thus, the null hypothesis of the present study was rejected.

This is the first study on the cyclic fatigue of a reciprocating EdgeFile instrument. A recent study has shown that reciprocating EdgeFile X1 induces low transportation, has a high centering ability,³⁵ and shows similar shaping ability to iRaCe and XP-endo Shaper.³⁶ According to the manufacturer, the annealed heat-treated Firewire NiTi increases flexibility, along with its 6% taper and a hyperbolic cross section.¹⁶ The association of a thermally treated alloy with a low core mass (taper .06) may explain the results obtained in this study. The elevated values for cyclic fatigue is in accordance with a previous study on a rotary EdgeFile X7, which presented the highest NCF values at different temperatures.²⁷ Additionally, another research study on rotary EdgeFiles X7 demonstrated that CM heat treatment has higher fatigue resistance than instruments without thermal or Fire-wire treatment.³⁷

Supporting the findings of the present study, previous research studies have reported that the resistance to cyclic fatigue of S-shaped endodontic files with two cutting edges (*e.g.*, Reciproc files) was greater than that of WaveOne files,^{38,39,40} attributing their findings to the different cross sections of the

files. Cheung et al.⁴¹ also reported, through finite elemental analysis, that NiTi instruments with an S-shaped or triangular cross-section present better fatigue resistance than does a square or rectangular cross section.

Grande et al.⁴² compared the cyclic fatigue resistance of two different file cross sections: S-shaped Mtwo NiTi files (VDW) and the convex triangular ProTaper Universal files (Dentsply Maillefer). They found that Mtwo files, which have a smaller core mass, were more resistant to cyclic fatigue, in accordance with later findings, showing that files with a greater metal core mass have lower fracture resistance.²⁹ There is no consensus about cross-sectional shape on cyclic fatigue resistance, but previous studies have indicated the dimension of the cross-sectional area as the most important factor in cyclic fatigue resistance than the type of alloy.^{8,40,41}

The curvature of the artificial canal was located 5-mm from the coronal end. Considering the taper of each file, the diameter at 5 mm from the tip (D5), which would be at the center of the curvature, shows different values. Wave One Gold has diameter 59 at D5, whereas Genius 25 is a 45, Genius 30 is a 50 and EdgeFile is also a 50. Therefore, the greater taper and, consequently, the large core mass of Wave One Gold at D5, associated with the parallelogram cross section, may have influenced the low values on the cyclic fatigue test. Corroborating previous results and the findings of the present study, we suggest that, although the Genius File does not undergo heat treatment in the martensite phase, its higher cyclic fatigue resistance compared with WaveOne Gold might be because of the reduced taper and therefore a low core mass, explaining its superior performance, since cyclic fatigue decreases when file diameters are increased.⁴⁵ In recent years, manufacturers have tended to produce lower taper files to ensure a more conservatively shaped canal. Lower taper files could enhance the fatigue resistance of NiTi endodontic files.⁴⁵

Another major aspect is the difference in the reciprocating angle recommended by each manufacturer, which might explain the high resistance, since decreasing the reciprocation range of instruments results in an increased cyclic fatigue

resistance.⁴⁶ A previous study regarding different reciprocation angles found that 90° CW-30° CCW was safer for enhancing instrument resistance to fatigue failure, when compared to instruments operating at greater angles.⁴⁷ Additionally, the present study also corroborates the findings of Ozyurek et al.,⁴⁸ which showed the highest cyclic and bending resistance in double (S-shaped) curved canal for Genius files, when compared to WOG Primary and Reciproc Blue.

The fractured length of each file was at the center of the curvature or just above this point, confirming the positioning of the instruments. The SEM images showed regular fractographic appearance of cyclic fatigue with crack initiation areas and overload zones, which was similar in the four experimental groups.

Conclusions

Within the limitations of the present study, our results showed that EdgeFile X1 had significantly higher cyclic fatigue resistance. In addition, both Genius files showed higher cyclic fatigue resistance than WaveOne Gold Primary. Further research is necessary to analyze fatigue at different temperatures and with different tapers.

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