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ORIGINAL ARTICLE

A laboratory study analysis of the cyclic fatigue strength of glide path instruments at simulated body temperature

ABSTRACT

Aim: *This study aimed to evaluate the cyclic flexural fatigue resistance of four glide path files (one rotary and three reciprocating) by using a simulated root canal model.*
Methodology: *25-mm-length files (n=10) (ProGlider, Dentsply Maillefer; X1-Glide Path, MK Life; WaveOne Gold Glider, Dentsply Maillefer; and R-Pilot, VDW) were mounted in a 6:1 reduction handpiece powered by a torque-controlled motor and introduced into a 1.4-mm-diameter and 19-mm-length stainless steel tube (9-mm-length curved segment with an 86-degree curvature angle. The files were worked under irrigation with 37 °C distilled water until visual and/or audible observation of fracture. The time to each file fracture was measured with aid of a digital stopwatch. X1-Glide Path, WaveOne Gold Glider, and R-Pilot files were subjected to reciprocating motion while ProGlider files were subjected to continuous 300-rpm clockwise rotation. The surface morphology of two specimens per group was observed under scanning electron microscopy before and after fatigue testing. The file types were compared using one-way ANOVA and posthoc Tukey (p<0.05). The Weibull analysis was used to determine the expected lifespan of the files.*
Results: *The mean time to file fracture was found significantly different among file types (p<0.001): X1-Glide Path (455.32 sec) > R-Pilot (315.13 sec) > WaveOne Gold Glider (235.65 sec) > ProGlider files (158.30 sec). The Weibull analysis confirmed that ProGlider and X1-Glide Path files are associated with the shortest and the longest mean time to failure, respectively.*
Conclusion: *X1-Glide Path files showed significantly higher cyclic flexural fatigue resistance than other file types.*

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Introduction

Manufacturing technology of root canal shaping files has significantly changed in terms of nickel-titanium (NiTi) alloy and geometry to improve their mechanical performance (1); however, unexpected file fractures can still occur due to deformations and high-stress levels. Torsional failure can occur when the file tip is locked and the shaft rotates, while cyclic flexural fatigue can occur when the file is submitted to repeated tensile and compressive stresses at the same point (2, 3).

The establishment of a glide path by widening the root canal with a small-sized flexible file aims to allow safe and clear passage of larger engine-driven files (4). The single-use rotatory glide path file ProGlider (Dentsply Maillefer, Ballaigues,

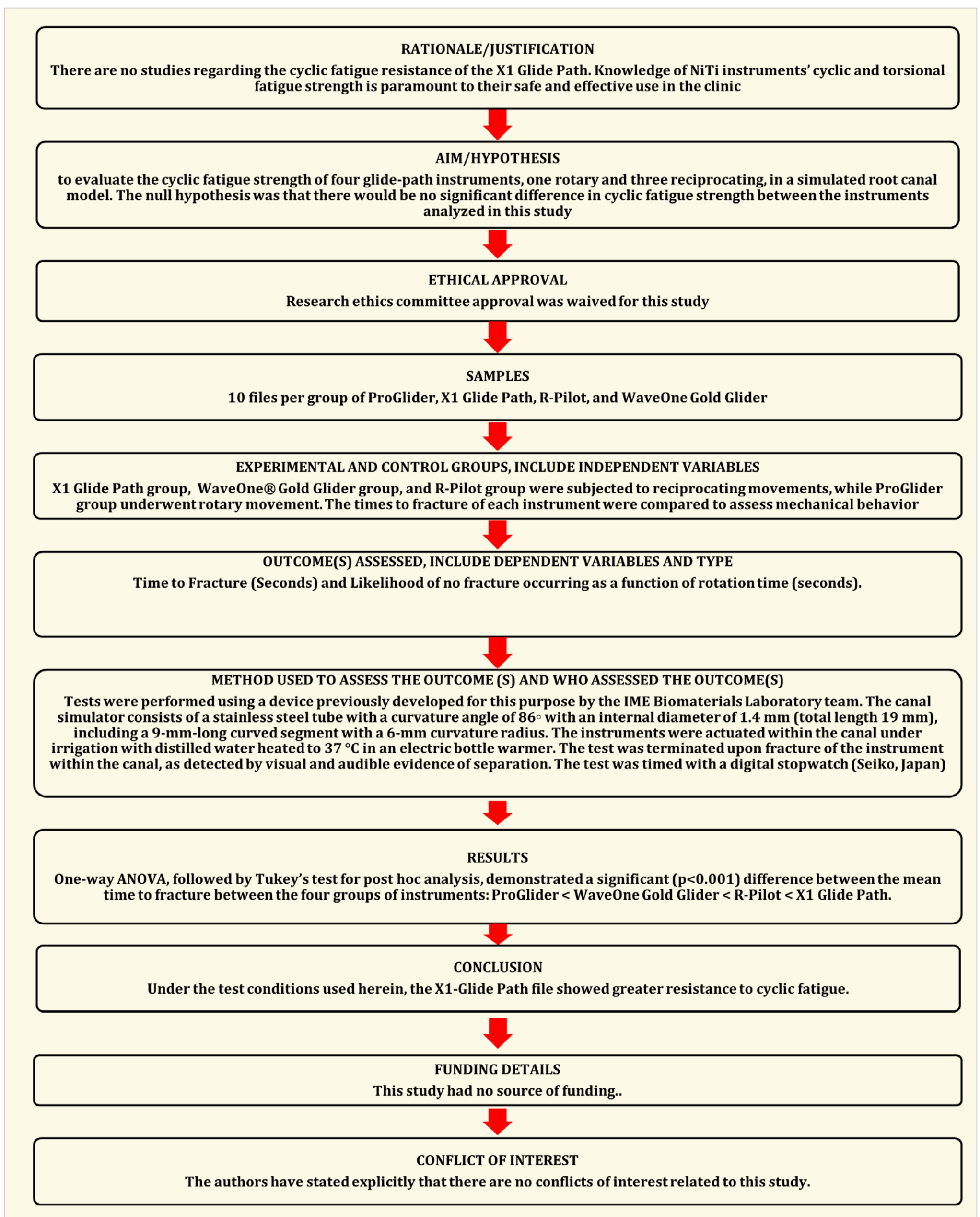

Figure 1
PRILE 2021 flowchart.

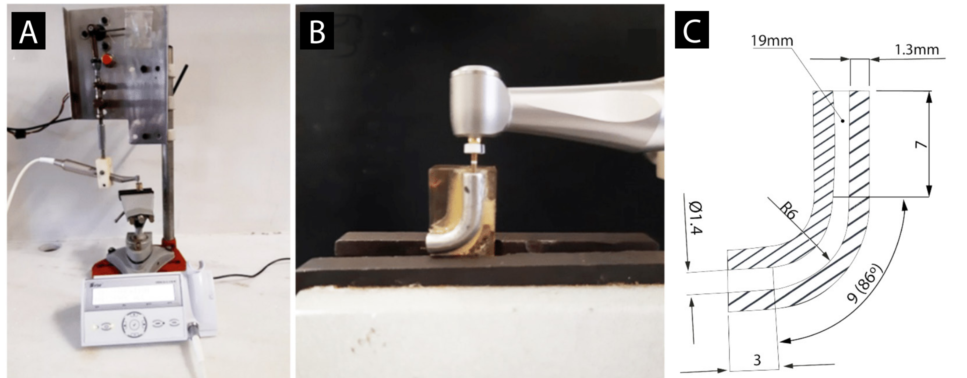

Figure 2
A) Apparatus used for fatigue testing; **B)** File placed into the artificial root canal; **C)** Dimensions of the artificial root canal.

Switzerland) is made with pre-heated NiTi (M-Wire technology), has a 0.16-mm-diameter tip, progressive taper design, square cross-section, and three different lengths (21, 25, and 31 mm) (5). The R-Pilot reciprocating glide path file (VDW, Munchën, Germany) is manufactured with M-Wire alloy and has a 0.125-mm-diameter tip, 4% constant taper, and S-shaped cross-section (6). The WaveOne Gold Glider reciprocating file (Dentsply Maillefer) is made with thermomechanically-treated alloy, has a 0.15-mm-diameter tip, 2 to 6% progressive taper, and parallelogram-shaped cross-section with two cutting edges (6). X1-Glide Path reciprocating files (MK Life, Porto Alegre, Brazil), are made with heated NiTi (Blue technology), have a controlled memory effect, have a 0.15-mm-diameter tip, 0.4-mm constant taper, 25-mm length, and square cross-section; however, there are still no studies on their cyclic flexural fatigue resistance.
Evidence of adequate mechanical behavior of NiTi files is essential to ensure their safe use in endodontics. Therefore, this study aimed to evaluate the cyclic flexural fatigue resistance of four glide path files (one rotary and three reciprocating) by using a simulated root canal model. The null hypothesis tested was that the file type does not have a significant influence on the cyclic flexural fatigue resistance.

Methodology

This study was reported by following the Preferred Reporting Items for Laboratory studies in Endodontology (PRILE) 2021 guidelines (Fig. 1) (7). The time to file fracture was considered the primary outcome of interest and the sample size of 10 specimens per group was based on Keskin et al. (6) with a power of 0.80 and significance level of 0.05 (G*Power 3.1.9.4; Universität Düsseldorf, Germany).
Cyclic flexural fatigue resistance testing of the 25-mm-length files (n=10) ProGlider (Dentsply Maillefer), X1-Glide Path (MK Life), WaveOne Gold Glider (Dentsply Maillefer), and R-Pilot (VDW) was performed at the Biomaterials Laboratory of the Military Institute of Engineering (Rio de Janeiro, Brazil). Each file was mounted in a static 6:1 reduction handpiece (Sirona, Bensheim, Germany) powered by a torque-controlled motor (Silver Reciproc; VDW) and introduced into an artificial canal held by a bench vise (Fig. 2A and 2B) previously described by Lopes et al. (8). The 19-mm-length stainless steel cylindrical tube had an internal diameter of 1.4 mm, including a 9-mm-length curved segment with a 6-mm curvature radius (86-degree curvature angle) (Fig. 2C). The files were worked under irrigation with distilled water heated at 37 °C with an electric bottle warmer until visual and/or audible observation of fracture. The time to each file fracture was measured with aid of a digital stopwatch (Seiko, Tokyo, Japan).
X1-Glide Path, WaveOne Gold Glider, and R-Pilot files were subjected to reciprocating motion (150-degree counterclockwise rotation followed by 30-degree clockwise) that needs three motor activations to

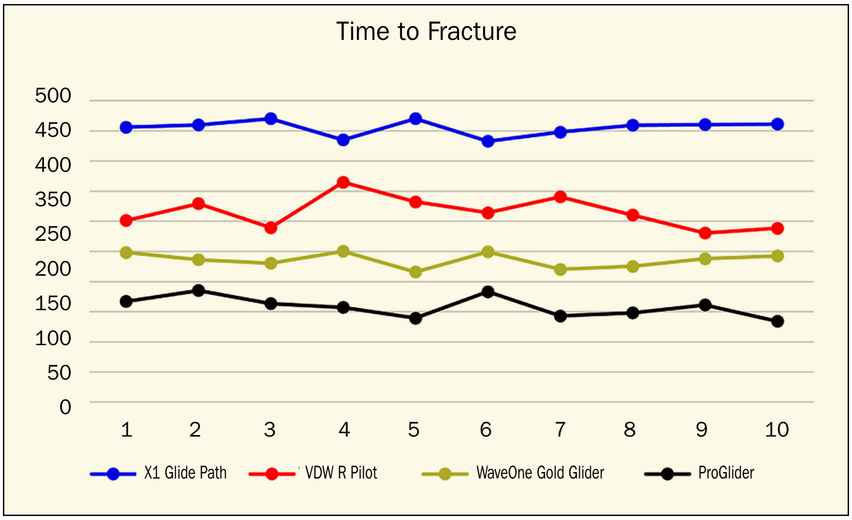

Figure 3
Time (sec) to file fracture for each specimen during cyclic flexural fatigue resistance testing.

complete a full 360-degree file rotation. ProGlider files were subjected to continuous 300-rpm clockwise rotation at a maximum torque of 2 N·cm. The surface morphology of two random specimens per group (www.randomizer.org) was observed under scanning electron microscopy (FEI Quanta FEG250; Thermo Fisher, Waltham, MA, USA) before and after fatigue testing.
The Kolmogorov-Smirnov test was used to assess the normal distribution of the data (jamovi v. 1.6.21, The jamovi project 2021) and the file types were compared using one-way analysis of variance (ANOVA) and posthoc Tukey multiple comparisons at a significance level of $p<0.05$. In addition, the Weibull analysis was used to determine the expected lifespan of the files (9).

Results

The mean time to file fracture was found significantly different among file types ($p<0.001$) (Table 1 and Figure 3).
The Weibull analysis confirmed that ProGlider and X1-Glide Path files are associated with the shortest and the longest mean time to failure, respectively. The coefficient of the Weibull equation indicates the reliability and homogeneity of the file's behavior (the higher the number, the smaller the results dispersion, and the greater the reliability).
R-Pilot: Probability of survival = -0.0396 sec +13.01
WaveOne Gold Glider: Probability of survival = -0.0883 sec +21.324
X1-Glide Path: Probability of survival = -0.0793 sec +36.673
ProGlider: Probability of survival = -0.0612 sec +10.209
The surface morphology of the files after cyclic flexural fatigue resistance testing is shown in Figures 4 and 5. All file types presented similar morphology with machining grooves of different extensions (Figures 6-8).

Discussion

This study compared the cyclic fatigue resistance of four glide path files through a well-established method reported by several studies (10-13). Since the X1-Glide Path file showed higher

Table 1
Mean time to file fracture during cyclic flexural fatigue resistance testing

File	Mean time to file fracture (sec)	Standard deviation	Standard error
X1-Glide Path	455.32^{A}	12.983	4.1057
R-Pilot	315.13^{B}	26.628	8.4204
WaveOne Gold Glider	235.65^{C}	12.387	3.917
ProGlider	158.3^{D}	17.44	5.5149

**Groups with the same capital letter are not significantly different (one-way ANOVA and Tukey multiple comparisons, p< 0.05). Different letters show significant differences between file types.*

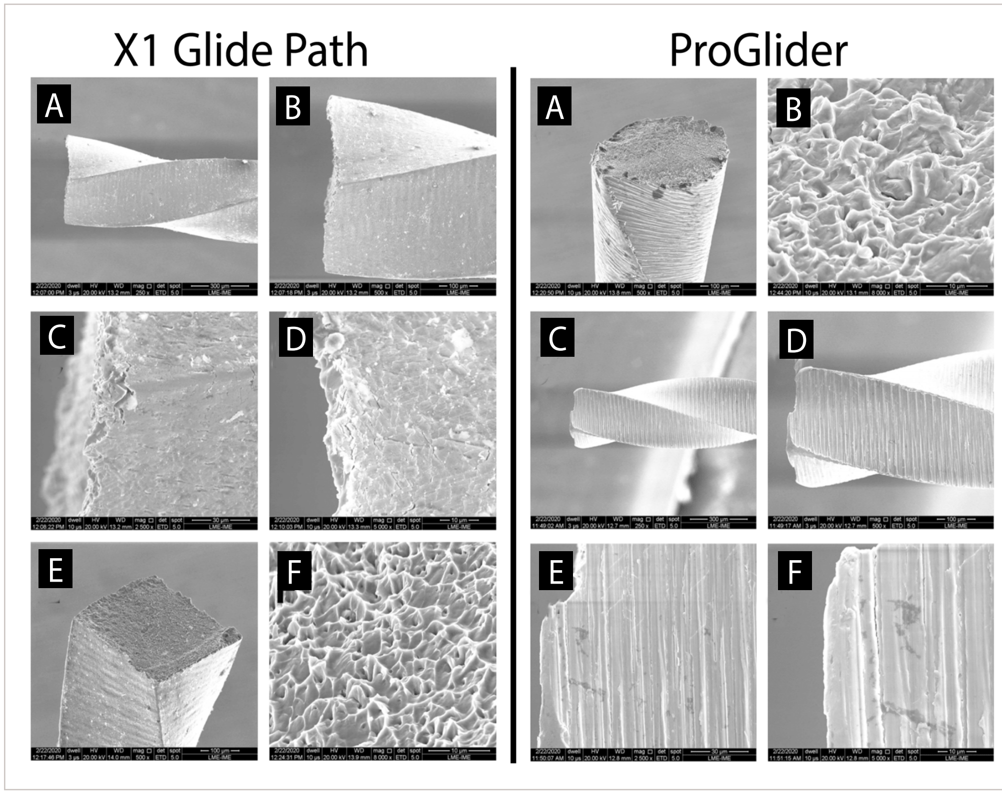

Figure 4
Manufacturing machining marks were observed on the tip surface morphology of X1-Glide Path and ProGlider files after fatigue cyclic flexural fatigue resistance testing. Lateral view at 250x **A)**, 500x **B)**, 2,500x **C)**, and 5,000x **D)** magnification. Upper view at 500x **E)** and 8,000x **F)** magnification.

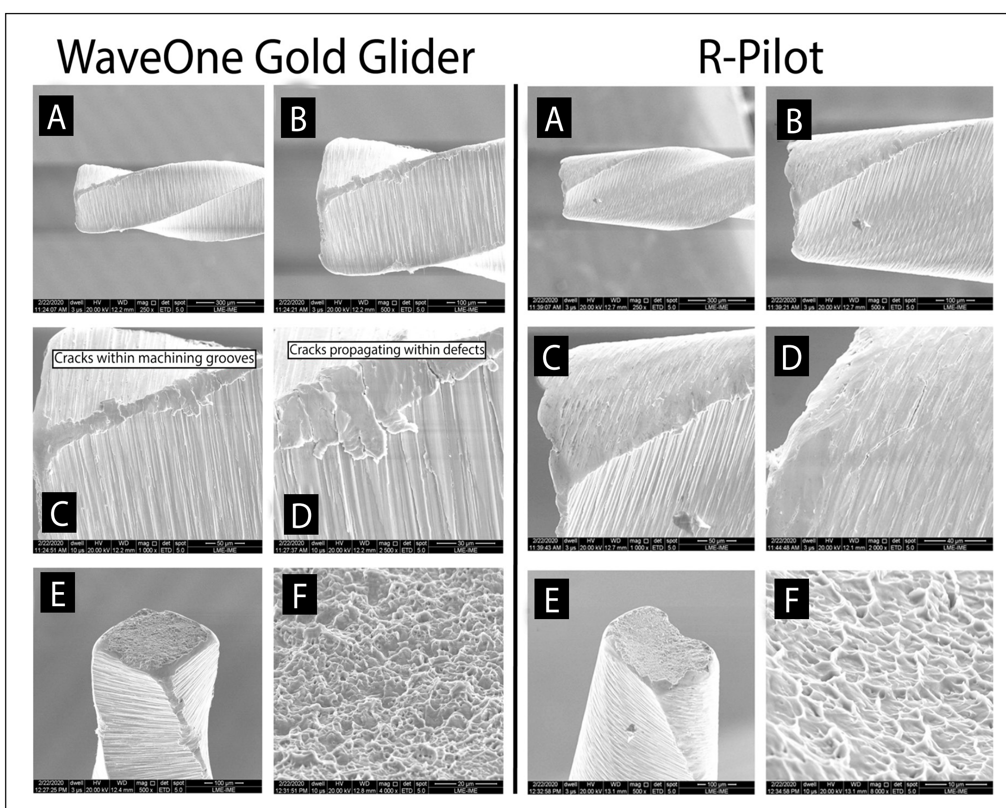

Figure 5
Surface morphology of fractured sites of WaveOne Gold Glider (cracks can be observed at the bottom of machining grooves) and R-Pilot (several cracks can be observed within the manufacturing machining marks) files after cyclic flexural fatigue resistance testing. Lateral view at 250x **A)**, 500x **B)**, 2,500x **C)**, and 5,000x **D)** magnification. Upper view at 500x **E)** and 8,000x **F)** magnification.

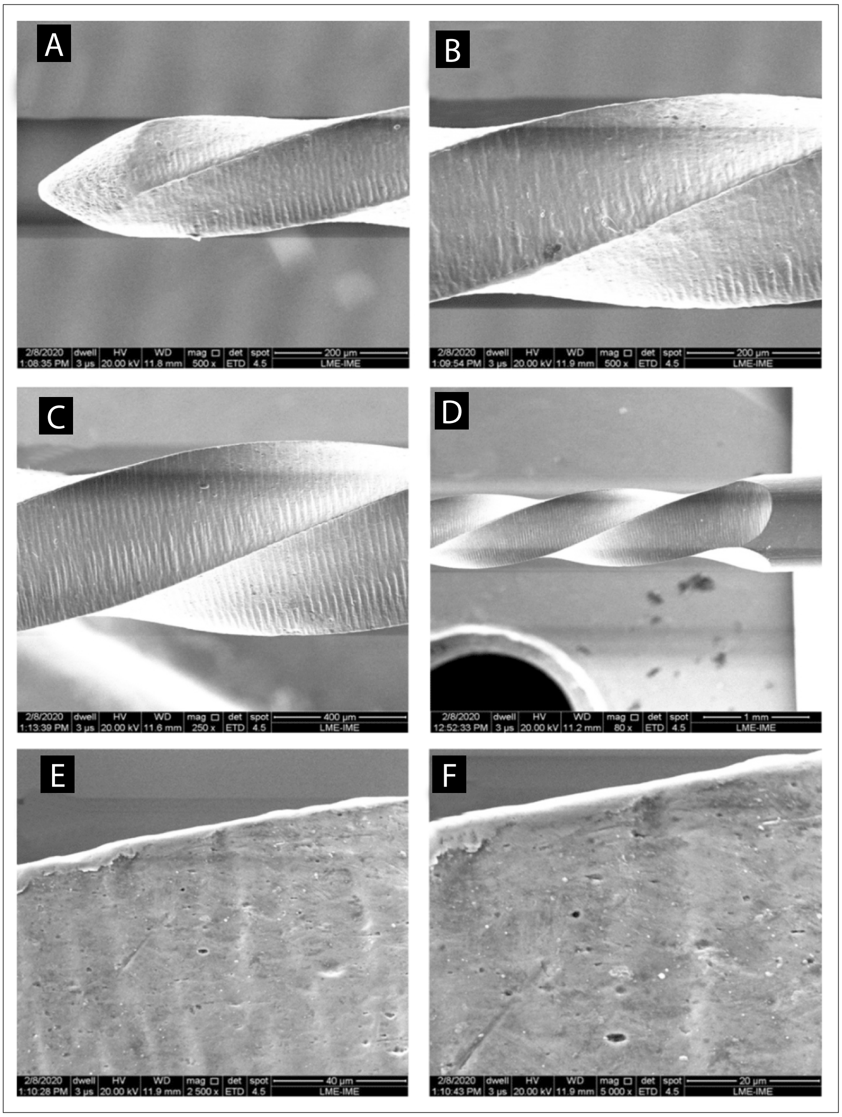

Figure 6
Morphology of the apical, middle, proximal, and 6.0 mm distant region (D6) of the X1 Glide Path® file before fatigue testing. Tooling marks left by the instruments manufacturing process are visible. **A)** Morphology 6.0mm distant region (D6) of the X1 Glide Path file before fatigue testing. Mag 500x. **B)** Morphology 6.0mm distant region (D6) of the X1 Glide Path file before fatigue testing, Mag 500x. **C)** Morphology 6.0mm distant region (D6) of the X1 Glide Path file before fatigue testing. Mag 250x. **D)** Morphology 6.0mm distant region (D6) of the X1 Glide Path file before fatigue testing. Mag 80x. **E)** Morphology6.0mm distant region (D6) of the X1 Glide Path file before fatigue testing. Mag 2500x. **F)** Morphology6.0mm distant region (D6) of the X1 Glide Path file before fatigue testing. Mag 5000x.

cyclic flexural fatigue resistance than other files, the null hypothesis had to be rejected. A static fatigue-testing model was used to avoid the root canal variations (angles and curvature length) of extracted human teeth (14, 15) as well as to eliminate operator-induced tensions (16). The use of a stainless steel tube to simulate the root canal has been reported to provide standardization and reliability to studies on the cyclic flexural fatigue resistance of NiTi files (17-19).

Pruett et al. (20) suggested the relevance of the radius of curvature as an independent variable of studies on root canal shaping. The authors observed that cycles to failure significantly decreased as the radius of curvature decreased due to increased tension and deformation of the files; in addition, all tested files fractured at the point of maximum flexure of the shaft that corresponds to the midpoint of the curvature. Therefore in this study, all file types were tested into the same artificial canal with an identical radius of curvature.

Kinematics has also been reported as a relevant variable in root canal shaping research since reciprocating glide path files have shown higher cyclic flexural fatigue resistance in comparison to rotary glide path files (21). Reciprocating files combine clockwise and counterclockwise movements to complete a rotation cycle; thus, stresses are released along the files and fracture strength is increased (22). The results of this study corroborate Serefoglu et al. (23), which also reported significantly lower cyclic flexural fatigue resistance for rotary files in comparison to reciprocating files.

The metal alloy, heat treatment, helical angle, cross-sectional shape, core mass, and dimensions also influence the flexibility and fatigue resistance of root shaping files (24). Heat-treated NiTi files (M-wire, Gold, or Blue technology) have been reported with higher flexural fatigue resistance than superelastic NiTi files due to superior mechanical properties (25); however, some studies have shown that these files are sensitive to temperature variation and have higher fracture strength at low temperatures (26, 27). The M-Wire technology applied in ProGlider and R-Pilot files relies on the reduction of transition temperature that maintains a high percentage of the

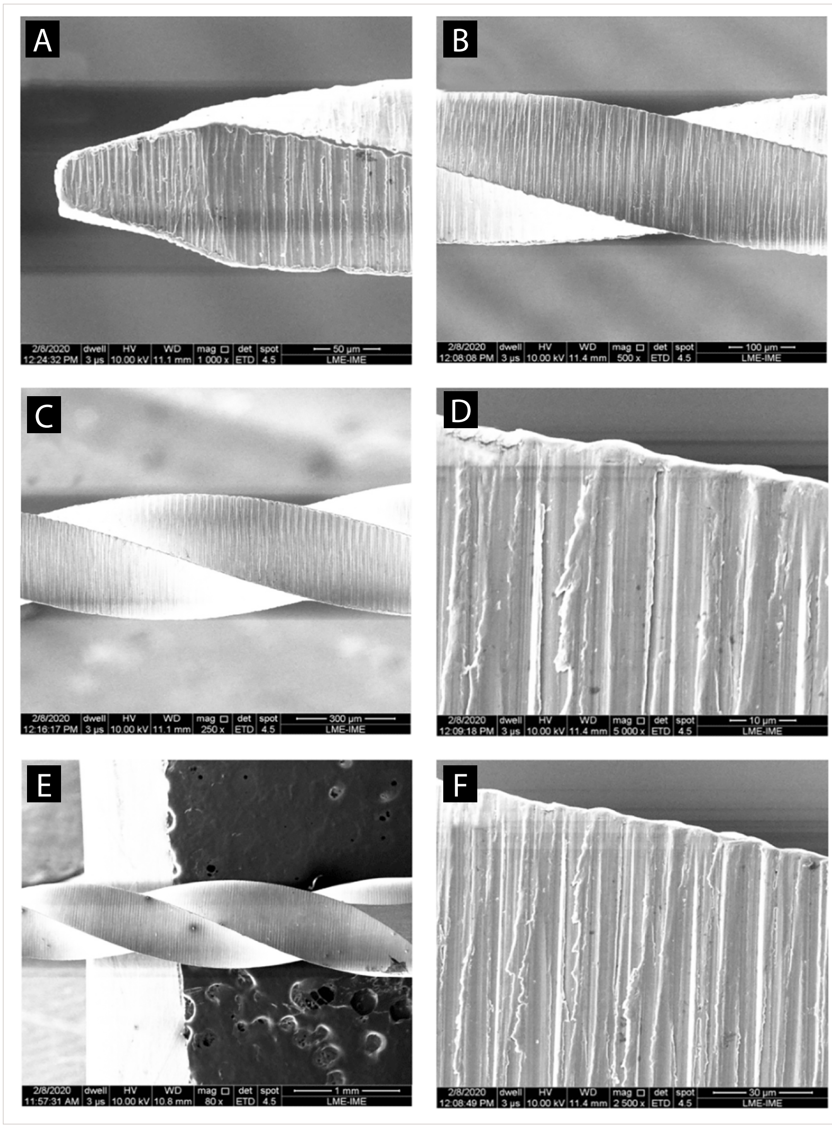

Figure 7
A) Morphology of the apical region, (D6) of the ProGlider file before fatigue testing. Tooling marks left by the instruments manufacturing process are visible. Mag 1000x. **B)** Morphology6.0mm distant region (D6) of the ProGlider file before fatigue testing. Mag 500x. **C)** Morphology6.0mm distant region (D6) of the ProGlider file before fatigue testing. Mag 250x. **D)** Morphology6.0mm distant region (D6) of the ProGlider file before fatigue testing. Mag 5000x. **E)** Morphology6.0mm distant region (D6) of the ProGlider file before fatigue testing. Mag 80x. **F)** Morphology-6.0mm distant region (D6) of the ProGlider file before fatigue testing. Mag 2500x. Mag 5000x.

martensite phase at room temperature. Conversely, X1-Glide Path files are heat-treated with Blue technology (28) and WaveOne Gold Glider files are treated with Gold technology, which can explain different cyclic flexural fatigue resistance results observed in this study. Klymus et al. (28) reported that X1-Glide Path and WaveOne Gold 25.07 files have similar cyclic flexural fatigue resistance at body temperature; however, in this study, the Blue-treated files showed significantly higher cyclic flexural fatigue resistance than both Gold-treated and M-wired files at 37 °C (body temperature). Therefore, further studies are encouraged to confirm the promising results of X1-Glide Path files and their clinical feasibility. This study is one of the few studies that determine the cyclic flexural fatigue resistance of NiTi engine-driven files by simulating the 37 °C body temperature observed in *in vivo* root canals (26).

In this study, both file types (X1-Glide Path and R-Pilot) manufactured with M-wire heat treatment showed the highest time to fracture; in addition, all files fractured approximately 8.5 mm from the tip (maximum shaft flexure), which corresponds to the midpoint of the canal curvature and corroborates with previous studies (29, 30) (Figure 6).

NiTi file's cross-sectional design and core diameter can increase their overall metal mass, and affect flexibility and fracture strength (31). However, in this study, two squared-shaped file types (X1-Glide Path and ProGlider) showed significantly different flexural fatigue resistance. Moreover, the results of this study corroborate Özyürek et al. (32), which observed higher flexural fatigue resistance for S-shaped files (R-Pilot) than WaveOne Gold Glider files (parallelogram-shaped files (WaveOne Gold Glider) due to less metal mass. Although laboratory studies cannot entirely simulate clinical conditions, their results can still provide substantial background knowledge.

Conclusion

X1-Glide Path files showed significantly higher cyclic flexural fatigue resistance than other file types. Further research is needed to validate these findings and provide safe and effective correlations for clinical practice.

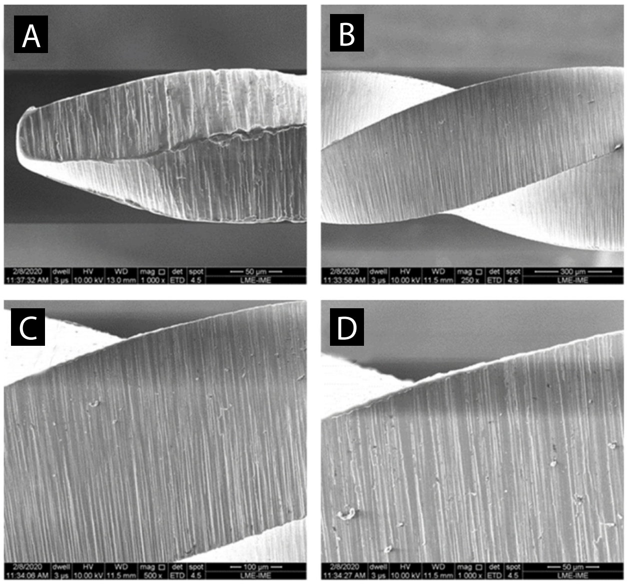

Figure 8
Morphology of the apical region and 6.0 mm distant region (D6) of the WaveOne Gold Glider® file before fatigue testing. Tooling marks left by the instrument manufacturing process are visible. **A)** Morphology of the apical region of the WaveOne Gold Glider® file before fatigue testing. Mag 1000x. **B)** Morphology 6.0 mm distant region (D6) of the WaveOne Gold Glider® file before fatigue testing. Mag 250 x. **C)** Morphology 6.0 mm distant region (D6) of the WaveOne Gold Glider® file before fatigue testing. Mag 500x. **D)** Morphology 6.0 mm distant region (D6) of the WaveOne Gold Glider® file before fatigue testing. Mag 1000x.

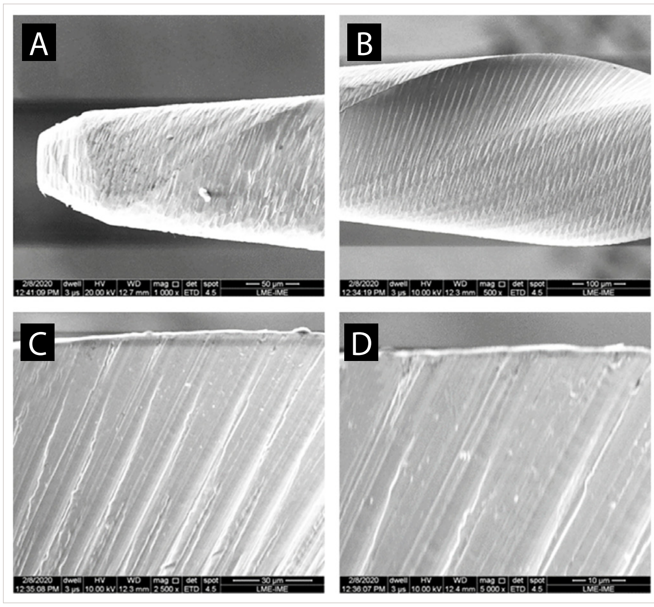

Figure 9
Morphology of the apical region and 6.0 mm distant region (D6) of the VDW R-Pilot® file before fatigue testing. Deep machining marks formed during the instrument manufacturing process are visible. **A)** Morphology of the apical region of the VDW R-Pilot® file before fatigue testing. Mag 1000x. **B)** Morphology 6.0 mm distant region (D6) of the VDW R-Pilot® file before fatigue testing. Mag 500x. **C)** Morphology 6.0 mm distant region (D6) of the VDW R-Pilot® file before fatigue testing. Mag 2500x. **D)** Morphology 6.0 mm distant region (D6) of the VDW R-Pilot® file before fatigue testing. Mag 5000x.

Clinical Relevance

Evidence of the proper mechanical behavior of glidepath files is essential to ensure their safe use in endodontics.

Conflict of Interest

The authors declare no conflicts of interest related to this study.

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None.

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