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Cyclic Fatigue Resistance of Three Glide-path File Systems in Double-curvature Simulated Canals: An *in Vitro* Study

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Abstract

Introduction: To compare the cyclic fatigue resistance of three rotary glide-path file systems (ProGlider, Px-One, and Pro-path) in simulated canals with double curvature. **Materials and Methods:** A total of 78 new files (n=26 per system) were evaluated and divided into six groups according to canal curvature (30° and 60°). Artificial stainless-steel canals (19 mm long, 8 mm curvature radius) were used. All files were operated at 300 rpm and 2.0 Ncm torque using continuous rotation at room temperature (22±2 °C). Cyclic fatigue resistance was assessed by recording the time to fracture. Shapiro-Wilk and Levene's tests were performed to evaluate normality and homogeneity of variance, respectively. Data were analyzed using Welch's ANOVA and Games-Howell post hoc test (P<0.05). **Results:** The Pro-path system showed significantly greater fatigue resistance than Px-One and ProGlider at both 30° and 60° canal curvatures (P<0.001). In 30° canals, Pro-path exhibited a mean fracture time of 76.42±12.50 min, compared to 57.41±11.77 min for ProGlider and 49.84±14.77 min for Px-One. In 60° canals, Pro-path again demonstrated superior performance (18.90±4.86 min), followed by ProGlider (5.71±1.23 min) and Px-One (4.70±1.20 min). **Conclusions:** Under these experimental conditions, Pro-path demonstrated significantly greater cyclic fatigue resistance than ProGlider and Px-One in double-curvature simulated canals. However, the absence of body temperature control and a static testing model limits clinical extrapolation. Further studies validating these findings under physiological conditions and dynamic kinematics are warranted.

Keywords: Cyclic Fatigue; Endodontics; Reciprocating; Rotary Files

Introduction

Root canal treatment is one of the most frequently performed treatments, and its prognosis depends on a series of interrelated factors [1, 2]. The main objective of this treatment is to promote the chemical-mechanical disinfection of the pulp cavity and its root canal system through the use of endodontic instruments and irrigation, as well as its three-dimensional obturation with an inert sealing material and a coronal seal, which prevent the entry of microorganisms [3].

For root canal preparation with a single file system, only one instrument is used to prepare the entire canal system from coronal to apical. Therefore, nickel-titanium (Ni-Ti) files used as single-file systems need increased flexibility, strength, and fracture resistance [4, 5] which has been developed through strategies including reciprocating kinematics instead of continuous rotation, modification of instrument design and heat treatment of the Ni-Ti alloy [6, 7].

A (glide path) is defined as the patency created in the root canal before using any rotary instrument during endodontic treatment. A glide path is achieved when a file can enter from the root canal entrance and pass through the smooth walls of the root canal to the apical constriction uninterruptedly [8]. This confirms a path for instrument rotation to pass through the canal. Several authors have recommended the use of stainless steel to prepare the glide path [9] but using the manual system is difficult and time-consuming [10].

Possible complications during root canal preparation include perforations, root canal transportation, smear layer formation, and instrument fracture [11]. New generation nickel-titanium (Ni-Ti) rotary instruments are used to minimize possible

complications during the preparation procedure. Various rotary files have been developed to create a better glide path [12, 13]. The authors report that when a glide path was created with Ni-Ti rotary files, the original canal morphology was better maintained than when created with stainless steel manual files [14-16]. Several single-file systems with their Ni-Ti rotary glide-path file have been recently introduced for root canal preparation.

The ProGlider file (Dentsply Sirona, Ballaigues, Switzerland) is a single-use file for creating a glide path in preparation for a root canal. It is made of M-Wire alloy. The file taper increases progressively from 2% to 8%. It is of continuous rotation and works at 300 rpm/2 Ncm. It has a square cross-section with four cutting edges and a tip diameter of 0.16 mm. The variable taper design enlarges the coronal portion of the canal and allows larger caliber files to be used later in the canal [16, 17].

Recently, two new glide-path instruments have been introduced, and they are designed to operate with a rotary motion. The first file is the gold heat-treated nickel-titanium file, the PX-One file (Shenzhen Perfect Medical/Dental Instruments, Shenzhen, China). This file works at a speed of 300 rpm and with a torque of 2.0-5.0 Ncm. It has a square cross-section with a 0.16 mm tip. The other file is a blue heat-treated nickel-titanium file, the Pro-path file (Denco, Longhua, Shenzhen, China). This file works at a speed of 300 rpm and with a torque of 2.0-0.5 Ncm. It has a square cross-section and is available in 3 different lengths. The file tip diameter is 0.16 mm. Both files are compatible with ProGlider files [18].

Various file systems manufactured with different heat treatments and operated by different kinematics have been released. In the study conducted by Oh *et al.* [4], they tested WaveOne Gold Primary (WOG), Reciproc Blue R25 (RPB), and HyFlex EDM OneFile (HDM) files and found that the OneFile (HDM) file was more flexible and more cyclic-fatigue resistant at body temperature. Likewise, in the study conducted by Kırıcı *et al.* [11], they compared the cyclic fatigue resistance of WaveOne Gold Glider, ProGlider and One G glide path instruments in double-curvature artificial canals and found that the resistance of the WaveOne Gold Glider nickel-titanium (Ni-Ti) file to cyclic fatigue in S-shaped curved canals was greater than that of the ProGlider and One G Ni-Ti files. In the study conducted by Martins *et al.* [18, 19], they evaluated the cyclic fatigue resistance of three files (ProGlider (Dentsply Sirona), Edge Glide Path (EdgeEndo), and R-Pilot (VDW)) and found that the alternative R-Pilot instruments showed longer cyclic fatigue time to fracture than the other rotary files studied. Finally, in the study conducted by Le *et al.* [20], they evaluated the cyclic fatigue resistance of the WaveOne Gold Glider (Dentsply Maillefer, Ballaigues, Switzerland), R-Pilot (VDW, Munich, Germany) and ProGlider (Dentsply Maillefer) instruments and found that the improved alloy properties and the reciprocating motion could improve cyclic fatigue resistance.

The mechanical properties of glide-path instruments are critical for achieving predictable and safe clinical outcomes in endodontic treatment. However, there is a lack of comprehensive studies evaluating the cyclic fatigue resistance of specific systems such as ProGlider, Px-One, and Pro-path, particularly under complex simulated conditions. Px-One and Pro-path were selected for this investigation due to their recent market introduction as cost-effective alternatives to well-established systems like ProGlider. Despite their growing clinical adoption, there is limited scientific evidence regarding their mechanical durability, especially under repetitive stress conditions typical of curved canal preparation. These systems differ in several key aspects, including cross-sectional geometry, alloy heat treatment, and rotational kinematics, which may influence their performance in fatigue resistance. Therefore, this study aimed to compare the cyclic fatigue resistance of three glide-path file systems in simulated canals with double curvature. The working hypothesis was that significant differences would be found among the systems, with newer instruments potentially exhibiting superior fatigue resistance due to differences in thermal treatment and design.

Materials and Methods

The relevant authorization was requested from the Ethics Committee of the Universidad Científica del Sur. After approval, the regulations established by the Committee were followed. The researchers had no conflicts of interest with the trade brands used in the study. The design was an *in vitro* experimental study. The sample was calculated using the mean comparison formula, with a confidence level of 95%, an error margin of 5% and 80% statistical power. The replaced data were obtained from the pilot test. The sample consisted of 78 files of the following systems: ProGlider (Dentsply Sirona, Ballaigues, Switzerland), Px-One (Shenzhen Perfect Medical/Dental Instruments, Shenzhen, China), and Pro-path (Denco, Longhua, Shenzhen, China), which were distributed in six groups (n=13). The inclusion criteria were new, unused files extracted from sealed boxes, files from the same lot, and the files were checked for manufacturing defects. Before conducting the study, a pilot test was carried out to train the researcher in the respective procedures and cyclic fatigue resistance measurement was calibrated. The calibration was carried out by an expert (an endodontic specialist with more than five years of experience) with a sample of six files for

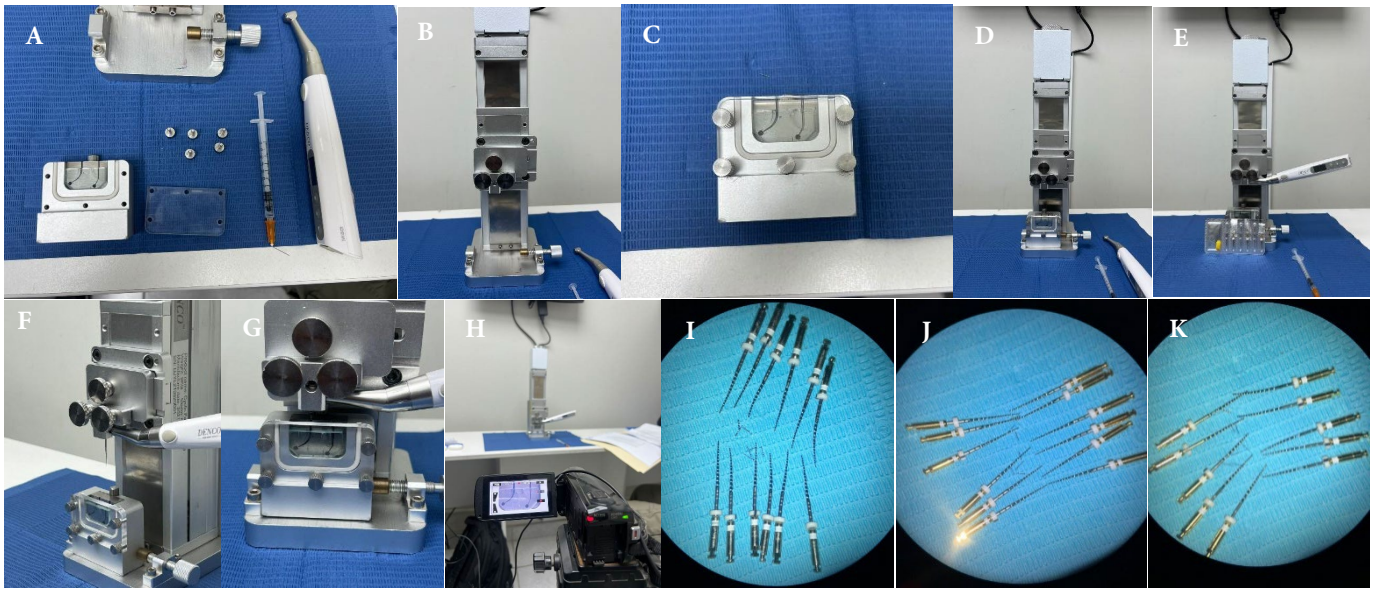

Figure 1. *A*) Simulation cube with 60- and 30-degree curvature angles, endodontic motor, and liquid glycerin; *B*) Cyclic fatigue machine that reproduces the single position of the file in the simulated cana ; *C*) Metal cube with 60- and 30-degree simulated canals; *D*) Metal cube placed in a cyclic fatigue machine; *E*) Placement of the file in the motor counter-angle to enter the metal cube with a 60-degree curvature angle; *F*) Placement of the file in the motor counter-angle to enter the metal cube with a 60-degree curvature angle.; *G*) Placement of the file in the simulated canal; *H*) Video recording of the cyclic fatigue resistance test of the instruments; *I*) ProPath files fractured after cyclic fatigue testing; *J*) Px-one files fractured after cyclic fatigue testing; *K*) ProGlider files fractured after cyclic fatigue testing

each brand, and they were subjected to fatigue in the two 30- and 60-degree curvatures. The intra-class correlation coefficient (ICC>0.8) was estimated to verify inter-observer measurement concordance.

Cyclic fatigue testing

In the execution phase, the files were distributed into three groups according to the system: ProGlider (Dentsply Sirona, Switzerland), Px-One (Perfect, China), and Pro-path (Denco, China). All files were tested in simulated canals with different curvature angles (30˚ and 60˚) and an 8 mm curvature radius, based on previously established parameters [19].

Cyclic fatigue resistance was tested using a standardized metal support device manufactured by Denco (China), which stabilized the endomotor in a fixed position to ensure consistent file insertion and simulate curved canal trajectories until fracture (Fig 1). This setup has been previously used in similar studies as a validated model for cyclic fatigue testing in artificial root canals [21]. The simulated canal was created within a 19 mm-long stainless steel tube with two curvatures (30˚ and 60˚) and an 8 mm curvature radius, as previously described [21-23]. It consisted of a 6.5 mm straight segment and a 12.5 mm curved segment. The steel walls were 1.3 mm thick and had an internal diameter of 1.4 mm [21].

The instruments of each rotary system were activated by a 6:1 reduction endo motor driven by an E-mate Pro torque-controlled motor (Denco, China) with a continuous clockwise rotation. Glycerin was used to reduce the friction of the file when in contact with the walls of the simulated canal. All tests were performed at room temperature (22±2 ˚C). The absence of controlled body temperature (37 ˚C) is acknowledged as a limitation of this study.

The motion used was continuous clockwise rotation until instrument separation occurred. This process was recorded using a digital camera to record the precise moment of fracture. The procedure was timed, and the clock was stopped as soon as a fracture was visually detected. For each file, the fracture time in seconds from the test starting time to the fracture moment was recorded to the nearest whole number using a timer with an accuracy of 0.1. Data were recorded on a data collection form.

Statistical Analysis

Data were entered into a Microsoft Excel spreadsheet and subsequently analyzed using the Jamovi statistical package (version 2.3.28), based on RStudio. A significance level of 5% ($P<0.05$) was established. In the descriptive analysis of quantitative variables, the mean, standard deviation, and minimum and maximum values were calculated. For inferential analysis, the Shapiro-Wilk test was first applied ($P>0.05$), indicating a normal distribution of the data. However, Levene's test was significant ($F=7.91$, $P<0.001$), suggesting heterogeneity of variances. Consequently, the Welch's ANOVA was used, followed by the Games-Howell post hoc test to compare group means.

Results

The Shapiro-Wilk normality test was not significant (P>0.05), indicating that the data followed a normal distribution. However, Levene's test was significant (F=7.91, P<0.001), indicating heterogeneity of variances. Therefore, Welch's ANOVA was used, followed by the Games-Howell post hoc test to compare the means.

Cyclic fatigue resistance was evaluated in three rotary instrumentation systems (Pro-Path, ProGlider, and Px-One) using simulated canals with curvatures of 30° and 60°. Data are presented as mean (standard deviation) and minimum–maximum range.

For the 30° curvature, Pro-Path showed the highest resistance (76.42±12.50), followed by ProGlider (57.41±11.77) and Px-One (49.84±14.77). For the more severe 60° curvature, resistance values dropped markedly in all systems, with Pro-Path again demonstrating the greatest resistance (18.90±4.86), significantly higher than that of ProGlider (5.71±1.23) and Px-One (4.70±1.20).

Within each curvature angle, statistically significant differences were found among the three systems (P<0.001). Different lowercase letters indicate statistically significant differences between groups. At 30°, Pro-Path (letter "a") was significantly different from ProGlider and Px-One (letter "b"). At 60°, Pro-Path (letter "c") was significantly superior to ProGlider and Px-One (letter "d") (Table 1).

Discussion

Multiple studies have been conducted over the years to evaluate the factors that may influence the types of failure and what conditions could minimize them [11, 17-19]. Regarding cyclic fatigue resistance in particular, the performance of instrumentation with continuous in and out movements, asymmetric oscillatory kinematics, and the use of heat-treated Ni-Ti instruments are among the conditions that tend to increase the cyclic fatigue time of endodontic files to fracture [18]. This research aimed to compare the cyclic fatigue resistance between three glide-path file systems in double-curvature simulated canals.

When evaluating the cyclic fatigue resistance of the ProGlider system, results showed significantly longer fracture times in canals with 30° curvature (57.41±11.77 min) compared to those with 60° curvature (5.71±1.23 min) (P<0.001). These findings were statistically significant based on Welch's ANOVA and Games-Howell post hoc test. This result aligns with the findings of Martins *et al.* [18], who also reported reduced fatigue resistance of ProGlider in high-curvature canals (86°), although their values were expressed in seconds and tested under different curvature parameters. These results are similar to those in the study conducted by Martins *et al.* [18], where they found that the cyclic fatigue resistance time of the ProGlider system was shorter in 86-degree curvature canals. Moreover, in the study conducted by Topçuoğlu *et al.* [19], they evaluated the fatigue resistance at angles of 45 and 60 degrees in R-PILOT and WaveOne Gold Glider files and found no significant differences between the two groups, whereas in the canal with a 60-degree curvature angle, the WaveOne Gold Glider files were more cyclic-fatigue resistant than the R-PILOT files (P<0.05). This result differs from what was found in this study, which could be due to increased flexibility and higher cyclic fatigue resistance at 37°C of the WaveOne Gold Glider files. Also, Kırıcı *et al.* [11] found that the cyclic fatigue resistance of the WaveOne Gold Glider nickel-titanium (Ni-Ti) file in S-shaped curved canals (a 60-degree angle in the coronal zone and a 70-degree angle in the apical zone) was higher than that of the ProGlider and One G Ni-Ti files. Recent studies have demonstrated that thermomechanical behavior and external conditions, such as temperature, significantly affect the cyclic fatigue resistance of NiTi instruments. For instance, Heck *et al.* [17] reported that applying a clinically replicable cooling protocol altered fatigue resistance in heat-treated files, highlighting the relevance of thermal control during testing.

When evaluating the cyclic fatigue resistance of the Px-One system, the results showed longer resistance time in 30-degree curvature simulated canals and a shorter resistance time in 60-degree curvature simulated canals. Likewise, a significant difference was found when comparing both 30- and 60-degree

Table 1. Cyclic fatigue resistance of three glide-path file systems in 30- and 60-degree curvature simulated canals in the format of Mean minutes (Standard Deviation), (Minimum-maximum), and P values

Degree of curvature	Cyclic fatigue resistance				
	30°		60°		
	Mean (SD)	(Min-max)	Mean (SD)	(Min-max)	P*
Pro-path	76.42 (12.50) [a]	(53.57-94.03)	18.90 (4.86)[c]	(10.78-24.08)	<0.001
ProGlider	57.41 (11.77)[b]	(44.33-85.95)	5.71 (1.23)[d]	(4.03-8.15)	<0.001
Px-One	49.84 (14.77)[b]	(31.43-86.77)	4.70 (1.20)[d]	(3.15-7.03)	<0.001
P*	<0.001		<0.001		

** Welch's ANOVA with Games-Howell post hoc test (P<0.005); Vertically different lowercase letters indicate statistically significant differences between means; Shapiro-Wilk test (P>0.05); Levene's test (F=7.91, P<0.001)*

curvature groups (P<0.001). This could be explained by the fact that the Px-One file is made of nickel-titanium with a gold heat treatment; in addition, it has a square cross-section, a feature that favors its mechanical and physical properties, contributing to a good performance of resistance in comparison with that of the ProGlider files, as obtained in this study [18].

Regarding the cyclic fatigue resistance of the Pro-path system, significantly higher resistance was observed at 30° curvature (76.42±12.50 min) compared to 60° (18.90±4.86 min) (P<0.001). The high standard deviation observed in the 60° group suggests potential variability in manufacturing or alloy consistency. Despite its recent introduction, Pro-path demonstrated the highest overall performance, exceeding that of ProGlider and Px-One in both curvature conditions. The high standard deviation observed in the Pro-path 30° group indicates considerable variability in the instrument's performance. This may be associated with inconsistencies in the heat treatment process or manufacturing variations. Further studies are needed to investigate these potential factors. This system, of Chinese origin, is a blue heat-treated nickel-titanium file with a square cross-section, designed to be compatible with ProGlider systems [18]. Although it has recently gained clinical presence, scientific evidence evaluating its mechanical performance remains scarce. The superior fatigue resistance observed in this study highlights the need for further investigation into the metallurgical properties and clinical behavior of this system. Its unexpected performance compared to a well-established system like ProGlider suggests that underlying material characteristics, such as alloy phase composition and heat treatment process, may play a significant role and warrant deeper analysis. The superior fatigue resistance of Pro-path, despite limited supporting literature, may be influenced by its heat-treated NiTi composition. Braga *et al.* [15] demonstrated that thermal treatment significantly impacts both torsional and cyclic fatigue resistance in NiTi files, supporting the importance of alloy processing. Similarly, Niño-Barrera *et al.* [6] compared the mechanical and structural properties of NiTi with alternative alloys and emphasized how compositional and microstructural variations can influence mechanical performance and fatigue behavior. These findings highlight the relevance of investigating the metallurgical characteristics of newly introduced systems like Pro-path.

Moreover, regarding the cyclic fatigue resistance among the three glide-path file systems in 30° and 60° simulated curvature canals, the Pro-path system showed the highest performance. At 30°, Pro-path reached a mean time to fracture of 76.42±12.50 minutes, significantly higher than ProGlider and Px-One. At 60°, Pro-path again outperformed the other systems with a mean of 18.90±4.86 minutes. Welch's ANOVA followed by the Games-Howell post hoc test confirmed statistically significant differences among the three systems at both curvature levels (P<0.001). These findings are consistent with those of Martins *et al.* [18], who reported lower fracture resistance in ProGlider using an 86° curvature and expressed values in seconds. Similarly, Le *et al.* [20] found shorter fatigue resistance for ProGlider in canals with 90° curvature, reinforcing that increasing curvature negatively impacts file performance.

Conversely, this contrasts with the findings of Heck *et al.* [17], who demonstrated that the use of a clinical-replicable cooling protocol significantly influenced the cyclic fatigue resistance of heat-treated NiTi files, highlighting the role of environmental factors such as temperature in fatigue performance. Topçuoğlu *et al.* [19] evaluated the R-PILOT (VDW GmbH, Munich, Germany) and WaveOne Gold Glider (Dentsply Sirona; Ballaigues, Switzerland) files in 45- and 60-degree curvatures and found that no significant differences were observed between the files in the canal with a 45-degree curvature angle, whereas the WaveOne Gold Glider files were more cyclic-fatigue resistant in artificial canals with a 60-degree curvature angle. This study used 30- and 60-degree curvatures and found significant differences between the systems evaluated in both types of curvature, where all the systems showed longer cyclic fatigue resistance time in the 30-degree curvature. In analyzing the evidence, it was confirmed that the type of system and the curvature in which it was evaluated influenced the cyclic fatigue resistance time; therefore, it is important to consider the different thermal treatments of the systems and to define the type of kinematics in which it will be applied.

Among the study limitations is principally the absence of literature on the Pro-path and Px-One files; however, this calls for new lines of research to deepen their properties. Moreover, this study provides information on the behavior of these new mechanized instruments used in endodontics to make better decisions under scientific criteria and help the professional to choose these systems not only for their affordable price but also for their performance.

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Conflict of interest

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Authors' contributions

Conceptualization: VBP; Methodology: VBP/CRG; Formal analysis and investigation: VBP; Writing-original draft preparation: VBP; Writing-review and editing: VBP/CRG; Supervision: CRG. All authors read and approved the final manuscript.

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