

A Comparative Study of Cyclic Fatigue of BlueShaper Pro and Pro Taper Gold Rotary files. An *In Vitro* Study

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<https://doi.org/10.58624/SVOADE.2026.07.018>

Received: May 08, 2026

Published: May 29, 2026

Citation: Baran M, Lallier TE, Edenfield K, Brooks J, Kee E, Arch G Jr, Kazandag MK, McMullen AF III. A Comparative Study of Cyclic Fatigue of BlueShaper Pro and Pro Taper Gold Rotary files. An *In Vitro* Study. *SVOA Dentistry* 2026, 7:3, 134-143. doi: 10.58624/SVOADE.2026.07.018

Abstract

Introduction: Cyclic fatigue is a primary cause of nickel–titanium (NiTi) rotary file separation during endodontic treatment. Thermomechanical heat treatments, such as gold and blue processing, alter phase transformation behavior to improve flexibility and fatigue resistance. The BlueShaper Pro system incorporates DualWire® technology, combining blue- and gold-treated alloys within a single file, while ProTaper Gold relies solely on gold treatment. This *in vitro*, laboratory study compared the cyclic fatigue resistance of both systems under standardized in-vitro conditions.

Materials and Methods: Sixty BlueShaper Pro (Z1–Z5) and sixty ProTaper Gold (S1–F3) files (25 mm) were tested in custom stainless-steel blocks simulating 30° and 90° canal curvatures (n = 30 per group). Files were operated per manufacturer parameters using an X-Smart Endo Motor. Time to fracture was recorded via high-definition video, and the number of cycles to failure (NCF) calculated as $NCF = (\text{time} \times \text{rpm})/60$. Data was analyzed with independent t-tests ($p < 0.05$).

Results: No files fractured at 30°, whereas all fractured at 90°. No significant differences were found for Z1/S1 or Z2/S2. ProTaper Gold showed greater fatigue resistance in intermediate files (F1, F2), while BlueShaper Pro demonstrated superior resistance in the final file (Z5) ($p < 0.05$). Fracture consistently occurred 9.08–14.5 mm from the tip within the canal curvature.

Conclusion: Both ProTaper Gold and BlueShaper Pro showed high cyclic fatigue resistance, with failure occurring only at 90° curvature. Because each system demonstrated sequence-specific advantages, a hybrid approach using BlueShaper Pro in the initial and final stages and ProTaper Gold in the intermediate stages may optimize performance. Overall, file behavior was influenced not only by heat treatment, but also by flute geometry, taper, cross-sectional design, and operating parameters, underscoring that the ideal rotary file must balance mechanical performance with minimally invasive canal shaping and dentin preservation.

Keywords: Nickel–titanium; cyclic fatigue; BlueShaper Pro; ProTaper Gold; Thermomechanical treatment; DualWire Technology.

Introduction

Nickel-titanium (NiTi) rotary file instruments (files) have become integral to contemporary endodontic treatment because of their bacterial removal within root canals, superior flexibility, shape memory, and fatigue resistance compared with stainless steel files (1,2). Despite these advantages, file separation remains a significant procedural complication, particularly in curved canals where repeated tensile and compressive stresses predispose files to cyclic fatigue failure (4-6). Fracture of files may hinder canal debridement and obturation, potentially compromising treatment outcomes (3).

The mechanical behavior of NiTi files is closely related to their metallurgical phase composition. Conventional austenitic files are generally stiffer and less resistant to cyclic fatigue, whereas martensitic heat-treated files demonstrate greater flexibility and improved fatigue resistance (6-9). Accordingly, thermomechanical processing has played a major role in the development of modern NiTi systems by altering phase transformation behavior and improving clinical performance without changing the base alloy composition (2,3, Figure 1).



Figure 1. Diagram illustrating the heat-treatment color spectrum of files, ranging from more austenitic to more martensitic.

ProTaper Gold (Dentsply Sirona) is a heat-treated NiTi system developed to improve flexibility and cyclic fatigue resistance relative to conventional files. BlueShaper Pro (Avalon Biomed) represents a more recent metallurgical innovation that incorporates DualWire technology, combining different thermomechanical treatments within a single file to balance cutting efficiency and flexibility. Because cyclic fatigue resistance is influenced by alloy treatment, file design, and canal curvature, comparative evaluation of these systems is clinically relevant (4,10,11).

Although previous studies have compared the cyclic fatigue resistance of several NiTi file systems, to our knowledge, no study has specifically evaluated the individual files of the BlueShaper Pro system in comparison with ProTaper Gold under standardized simulated canal conditions. Therefore, the purpose of this study was to compare the cyclic fatigue resistance of the individual files within the ProTaper Gold and BlueShaper Pro systems (12-15). The null hypothesis was that no significant differences would be found between corresponding files of the 2 systems.

Materials

The manuscript of this laboratory study has been written according to Preferred Reporting Items for Laboratory studies in Endodontology (PRILE) 2021 guidelines.

The following equipment and materials were utilized in this study:

- Endodontic Motor: X-Smart Endo Motor (Dentsply Sirona, Charlotte, North Carolina, USA).

- **Table 1: BlueShaper Pro System (25 mm)** (Avalon Biomed, Houston, Texas, USA): files Z1–Z5 were selected for testing. These files are composed of heat-treated blue nickel–titanium (Ni-Ti) alloy and feature a convex triangular cross-sectional design with a 3 mm partially cutting gold-colored tip and a maximum flute diameter of 0.95 mm. Files Z6 and Z7 were excluded from testing due to their limited clinical application in curved canals.

File	Tip Diameter (mm)	Taper	RPM	Torque (N·cm)
Z1	0.14	.02-.10	500	4
Z2	0.17	.02-.10	500	4
Z3	0.19	.05-.06	500	4
Z4	0.25	.05-.06	500	4
Z5	0.30	.06-.05	500	4

- **Table 2: ProTaper Gold System (25 mm)** (Dentsply Sirona, Johnson City, Tennessee, USA): files S1, S2, F1, F2, and F3 were selected. These files are fabricated from heat-treated gold Ni-Ti alloy and possess a convex triangular cross-sectional design with a maximum flute diameter of 1.20 mm. The F4 and F5 files were not included due to their infrequent use in curved canals.

File	Tip Diameter (mm)	Taper	RPM	Torque (N·cm)
S1	0.18	.02	300	5.20
S2	0.20	.04	300	1.50
F1	0.20	.07	300	1.50
F2	0.25	.08	300	3.12
F3	0.30	.09	300	3.12

- Custom-fabricated metal block with two precision-milled canals.
- Bench vises and ball-jointed vise assembly.
- Laptop computer with Microsoft Excel for data processing.

Methods

For each file type, two experimental groups were established, each consisting of 30 files. One group was tested in simulated canals with a 30° curvature, and the other in canals with a 90° curvature (Figure 2). The sample size of 30 files per group was selected to enhance statistical power and reduce sampling error, consistent with previous studies on cyclic fatigue resistance of rotary Ni-Ti files (4). Prior investigations employing GPower statistical software determined this sample size to provide sufficient power for detecting significant differences in cyclic fatigue performance (4).

To evaluate cyclic fatigue resistance without interference from canal wall contact, a custom stainless-steel testing block was fabricated (Figure 2). The design methodology was adapted from previously published protocols by Greco et al., Gambarini et al., Al-Sudani et al., Whipple et al and Pruett et al (4, 6, 8, 16, 17). The X155 steel block measured 60 mm × 40 mm × 20 mm (height × width × depth) and was produced using computer-aided design (CAD) and precision micro-milling technology. Two simulated curved canals were incorporated with the following dimensions:

- Canal 1: curvature = 30°, length = 25 mm, diameter = 2 mm, milling depth = 3 mm.
- Canal 2: curvature = 90°, length = 25 mm, diameter = 2 mm, milling depth = 3 mm.

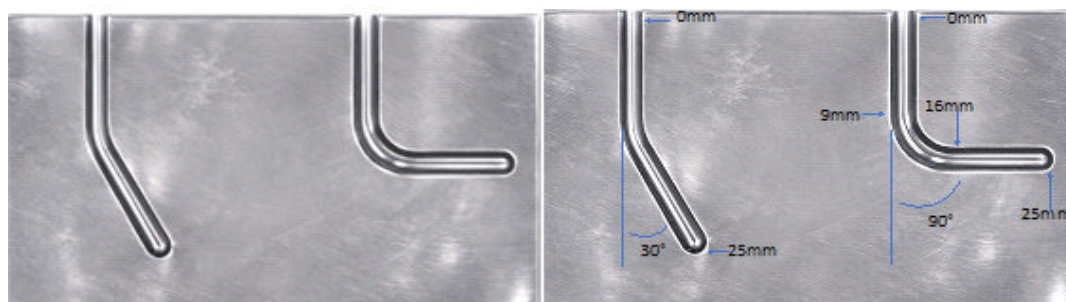


Figure 2. Intra experiment image of the metal block used to test cyclic fatigue of rotary files with second identical image showing measurements of each simulated canal (Images were captured with an iPhone 15 Pro (Apple Inc., Cupertino, CA, USA) using the native camera application.)

During testing, the metal block was secured to a stable wooden platform using bench vises, while the endodontic motor was fixed via a ball-jointed vise to maintain alignment and permit controlled lateral movement. A glass plate was positioned over the block to ensure that the file remained centered within the canal throughout instrumentation (Figure 3).



Figure 3. Intra-experiment image of bench vise set-up with endo handpiece and metal block (Images were captured with an iPhone 15 Pro (Apple Inc., Cupertino, CA, USA) using the native camera application).

Each 25 mm file was fully inserted into the simulated canal and operated continuously under the specified parameters until either file fracture occurred or a 15-minute maximum duration was reached, as recommended by Greco et al. (4). The entire process was recorded using a high-definition digital camera, and time to fracture was determined using *iMovie* software (Version 10.4.2; Apple Inc., Cupertino, CA, USA). In addition to recording the time to file fracture, the length of the separated fragment was measured with a digital caliper to the nearest 0.5 mm.

The number of cycles to fracture (NCF) was calculated using the formula:

$$\text{NCF} = \text{time to fracture (s)} \times \text{RPM} / 60 \text{ (4)}.$$

Results

No file separation occurred in the 30° curvature group, whereas all files fractured in the 90° curvature group. Statistical analysis was therefore conducted exclusively on the 90° group using pairwise comparisons with independent *t*-tests ($p < 0.05$). There were no statistically significant differences among the equivalent file groups Z1 and S1; and Z2 and S2 (Table 4). Analysis of normalized cyclic mean (NCM) values showed that BlueShaper Pro and ProTaper Gold exhibited comparable performance for the first two file sizes ($p > 0.05$) (Table 4). ProTaper Gold demonstrated significantly higher performance for the third and fourth files ($p < 0.05$), whereas BlueShaper Pro exhibited significantly superior performance for the final file ($p < 0.05$) (Table 4). A notable finding is that the revolutions to failure for BlueShaper Pro Z4 and ProTaper Gold F2 observed in the present study were comparable to those reported by Greco et al (4), under the same 90° curvature condition.

A 25 mm file was able to fully engage within the simulated canal. When positioned in the 90° curvature model, approximately 7 mm of the file conformed to the curve (Figure 2). This curved segment extended from 9 mm to 16 mm from the file tip, corresponding to a region located 9 mm from the hub, which lacked flutes (Figure 2). Across all file types, the average fracture point ranged from 9.08 mm to 14.5 mm from the tip, indicating that file separation occurred within the curved portion of the canal (Figure 5). These findings suggest that failure was primarily caused by cyclic fatigue at the 90° curvature, rather than by structural variations or the distinct heat-treated 3 mm apical segment.

For the third and fourth file sizes, ProTaper Gold exhibited substantially greater cyclic fatigue resistance than BlueShaper Pro (Table 3 and Figure 4). Therefore, an electronic digital caliper (resolution: 0.1 mm) was used to measure the flute diameter at the fracture location. The measurements are presented in Table 5. These values were intended as an approximate estimate to explore whether differences in flute diameter could contribute to the higher cyclic fatigue resistance observed for ProTaper Gold F1 and F2 compared with BlueShaper Pro Z3 and Z4. The BlueShaper Pro files fractured at sites with greater flute diameters than ProTaper Gold, indicating a larger cross-sectional dimension at the point of maximum stress. This geometric difference may contribute to reduced fatigue resistance under severe curvature, as larger diameters generally increase bending stiffness and local tensile-compressive strain during cyclic loading. However, because only one file was measured at the mean fracture location for the F1, F2, Z3, and Z4 groups, statistical analysis could not be performed. Future studies should measure the flute diameter of all files at their individual fracture locations to permit calculation of *p* values. Additional measurements at multiple points along the fracture region may also provide more robust data for statistical analysis.

Table 3. Average times to failure (in seconds and minutes) and average revolutions to failure for the file's tested.

File	Time to Failure (seconds)	RPM	Revolutions to failure (NCF)	Torque (NCM)
BlueShaper Pro Z1	1.846	500	15.383	4
BlueShaper Pro Z2	2.648	500	22.066	4
BlueShaper Pro Z3	2.932	500	24.432	4
BlueShaper Pro Z4	2.313	500	19.274	4
BlueShaper Pro Z5	2.107	500	17.558	4
ProTaper Gold S1	2.452	300	12.260	5.2
ProTaper Gold S2	4.190	300	20.950	1.5
ProTaper Gold F1	9.810	300	49.050	1.5
ProTaper Gold F2	9.536	300	47.680	3.12
ProTaper Gold F3	2.669	300	13.345	3.12

Table 4. P-Values for Average Number of Cycles to Fracture for Each Rotary File Pairwise Comparison (P < 0.05 Indicates Significant Difference).

Rotary File Comparison	P-Value
Z1 and S1	0.0856
Z2 and S2	0.0860
Z3 and F1	0.0001
Z4 and F2	0.0001
Z5 and F3	0.0001

Table 5. Flute Diameter at Location of File Fracture for the Third and Fourth File in each File Sequence.

File	Average Fracture Location from File Tip (mm)	Flute Diameter (mm)	RPM	Torque (NCM)
ProTaper Gold F1	13.33	0.45	300	1.5
ProTaper Gold F2	12.18	0.45	300	3.12
BlueShaper Pro Z3	12.07	0.55	500	4
BlueShaper Pro Z4	13.17	0.65	500	4

Figure 4: Average Number of Cycles to Fracture for Each Rotary File

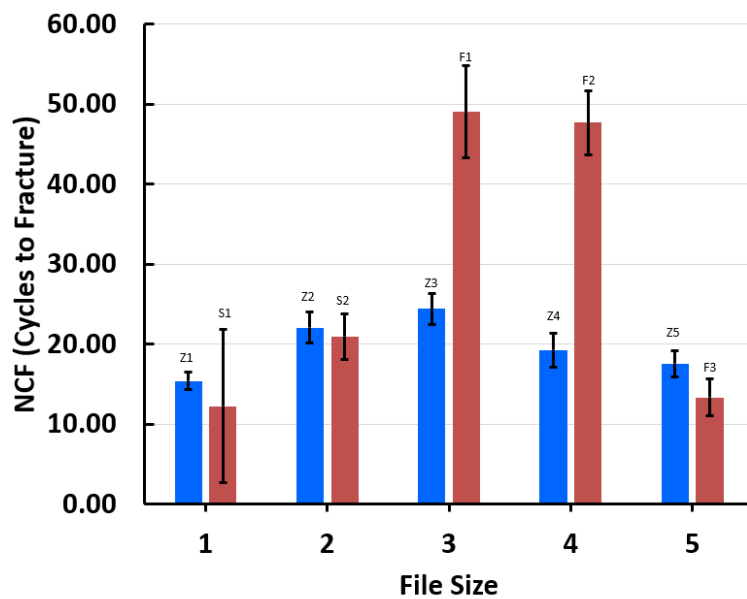


Figure 5: Average Fracture Length of Each Separated Rotary File From the Tip of the Rotary File.

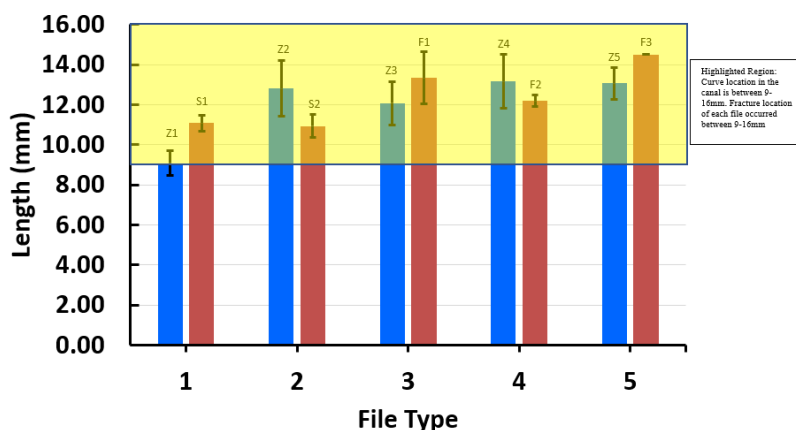
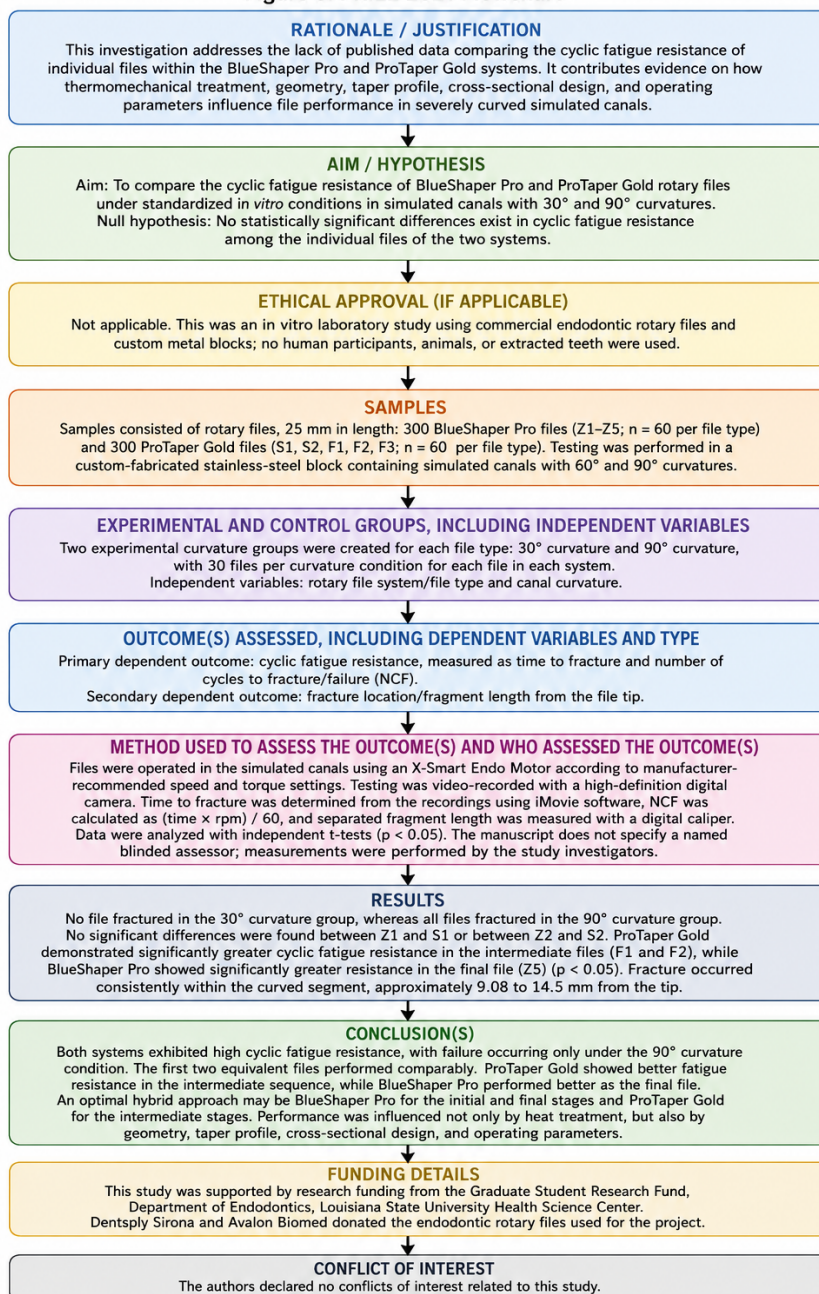


Figure 6: PRILE 2021 Flowchart



Discussion

The present study compared the cyclic fatigue resistance of ProTaper Gold and BlueShaper Pro NiTi rotary systems under simulated canal conditions. The results revealed no file separation at 30° curvature, whereas all files fractured at 90°, confirming the strong influence of canal curvature on fatigue behavior. Pairwise comparisons indicated that both systems demonstrated comparable performance for the initial file sizes, with ProTaper Gold showing superior fatigue resistance for intermediate file sizes and BlueShaper Pro outperforming in the final file (Table 3 and 4, Figure 4). These findings partially reject the null hypothesis and underscore the complex interplay between thermomechanical treatment, alloy phase composition, and file geometry in determining fatigue performance.

Cyclic fatigue represents one of the most clinically significant causes of file failure during endodontic treatment, resulting from alternating tensile and compressive stresses as files rotate within curved canals (4). The location of fracture observed between 9 mm and 14.5 mm from the tip corresponds to the apical curvature (Figure 5), consistent with previous studies identifying this region as the site of maximum flexural stress (4, 6, 8, 16, 17). No separation at 30° curvature further confirms that greater canal angulation amplifies cyclic loading and accelerates crack propagation, leading to earlier failure (4).

For the third and fourth files, the ProTaper Gold files exhibited greater cyclic fatigue resistance, likely because fracture occurred at a segment with a smaller flute diameter than the corresponding fracture region in the BlueShaper Pro files. The larger flute diameter at the BlueShaper Pro fracture sites would increase the local cross-sectional mass and bending stiffness, which can reduce fatigue life during repeated compression–tension cycling in a severe (90°) curvature (4). Accordingly, despite the alloy's favorable martensitic characteristics, a thicker segment is less able to flex and negotiate a 90° curve, providing a plausible explanation for the lower cyclic fatigue performance observed for the third and fourth BlueShaper Pro files relative to ProTaper Gold. Although the maximum flute diameter (MFD) was lower for all BlueShaper Pro files than for ProTaper Gold, the BlueShaper Pro files' geometry and variable taper profile resulted in a larger diameter at the point of file separation than for ProTaper Gold. In addition, the higher rotational speed and torque setting, recommended by the manufacture, for the BlueShaper Pro third and fourth files, compared with the corresponding ProTaper Gold files, may have also influenced cyclic fatigue performance, as a higher speed and torque setting can increase the rotational force applied through the 90° curvature and potentially contribute to earlier fracture (5).

The findings suggest that file design—not just overall flute size and heat treatment—plays a major role in cyclic fatigue behavior. Specifically, differences in geometry and variable taper profile between ProTaper Gold and BlueShaper Pro appear to influence the diameter at the point of separation, which in turn affects how each file performs in severe canal curvature. In this comparison, the BlueShaper Pro files fractured at a larger diameter location despite having a lower maximum flute diameter overall, indicating that taper distribution and design along the active portion of the file are critical determinants of stress concentration and fatigue resistance.

The superior performance of the BlueShaper Pro in the final file likely reflects the influence of the optimized blue-heated treatment. BlueShaper Pro would be the preferred final file because it is heat-treated and highly martensitic. NiTi metallurgy provides greater flexibility and resistance to cyclic fatigue in the larger apical file sizes, allowing safer shaping to working length with a lower risk of separation during the most demanding (final) enlargement step.

These findings align with previous investigations reporting that heat-treated martensitic files—such as Blue or Gold NiTi systems—demonstrate significantly greater cyclic fatigue resistance compared with conventional austenitic files. The metallurgical engineering underlying these treatments alters the phase transformation pathway rather than the alloy composition itself, effectively tuning the elastic modulus and deformation behavior. Blue-treated files, in particular, contain a higher martensitic fraction and exhibit lower stiffness than gold treated files, which enhances flexibility and delay in crack initiation (3).

Clinically, enhanced cyclic fatigue resistance translates to improved safety when navigating complex or severely curved canals (3,4). The observed differences between the two systems suggest that BlueShaper Pro may offer advantages in the later stages of canal shaping—where curvature and canal anatomy impose higher stresses—while ProTaper Gold maintains stability and cutting efficiency in intermediate stages. Selecting files based on their thermomechanical phase balance, file design and sequence design may therefore optimize performance and minimize procedural errors such as file separation (2,3).

While this study provides insight into the fatigue characteristics of these systems, several limitations should be acknowledged. The simulated canal model cannot fully replicate intraoral conditions, such as body temperature variation, irrigation dynamics, and cyclic load variation due to clinical handling. Future investigations should include dynamic fatigue testing at physiologic temperature and evaluate additional parameters such as torsional resistance, surface topography, and metallographic phase distribution. Future studies should also incorporate a modified canal design featuring a secondary curvature within the apical 3 mm to specifically evaluate cyclic fatigue resistance in the apical segment, where localized thermomechanical heat treatments may produce distinct metallurgical behavior and stress responses. Another future study could evaluate the same file systems in this current study alongside minimally invasive files—such as a variable-taper system (e.g., SlimShaper) and a constant 3% taper system (e.g., Apical Shaper or NanoShaper)—to compare cyclic fatigue resistance and determine whether smaller file sizes can negotiate a 90° curvature more efficiently than the larger variably tapered files (e.g. ProTaper Gold, ProTaper Ultimate, and BlueShaper Pro). In addition, as previously stated, future studies should measure the flute diameter of all files at their individual fracture locations to permit calculation of p values.

In summary, both ProTaper Gold and BlueShaper Pro exhibited favorable cyclic fatigue resistance under severe curvature, with each system demonstrating strengths in different file sequences. However, while thermomechanical heat treatment clearly enhances cyclic fatigue resistance, the development of an ideal file requires deliberate integration of all relevant manufacturing factors—including alloy heat treatment, geometry, torque and rotational speed, cross-sectional design, and taper profile—with increasing emphasis on minimally invasive shaping strategies that preserve dentin and maintain root structural integrity. These findings highlight the impact of proprietary heat-treatment protocols on NiTi performance and underscore the importance of matching file selection to clinical canal complexity. Continued development of hybrid and multi-phase NiTi alloys, such as those used in the BlueShaper Pro system, represents a promising direction for achieving greater balance among flexibility, cutting efficiency, and fatigue resistance in contemporary endodontic instrumentation.

Conclusion

Within the limitations of this *in vitro* study, both ProTaper Gold and BlueShaper Pro demonstrated high cyclic fatigue resistance in simulated curved canals, with no separation at 30° curvature and fracture consistently occurring within the 90° curvature segment. Based on normalized cyclic mean values, the first two files of each system showed comparable performance, whereas ProTaper Gold demonstrated greater fatigue resistance in the intermediate files and BlueShaper Pro performed better in the final finishing file. Fracture location was consistently associated with canal geometry, indicating that curvature was the primary determinant of failure. These findings suggest that cyclic fatigue resistance is influenced not only by thermomechanical treatment, but also by flute diameter, geometry, cross-sectional design, taper, and operating parameters. A hybrid sequence using BlueShaper Pro for the initial and final files and ProTaper Gold for the intermediate sequence may provide mechanical advantages; however, further investigation is needed to determine its clinical relevance.

Conflict of Interest

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

Acknowledgements

This study was supported by research funding from the Graduate Student Research Fund, Department of Endodontics, Louisiana State University Health Science Center. Thank you to Dentsply Sirona and Avalon Biomed for the donation of endodontic rotary files for this research project. The authors deny any conflicts of interest related to this study.

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