 DOI: 10.21608/adjalexu.2025.368719.1607

CYCLIC FATIGUE RESISTANCE OF HYFLEX EDM ROTARY FILES COMPARED TO M3 PRO GOLD AND MG3 BLUE ROTARY FILES (AN IN VITRO STUDY)

Ali M. Buran[1*] BDS, Raef A. Sherif[2] PhD, Ahmed M. Mobarak[3] PhD

ABSTRACT

INTRODUCTION: Despite the introduction of more durable files of various costs designed to minimize file separation and enhance the success rate of curved canal instrumentation. Given the benefits of NiTi rotary files, cyclic fatigue continues to pose considerable difficulty.

AIM OF THE STUDY: This study aimed to assess the cyclic fatigue resistance of three different types of rotary files.

MATERIALS AND METHODS: Three NiTi rotary file systems of different costs were assessed for their resistance to cyclic fatigue in vitro. All 48 files were divided into three equal groups (n=16): Group I: Hyflex EDM (Coltene). Group II: M3 ProGold (United Dental) and Group III: MG3 Blue (Shenzhen Perfect Medical Instruments). Each file was tested in a dynamic custom-made cyclic fatigue device simulating a 60° canal curvature with a 5mm radius of curvature. The TTF, the NCF, and the length of the fractured tip were recorded for each file.

RESULTS: Hyflex EDM files demonstrated a higher resistance to cyclic fatigue, followed by M3 ProGold and MG3 Blue files in TTF and NCF. Hyflex EDM's NCF was significantly higher than MG3 Blue ($P < 0.001$), but not statistically significant compared to M3 ProGold ($P > 0.05$). The fractured tips' lengths varied significantly between MG3 Blue and M3 ProGold ($P < 0.05$).

CONCLUSION: Based on the cyclic fatigue results and the affordability of these files, Hyflex EDM and M3 Pro Gold demonstrated superior resistance, indicating that they may be viable options for root canal treatment of curved canals.

KEYWORDS: Cyclic fatigue, Hyflex EDM, M3 Pro Gold, MG3 Blue, Nickel-Titanium (NiTi).

RUNNING TITLE: Cyclic Fatigue Resistance of Various NiTi Rotary Files.

1-BDS 2010, Faculty of Dentistry, Nizhny Novgorod State Medical Academy University, Russia.
2-Professor of Endodontics Department, Faculty of Dentistry, Alexandria University, Egypt.
3-Lecturer of Endodontics, Endodontics Department, Faculty of Dentistry, Alexandria University, Egypt

Corresponding author:
ali.boran.dent@alexu.edu.eg

INTRODUCTION

Walia et al. first introduced Nickel-Titanium (NiTi) rotary files to endodontics in the late 1980s, and they have since grown in popularity. Their enhanced qualities may have contributed to their growing popularity (1). The improved mechanical properties of NiTi instruments, which facilitated curved canal instrumentation due to their super-elasticity, resulted in superior root canal preparation (2). The capacity of NiTi rotary files to shape root canals with severe curvature in a safe, effective, and well-suited way is what has led to their growing popularity (3). In order to overcome their unanticipated failures, manufacturers focused their efforts on enhancing NiTi performance as the popularity of conventional NiTi files increased (4). This was done so that the files could be used more effectively and withstand deformation and breakage, regardless of their obviously persistent plastic deformation-free surface (5).

The aforementioned characteristics led to less canal transportations and fewer preparation errors as compared to stainless steel hand files, particularly in the root canal's curvatures, which are crucial to the final result (6).

File separation remains one of the primary issues with NiTi rotary instruments in clinical settings (7). Cyclic fatigue is one of the ways that fractures can occur. When the NiTi instrument spins in a curved canal, cyclic fatigue takes place within its elastic limit (8). Until the instrument breaks, cycles of tension and compression are repeatedly produced at the point of peak flexure (9).

The entire cyclic life of NiTi endodontic instruments is divided into two phases: crack commencement, when micro-cracks form and grow preferentially along particular grain boundaries or crystallographic planes, and crack propagation, which lasts until the final fracture (10). Numerous factors, such as the NiTi alloy's metallurgical characteristics, instrument dimensions, file cross-sectional shape, design, and metal surface treatments, might result in broken files (11).

In order to generate a highly elastic NiTi alloy with a stable martensitic phase under clinical settings, a number of manufacturers attempted to develop novel thermo mechanical processing methods (12). Numerous cross-sectional designs have been displayed, but the advent of unique production methods is more important. These treatments can be applied during or after manufacture and include heat treatment, surface treatment, and other machining processes (13).

Modern Electric Discharge Machinery (EDM) technology is used in the manufacturing of Hyflex EDM (Coltene/Whaledent, Altstätten, Switzerland) rotary files. EDM is a non-contact machining technique that increases a material's fracture resistance by up to 700% by accurately removing material using pulsed electrical discharge (14,15). Throughout the file, its cross section changes. According to the manufacturer, a routine autoclaving process will return the file to its original form and fatigue resistance after it has been used (16). Unlike traditional grinding, Hyflex EDM reduces the possibility of mechanical stress by avoiding direct contact with the workpiece during manufacture. This contrasts with the traditional grinding method (12).

Chinese-made files are a reliable and reasonably priced alternative to more expensive European ones. Dental students and clinics in low-socioeconomic areas are increasingly using them. Their affordability and accessibility to the market are the main reasons for their appeal.

The M3 Pro Gold Rotary file (United Dental, Shanghai, China) is one of these files. Its passive tip is designed to be used in continuous rotation motion, and has a convex triangular cross-section (17). The manufacturer claims that this file's significant flexibility enables quick and secure preparation, especially in curved root canals. The better triple surface coating and CM wire used in the production of M3 Pro Gold files provide for greater flexibility and resistance to cycle fatigue (18).

Another affordable blue rotary file produced in China is the MG3 Blue rotary file (Shenzhen Perfect Medical Instruments, Shenzhen, China). The complex heating-cooling unique technique used to create these files gives the alloy a blue hue and leaves a visible coating of titanium oxide on the surface (19). Despite having lower transformation temperatures, these systems have more stable martensite than M-wire, which improves the ductility and softness of the alloy (12). It was found that all blue heat-treated and gold instruments exhibited remarkable levels of flexibility and fatigue resistance in comparison to conventional Ni-Ti and M-wire instruments (20).

Hyflex EDM, a premium European brand, is priced higher than competing Chinese rotary file systems such as M3 Pro Gold and MG3 Blue. These more affordable alternatives are widely distributed by regional wholesalers and online retailers worldwide. Despite their extensive use, data on their mechanical performance remains limited (17).

Therefore, the study's research question was: when utilized in curved canals, would the affordable, low-cost rotary files (M3 Pro Gold and MG3 blue files) exhibit cyclic fatigue resistance that is comparable to that of the expensive, premium Hyflex EDM rotary files?

MATERIALS AND METHODS

This study assessed the cyclic fatigue resistances of Hyflex EDM Ni-Ti rotary files compared to M3 Pro Gold and MG3 Blue rotary files. The Ethics Committee of Faculty of Dentistry, Alexandria University gave its approval for this study (IRB No. 001056 – IORG 0008839). The cyclic fatigue resistance test was conducted in the Endodontic department of the Faculty of Dentistry at Ain Shams University, while the files were inspected in the Biomaterials department's research facilities at Alexandria University. The primary objective of this study was to evaluate the time till fracture (TTF), and the number of cycles to fracture (NCF) among the three types of rotary files. The secondary objective was to evaluate the length of the fractured file tip.

Sample Size calculations

The sample size was estimated based on assuming a confidence level of 95% and study power of 80%. The mean NCF was 8359.21 ± 880.72 cycles for Hyflex EDM, 7636.93 ± 716.72 cycles for M3 Pro Gold, and 7526.89 ± 661.99 cycles for AF F One Blue (18). Based on a comparison between independent means using pooled SD= 753.14, a minimum sample size of 15 files was required per group yielding an effect size of 0.490. This was increased to 16 files to compensate for any processing errors. Total sample size = Number per group x Number of groups = 16 x 3 = 48 files.

Software

The sample size was based on Rosner's method (21) calculated by G*Power 3.1.9.7 (22).

In this study forty-eight Ni-Ti rotary files were divided into three groups according to the type of rotary file system (n=16 each). For cyclic fatigue resistance, each file system was examined for the number of cycles till fracture, time till fracture and length of fractured fragment.

Group (I): Hyflex EDM (n=16) (25, /~ [variable taper])

Group (II): M3 Pro Gold (n=16) (25, taper.04)

Group (III): MG3 Blue (n=16) (25, taper.04)

To make sure there were no manufacturing flaws, files were inspected using a stereomicroscope (x1.8 magnification). A dynamic cyclic fatigue testing apparatus that was manufactured by ElWakeel was used in this study (Figure 1). A 16 mm long stainless-steel canal groove was fabricated. At a 60-degree angle canal curvature, and a 5 mm radius of curvature (Figure 2). The canal had a tip size

#25/0.08 taper with a 0.2 mm offset (23,24). A glass cover was placed over the canal to primarily prevent the files from slipping out of the artificial canal and also allow for visual confirmation of the fracture.

The endodontic motor was installed on the cyclic fatigue testing apparatus to guarantee three-dimensional alignment and uniform depth positioning of every instrument, allowing for precise and repeatable file insertion within the curved artificial canal. The apparatus offered a 1.5 mm/0.5 second upward and downward dynamic pecking action. Within a one-second relay, the cycles were repeated (25).

Endodontic motor was set according to the speed and torque of each manufacturer's recommendation for their respective file system (25).

Group I: Hyflex EDM size 25 /~ at 500 rpm and torque 2.5 N/cm.

Group II: M3 Pro Gold size 25 taper .04 at 500 rpm and torque of 2.0 N/cm.

Group III: MG3 Blue size 25 taper .04 at 350 rpm and torque of 2.0 N/cm.

Using the aforementioned settings for each group, each file was first secured to the endodontic motor. A synthetic oil (WD40 Company, Milton Keynes, U.K.) was used to flood the artificial canal as a lubricant in all groups. After lubrication of the artificial canal, the file connected to the endodontic motor was inserted into the canal. Once the file was inserted to full length of the artificial canal, the stopwatch and the endodontic motor were started at the same time. The entire process was timed, noted and video recorded. The timer was stopped as soon as a fracture occurred (Figure 3). It was recorded how long it took from the beginning of the process to the instrument time to fracture (TTF). Every file utilized in this study was only used once and didn't undergo any sterilization processes (16). The following formula was then used to calculate the Number of Cycles to Fracture (NCF): Time (min) × speed (rpm).

Statistical Analysis

Normality was tested using descriptive statistics, Q-Q plots, histograms, and normality tests. All data showed normal distribution, so parametric analysis was adopted. Means, standard deviation (SD), and range (Min – Max) were calculated for all variables. Comparisons between the three study groups were performed using one-way ANOVA, followed by multiple pairwise comparisons using Bonferroni adjusted significance level. Significance was set at p-value <0.05. Data was analyzed using IBM SPSS for Windows (Version 26.0).

Figure 1: Dynamic cyclic fatigue device.

Figure 2: Stainless steel simulated canal.

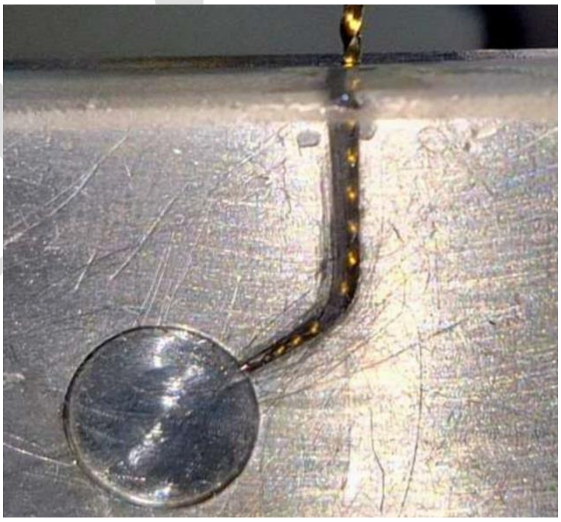

Figure 3: Fractured file in the artificial canal.

RESULTS

Three distinct Ni-Ti rotary file systems—Hyflex EDM, M3 Pro Gold, and MG3 Blue—were tested in this study for their cyclic fatigue resistance. The outcomes were recorded as TTF, NCF and length of fractured file tip.

Time to Fracture (TTF) and Number of Cycles to Fracture (NCF)

The analysis of TTF indicated that Hyflex EDM files exhibited the longest fracture time, with a mean duration of 1.44 (±0.35) minutes. M3 Pro Gold and MG3 Blue exhibited mean values of 1.15

(±0.36) and 1.08 (±0.33) minutes, respectively as shown in Table 1. The TTF across the three study groups. ANOVA revealed significant differences among the groups (F=4.80, P=0.01) is presented in Figure 4. Pairwise comparisons indicated a statistically significant difference between Hyflex EDM and MG3 Blue (P=0.02), but no significant difference between Hyflex EDM and M3 Pro Gold as presented in Table 2.

The Hyflex EDM files had the better NCF, with a mean of 725.00 cycles (±181.90), greatly surpassing MG3 Blue, which had 373.56 cycles (±114.49). The average NCF for M3 Pro Gold was 604.69 (±197.95) cycles as shown in Table 1. Figure 5 illustrates the NCF across the three research groups. The one-way ANOVA test indicated statistically significant differences between the groups (F=17.93, P<0.001). Pairwise comparisons indicated that Hyflex EDM and M3 Pro Gold exhibited substantially elevated NCF values compared to MG3 Blue (P-values <0.001 and 0.001, respectively), but there is no significant difference between Hyflex EDM and M3 Pro Gold as presented in Table 2.

Length of Fractured File Tip

The length of the fractured file tip differed significantly among the groups. MG3 Blue had the highest mean tip length with 4.78 (±0.36) mm, followed by Hyflex EDM with 4.50 (±0.37) mm and M3 Pro Gold with 4.31 (±0.40) mm as shown in Table 1. Figure 6 shows the length of the fractured file tip among the three study groups. ANOVA results showed significant differences (F=6.24, P=0.004). Pairwise comparisons indicated a significant difference between MG3 Blue and M3 Pro Gold (P=0.003) as presented in Table 2.

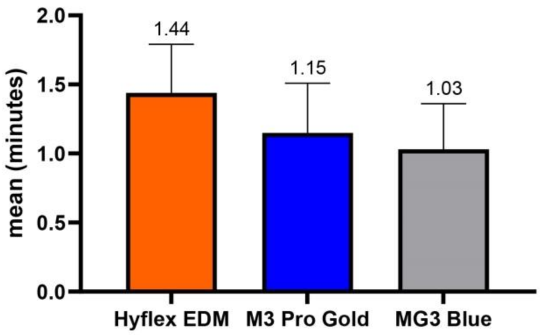

Figure 4: TTF among the three study groups.

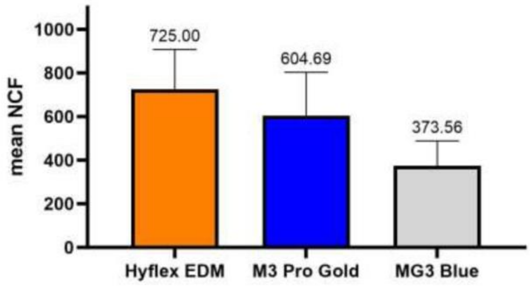

Figure 5: NCF among the three study groups.

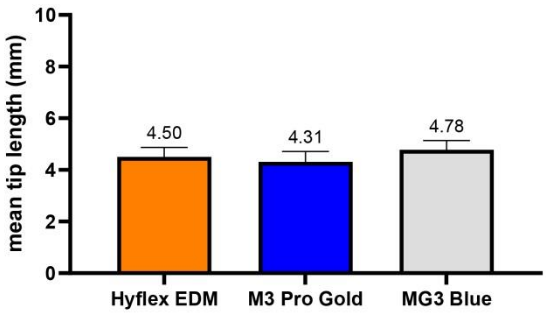

Figure 6: Length of fractured tip among the three study groups.

Table 1: Comparison among the three study groups.

		Hyflex EDM (n= 16)	M3 Pro Gold (n= 16)	MG3 Blue (n= 16)	F of ANOVA P value
Time to fracture (minutes)	Mean (SD)	1.44 (0.35) a	1.15 (0.36) ab	1.08 (0.33) b	F= 4.80 *P= 0.01**
	Min – Max	0.58 – 1.88	0.52 – 2.00	0.72 – 1.97	
NCF (Number of cycles to fracture)	Mean (SD)	725.00 (181.90) a	604.69 (197.95) a	373.56 (114.49) b	F= 17.93 *P <0.001**
	Min – Max	290.00 – 1000.00	260.00 – 1000.00	252.00 – 690.00	
Length of fractured file tip (mm)	Mean (SD)	4.50 (0.37) ab	4.31 (0.40) a	4.78 (0.36) b	F= 6.24 P= 0.004*
	Min – Max	4.00 – 5.00	4.00 – 5.00	4.00 – 5.00	

SD: Standard Deviation, Min: Minimum, Max: Maximum
One way ANOVA was used
*Statistically significant at p-value <0.05
a,b: different letters denote statistically significant differences between groups using Bonferroni correction

Table 2: Pairwise comparison among the three study groups.

	Group	Compared to	P value
Time to fracture (minutes)	Hyflex EDM	M3 Pro Gold	0.10
		MG3 Blue	0.02*
	M3 Pro Gold	MG3 Blue	1.00
NCF (Number of cycles to fracture)	Hyflex EDM	M3 Pro Gold	0.15
		MG3 Blue	<0.001*
	M3 Pro Gold	MG3 Blue	0.001*
Length of fractured file tip (mm)	Hyflex EDM	M3 Pro Gold	0.50
		MG3 Blue	0.12
	M3 Pro Gold	MG3 Blue	0.003*

*Statistically significant using Bonferroni corrected significance ($P < 0.05$)

DISCUSSION

Root canal therapy has seen notable improvements due to the introduction of NiTi rotary files, which have optimized the mechanical preparation of root canals, particularly in instances with pronounced curvatures (26). Despite their benefits, NiTi rotary files are susceptible to cyclic fatigue, resulting in file fracture, especially in curved canals (27). Cyclic fatigue arises from repeated stress and compression cycles at the point of greatest flexure, ultimately leading to file fracture (28). Comprehending the cycle fatigue resistance of various NiTi rotary file systems is essential for enhancing the success rate of endodontic procedures and reducing the likelihood of file separation (17).

This research sought to evaluate and compare the cyclic fatigue resistance of three distinct NiTi rotary file systems: Hyflex EDM, M3 Pro Gold, and MG3 Blue, with regard to their cost-effectiveness. The research aimed to assess whether cost-effective file systems can rival the performance of high-end files regarding cycle fatigue resistance. The null hypothesis of this research was that there would be no significant difference in the cyclic fatigue resistance of Hyflex EDM, M3 Pro Gold, and MG3 Blue rotary files when used in curved canals.

This research used a custom-made cycle fatigue device to accurately replicate the clinical conditions seen during endodontic procedures. The custom-made device enabled the establishment of a controlled and uniform environment, ensuring precise and reproducible outcomes. This methodology is endorsed by ElWakeel et al., who emphasized the advantages of using custom devices to replicate authentic situations overcoming the operator variability which might affect the results (25).

The selected 60° canal curvature with a 5mm radius of curvature signifies a clinically relevant condition often seen in endodontic procedures. This standardized curvature emulates real-world challenges in root canal instrumentation, where resistance to cyclic fatigue is essential to avert file separation (24). Research has underscored the significance of radius selection, as a 5mm radius ensures uniform mechanical stress on NiTi rotary files, enabling a dependable evaluation of their durability under repeated flexural strain (29). Moreover, research substantiates the imperative of integrating both angle and radius standardization to guarantee repeatability in fatigue resistance assessments (30). The technique used in this study is consistent with other research that underscores the importance of controlled conditions for fatigue testing (25), hence corroborating the selected parameters as a viable means of assessing the endurance of NiTi rotary files.

Dynamic cycle fatigue testing was used over static testing to more accurately simulate the clinical settings in which files endure constant in-and-out pecking movements during root canal preparation. Dynamic testing facilitates a more authentic evaluation of the files' performance in clinical settings by evenly distributing stress over the file's length, hence diminishing stress concentration at any one place (30). In contrast, static testing maintains the file in a fixed position inside the canal, failing to correctly simulate the clinical setting and perhaps underestimating the cycle fatigue resistance of the files (31).

This study used synthetic oil as a lubricant to reduce friction between the file and the canal walls, facilitating smooth rotation and decreasing the likelihood of file binding or stalling. Synthetic oil has shown the ability to provide a thin, uniform lubricating layer without obstructing the file's movement, making it an optimal selection for cyclic fatigue testing (30,32,33). Moreover, the characteristics of synthetic oil maintain stability throughout the testing duration, yielding uniform results (29). In a few studies a different type of lubricant was used, Martins et al. (34) used glycerin. Unfortunately, using synthetic oil in this study may not fully represent the clinical irrigation and lubrication conditions (32). While synthetic oil reduces friction and facilitates smooth rotation, its properties differ from conventional irrigants and lubricants used in clinical settings, which may influence fatigue resistance results.

The files were not sterilized before being tested to guarantee that their metallurgical qualities remained unchanged. Sterilization methods, including autoclaving, may induce phase changes in nickel-titanium alloys, possibly impacting their mechanical characteristics and cyclic fatigue resistance (33). By using non-sterilized files, the aim was to evaluate their performance in their original condition, hence yielding a more precise evaluation of their cycle fatigue resistance (30). This methodology is consistent with prior research that has similarly examined files in their non-sterilized condition to preserve their essential characteristics (31).

Environmental factors, including temperature and humidity, may affect the cyclic fatigue resistance of NiTi rotary files. Temperature fluctuations may modify the metallurgical characteristics of NiTi alloys, influencing their phase transformation and mechanical properties (12,25). Elevated temperatures accelerate phase transitions, potentially affecting flexibility and durability, whereas humidity may influence lubricant efficiency and lead to surface oxidation, thereby compromising the structural integrity of the files (29,32). Prior research has emphasized the impact of various environmental conditions on the performance and durability of NiTi files (33). While this research was performed in a controlled laboratory setting, it is important to recognize the lack of particular environmental controls (35, 36).

Due to the differences in cycle fatigue resistance, the null hypothesis asserting no significant difference among the three file systems was rejected. This suggests that the various costs of the different file systems did affect their quality in terms of cycle fatigue resistance.

Hyflex EDM and M3 Pro Gold exhibited similar cyclic fatigue resistance when compared to one another, yet there were statistically significant differences when contrasted with MG3 Blue. The findings revealed that Hyflex EDM files exhibited the longest time to fracture (TTF), with a mean duration of 1.44 (±0.35) minutes. M3 Pro Gold had a mean time to failure (TTF) of 1.15 (±0.36) minutes, whilst MG3 Blue registered the quickest TTF of 1.08 (±0.33) minutes. The statistical analysis revealed significant differences between Hyflex EDM and MG3 Blue ($P = 0.02$), affirming the greater resistance of Hyflex EDM compared to MG3 Blue, however the difference between Hyflex EDM and M3 Pro Gold was not statistically significant.

The improved cycle fatigue resistance of Hyflex EDM files is confirmed by the NCF results, which concur with the TTF findings. They demonstrated the greatest average NCF of 725.00 cycles (±181.90), followed by M3 Pro Gold with an average of 604.69 cycles (±197.95). The MG3 Blue files had the lowest NCF, with a mean of 373.56 cycles (±114.49). Statistically significant differences were noted between Hyflex EDM and MG3 Blue ($P < 0.001$) and between M3 Pro Gold and MG3 Blue ($P = 0.001$), however the difference between Hyflex EDM and M3 Pro Gold was statistically insignificant.

The enhanced TTF and NCF of Hyflex EDM files are due to their sophisticated production process using Electric Discharge Machining (EDM) technology. This technique enhances the uniformity of the material and diminishes the occurrence of micro-cracks, hence substantially augmenting their resistance to cycle fatigue (37). The M3 Pro Gold files, subjected to gold heat treatment, exhibited notable performance. The thermal processing improves the flexibility and endurance of these files, making them dependable for clinical applications (33). However, MG3 Blue files had lower TTF and NCF values even though they benefited from blue heat treatment. The blue heat treatment enhances flexibility but does not considerably enhance fatigue resistance compared to the EDM or gold heat treatment procedures (20).

The impact of rotational speed differences across groups must be acknowledged, as ElWakeel et al. (25) suggested that variations in speed may act as a confounding factor. Specifically, MG3 Blue operated at 350 rpm, whereas Hyflex EDM and M3 Pro Gold ran at 500 rpm, potentially influencing cyclic fatigue resistance outcomes.

A significant element influencing cycle fatigue resistance in this investigation is the variability in file size and taper across the groups. Hyflex EDM files include a variable taper design (25/~), while both M3 Pro Gold and MG3 Blue files have a constant 25/.04 taper. The variation in taper affects the interaction of files with curved canals, since differing taper designs reduce stress concentration and improve flexibility during instrumentation (25). Moreover, research has shown that differences in taper influence the distribution of cyclic fatigue resistance, with bigger tapers often experiencing increased flexural stresses (24).

These results correspond with those of Iacono et al. (26), who emphasized the influence of manufacturing methods on fatigue resistance, and Shen et al. (27), who verified that heat treatments substantially improve file durability. Additionally, Capar et al. (29) underscored the significance of standardized canal curvature in evaluating cycle fatigue resistance, hence endorsing the methods used in this investigation.

The results corroborate existing literature on NiTi file performance. Studies have demonstrated that EDM-treated NiTi files, such as Hyflex EDM, exhibit enhanced durability due to reduced micro-cracks, improving fatigue resistance (37). Likewise, gold heat-treated files like M3 Pro Gold have shown improved flexibility and mechanical performance, reinforcing their cyclic fatigue resistance (33). However, MG3 Blue files, despite their blue heat treatment, presented significantly lower resistance, consistent with findings by Hou et al. (20), which indicate that blue heat treatment primarily enhances flexibility rather than fatigue endurance.

The fractured tip length varied significantly among the studied groups. MG3 Blue files had the longest mean fractured tip length of 4.78 mm (±0.36), followed by Hyflex EDM at 4.50 mm (±0.37) and M3 Pro Gold at 4.31 mm (±0.40). Notably, MG3 Blue files tended to fracture at the beginning of the curve, which, combined with their reduced cyclic fatigue resistance, makes them less suitable for severely curved canals where instruments are subjected to high flexural stress (35). In contrast, Hyflex EDM files, with their moderate fractured tip length and superior cyclic fatigue resistance, provide a balanced performance, making them a more reliable option for curved canals. Their enhanced durability might be attributed to the Electric Discharge Machining (EDM) process, which improves material integrity and minimizes micro-cracks (37). Similarly, M3 Pro Gold files demonstrate notable cyclic fatigue resistance due to their gold heat treatment, which enhances flexibility and durability, making them a preferable choice for navigating severely curved canals (33).

Although this research offers significant information, it has several limitations. The in vitro design of cyclic fatigue testing does not completely emulate the clinical context, as patient-specific variables, operator proficiency, and canal morphology might affect file efficacy. Another limitation is the use of synthetic oil as a lubricant, which may not entirely emulate the conditions present inside the root canal system. Moreover, the research failed to include differences in canal diameters, lengths, and curvature angles, which might influence the efficacy of the files.

Subsequent studies need to concentrate on clinical studies to corroborate these results in practical environments. Furthermore, examining the effects of frequent use and sterilization on the cycle fatigue resistance of these files would provide a more thorough comprehension of their durability (34).

Subsequent research should investigate the efficacy of a wider array of file systems and the impact of differing canal anatomies, radii, and curvature angles on cycle fatigue. Comprehending these aspects will enable clinicians to make more informed judgements in their endodontic practice, hence enhancing patient outcomes (36).

CONCLUSIONS

Within the limitations of this study, highlighting the differing cycle fatigue resistance of Hyflex EDM, M3 Pro Gold, and MG3 Blue rotary file systems, stressing the need to choose the suitable file according to clinical requirements and financial implications. While Hyflex EDM and M3 Pro Gold exhibited better cyclic fatigue resistance. M3 Pro Gold's affordability suggests that they may be a suitable choice for curved canal treatment. However, quantitative cost data analysis and clinical outcomes correlation studies should be done to support the results.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

FUNDING STATEMENT

The authors received no specific funding for this work.

REFERENCES

1. Agrawal PR, Chandak M, Nikhade PP, Patel AS, Bhopatkar JK. Revolutionizing endodontics: Advancements in nickel-titanium instrument surfaces. J Conserv Dent Endod. 2024;27:126-33.
2. Balic M. Evaluation of surface wear in rotary and reciprocating nickel-titanium instruments after use in curved root canals. Ph.D. Thesis. Endodontics and Restorative Dentistry Department. School of Dental Medicine. University of Zagreb. Zagreb. 2022.
3. Jordan L, Bronnec F, Machtou P. Endodontic Instruments and Canal Preparation Techniques. Endodontic Materials in Clinical Practice. Hoboken, New Jersey: Wiley Blackwell; 2021. pp. 81-131.
4. Maroof M, Sujithra R, Tewari RP. Superelastic and shape memory equi-atomic nickel-titanium (Ni-Ti) alloy in dentistry: A systematic review. Mater Today Commun. 2022;33:104352.
5. Ohri K, Chien PY, Peters OA. The Biomechanics of Nickel Titanium Instrument Fracture in Root Canal Therapy: A Narrative Review. Materials. 2024;17:6147.
6. Bhat A. Comparative Evaluation of Centering Ability and Canal Transportation of Two Anatomic File Systems with a Conventional Rotary File System by Using Cone Beam Computed Tomography-An in Vitro Study. M.Sc. Thesis. Rajiv Gandhi University of Health Sciences. India. 2020.
7. Zanza A, D'Angelo M, Reda R, Gambarini G, Testarelli L, Di Nardo D. An Update on Nickel-Titanium Rotary Instruments in Endodontics: Mechanical Characteristics, Testing and Future Perspective-An Overview. Bioengineering (Basel). 2021;8:218.
8. Abdellatif D, Iandolo A, Scorziello M, Sangiovanni G, Pisano M. Cyclic Fatigue of Different Ni-Ti Endodontic Rotary File Alloys: A Comprehensive Review. Bioengineering (Basel). 2024;11:499.
9. Martins JNR, Martins RF, Braz Fernandes FM, Silva E. What Meaningful Information Are the Instruments Mechanical Testing Giving Us? A Comprehensive Review. J Endod. 2022;48:985-1004.
10. Kamha SM. Topographic Changes of Two different Ni Ti File Systems After Multiple Uses. Egypt Dent J. 2018;64:3683-96.

11. AbdAllah DM, Elddamony EM, Abdelgawad RA. Surface topography and chemical characteristics of rotary ni ti files of different manufacturing techniques after multiple use. Egypt Dent J. 2020;66:633-43.
12. Zupanc J, Vahdat-Pajouh N, Schäfer E. New thermomechanically treated NiTi alloys - a review. Int Endod J. 2018;51:1088-103.
13. Silva EJNL, Souza E, De Deus G, Versiani MA, Zuolo M. NiTi rotary systems: From revolution to the "more of the same" phenomenon. Shaping for Cleaning the Root Canals: A Clinical-Based Strategy. Switzerland: Springer; 2021. pp. 127-57.
14. Lakshmi S. CBCT Evaluation of Centering Ability and Canal Transportation of Different NiTi File Systems Working Under Varying Kinematics–An Invitro Study. M.Sc. Thesis. Rajiv Gandhi University of Health Sciences. India. 2019.
15. Harrison T. Cyclic fatigue resistance of nickel titanium rotary files in the martensitic state: a systematic review. University of Chester. 2020.
16. Arias A, Macorra JC, Govindjee S, Peters OA. Effect of gamma-ray sterilization on phase transformation behavior and fatigue resistance of contemporary nickel-titanium instruments. Clin Oral Investig. 2020;24:3113-20.
17. Pedullà E, Lo Savio F, La Rosa GRM, Miccoli G, Bruno E, Rapisarda S, et al. Cyclic fatigue resistance, torsional resistance, and metallurgical characteristics of M3 Rotary and M3 Pro Gold NiTi files. Restor Dent Endod. 2018;43:e25.
18. Abd ElHamid HM. Cyclic Fatigue Resistance of Newly Introduced Surface and Thermal Treated Nickel-Titanium Rotary Files. Egypt Dent J. 2020;66:683-94.
19. Tabassum S, Zafar K, Umer F. Nickel-Titanium Rotary File Systems: What's New? Eur Endod J. 2019;4:111-7.
20. Hou XM, Yang YJ, Qian J. Phase transformation behaviors and mechanical properties of NiTi endodontic files after gold heat treatment and blue heat treatment. J Oral Sci. 2020;63:8-13.
21. Rosner B. Fundamentals of biostatistics. Toronto: Nelson Education; 2015.
22. Universität Düsseldorf. G*Power. 2019. Available at: http://www.gpower.hhu.de/.
23. Fouad HK, Hashem AAE, Abdel Aziz TM. Evaluation of cyclic fatigue of three different Rotary Nickel Titanium Systems. Ain Shams Dent J. 2021;22:39-50.
24. Bürklein S, Maßmann P, Donnermeyer D, Tegtmeyer K, Schäfer E. Need for standardization: Influence of artificial canal size on cyclic fatigue tests of endodontic instruments. Appl Sci. 2021;11:49-50.
25. Elwakeel MSAA, Hashem AAR, Fahmy SH, Saber SM, Plotino G. The impact of composition, core metal mass and phase transformation behavior on the dynamic cyclic fatigue of Ni-Ti files at different temperatures. G Ital Endod. 2022;36:101-9.
26. Iacono F, Pirani C, Generali L, Bolelli G, Sassatelli P, Lusvarghi L, et al. Structural analysis of HyFlex EDM instruments. Int Endod J. 2017;50:303-13.
27. Shen Y, Coil JM, Zhou H, Zheng Y, Haapasalo M. HyFlex nickel-titanium rotary instruments after clinical use: metallurgical properties. Int Endod J. 2013;46:720-9.
28. Miccoli G, Gaimari G, Seracchiani M, Morese A, Khrenova T, Di Nardo D. In vitro resistance to fracture of two nickel-titanium rotary instruments made with different thermal treatments. Ann Stomatol (Roma). 2017;8:53-8.
29. Capar ID, Ertas H, Arslan H. Comparison of cyclic fatigue resistance of novel nickel- titanium rotary instruments. Aust Endod J. 2015;41:24-8.
30. Pedullà E, La Rosa GRM, Virgillito C, Rapisarda E, Kim HC, Generali L. Cyclic Fatigue Resistance of Nickel-titanium Rotary Instruments according to the Angle of File Access and Radius of Root Canal. J Endod. 2020;46:431-6.
31. Plotino G, Grande NM, Cotti E, Testarelli L, Gambarini G. Blue treatment enhances cyclic fatigue resistance of vortex nickel-titanium rotary files. J Endod. 2014;40:1451-3.
32. Gundogar M, Özyürek T. Cyclic Fatigue Resistance of OneShape, HyFlex EDM, WaveOne Gold, and Reciproc Blue Nickel-titanium Instruments. J Endod. 2017;43:1192- 6.
33. Fikry MA, Nagy MM, Fahmy SH. Comparison of the Shaping Ability of M3 Pro Gold, M Pro and Pro Taper Universal Rotary Nickel Titanium Systems (An In Vitro Study). Ain Shams Dent J. 2024;35:95-104.
34. Martins JN, Silva EJ, Marques D, Ginjeira A, Fernandes FM, De Deus G, Versiani MA, et al. Influence of Kinematics on the Cyclic Fatigue Resistance of Replicalike and Original Brand Rotary Instruments. J Endod. 2020;46:1136-43.
35. Alnoury A. Cyclic fatigue resistance of ProTaper gold and two replicalike rotary systems: An in vitro study. Saudi Endod J. 2024;14:25-30.
36. Unno H, Ebihara A, Hirano K, Kasuga Y, Omori S, Nakatsukasa T, et al. Mechanical Properties and Root Canal Shaping Ability of a Nickel-Titanium Rotary System for Minimally Invasive Endodontic Treatment: A Comparative In Vitro Study. Materials (Basel). 2022;15:1234.
37. Nafi MA, Jahan MP. Functional surface generation by EDM: a review. Micromachines. 2023;14:115.