ASDJ
AINSHAMS DENTAL JOURNAL

Print ISSN 1110-7642

Online ISSN 2735-5039

AIN SHAMS DENTAL JOURNAL
Official Publication of Ain Shams Dental School
september2022 • Vol. 27

Cyclic Fatigue Resistance of Protaper Gold, HyFlex EDM and K3XF Rotary Instruments

Mohamed M.N El-Tayeb[1], *Mohamed Nabeel*[2]

Aim: The aim of the present study was to evaluate the resistance to cyclic fatigue of different nickel-titanium (NiTi) rotary instruments. The tested instruments were Protaper Gold (PTG), HyFlex EDM (HEDM) and K3XF.

Materials and Methods: A total of forty-five NiTi rotary instruments were divided into three experimental groups (n = 15 each). Group 1: Protaper Gold (F2 25/.08), group 2: HyFlex EDM (25/.08) file and group 3: K3XF file (25/.08). The testing device was specially designed for this experiment. The cycles to failure were calculated. The data were statistically analyzed using one-way analysis of variance ($p < 0.05$).

Results: The results revealed that HyFlex EDM showed statistically significant highest mean cyclic fatigue value, while K3XF showed statistically significant lower mean cyclic fatigue value. Protaper Gold system showed statistically significant lowest mean cyclic fatigue value.

Conclusions: The geometrical design features and mode of manufacturing of the tested nickel-titanium rotary systems have a direct influence on their resistance to cyclic fatigue. HyFlex EDM files demonstrated significantly higher cyclic fatigue resistance than Protaper Gold and K3XF. The electrical discharge machining (EDM) technology and the unique cross section of HyFlex EDM may be the main reason for this difference.

Keywords: Cyclic Fatigue, Protaper Gold, HyFlex EDM, K3XF

1. Lecturer, Department of Endodontics, Faculty of Oral and Dental Medicine, Badr University in Cairo, Cairo, Egypt.
2. Lecturer, Endodontic Department, Faculty of Oral and Dental Medicine, Misr International University, Cairo, Egypt.
Corresponding author: Mohamed M.N El-Tayeb, email: eltayeb65@hotmail.com

Introduction

The effectiveness of endodontic cleaning and shaping procedures has significantly increased with the introduction of rotating nickel-titanium devices. These tools can provide more rounded preparations that remain centered in the canal area while reducing procedural mistakes like ledging and transporting. With these instruments, separation is a big challenge even with their greater flexibility. It appears that fracture may occur within the elastic limit of the instrument, even in the absence of any obvious evidence of prior permanent deformation [1]. The lack of defined standards for the production and testing of these devices is one issue with the nickel-titanium file systems. Without performing a thorough analysis, any new rotary nickel-titanium file system may be produced, designed, and commercialized in any shape or taper.

The two main factors responsible for the fracture in rotating NiTi files are torsional stress and cyclic fatigue [2]. When a file rotates freely in a canal, it experiences cyclic fatigue and bends until it fractures. This is caused by the alternating cycles of compression and tension that files endure to when they are strained in canals with great curvature [2]. There have been several solutions proposed to strengthen the instruments resistance to cyclic fatigue. These include the production of novel alloys with enhanced mechanical characteristics and refining the manufacturing process.

To overcome these limitations, sophisticated manufacturing techniques for NiTi endodontic tools have recently been developed. To enhance their mechanical qualities, the new NiTi endodontic implements have undergone sophisticated metallurgy and several surface treatments [3].

Recently released ProTaper Gold files (Dentsply Tulsa Dental Specialties, OK, USA) have shown enhanced mechanical qualities due to its novel metallurgy, with high Af temperatures and a two-stage unique transformation behavior. PTG files feature a convex triangular cross section with a varying helical angle [4].

Electrical discharge machining (EDM) is used to improve the mechanical characteristics of controlled memory (CM) wires, which is how Hyflex EDM (HEDM) (Coltene/Whaledent, Altstätten, Switzerland) is performed [5]. In order to optimize flexibility, torsional resistance, and cyclic resistance, the instrument also displays different cross-sectional forms that change from triangular to rectangular from shaft to tip [6].

R-phase technology was used in the production of K3XF (SybronEndo, Orange County, CA, USA). R-phase is a rhombohedral phase that is present in a relatively narrow temperature ranging between austenite and martensite. These files have the same primary features of K3 files. As a result, according to the manufacturers, K3XF is more flexible and resistant to cyclic fatigue [8].

Therefore, the present study was carried out to evaluate the resistance to cyclic fatigue of different nickel-titanium (NiTi) rotary instruments. The tested instruments were PTG, HEDM and K3XF Files.

Materials and Methods

Sample size calculation

Using cyclic fatigue as the primary outcome, power analysis was used to calculate the total sample size. With a power of 90%, the effect size (w) of 0.56 was calculated at the alpha (α) level of 0.05 (5%) and beta (β) level of 0.10 (10%). The minimum estimated sample size was 45 samples. This analysis was made using the findings of an earlier study [7]. Thus, there were 15 samples in each group, for a total sample size of 45. To calculate the sample size, G*Power Version 3.1.9.2 was used.

Selection of samples:

A number of forty-five NiTi rotary files including Protaper Gold file F2 size 25 and 0.08 taper, HyFlex EDM file size 25 with 0.08 taper, and K3XF file 25 and 0.08 taper (15 each) were selected and used in the current study.

Grouping of samples:

Selected NiTi rotary instruments were divided into three equal groups (n=15):

Group 1: Protaper Gold (PTG) file (Dentsply Tulsa Dental Specialties, OK, USA) F2 size 25 and 0.08 taper was rotated at a speed of 300 rpm and 3.1 g/cm torque using an X-Smart endo motor that was fixed on a cyclic fatigue assessment device until the fracture of the file.

Group 2: HyFlex EDM file (Coltene/Whaledent, Altstätten, Switzerland) size 25 and 0.08 taper was rotated with an X- Smart endo motor at a speed of 500 rpm and torque of 2.5 g/cm until fracture was observed in the same manner as group 1.

Group 3: K3XF file (SybronEndo, Orange County, CA, USA) size 25 and 0.08 taper was also used at rotational speed 500 rpm and torque of 2.5 g/cm until fracture in the same manner as the other groups.

Measuring Device:

The measuring device was modified from the one used by Haikel et al. [9]. The hand-piece was precisely positioned by means of a machined holder that was linked to a steel base. There was a 5 mm radius curvature on the block. The assessed file was placed in the handpiece, and by using Schneider's method, the curvature was adjusted to 51 degrees [10] [Figure 1].

Assessment methods

A digital chronometer was utilized to record the fracture time. The following formula was used to determine the number of cyclic failures using the time data: Time to fracture (seconds) x rotations per minute equals Cyclic failure [11–13].

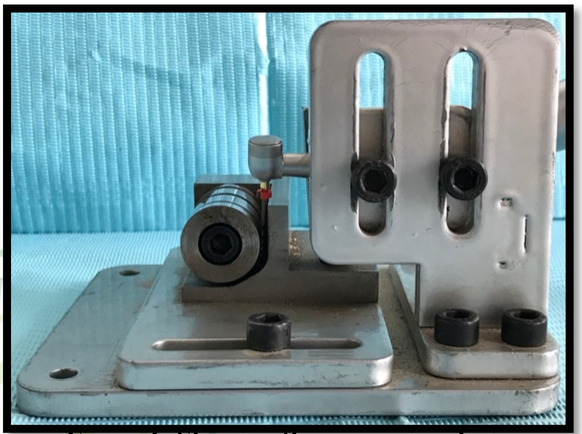

Figure 1: Showing the measuring device.

Statistical analysis:

All data was collected, tabulated and statistically analyzed. By examining the data distribution and using Kolmogorov-Smirnov and Shapiro-Wilk tests, numerical data were checked for normality. Parametric (normal) distribution was seen in the data. The data were shown as mean, standard deviation (SD) and mean (95% CI) confidence intervals. A One-way ANOVA test was used to compare the differences among the three groups. When ANOVA test is significant, pair-wise comparisons were performed using Bonferroni's post-hoc test.

The significance level was set at $P \leq 0.05$. IBM® SPSS® Statistics Version 20 was used for statistical analysis.

Results

Results have shown that HyFlex EDM had the highest cyclic fatigue mean value followed by K3XF, PTG files have shown the least cyclic fatigue mean value. There was a statistical significant difference (P-value = 0.001) (Table 1, Figure 2).

Table 1. Descriptive statistics and result of one-way ANOVA test for comparison between the three groups.

System	Mean	SD	95% CI		*P*-value
			Lower bound	Upper bound	
PTG	374.75 ^{C}	20.33	364.30	384.68	0.001*
HEDM	774.29 ^{A}	64.15	722.16	850.92	
K3XF	645.85 ^{B}	84.33	613.49	695.81	

** Significant at P ≤ 0.05, Different superscripts are statistically significantly different*

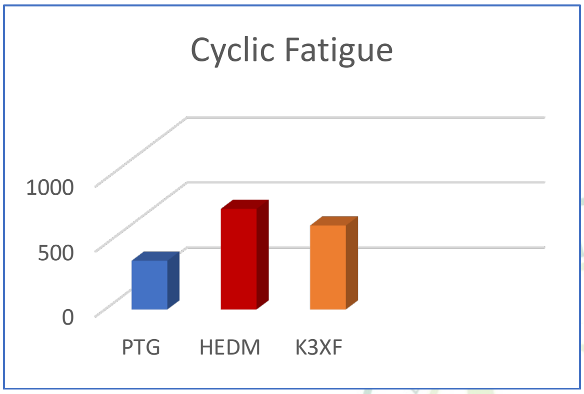

Figure (2): Bar chart representing mean and standard deviation values of the three groups.

Discussion

Numerous research has been performed to determine the causes of instrument fracture and how it could be avoided rather than being treated. A review of literature reveals that the deformation and fracture of nickel-titanium rotary instrument is a multi-factorial problem [2].

There are number of reasons responsible for rotary instrument fracture, such as the handling of the files, anatomy of the root canal, and NiTi rotary instrument design. As a result, several investigations into the causes and mechanics of the instrument fracture have been carried out [14]. It has been stated that cyclic fatigue fracture and torsional failure are the mechanisms of rotary instrument separation [15]. Torsional failure happens when the shank of the file rotates while the instrument's tip becomes stuck or jammed in the canal. As a result of repetitive tensile and compressive stresses on the file in curved canals, Cyclic failure occurs [16].

According to previous studies, during extended usage of rotary NiTi files, torsional failure occurred more frequently (56%) than cyclic fatigue (44%) [14, 17]. The torsional and flexural stresses develop simultaneously, which is hard to prevent, however, only few studies have linked them [18].

In other research, the experimental design used human teeth [19, 20]. When the device is employed in human canals, the stresses cannot be controlled. Additionally, different root canal curvatures between teeth are thought to be another significant variance. Additionally, using human root canals will always result in a combination of cyclic fatigue and torsional stress. A fabricated metal block was utilized to avoid these biases.

In order to prevent operator-induced stresses from interfering with endodontic instruments during cyclic fatigue assessment, a device was used in the current study to hold the handpiece [21, 22].

As it has been suggested that the size of instruments size altered the resistance of rotary files to cyclic fatigue [23]. Thus, rotary files used in this study, have a tip diameter that is equal to 0.25 mm in size.

In the current study, three differently designed rotary files were utilized to assess their resistance to cyclic fatigue. Hyflex EDM files are produced using electrical discharge machining (EDM) process. The revolutionary HyFlex EDM possesses its unique features to a Electrical Discharge Machining, a groundbreaking technology. Through the application of spark erosion, this novel technique hardens the NiTi file surface enhancing the cutting efficiency and fracture resistance. HyFlex EDM files have regenerative qualities and reliable controlled memory effect, similar to Hyflex CM files [24]. K3XF are produced by thermally processing a raw NiTi wire to change it from the austenite phase into the R-phase [9]. Using a patented improved metallurgy and heat treatment approach, the ProTaper Gold files were manufactured [25].

Results of the current study showed the highest resistance to cyclic fatigue with

HyFlex EDM file, which was statistically significant. Its EDM approach, novel cross-section design, and higher austenite final temperature (over 370°C), which contains both austenite and martensitic structure mixes at room temperature, may be responsible for these results [26]. Since martensite has a higher density than austenite, files made with CM wires have less stiffness than austenite, which impacts the file fatigue behavior [27].

In contrast to Twisted files and Wave One Gold files, Hyflex EDM demonstrated the highest resistance to cyclic fatigue, according to another study [28]. Furthermore, HyFlex EDM file had the different cross-section designs that may be contributed to high fracture resistance [29].

In the cuurent study K3XF file showed resistance to fatigue higher than PTG files, a possible explanation for the superiority of K3XF file might be related to its unique feature in its design which is the variable core diameter or flute depth. Throughout the whole working length, the correlation between the core and the outer diameter differs from D1 to D16 to preserve flexibility. It was stated that the cross-sectional dimensions of instruments with deep cutting flutes and progressively greater varying tapers, change across the full length. These instruments are particularly vulnerable to metal fatigue and fracture, due to the high torque rates they create. conversely, torsional loading is less likely to affect instruments with shallow cutting flutes, uniformly tapered shafts and regularly formed cross-sectional areas. This is due to the homogenous distribution of the torsional and bending forces along the whole length that arises during usage [9, 30].

On the other hand, the PTG file had the least resistance to cyclic fatigue This may be related to the progressive taper of these files, which increase the cutting efficiency, while decreasing resistance to cyclic failure. The results of our study seem to suggest that these previous findings may well be true. In addition, these files had a constant convex triangular that is expected to show a lower fatigue resistance, because of the large concentration of stresses [31]. Alternatively, enlarging the cross-section inner core diameter improves the rotary file torsional resistance [32]. Madarati et al. [33] showed the effects of the total mass of the file, its flexibility and strength, the way of contact with the canal walls, the quantity of cutting, and the stress induced on the canal walls were all influenced by the cross-section of the file; and all these factors affected on the file fatigue.

Based on the results limitations of the current study, it would be stated that HyFlex EDM files, with their better resistance to cyclic failure, could be a safer option for use in curved canals.

Conclusion

The geometrical design features and mode of manufacturing of the tested nickel-titanium rotary files have a direct influence on their resistance to cyclic fatigue. HyFlex EDM files had the most superior resistance to cyclic fatigue over Protaper Gold and K3XF. This could be related to the electrical discharge machining (EDM) technology and the unique cross section of HyFlex EDM.

References

1. Iacono F, Pirani C, Generali L, Bolelli G, Sassatelli P, Lusvarghi L, Gandolfi MG, Giorgini L, Prati C. Structural analysis of HyFlex EDM instruments. Int Endod J. 2017;50:303-313.
2. Gavini G, Santos MD, Caldeira CL, Machado MEL, Freire LG, Iglecias EF, Peters OA, Candeiro GTM. Nickel–titanium instruments in endodontics: a concise review of the state of the art. Braz Oral Res. 2018;32: e67.
3. Pirani C, Iacono F, Generali L, Sassatelli P, Nucci C, Lusvarghi L, Gandolfi MG, Prati C. HyFlex EDM: superficial features, metallurgical analysis and fatigue resistance of innovative electro discharge machined NiTi rotary instruments. Int Endod J. 2016;49:483-493.

4. Shen Y., Zhou H., Campbell L., et al. Fatigue and nanomechanical properties of K3XF nickel-titanium instruments. *International Endodontic Journal.* 2012;**47**(12):1160–1167.
5. Haikel Y, Serfaty R, Bateman G, Senger B, Allemann C. Dynamic and cyclic fatigue of engine-driven rotary nickel titanium endodontic instruments. J Endod. 1999; 25: 434–40.
6. Schnieder WE. A comparison of canal preparations in straight and curved root canals. Oral Surg. 1971; 32: 27-5.
7. Ozyurek T. Cyclic fatigue resistance of Reciproc, WaveOne, and WaveOne Gold Nickel-titanium instruments. J Endod. 2016; 42:1536-1539.
8. Gundogar M and Ozyurek T. Cyclic fatigue resistance of OneShape, HyFlex EDM, WaveOneGold, and Reciproc Blue Nickel-titanium instruments. J Endod. 2017; 43:1192-1196.
9. Keskin C, Inan U, Guler DH, Kalyoncuoglu E. Cyclic fatigue resistance of XP-Endo Shaper, K3XF, and Protaper Gold Nickel-titanium instruments. J Endod. 2018; 44:1164-1167.
10. Crump MC, Natkin E. Relationship of broken root canal instruments to endodontic case prognosis: a clinical investigation. J Am Dent Ass. 1970;80:1341–7.
11. Al-Fouzan KS. Incidence of rotary ProFile instrument fracture and the potential for by passing in vivo. Int Endod J. 2003;36:864 –7.
12. McNicholls JL, Brookes PC, Cory JS. NiTi fatigue behaviour. J Appl Phys 1981;52: 7442–7444.
13. Christ HJ. Fundamental mechanisms of fatigue and fracture. Student Health Technology Information. 2008;133:56–67.
14. Anderson ME, Price JW, Parashos P. Fracture resistance of electropolished rotary nickel-titanium endodontic instruments. J Endod. 2007;33:1212–1226.
15. Wei X, Ling J, Jiang J, et al. Modes of failure of ProTaper nickel-titanium rotary instruments after clinical use. J Endod. 2007;33:276–279.
16. Cheung G. S. P., Darvell B. W. Low-cycle fatigue of rotary NiTi endodontic instruments in hypochlorite solution. Dental Materials. 2008;24(6):753–759.
17. Gary S. P., Cheung Instrument fracture: mechanisms, removal of fragments, and clinical outcomes. Endodontic Topic. 2007;16(1):1–26.
18. Cheryl Gary S. P., Cheung Y. Effect of environment on low-cycle fatigue of a nickel–titanium instrument. Journal of Endodontics. 2007;33(12):433–437.
19. Chi C.-W., Li C.-C., Lin C.-P., Shin C.-S. Cyclic fatigue behavior of nickel-titanium dental rotary files in clinical simulated root canals. *Journal of the Formosan Medical Association.* 2017;116(4):306–312.
20. Šošić A., Šalinović I., Brzović Rajić V., Ivanišević Malčić A., Jukić Krmek S., Miletić I. Assessment of damage of endodontic instruments with naked eye and optical instruments. Acta Stomatol Croat. 2021;55(2):129–136
21. Daugherty DW, Gound TG, Comer TL. Comparison of fracture rate, deformation rate, and efficiency between rotary endodontic instruments driven at 150 rpm and 350 rpm. J Endod. 2001;27:93–5.
22. Ankrum MT, Hartwell GR, Truitt JE. K3 Endo, ProTaper, and ProFile systems: breakage and distortion in severely curved roots of molars. J Endod. 2004;30:234–237.
23. Pruett JP, Clement DJ, Carnes DL Jr. Cyclic fatigue testing of nickel-titanium endodontic instruments. J Endod. 1997;23:77–85.
24. Inan U, Aydin C, Tunca YM. Cyclic fatigue of ProTaper rotary nickel-titanium instruments in artificial canals with 2 different radii of curvature. Oral Surg Oral Med Oral Pathol Oral RadiolEndod. 2007;104:837–840.
25. Capar ID, Ertas H, Arslan H. Comparison of cyclic fatigue resistance of nickel- titanium coronal flaring instruments. J Endod. 2014;40:1182–1185.
26. Hülsmann M., Donnermeyer D., Schäfer E. A critical appraisal of studies on cyclic fatigue resistance of engine-driven endodontic instruments. International Endodontic Journal. 2019;52(10):1427–1445.
27. Kim H. C., Kim H. J., Lee C. J., Kim B. M., Park J. K., Versluis A. Mechanical response of nickel-titanium instruments with different cross-sectional designs during shaping of simulated curved canals. International Endodontic Journal. 2009;42(7):593–602.
28. Gambarini G. Rationale for the use of low-torque endodontic motors in root canal instrumentation. Dental Traumatology. 2000;16(3):95–100.
29. Ninan E., Berzins D. W. Torsion and bending properties of shape memory and superelastic nickel-titanium rotary instruments. Journal of Endodontics. 2013;39(1):101–104.
30. Zupanc J, Vahdat-Pajoh N, Schäfer E. New thermomechanically treated NiTi alloys a-Review. Int Endod J. 2018; 51(10): 1088-1103.
31. Bapna P, Ali A, Makandar SD, Nik Abdul Ghani NR, Metgud S. Comparative Evaluation of Fracture Resistance of Endodontically Treated Teeth Instrumented With K3XF Rotary Files Using Different Tapers. Cureus. 2023 Jan 26;15(1):e34247.

32. Xu X, Eng M, Zheng Y, Eng D. Comparative Study of Torsional and Bending Properties for Six Models of Nickel-Titanium Root Canal Instruments with Different Cross-sections. J Endod 2006; 32: 372-375.
33. Madarati AA, Watts DC, Qualtrough AJE. Factors contributing to the separation of endodontic files. B D J. 2008; 204(5): 241-245.