Evaluation of Anti-bacterial Effect of …. Vol.18 : No.2 :28/12/ 2022
DOI: https://doi.org/ 10.32828/mdj.v18i2.919

MDJ

Cyclic Fatigue Resistance of Hyflex EDM and ProTaper Gold Files at Different Locations of Canal Curvature

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Abstract

Aim: Study's purpose was to evaluate and compare the fatigue resistance of ProTaper Gold and Hyflex EDM files at five different locations of canal curvature.

Methods: Two types of NiTi files; ProTaper Gold and Hyflex EDM (n=80) with similar sizes (25/0.08) were used as two main groups (n=40), each group subdivided into five subgroups (n=8) according to distance from the orifice to curvature which are; 11, 10, 8, 6 and 5 mm. Five stainless steel canals were fabricated. Each canal had 16 mm length, 1.5 mm width and single curvature with 3-mm radius and 60° angle. Fractured samples were examined under a scanning electron microscope. Independent t-test, One-way ANOVA and Posthoc tests assessed the data statistically.

Results: Number of cycles to fatigue for the Hyflex EDM file was significantly higher than the ProTaper Gold file at all curvature levels ($p \leq 0.05$). The files demonstrated significantly higher number of cycles to fatigue in canals of (10 and 11) mm when compared to the canals of (5, 6, and 8) mm ($p \leq 0.05$).

Conclusion: Hyflex EDM files showed higher fatigue resistance than ProTaper Gold files. The canal curvature position had a substantial impact on the resistance of the NiTi file, with short life coronally.

Keywords: Cyclic fatigue, curvature location, nickel-titanium file, ProTaper Gold, Hyflex EDM.

INTRODUCTION

Over the last thirty years ago, rotary instruments made from nickel-titanium (NiTi) have become widely used [(1)]. These instruments were able to prepare the root canals in a short time with better-centered preparations and control most of the iatrogenic instrumentation issues that came with stainless steel (S.S.) files [(2, 3)].

Despite the numerous advantages of the NiTi endodontic instruments, fracture was the most common failure that occurred during preparations, either due to flexural (cyclic) or torsional fatigue [(4)]. Cyclic fatigue had been reported to occur without any prior evidence of irreversible deformation. This can happen when an instrument was rotated at the peak of the root canal curve and exposed to an excessive amount of compression and tension cycles. But, when the instrument's tip binds inside the canal wall when the file was rotated beyond the elastic limit of the NiTi alloy, torsional fatigue was developed [5]. Utilizing microscopic and fractographic examination, researchers discovered that cyclic fatigue failure caused 66–93% of the rotary instrument fractures, while shear failure caused 7–34% [6].

Manufacturers used a variety of treatments on NiTi instruments to improve the instrument elasticity and resistance to separation, including electropolishing of the surface and thermomechanical treatments [7].

ProTaper Gold (PTG, Dentsply Sirona. Switzerland) files were developed with a proprietary advanced process from M wire metallurgy with a gradual taper and a convex triangle cross-section to decrease the friction and increase the cutting efficiency [8].

HyFlex EDM file (HEDM, Coltene/Whaledent. France) was a single- system utilized with full rotation. Electric discharge machining (EDM) technology was employed to produce this file by utilizing controlled memory (CM) alloy. This allowed for the precise shaping, manipulation, and improvement of the mechanical characteristics of files [9].

The root canal morphology, in addition to metallurgy improvement of the file, was affected by the probability of NiTi instrument fatigue [10]. An early study found that the cervical curvature was predominant (45.2%) in the posterior teeth, while the apical curvature was predominant in the anterior teeth [11]. Divine *et al.* [12] used a micro-CT to investigate the palatal root shape of upper first and second molars. They found that the most percentage of first molar curvature at the mid-root level (40%) and respectively the percentage at the junction of the middle and apical thirds (33%). Furthermore, they discovered a curvature percentage at the junction of the middle and coronal thirds (12%) of the second molars.

Because the root canal shapes were shown to be varied, and the curvature may be found at any level of the canal, it is interesting to compare the resistance of instruments to cyclic fatigue at different levels of curvature. Furthermore, unavailable studies were found to compare the fracture resistance of PTG with proprietary technology of M wire and HEDM process of CM wire at different levels of canal curvature. So, this study aimed to evaluate and compare the resistance to fatigue of ProTaper Gold and Hyflex EDM NiTi rotary files at five different locations of canal curvature.

MATERIALS AND METHODS

The software G*Power version 3.1.9.7 (Franz-Faul, Universitatits Kiel, Germany) was used to calculate the sample size. The effective sample size was (n=8) files for each subgroup, with a significance level of 0.05 and a power of 0.85. Two types of rotary NiTi files, namely; ProTaper Gold (Dentsply Sirona. Switzerland) and Hyflex EDM (Coltene/Whaledent.France) were used in this study, with a similar distribution of samples (n=40) for each file. Each main group was subdivided into five subgroups (n=8) according to the location of canal curvature. All tested files had similar tip size and taper (25/0.08) with the same length (25 mm). A stereomicroscope (Koolertron, China) at 20 x magnification was utilized to inspect the new instruments for any defects. Based on the method of Pruett in 1997, the S.S. block was used to create five artificial canals. Each canal was 16 (mm) in length with 1.5 mm in width which had a single curvature 3 mm radius and 60° angle [13, 14]. The five canals were fabricated according to the distance from the orifice to curvature (DOC) which are; (11, 10, 8, 6, and 5) mm. A removable glass plate was used to cover the S.S. block that facilitated the visualization of file motion in addition to the removal of instrument fragments after each measurement as shown in Figure 1.

Cyclic fatigue test

Before starting the fatigue test and for standardization of the procedure, two special tools were designed and fabricated. The first tool was designed to fit and hold the dental handpiece (Dentsply Maillefer, Switzerland) within the surveyor (Denturum Paroline, Germany) which allowed for the simple and accurate replacement of the instrument in each measurement. A second special tool was designed according to the dimension of the block on the modified cast holder to fit and hold the block. Cyclic fatigue test for all files were conducted at 37 °C by submerging the metal block in water inside the glass container after being fixed to a modified cast holder to ensure that the instruments were aligned and positioned to the same depth in three dimensions as shown in Figure 2. The glass container was positioned on the digital hotplate (Magnetic stirrer-HEB-China) until the temperature of the water reached 37 °C and remained monitored by using the adjustable sensor (digital thermometer). The test was performed with the specified manufacturer's speed and torque. Group (A) PTG files at a speed of 350 rpm and torque of 3 N.cm. Group (B) HEDM files at a speed of 500 rpm and torque of 2.5 N.cm. All files were rotated until the fracture occurred, and the time was recorded by using a digital timer (TA228, China) and by using the camera (Nikon, Japan) to obtain capturing videos to determine the moment of fracture to avoid human error and standardize the test [15]. The total number of cycles to fracture (NCF) and the file fragment length (FFL) were calculated.

Scanning electronic microscope

A Scanning electronic microscope (SEM) was used to evaluate the mode of the file's fracture. The fragments were immersed in alcohol for 60 seconds before being ultrasonically cleaned, and then ten samples of fragments were mounted where the fractured surface facing up at magnification 300x-600x at 30.00KV (Thermo Scientific Axia ChemiSEM UK & Ireland) [14].

Statistical analysis

The maximum (Max), minimum (Min), mean and standard deviation (SD) values were calculated. Shapiro–Wilk test for the NCF and FFL of the files revealed that the data were distributed normally *(P > 0.05)*. An Independent t-test was done to evaluate the NCF and FFL data between the main two groups at the same DOC. Then, the data were evaluated by one-way analysis of variance (ANOVA) to determine the difference among subgroups in each main group. The Posthoc test was used for multiple comparisons of the data at the different DOC between subgroups. The data assessed statistically at a 5% significant level by the version 23 software (SPSS).

RESULTS

The Max, Min, mean, and SD values of PTG and HEDM files were presented in Table 1. The Independent t-test showed a significant difference between the two tested instruments (P≤0.05). The highest resistance to fatigue showed by HEDM files at all levels of curvature. ANOVA and Post hoc tests revealed significantly higher NCF in canals with (10 and 11) mm of DOC when compared to the canals with (5, 6, and 8) mm of DOC in the same group (P≤0.05*)*. No significant difference (P>0.05) was found regarding the FFL between two files on the same level of curvature as shown in Table ٢. Based on the mean length of the fractured file, the breakage occurred at or near the point of peak curvature of each canal.

The surfaces of broken file fragments showed the signs of cyclic fatigue type. In the high-stress concentration region, crack initiation points were observed under SEM as shown in Figure 3.

DISCUSSION

It had been found that the file fatigues test done at room temperature didn't accurately indicate the file behavior at body temperature; moreover, the ability of NiTi rotary files to resist fatigue was greatly influenced by temperature [3, 16]. Therefore, to more accurately mimic a clinical circumstance, the current study was carried out at a body temperature of 37 °C. In this study, the size and taper (25/0.08) were used because it's the most used diameters during canal preparation. In the present study, the canals were created with an angle of 60° and a radius of 3 mm because that was the only link that permitted the five locations with varying curvatures to share the same radius, curvature angle, and arc length [14].

The HEDM file showed superior fatigue resistance to the PTG file at all levels of curvature location. This finding can be explained based on the CM wire metallurgy, its EDM manufacturing process, and the cross-section design of the file. CM wire had more superelasticity than the conventional NiTi and M-Wire [17]. EDM process reduced the possibility of concentrated stress on file more than the conventional grinding machining [18]. Additionally, the EDM process increased the resistance to fatigue and phase transformation of temperatures. The austenite start and austenite finish temperature was around (42 -55 °C) for the HEDM file [19, 20]. HEDM files work mostly in the martensite phase while the PTG files (martensites with austenite and R-phases) during canal preparation, so HEDM has higher flexibility at body temperature [17].

The HEDM file had the different cross-section designs that may be contributed to high breakage resistance [17], even though the taper and diameter were nearly similar in both files. The different cross-section designs of HEDM were quadratic in the apical part, trapezoidal design in the middle part, and almost triangular design in the coronal part. "On the other hand" the PTG file had a constant convex triangular cross-section. Madarati *et al.* [21] 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.

The current study found that two files (PTG and HEDM) had a lower resistance to fatigue, significantly when shifting the curvature point from an apically located position to a more coronal position. This finding was confirmed by the previous modeling of finite elements, which demonstrated that the degree of load and deformation exerted along the file was determined by the location of curvature [22]. Also, this outcome was agreed upon with Altaay and Shukri [13]. This may be attributed to the lowest flexibility of the instruments at a coronally located position of curvature due to the largest diameter of the file coronally increased the risk of fracture. So even in the improvement of wire metallurgy and designs of instruments, the location of canal curvature still had an impact on cyclic fatigue and should be considered during preparation, especially with the new concept of minimally invasive endodontics.

A non-significant difference was found regarding the fractured fragments' length on the same level of curvature between the main two groups. The FFL of each instrument followed the curvature center or nearby this point. Thus, greater stress was produced inside the file at this point during the test [23].

The scanning electronic micrographs of the fractured fragments showed the mechanical characteristic nature of the cyclic fatigue (many dimples and microvoids). The magnification of 300 x in (5-6-8) mm of DOC was used, this was due to the fracture files having a large dimension at these levels. While in (10-11) mm of DOC, the magnification of 600 x was used, this was due to the fracture files having small dimensions, so using these magnifications to appropriate view of cross-section area. This degree of magnification was in agreement with the previous study [14].

Conclusion

The HEDM files showed higher fatigue resistance to the PTG files at all levels of curvature. The resistance to fatigue of PTG and HEDM NiTi rotary files was significantly affected by the canal curvature position, with a short failure life coronally.

Conflicts of Interest

The authors reported that they have no conflicts of interest.

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Table (1): The Min, Max, mean and Standard deviation values for NCF of instruments in each subgroup.

DOC (mm)	Files	Min.	Max.	Mean	±SD
11	PTG	554.050	834.050	649.600	85.826
	HEDM	1425.000	2866.500	2061.313	529.703
10	PTG	431.550	828.100	635.731	137.600
	HEDM	1125.000	2425.000	1653.000	500.061
8	PTG	420.000	618.100	481.163	65.784
	HEDM	1125.000	1583.000	1345.688	170.038
6	PTG	122.500	379.050	241.281	87.482
	HEDM	566.500	808.000	644.625	96.925
5	PTG	52.500	145.600	82.250	29.787
	HEDM	166.500	325.000	262.375	61.444

*There is statistically significant difference at 95% significant level P≤0.05.NCF: Number of cycles to fracture, DOC: Distance from orifice to canal's curvature in (mm), PTG: ProTaper Gold, HEDM: Hyflex EDM, SD: Standard deviation.

Table (2): Independent t test for FFL between main groups at the same DOC.

DOC	T test	df	*P value	Difference in Mean	95% Confidence Interval	
					Lower	Upper
11	1.181	14	0.257	-0.21250	-0.59849	0.17349
10	0.497	14	0.627	-0.13750	-0.73105	0.45605
8	0.251	14	0.806	0.06250	-0.47245	0.59745
6	1.776	14	0.098	-0.6250	-0.80034	0.07534
5	0.045	14	0.965	-0.01250	-0.60708	0.58208

*There is statistically non-significant difference at 95% significant level P≤0.05. DOC: Distance from orifice to canal's curvature in(mm), FFL:Fractured fragment length, df: degree of freedom.

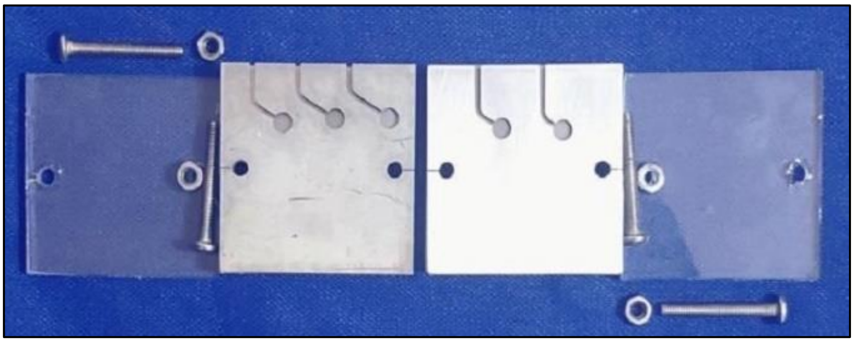

Figure (1): Customized artificial canals with different locations of curvature.

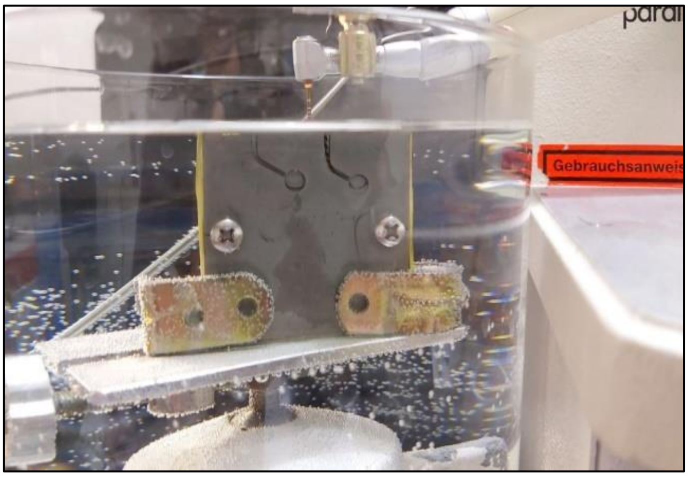

Figure (2): Experimental set-up showing the S.S. block fixed by a modified cast holder and submerged inside theglass container with water on the digital hotplate.

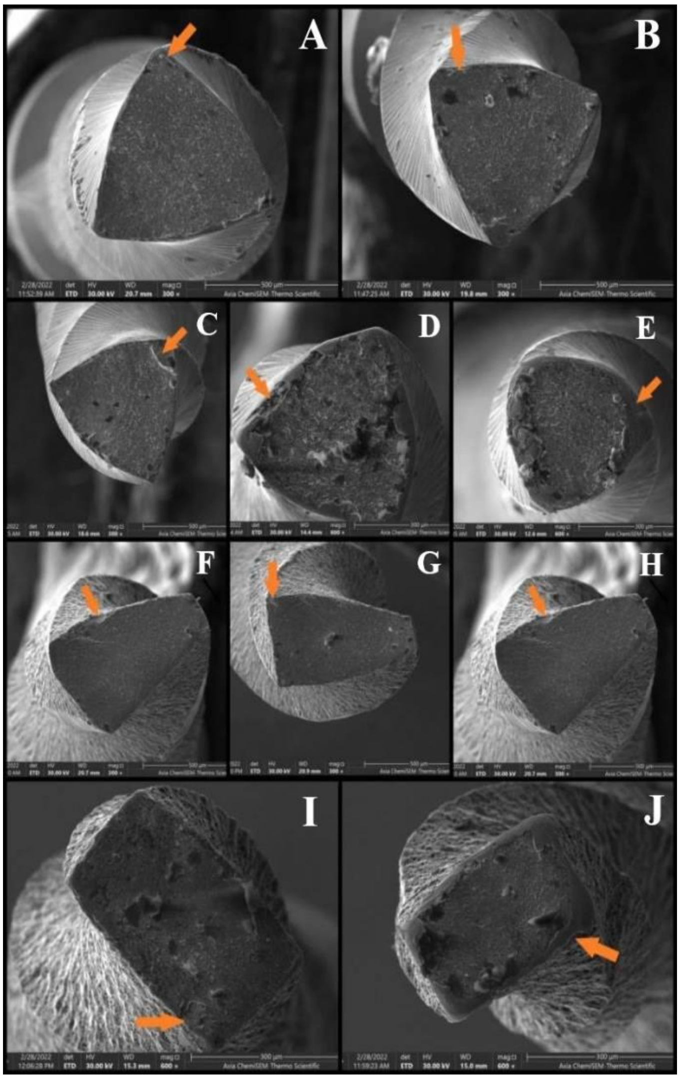

Figure (3): Scanning micrographs of fracture surfaces; PTG files (A, B, C, D, and E). HEDM files (F, G, H, I and J) at (5, 6, 8, 10, and 11mm) of DOC (arrows point referred to initiation origin of crack).