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A Comparative Study Of Cyclic Fatigue Resistance Of Different Types Of Endodontic Instruments: An In Vitro Study

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ABSTRACT

Background and Objectives: Nickel-titanium (NiTi) rotary files are routinely utilized in root canal instrumentations for their flexibility and competency. However, they are susceptible to fracture due to cyclic fatigue, particularly in curved canals. The objective of the current study is to investigate and compare the cyclic fatigue resistance of different nickel-titanium (NiTi) rotary instruments. The tested instruments were Protaper Gold (PTG), HyFlex EDM (HEDM), 2Shape (TS1) and TruNatomy (TN).

Materials and Methods: A total of forty NiTi endodontic rotary instruments were split into four study groups (n = 10 each). Group 1: Protaper Gold (F2 25/.08), group 2: HyFlex EDM (25/.08), group 3: 2Shape (25/.04) and group 4: Trunatomy (26/.04). A custom made stainless steel block having simulated canal with 60° angle of curvature and 5 mm radius of curvature was used to test the cyclic fatigue resistance. The number of cycles required for fracture with the length of the fractured segment were calculated and the data were statistically analyzed utilizing one-way analysis of variance ($p < 0.05$).

Results: The results demonstrated that HyFlex EDM had the highest statistically significant mean cyclic fatigue value, followed by 2Shape, Protaper Gold and Trunatomy respectivly.

Conclusion: The alloy properties and manufacturing processes of the evaluated rotary nickel–titanium systems had a direct influence on their capability to resist cyclic fatigue. HyFlex EDM files demonstrated greater fatigue resistance compared to 2 Shape, Protaper Gold and TruNatomy.

Keywords: Cyclic Fatigue, NiTi rotary intstruments, Protaper Gold, HyFlex EDM, 2Shape, Trunatomy

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INTRODUCTION

nickel-titanium (NiTi) rotary instruments are favored in clinical endodontic work due to the preferable physical behavior of nickel-titanium alloy, which could lower the risk of procedural errors, such as endodontic file fracture. However the possibility of an "unexpected" fracture with NiTi instruments persists despite the ongoing progression in design and production of NiTi endodontic rotary files.[1] Rotary instrument fractures occur in two modes: torsional fracture and cyclic fatigue fracture. Cyclic fatigue happens when metal undergoes repeated tension and compression cycles, gradually weakening its structure and eventually causing it to break.[2,3] Cyclic fatigue resistance is an important property of rotary NiTi instruments. To enhance their fracture resistance, manufacturers implement various advanced processing techniques, including the careful selection of raw materials, optimization of instrument diameter and design, electropolishing, surface modifications, and thermomechanical processing.[4] Among these, thermomechanical processing is a complex method that combines work hardening with thermal treatment into one single streamlined procedure.[5] A separated instrument can pose a notable threat to the extended prognosis of root canal therapy by obstructing the cleaning and shaping of the canal, thereby compromising disinfection process.[6] Furthermore, its presence may lead to underfilling of the instrumented canal, potentially weakening its apical seal. Instances of instrument separation have been associated with reduced periapical healing in root canal treatments.[7] Nickel–titanium alloys used in endodontics can be split into two main categories. One that to a great degree exists in the austenite phase (e.g., conventional NiTi, M-Wire and R-phase). These are super-flexible, meaning they can bend under pressure and go back to their initial form when the pressure is removed. The other category is mostly in the martensite phase (e.g., CM Wire, Gold and Blue heat-treated NiTi). These are easier to bend and have shape memory effect. Martensite-phase endodontic rotary files generally are more flexible and last longer under repeated bending compared to austenite-phase instruments.[8] ProTaper gold files (PTG) (Dentsply Tulsa Dental Specialties, Tulsa, OK) are heat treated gold wires, that were launched as an improved version of conventional ProTaper files with Austenite Finish temperature (Af) around 48 °C, ensuring it remains predominantly in the martensitic/R-phase region at body temperature, offering enhanced flexibility and fatigue resistance. The system includes shaping and finishing files (Sx, S1, S2, F1, F2, F3), with taper varying along the length. Specifically, the F2 file has an 8% taper at the apical 3 mm, gradually decreasing toward D16.[9] HyFlex EDM endodontic rotary intruments (Coltene/Whaledent, Switzerland) are optimized NiTi rotary file systems that are Processed from controlled memory (CM) wire (demonstrating Af of approximately 56 °C, fully martensitic in the canal, enabling extreme flexibility and thermal shape-memory recovery) using Electrical Discharge Machining (EDM) technology. This noncontact machining process removes material through pulsed electric discharge, generating sparks that melt and evaporate the surface layer. As a result, NiTi files gain a unique rough, hardened texture that enhances mechanical properties, improves cutting efficiency, and allows precise, non-contact shaping.[10] HyFlex EDM One files possessing a tip size of 25, feature a constant taper of 0.08 in their apical 4 mm, which gradually drops to 0.04 in the coronal region. Their cross-section transitions from a rectangular shape apically to two trapezoidal forms in the middle and coronal sections.[11,12]

TruNatomy files (Dentsply-Sirona, Ballaigues, Switzerland) are recently announced rotary files manufactured from 0.8 mm nickel titanium wires, which is smaller than the 1.2 mm NiTi wires frequently applied in manufacturing of most files. These files also encounter a special heat treatment, which improves their cyclic fatigue resistance (CFR) with an Af temperature of about 23.8–26.5 °C, meaning it is predominantly in the austenitic phase under clinical conditions. This system is achievable in different sizes: small, medium, and prime. The file system is also obtainable in variable conicity designs with off-centered parallelogram cross-section. Thermal processing enhances the elastic behavior and bendability by inducing a metallurgical phase shift from austenite to martensite.[12] 2Shape (MicroMega, Besancon, France) endodontic rotary system incorporates two instruments: TS1 (25/.04) and TS2 (25/.06). The T-Wire machinery applied in fabrication of these endodontic files is believed to elevate their resistance to fatigue by 40%, when comparing to One Shape (MicroMega) files. The T-Wire heat treatment places 2Shape files in a martensitic/R-phase dominant state at both room and body temperatures, which improves flexibility and fatigue resistance. 2Shape rotary instruments posses latest-generation cross-section featuring a triple-helix design through two primary cutting edges to enhance their efficiency and a secondary edge for better debris elimination.[13] This investigation aimed to differentiate and assess the ability of ProTaper Gold, HyFlex EDM, TruNatomy, and 2Shape file systems to resist fracture during instrumentation in curved root canals.

METHODS

The current analysis compared four different rotary NiTi instruments, which were distributed into four groups. Group 1: HyFlex EDM (size 25, .08), Group 2: TruNatomy file (size 26, .04), Group 3: 2shape TS1(size 25, .04), and Group 4: Protaper Gold (size: 25, .08). All the files had 25mm length. Each of the group contained 10 files. All the tested files were over examined using an optical stereo microscope with X20 magnification to conduct a morphological analysis and check for any deformation. None of the files were excluded. A static cyclic fatigue testing mold, that was particularly customized for this experiment was employed to assess the files. An artificial groove simulating root canal was drawn using a software program (AutoCad 2024), this artificial canal had 60 degree curve, 5mm radius, 1.5mm inner diameter to allow free rotation of the instrument, and 21mm length as outlined by Pruett et al.[14] The midpoint of the curve was positioned 5 mm away from the tip. The canal was machined into the stainless-steel block by using a hyper spark laser machine. To prevent the instrument from being displaced, the canal was capped with a 4mm glass cover,[15] while also securing the separated fragment to be retrieved and to allow vision (figure 1).

Figure 1. The AutoCad design and the Stainless-Steel Mold

X-Smart rotary endodontic device (X-Smart; Dentsply Maillefer) was used in this study. The Endo-motor handpiece was mounted to the vertical arm of a surveyor by customizing a special holder to guarantee accurate and standardized placement of all instruments within the artificial canal keeping the relation of the handpiece to the metal mold the same for all tested instruments (figure 2). The mold was fixed in a table jack. Both the metal mold and the handpiece were kept parallel to the floor by using a small balance to adjust their position (figure 3).

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Figure 2. The Holder customized to fix the dental handpiece on the surveyor

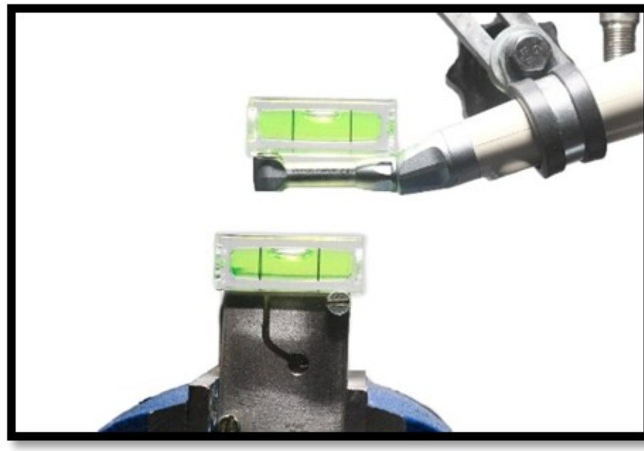

Figure 3. Checking the parallelism of the handpiece and the mold with the floor

The instruments were driven following manufacturer's guidelines. The speed and torque were as follow: Hyflex EDM (400 rpm and 2.5 Ncm), 2Shape TS1(300 rpm and 2.5 Ncm), Protaper Gold (300 rpm and 3.1Ncm) and TruNatomy (500 rpm and 1.5 Ncm) . All tested files were placed at the same working length 19mm, which was marked on the metal mold with black ink. W&H oil (F1 service oil, Bürmoos , Austria) was administered with the aid of a syringe inside the canal before each file as a lubricant to lower the friction. Instruments were permitted to rotate until the separation was observed (figure 4). The time required for the resultant separation was documented in seconds using Digital Camera (Nikon 7500). Thereafter, the number of cycles until fracture (NCF) was determined by multiplying the time required (in seconds) to fracture by rotational speed [NCF= Time to fracture (sec) * rotational speed (rpm)], the fractured piece length was also measured using a digital caliper . A single operator accomplished the experiment.

Statistical Analysis

Data analysis was performed with SPSS software (version 24; IBM Corp., Armonk, NY, USA), and descriptive statistics were computed, including the mean values and their corresponding standard deviations, and were displayed in tables and figures. The normality of data distribution was tested by the Shapiro-Wilk test, Which presented normal distribution of the length of fragment measure and a non-normal distribution of time to fracture and NCF measures. Thus, ANOVA was undertaken to compare the mean length of fragments among different groups, and the Kruskal-Wallis test was used to compare the mean time to fracture and NCF among different groups. A P value of <0.05 was considered statistically significant.

Figure 4. Instrument rotating in the simulated canal until separation

RESULTS

Table 1 highlights the raw data and the mean and SD of time to fracture in seconds, fragment length, and number of cycles to fracture (NCF) for the 10 samples in the four different groups.

Within-group statistical analysis showed a significant difference among the four groups for each time fracture, fragment length, and NCF (P <0.001), as shown in Table 2. The mean time to fracture was highest in the HyFlex EDM group (1056.43), followed by TS1(279.32), Protaper Gold (273.29), and TruNatomy (150.58).

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Table 1. Time to fracture in seconds, fragment length, and NCF for different groups

No.	Protaper Gold F2			TS1(micromega)			TruNatomy (26/0.4)			HyFlex EDM onefile		
	speed:300rpm	torque:3.1 Ncm		Speed:300 rpm	Torque: 2.5Ncm		Speed:500 rpm	Torque: 1.5Ncm		Speed:400 rpm	Torque: 2.5Ncm	
	Time (sec)	Length (mm)	NCF	Time (sec)	Length (mm)	NCF	Time (sec)	Length (mm)	NCF	Time (sec)	Length (mm)	NCF
1	210	4.5	63000	167	3.5	50100	145	4	72500	911	3	364400
2	290	4.5	87000	237	4	71100	130	3	65000	924	3	369600
3	170.8	4.5	51240	330	4	99000	210.8	4	105400	1356	3	542400
4	290.5	5	87150	350	3.5	105000	130	4	65000	1234	3	493600
5	290.2	4.5	87060	280	4.5	84000	87	3	43500	914	3.5	365600
6	310.3	4	93090	166	2.5	49800	180.3	4	90150	1240	3	496000
7	260	4	78000	283	3.5	84900	98	3	49000	900.3	3	360120
8	330.2	4.5	99060	299	4	89700	148	4	74000	1221	3	488400
9	320.6	4.5	96180	360.2	4	108060	210.7	3	105350	933	3	373200
10	260.3	4	78090	321	4	96300	166	3	83000	931	3	372400
Mean	273.29	4.40	81987	279.32	3.75	83796.00	150.58	3.50	75,290	1056.43	3.05	422,572
SD	50.070	0.316	15021.075	69.516	0.540	20854.835	42.235	0.527	21117.302	181.467	0.158	72586.824

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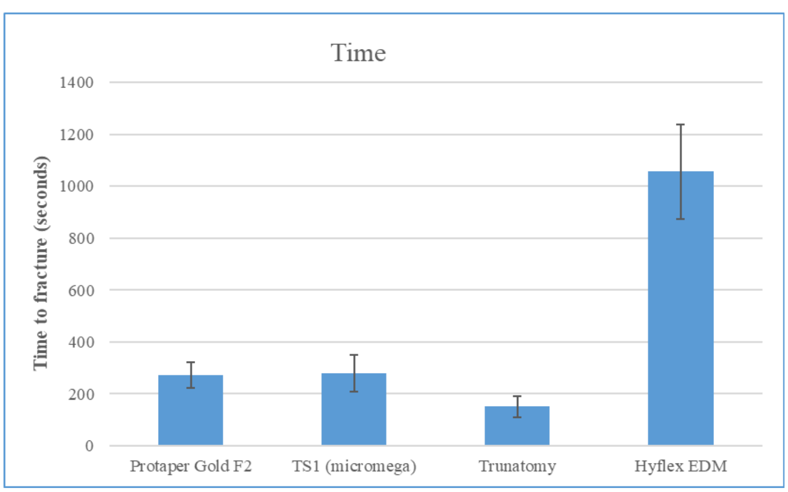
The mean length of the fragment was highest in Protaper Gold (4.4), followed by TS1 (3.75), TruNatomy (3.5), and HyFlex EDM (3.05). The mean NCF was highest in HyFlex EDM group (422572), followed by TS1 (83796), Protaper Gold (81987), and TruNatomy (75290).

Table 2. Comparison of mean time to fracture in seconds, fragment length and NCF among different groups

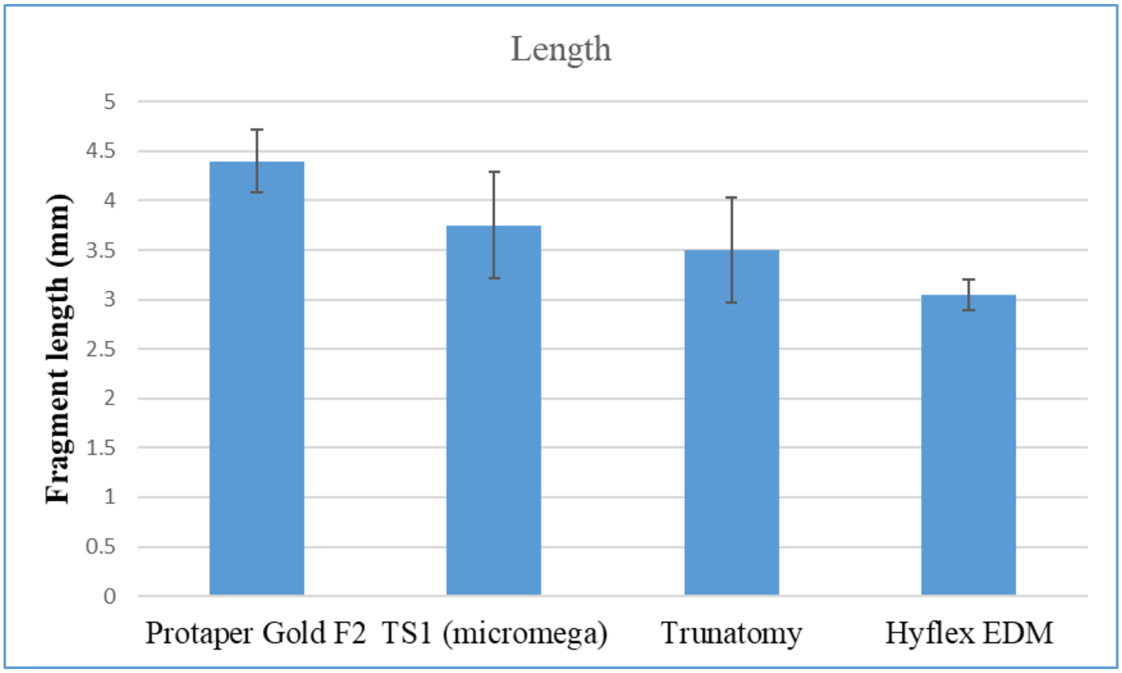
Group	Time to fracture			Length of fragment			NCF		
	Mean	SD	P value	Mean	SD	P value	Mean	SD	P value
Protaper Gold F2	273.29	50.070	<0.001*	4.4	0.316	<0.001**	81987	15021.075	<0.001*
TS1 (micromega)	279.32	69.516		3.75	0.54		83796	20854.835	
Trunatomy	150.58	42.235		3.5	0.527		75290	21117.302	
Hyflex EDM	1056.43	181.467		3.05	0.158		422572	72586.824	

* Kruskal Wallis test
** ANOVA

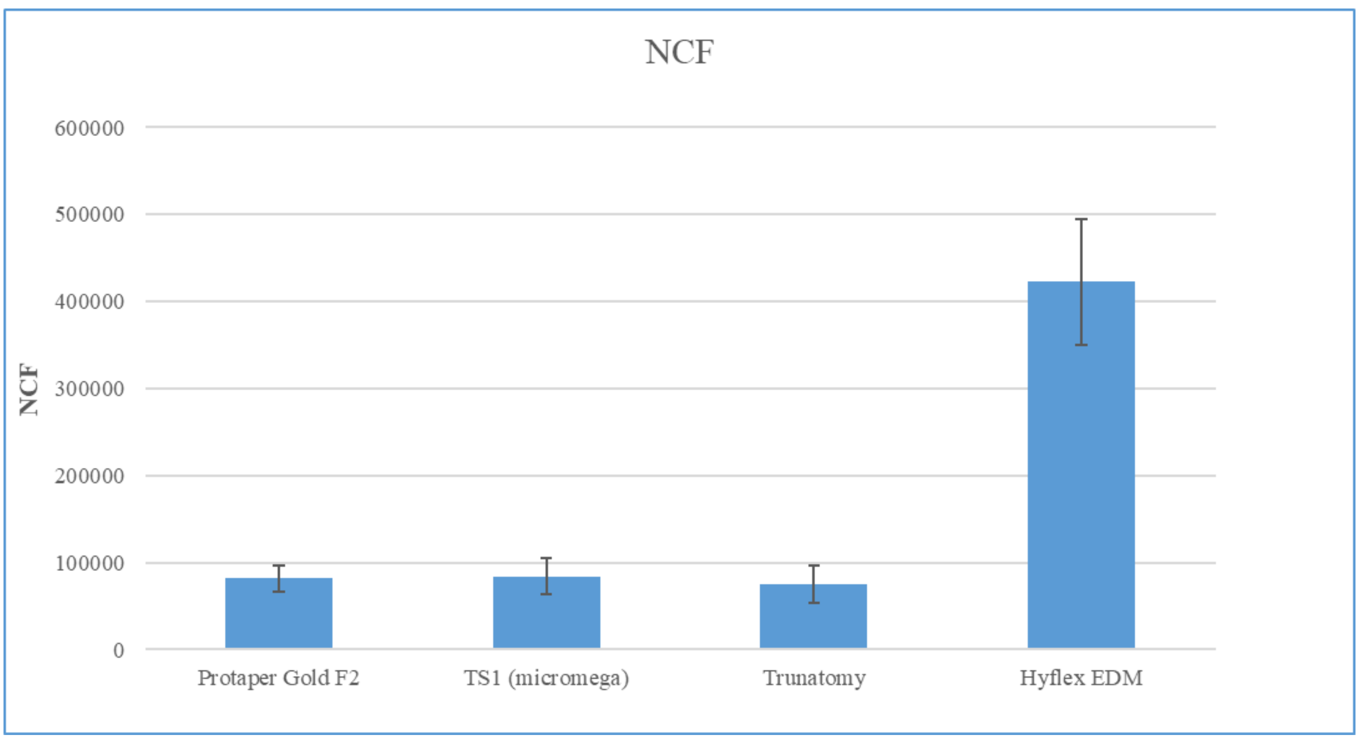
For each measure of the four groups, intragroup analysis was conducted through pairwise multiple comparison testing (Table 3). A significantly increased mean time to fracture was observed in Protaper Gold group than TruNatomy (P=0.014), TS1 than TruNatomy (P=0.009), and HyFlex EDM than each of Protaper Gold (P=0.002), TS1 (P=0.004), and TruNatomy (P <0.001). The mean length of the fragment was significantly higher in Protaper Gold than each of TS1 (P=0.001), TruNatomy (P <0.001), and HyFlex EDM (P <0.001). The mean length of the fragment was also significantly higher in TS1 than HyFlex EDM (P=0.001) and TruNatomy than HyFlex EDM (P=0.021). The mean NCF was significantly higher in HyFlex EDM than each of Protaper Gold (P <0.001), TS1 (P <0.001), and TruNatomy (P<0.001). Detailed comparison of the mean (SD) of time to fracture, length of fragment, and NCF among different groups are also shown in graph 1, 2, and 3.



Graph 1: Bar chart showing comparison of mean (SD) time to fracture among different groups



Graph 2: Bar chart showing comparison of mean (SD) fragment length among different groups.



Graph 3: Bar chart showing comparison of the mean (SD) NCF among different groups.

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Table 3. Pairwise multiple comparisons between different groups for time to fracture, fragment length, and NCF

Groups		Time to fracture		Length of fragment		NCF	
		Mean Difference	P value*	Mean Difference	P value**	Mean Difference	P value*
Protaper Gold F2	TS1 (micromega)	-6.030	0.871	0.650	0.001	-1809	0.818
Protaper Gold F2	TruNatomy	122.710	0.014	0.900	<0.001	6697	0.566
Protaper	HyFlex	-783.140	0.002	1.350	<0.001	-340585	<0.001
TS1 (micromega)	TruNatomy	128.740	0.009	0.250	0.188	8506	0.422
TS1	HyFlex	-777.110	0.004	0.700	0.001	-338776	<0.001
TruNatomy	HyFlex	-905.850	<0.001	0.450	0.021	-347282	<0.001

* Kruskal Wallis test
** ANOVA

DISCUSSION

The cyclic fatigue test intended to analyze mechanical behavior of NiTi instruments. Various studies measured resistance of different rotary file systems to separation utilizing various dynamic and static models.[16] The static tests include placing the files at a fixed working length and allowing them to rotate until fracture occurs.[17] In contrast, dynamic testing equipment incorporate axial mobilities alongside the static ones.[18] Gavini et al. studied the significance of opting for an appropriate experimental model and demonstrated that the dynamic model exhibits limitations relative to the static model.[19] The static model establishes a well-defined path within the artificial canal. Besides, one key advantage of the static model is that the results are reliable and reproducible, aligning well with clinical practice.[20] Multiple factors contribute to the fracture resistance of rotary instruments such as the cross-sectional design of the instrument, alloy's chemical composition, and the thermo-mechanical processes involved in its manufacturing. The present study investigated four file systems with continuous rotation motion, but featuring different alloys, cross-sectional designs, tapers, speeds, and torque settings.

The resistance to fatigue values of the examined systems were significantly varied ($p < 0.05$). As evidenced by the results, HyFlex EDM files displayed superior resistance to cyclic fatigue, the control memory or CM-Wire alloy implemented in the manufacturing of HyFlex EDM files have greater martensitic structure than austenite, which might explain their high flexibility and improved fatigue resistance. In addition to the EDM process used in the production of HyFlex EDM files, which strengthens the file surface, improves cutting efficiency and resistance to fracture.[10] The unique cross-section design of HyFlex EDM files having a rectangular cross section in the apical part, that subsequently transitions into two trapezoidal configurations at the middle and coronal levels play a role in their increased fatigue resistance.[11] 2Shape files displayed the second highest CFR values, the decreased taper of 2 shapes beside the novel thermal treatment (T wire) and triple helix cross section can be attributed to the higher CRF of 2 shapes, as from a metallurgical perspective, when the taper increases, the metal mass increases and CFR decreases.[12] Protaper Gold files demonstrated a moderate resistance to cyclic fatigue. The heat treatment applied to ProTaper Gold files increases their flexibility compared to traditional NiTi instruments. However, their convex triangular cross-section and progressive taper may lead to stress accumulation in specific regions, which can compromise their overall resistance to fatigue. TruNatomy files exhibited the lowest CFR among the tested files. Earlier investigation reported that increased file size resulted in reduced fatigue resistance,[21] Trunatomy Prime files have a slightly greater tip size (0.26) compared to other files (0.25) used in this study. This may explain the lower resistance of Trunatomy prime files to fracture in the current work.[22] Decreased cyclic fatigue resistance of TruNatomy Prime file is also influenced by its cross-section. According to published findings, the cross-sectional design significantly influences cyclic fatigue resistance, with triangular files showing superior performance compared to rectangular ones.[23]

The finding of this study align with those of Özyürek et al. who exhibited less susceptibility of HyFlex EDM instruments to fracture compared to 2Shape TS1 files, suggesting that the alloy characteristics contributed to this outcome.[24] Gündoğar et al. also found similar results when compared the CFR of Hyflex CM, 2Shape TS1 and Trunatomy Prime file and concluded that Hyflex CM had a greater CFR followed by 2Shape and TruNatomy respectively and attributed the results to the CM wire alloy used to manufacture Hyflex CM file as compared to Twire alloy used is manufacturing TS1 and the different heat treatment method used to manufacture TruNatomy prime file.[12] Another study by Khandagale et al. also revealed that HyFlex EDM had the highest CFR when compared to Protaper Gold and attributed the cause to EDM process used in manufacturing of HyFlex EDM file, and the greater austenite finish temperature (more than 370°C).[9]

Regarding the length of the fractured piece, which reflects the site of maximum stress, cyclic fatigue tests intend to reproduce stress points on files and result in the same length of fractured segment. However, variations in alloy features and cross section design of instruments can result in different bending moments which may shift the location of maximum stress point and result in different fragment lengths,[25] as observed in this study Protaper Gold exhibited the longer fragment and HyFlex EDM exhibited the shorter fragment.

CONCLUSION

The fracture resistance of rotary nickel-titanium file systems is significantly affected by their metallurgical specifications, such as composition of alloy, heat treatment methods, and fabrication process. HyFlex EDM files demonstrated greater fatigue resistance. Followed by 2 Shape TS1, Protaper Gold and TruNatomy respectively.

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CONFLICTS OF INTEREST

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