Evaluation of Cyclic Fatigue Resistance of Different Rotary Endodontic File Systems

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Abstract

Aim of the present study was to compare the cyclic rotations needed to fracture four different rotary nickel titanium endodontic instruments.

Four different endodontic Nickel Titanium rotary systems were selected for this study: OneShape, OneCurve, ProTaper Next and HyFlex EDM of ISO size 25, 25 mm instrument length and 0.06 instrument taper. All were exposed to cyclic fatigue tests in a custom-made simulated canal having 60° curvature. Cyclic fatigue was calculated for each rotary system by calculating the time needed to fracture the instrument in seconds while being rotated in a steel block curved canal. Data was statistically analyzed by calculating the mean time to fracture the instrument in seconds, standard deviation, one way ANOVA and t-test at 5% level of significance.

HyFlex EDM instruments had the highest cyclic fatigue resistance among all the other instruments being tested. One-way ANOVA test revealed that there was a statistically significant difference between all the four groups being tested ($P \leq 0.05$). Further analysis of the data was done using t-test, also indicated that there was statistically significant differences ($P \leq 0.05$) between all the pairs of groups being tested individually.

Cyclic flexural fatigue resistance was observed highest for Group IV (HyFlex EDM) and lowest for Group I (One Shape). HyFlex CM files had the exceptional lengthiest survival time while files from One Shape showed limited survival. We obtained the clinical significance from this in- vitro study: showing their exceptionalism in resistance and prolonged survival time.

Proving their superiority in resistance and longer survival time, HyFlex CM rotary NiTi files can be used in curved root canals and eventually will be helpful in eradicating one of the factors for file fracture clinically during root canal treatment i.e., cyclic fatigue- where root canal exhibits a sharp bend or curve.

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Introduction

Cleaning and shaping of the root canal system is one of the most important procedure in endodontic treatment [1.] Various root canal instruments and techniques have been proposed for cleaning and shaping the root canal system. However the creation of a continuously tapering conical form, thorough debridement, maintenance of the original canal shape and position of the root canal and apical foramen are still difficult, especially in curved canals [2.] In addition procedural accidents such as ledges, zips, perforations and instrument fracture may occur while instrumenting the curved canals [3.]

Endodontic instrumentation is undergoing a phase of transition. Nickel titanium instruments were found to be quite efficient in root canal preparation particularly in curved canals. These instruments have gained popularity because of its elastic flexibility and resistance to torsional fracture. [4]

Thus these instruments offer possibilities of improving the speed and efficacy of root canal instrumentation [5.]

The clinical concern is that they have been reported to undergo fatigue failure which occurs unexpectedly without any sign of previous deformation and therefore visual inspection would not seem to be the ideal way of evaluating

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nickel titanium instruments in order to prevent fracture [3, 6-8.]

Cyclic fatigue resistance of NiTi instruments is under the influence of various factors including instrument size, taper, cross-sectional design, and manufacturing techniques [9, 10.]

The aim of the present study is to evaluate and compare the cyclic fatique time of four different rotary nickel titanium endodontic instruments namely HyFlex EDM, One Shape, ProTaper Next and One Curve in simulated curved canals having constant angle of curvature of 60°.

Materials and methods

Forty rotary nickel titanium instruments were used for cyclic fatigue evaluation in this study. The instruments were divided into four groups (n=10). G1: OneShape (Micro-Mega, France), G2: OneCurve (Micro-Mega, France), G3: ProTaper Next (Dentsply, Maillefer, Ballaigues, Switzerland) made from M wire alloy and G4: HyFlexEDM (Coltene) made from CM wire technology and EDM. All the four rotary instruments groups were standardized by having the same ISO size 25, 25 mm instrument length and 0.06 instrument taper. The instruments were firmly held with clamping mechanism as shown in Figure 1 with passive adjustment and without pressure in a stainless-steel block containing an artificial canal. A custom made experimental set (Figure 1) up was used for evaluating cyclic fatigue of the Ni-Ti instruments. To guarantee that the instruments would not move and to maintain standard position in all testing procedures, a reduction contra-angle handpick was mounted (attached and fixed) to a wooden block keeping the same 3D relationship to the stainless steel shaping block during all the 40 testing procedures. The shaping block was also attached and fixed to the wooden block by screws in such a way that the same setup was maintained in each individual testing allowing only changing the file. The shaping block consisted of concave tempered steel radius and a convex tempered steel cylinder that guaranteed curve of the instruments during rotation. A custom fabricated metal block was used to expose the instruments to cyclic fatigue tests. This block had a wide simulated canal with 60-degree curve curvature and a 5-mm radius of curvature was used. Files were rotated at a speed of 300 rpm in a custom made experimental set up which simulated curved canals. . The files were observed carefully while they are rotating within the canal in a steel block with dimensions 20 mm length, 1 mm width, and 2.5 mm depth and when these files broke after being tested, they were readily removed. The characteristics of the model were similar to the block used by other studies [11, 12.] These instruments were mounted on an electric motor (Aimer Endo) operated with a 16:1 reduction handpiece which was used to rotate the files during testing by adjusting the speed and torque of each individual rotary instrumentation system based on manufacturer's data. The rotary files were rotated in steel shaping block until fracture and the time from starting rotation till fracture was recorded for each individual specimen in seconds as cyclic fatigue resistance for that file. Data was statistically analyzed by calculating the mean time to fracture the instrument in seconds, standard deviation, one way ANOVA and t-test at 5% level of significance.

Figure 1. Experimental set up showing rotary endodontic handpiece attached to a wooden block keeping the same relationship to the stainless steel shaping block.

Results

Cyclic Fatigue in seconds raw data, mean and SD of the four groups are listed in Table (1). Figure 2 represents mean cyclic fatigue time in seconds for the four groups being tested in this study. One-way ANOVA test revealed that there was a statistically significant difference between all the four groups being tested ($P \leq 0.05$) Table 2. Further analysis of the data was done using t-test (Table 3) indicated that there was statistically significant differences (P ≤ 0.05) between all the pairs of groups being tested individually.

Group	G1 OneShape	G2 OneCurve	G3 ProTaper Next	G4 Hyflex
1	65	1006	236	1800
2	77	895	297	1800
3	59	970	259	1800
4	73	795	314	1800
5	57	817	288	1800
6	70	651	244	1800
7	44	760	415	1800
8	59	963	259	1800
9	69	739	267	1800
10	80	960	286	1800
Mean	65.3	855.6	286.5	1800
SD	10.247	113.777	48.611	0

Table 1. Cyclic Fatigue time in seconds raw data, mean and SD for the four groups.

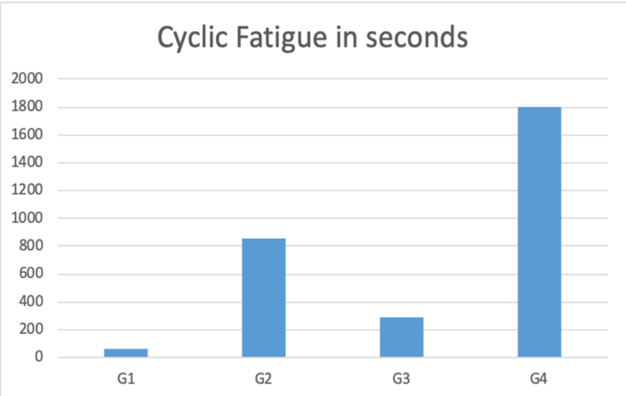

Figure 2. Mean cyclic fatigue time in seconds for the four groups.

ONE WAY ANOVA				
Source	***SS***	***df***	***MS***	
Between-treatments	17972840.1	3	5990946.7	*F* = 1399.27258
Within-treatments	154133	36	4281.4722	
Total	18126973.1	39		

Table 2. One way ANOVA for the four groups.
The f-ratio value is 1399.27258. The p-value is < .00001. The result is significant at p < .05.

t-test			
Pairs	t-value	p-value	Sig/non Sig. at p < .05
G1XG2	-20.7541	p-value is < .00001	significant
G1XG3	-13.3576	p-value is < .00001	significant
G1XG4	-507.84397	p-value is < .00001	significant
G2XG3	13.79897	p-value is < .00001	significant
G2XG4	-24.90131	p-value is < .00001	significant
G3XG4	-93.40438	p-value is < .00001	significant

Table 3. t-test for the four groups.

Discussion

When an instrument is freely rotating inside a curved root canal, the chief cause of the sudden unpredicted instrument fracture that occurs at the instrument's maximum flexure point is cyclic fatigue [13]. Consequently, cyclic fatigue tests are very crucial to be carried out on the newest NiTi instrument systems, resultantly providing clinicians with the knowledge regarding their fracture resistance [14].
A non-tooth artificial stainless-steel simulated root canal model with a 60° angle of curvature and a 5-mm radius of curvature was used, like many others in different literature re-views; to test the instruments for cyclic fatigue resistance. During the manufacture of the alloy, the cross-section design, the chemical composition of the alloy and the thermo-mechanical processes used all influence cyclic fatigue [15] but not significantly affecting fracture resistance of obturated roots [16].
In the current study, all NiTi files were tested for cyclic fatigue resistance CFR on a dynamic test model to simulate clinical use. Also, to eliminate the effect of movement type (i.e. rotation or reciprocating) of the files, only files that use continuous rotation movement were selected for CFR testing [17].

Ideally, the approach for testing the flexural CFR of endodontic instruments should be to use real human teeth, because they can reliably mimic clinical situations, but a tooth can only be used once as the shape of the root canal varies during instrumentation, making it difficult to standardize the experimental situations [18]. Therefore, a custom-made model of stainless-steel canal was used in this study to ensure that a fixed curvature radius, a fixed curvature angle, and a fixed maximum curvature center were all achieved. Flexibility and super-elasticity were among the common features that all of these instruments possessed. When a material recovers from a great amount of strain triggered by mechanical stress, this isothermal phenomenon is referred to as Super-elasticity [19.] The instruments in this study can be easily used even in the most anatomically complex root canals due to the fact that unlike traditional NiTi instruments, they can change their shape against very low mechanical stress and therefore do not tend to return to their previous shape upon removal of the stress. Our findings agreed with Kaval et al., 2016 [20] who found that HyFlex EDM instruments proved to have the highest cyclic fatigue resistance over Pro Taper instruments. Sinan et al., 2016 [21] proved in his study that ProTaper Next exhibited the lowest cyclic fatigue resistance compared with One Curve and HyFlex systems. His findings also agreed with our findings since CM Wire files have a significantly enhanced CFR compared with M-Wire and conventional NiTi files. Due to an increased amount of the martensite phase, martensitic files (i.e. CM files) are more flexible with an enhanced CFR compared with austenitic files (i.e. M-Wire files) [22.] Among the justifications that contributed to the increased cyclic fatigue resistance of HyFlex EDM files were the formulation of HyFlex CM files of low percent nickel weight, Secure Martensitic active structure, Greater Austenite finish (AF) temperature which mixed both Austenite and Martensitic frameworks at room temperature and Innovative Manufacturing [23.] Unlike super-elastic NiTi type, where only a handful fatigue cracks nucleate and perpetuate at a quicker pace, a great number of highly branched cracks that propagate quite slowly are provided by these instruments. This is referred to as the crack propagation mechanism and can also be the cause of the increased fatigue resistance of HyFlex EDM files. Another reason behind the superior CFR obtained in our study and in other comparative studies might be due to phase transformation temperatures and hardness are increased due to the processing of the CM wire using electrical-discharge machining technology [24.]

Group 4 rotary file (HyFlex CM) had longest survival time as none of the 10 samples within this group was fractured before 30 minutes (1800 seconds) (Table 1, Figure 2) with continuous rotation during that time so that we considered the CFR time for that group to be 1800 seconds and in reality it might be much more than that time due to its super-elasticity and flexibility making them difficult or impossible to be fractured within half an hour interval due to the fact that from practical point of view, it is extremely impossible to use any rotary file to be continuously rotated in any canal preparation in reality inside the patient's mouth.

OneCurve instrument is the modified and updated version of Micro Mega old design named OneShape file product by the same company. Although there are similarities between the two products, such as cross-sectional designs, cross-sectional area at 5 mm of OC is smaller than OS instruments. Despite the fact that they both exhibit similar properties like cross-sectional designs, One Curve's cross-sectional area at 5 mm is smaller than OneShape instruments. Moreover, OneCurve instrument is produced from an alloy with a martensitic transformation called the C. Wire which makes them greater fracture resistant, unlike OneShape instruments and this finding was approved in our study and other previous studies [25.] In another test done by Keskin et al. 2018 [26] comparing the cyclic fatigue resistance of new and used ProTaper Universal and ProTaper Next NiTi rotary instruments, results concluded that PTN produced by M-Wire technology enhanced cyclic fatigue resistance compared with PTU produced by traditional NiTi alloy. Within the limitation of the present study, reduction in the cyclic fatigue resistance for PTN and PTU instruments was observed after clinical use when compared to new groups. Our findings also agreed with this study results.

Microfracture points and defects were produced during the manufacturing process of One Shape files across the length of the whole instrument created by the grinding across the grain structure. It ultimately caused the file to crack as these defects were serving as stress fixation sites which in response deteriorated the instruments. The fatigue life of NiTi rotary instruments might be influenced by the size in the point of maximum stress when undergoing testing for cyclic fatigue. The greater the metal volume, however the lower the fatigue resistance [27.]Moreover, it is imprecise to evaluate the cyclic fatigue resistance based on the taper angles that manufacturer companies claim due to the fact that the taper of these instruments' changes in different values of the file, hence the name: variable taper.

The use of a virtual timer manually to capture the moment when a rotary file breaks while rotating is among the potential failure modes in the onlooker-related cyclic fatigue studies. All reputed reports of cyclic fatigue recruit this approach. In addition, there were no recorded instances in this current study where the observer skipped or ignored the instrument's breakage during rotation [28].

Conclusions

HyFlex EDM and One Curve demonstrated dominance over ProTaper Next and One Shape in the cyclic fatigue resistance. In descending order Group 4 HyFlex CM, Group 2 One Curve, Group 3 ProTaper Next, Group 1 One Shape; these were the outcomes of the different study groups after having been examined for cyclic flexural fatigue strength.
HyFlex CM files had the exceptional lengthiest survival time while files from One Shape showed limited survival. We obtained the clinical significance from this in- vitro study: showing their exceptionalism in resistance and prolonged survival time.

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Declaration of Interest

The authors report no conflict of interest.

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