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Cyclic Fatigue of Nickel-Titanium Rotary Instruments in Single Curvature Canals

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Abstract

Aim: the aim of current research was to evaluate and compare cyclic rotations required to fracture different rotary nickel titanium (NiTi) endodontic files in single curvature canals.

Methods: Four different NiTi rotary instruments were selected for the present study: F6 SkyTaper, EndoSequence ESR, Endosequence CM, and Ordeka plex-v file of ISO 25, 0.06 instrument taper and 25 mm instrument length. All files were subjected to cyclic fatigue test inside custom-made simulated canals with 60° curvature. Time required to fracture rotary files (in seconds) while being rotated in a steel block canal was determined to calculate cyclic fatigue. Data was statistically evaluated ANOVA test at 5% level of significance.

Results: EndoSequence ESR instrument reported the highest cyclic fatigue resistance among all other tested rotary instruments. Endosequence CM expressed the lowest fatigue resistance. One-way ANOVA test expressed a statistically significant difference between all four groups regarding number of cycles to fracture (NCF) and non-statical significant difference relating to length of fracture segment (FL).

Conclusion: EndoSequence ESR and Ordeka plex-v files demonstrated dominance over Endosequence CM and F6 SkyTaper files in cyclic fatigue resistance.

Keywords: NiTi rotary files, Cyclic Fatigue resistance, and Single curvature canals

Introduction

Nowadays, NiTi rotary instruments are commonly used for endodontic treatment(1).They provide many advantages over the traditional stainless-steel files since they have high cutting efficiency and are more flexible (2). However, clinically, the main issue of NiTi rotary instruments is their unexpected fracture because of flexural or torsional fatigue (3, 4). Torsional fatigue



happens when the file tip binds in the root canal while the rotary instrument continues turning. Cyclic fatigue failure happens unexpectedly without any signs of previous deformation (5, 6). Canal curvature is suggested to be a predisposing risk factor for rotary instrument failure due to flexural stresses and cyclic fatigue [(2, 7, 8).

However, to overcome cyclic fatigue failure of rotary instruments, manufacturers are continuously trying to improve rotary instruments via variety strategies such as positioning of new reciprocating working motion, adjustment of geometrical parameters, surface treatment such as electropolishing, single-use instruments, and utilisation of new machining procedures (electrical discharge and twisting machining) to minimize surface micro-cracks and promote thermomechanical treatment to achieve Ni-Ti alloys with martensite or R-phase (9-12).

F6 SkyTaper (size: 0.25 mm, 6% taper) (Komet Brasseler, Lemgo, Germany) is characterized by an S-shaped cross-section and a constant taper of 6% (13). It is made of a conventional equiatomic austenitic NiTi alloy followed by electropolishing after machining (14). F6 SkyTaper rotary file is also considered a single-use instrument used for the entire shaping of the root canal prior to being discarded (12).

Introducing reciprocating motion to rotary files has increased their resistance to fractures compared to continuous rotation (14-16). This is because reciprocating motion creates less stress on rotary files than continuous one, and subsequently reduces the

likelihood of failure (17, 18). Clinical studies reported a very low incidence of fracture in reciprocating instruments and must be declared as rare (19-21).

To our knowledge, this study is the first that evaluated cyclic fatigue resistance of ES-reciproc. Therefore, the aim of this study was to estimate and compare cyclic fatigue resistance of four different rotary nickel titanium rotary files, namely F6 SkyTaper, ES-reciproc, and ES-cm rotary files in simulated curved canals having constant angle of curvature of 60°. The null hypothesis is that (i) there is no difference between the different rotary instruments under the same laboratory conditions.

Methodology

In this in-vitro study, a total of 48 NiTi rotary files were used and distributed into four groups with 12 files in each group. Group I: F6 Sky Taper, Group II: ES-reciproc, Group III: ES-cm. All tested rotary groups were standardized by having the same ISO of 25 size, 0.06 taper and 25 mm instrument length.

Cyclic fatigue testing was done by a specialized stainless-steel block that was custom-made with a single curvature canal (60° angle of curvature with 5 mm radius; the beginning of curvature was 5 mm distant from the end of the canal). The center of the curvature was located at 5.25 mm from the end of the canal and it represents the curve length (Figure 1). The total length of the artificial canal was 18 mm and the inner diameter of the canal was 1.5 mm.



Figure 1: Method of artificial canal manufacture in the stainless-steel block



AutoCAD 2018 programme was used to draw canals in 3D and after that transferred to DWG, DXF2005 file extension in order to understand and construct them by electrical discharge wire cutting machine. The artificial canals were milled in stainless steel.

The artificial canals were manufactured by two slices of stainless steel (316). The first one is a 1.5 mm thick stainless-steel sheet, in which the canal was milled. The second slice was used to give the adequate thickness to the block. The two parts were then connected by four screws. The canal

design was based on previous models approached by Larsen et al. (2009), Al-Sudani et al. (2012), and Yılmaz et al. (2017) (22-24). The artificial canal was then covered by tempered glass (8×3 cm) to prevent the instrument from slipping out and to allow for observation of the instrument during operation and when fracture occurs; subsequently, the fracture was readily observed through the cover glass (25). The manufacturing process of the artificial canal in the stainless-steel block is shown in Figures 2–10. All the rotary instruments were evaluated by stereomicroscope to detect any deformation for exclusion.



Figure 2: (A): Files used in experiment



Figure 2: (B): Cyclic fatigue testing device

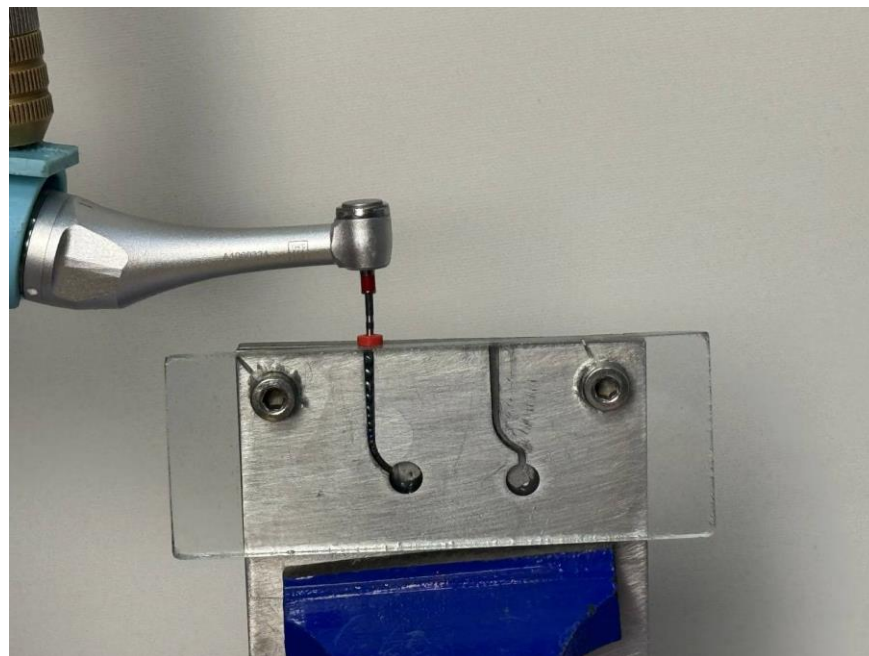


Figure 2 (C): File position inside the block



Flies were worked by an electric motor according to the manufacturer's instructions regarding torque and speed for each system.

The handpiece was mounted on a surveyor to keep it in a constant position during operation, allowing precise positioning of each file within the simulated canal and ensuring insertion of the instrument to the same depth each time. All tested rotary instruments were rotated until a separation occurred.

The time was recorded as soon as fracture was identified audibly and/or visually. The number of cycles to failure (NCF) was determined by multiplying the time recorded in minutes by the speed of the motor recommended by the manufacturer. The length of the fractured segment for each rotary file was obtained using a digital Vernier caliper.

Statistical analysis:

All statistical analysis was done with the SPSS version 21 software edition (IBM-SPSS Inc., Chicago, USA). One-way ANOVA and independent t-test were used to analyze NCF and FL data, at 0.05 level of statistical significance was fixed

Results

The Shapiro-Wilk test was used to evaluate normal distribution of data; descriptive statistics (mean ± standard deviations SD) were reported. A significant difference in cyclic fatigue resistance among four groups of tested rotary instruments ($P=0.000$), was reported according to the ANOVA test. The *post hoc* Turkey test demonstrated that NCF of EndoSequence ESR (Es-reciproc) was significantly superior to other groups ($p < 0.05$), except Ordeks group ($P=0.112$). ANOVA test reported no significant difference in NCF between F6 SkyTaper and EndoSequence CM (Es-cm). (Table 1 & 2).

Table 1: Mean and standard deviation (SD) of NCF and FL for the four groups.

<i>FL</i>		<i>NCF</i>		
<i>ANOVA p-value</i>	<i>Mean ± SD</i>	<i>ANOVA p-value</i>	<i>Mean ± SD</i>	<i>Endodontic files</i>
0.177	3.958 ± 0.47	0.000	1153.75 ± 133.48	F6 SkyTaper
	4.625 ± 0.36		2972.25 ± 657.60	<i>ES-reciproc</i>
	3.75 ± 0.25		960.83 ± 331.90	<i>Es-cm</i>
	3.916 ± 0.67		2401.67 ± 887.67	<i>Ordeka</i>

Table 2: Multiple comparison of NCF between four groups (P-value).

<i>P-value</i>	<i>Endodontic files</i>	
0.000	<i>ES-reciproc</i>	F6 SkyTaper
0.863	<i>Es-cm</i>	
0.000	<i>Ordeka</i>	
0.000	<i>Es-cm</i>	<i>ES-reciproc</i>
0.112	<i>Ordeka</i>	
0.000	<i>Ordeka</i>	<i>Es-cm</i>



Discussion

Fracture of instruments during endodontic treatment continues to pose issues for clinicians (26, 27). Stainless steel files lack adequate flexibility, which can result in iatrogenic errors like apical transport along with zip and ledge formation, especially in curved canals. To overcome this problem, NiTi files have been developed to reduce the risk of such errors and ensure easier and faster procedures (27, 28).

The intracanal separation of the rotary instrument is a vital event during root canal treatment as the fractured portion of the rotary file could limit biomechanical instrumentation, preventing irrigation solution from reaching the apex of root canal, and subsequently, perfect elimination of microorganisms is hindered (29). Cyclic fatigue is main causative factor of sudden fracture of rotary files inside the curved canals. Thus, cyclic fatigue tests are very essential to be performed on the new generation of NiTi rotary systems, providing practitioners with knowledge relating to their fracture resistance(30).

In literature, the previous studies used an artificial stainless steel simulated canal model with a curvature angle of 60° and a 5 mm radius curvature to test cyclic fatigue resistance (31). In the present study, to simulate clinical use, all rotary files were examined for cyclic fatigue resistance on a dynamic test model, since it is impossible to use real human teeth due to variation in root canal shape during instrumentation, making it hard to standardize the experimental situation (32, 33).

In this in vitro study, ES-Reciproc files expressed highest cyclic fatigue resistance than the other tested groups. This could be attributed to several factors; it is well accepted that instrument cross-sectional design, dimensions, and manufacturing mechanisms affect cyclic fatigue resistance of rotary files. Reciproc files are made from a new M-Wire NiTi alloy with a concave triangular shape. Researchers demonstrated that instruments fabricated from M-Wire NiTi have high level of flexibility and resistance to cyclic fatigue compared to those made from traditional alloys (34). No significant difference in NCF was seen between ES-Reciproc and Orokeda Plex V rotary files, where the latter expressed the second-highest NCF. Plex files are made of CM-Wire alloy with special heat treatment and a triangular convex cross-section (34). This finding is in agreement with previous study, where M-Pro files (convex triangular cross-section) had lowest cyclic fatigue resistance among tested files (35). Heat treatment promotes flexibility and prevents propagation of cracks, subsequently reducing stress

(35). Also, the triangular cross-section of instruments induces high fatigue resistance (31).

However, results from this study regarding EndoSequence CM rotary files were in agreement with a previous study (36), where EndoSequence files (produced by traditional grinding of NiTi) expressed the highest bending moment among tested files and, as a consequence, the lowest cyclic fatigue resistance. It is well demonstrated that cyclic fatigue is greatly influenced by the design of flutes, and thus the complicated design of EndoSequence rotary instruments could yield more stress concentration points and subsequently less resistance to cyclic fatigue (37).

In this study, the cyclic fatigue life of the F6 SkyTaper file (S-shaped cross-section) was statistically not different significantly from that of the ES-CM rotary instrument. This result was in contrast to the results of previously published studies (12, 13, 38), whereas the F6 SkyTaper rotary file expressed high cyclic fatigue resistance compared to other tested instruments. This may be attributed to different methodology, since the mentioned study measured cyclic fatigue resistance to rotational bending using a rotary bending machine (12, 39, 40).

To our knowledge, no research in the literature has investigated the cyclic fatigue resistance of EndoSequence ES-Reciproc rotary systems. It is worth confirming that this rotary file reported statistically significant resistance. In the future, this paper could be augmented by examining cyclic fatigue resistance of rotary instruments under different experimental conditions.

Conclusion

Within the limitations and conditions of the current study, the new endosequence ESR instrument expressed the highest cyclic fatigue resistance among tested rotary files. Ordeka rotary files presented the second highest resistance to cyclic fatigue without statistically significant difference from endosequence ESR instrument.

Ethical Approval

Since the study was an in-vitro study, authors declare that no ethical approval was needed.

Data Availability

Data that support the findings of current study are available from the corresponding author upon reasonable request.



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