

Comparative Evaluation of Cyclic Fatigue Resistance of Two Single-file Rotary Instruments in Simulated Stainless Steel Curved Canals

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Article History

Received: 14 July 2021

Accepted: 24 October 2021

Abstract

Background and Aim: Despite the advantages and conveniences that NiTi files offer, their main drawback is their catastrophic fracture due to cyclic and torsional fatigue leading to instrument separation. This study aimed to compare the cyclic fatigue resistance of two single file engine-driven instruments, HyFlex EDM and NeoNiTi A1, in simulated curved canals.

Materials and Methods: In this experimental study, NiTi endodontic instruments with a similar tip size of 0.25 mm were investigated in two groups of 20: HyFlex EDM (group A) and Neoniti A1 (group B). Evaluation of cyclic fatigue was conducted in a stainless steel artificial canal with a 60° angle and 5-mm radius curvature. HyFlex EDM and Neoniti A1 instruments were operated based on the instruction for use provided by the manufacturers. All instruments were rotated (at 400 rpm) until fracture, and the number of cycles to fracture (NCF) and the length of the fractured tip were documented. Means and standard deviations of NCF and fragment length were determined for each system and compared using the Mann-Whitney test ($P < 0.05$).

Results: A statistically significant difference was detected when comparing the NCF, and time until fracture of HyFlex EDM and Neoniti A1 instruments ($P = 0.001$). HyFlex EDM instruments showed significantly greater mean NCF in comparison with Neoniti A1 instruments (2984.75 ± 576.14 vs. 839.55 ± 305.5 NCF). No statistically significant difference was found in the mean length of the fractured fragments between the instruments ($P = 0.683$).

Conclusion: HyFlex EDM instruments showed significantly greater cyclic fatigue resistance compared with Neoniti A1 instruments.

Key Words: Fatigue; Root Canal Therapy; Stainless Steel

Cite this article as: Sedigh-Shams M, Ebrahimi R, Asheghi B, Eskandari F. Comparative evaluation of cyclic fatigue resistance of two single-file rotary instruments in simulated stainless steel curved canals.

J Res Dent Maxillofac Sci. 2022; 7(1):48-54. DOI: 10.29252/jrdms.7.1.48

Introduction

Development of nickel titanium (NiTi) files started a new era in root canal treatments four decades ago.[1] Physical characteristics of NiTi instruments increase the flexibility of files and

enhance the preparation of curved canals.[2] By employing NiTi rotary files, we can avoid the complications caused by the use of stainless steel files such as ledge formation, zipping, perforation, and straightening of

canals.[1,3] However, their main disadvantage is the high rate of catastrophic fracture of NiTi Files.[3]

Two main mechanisms which may result in fracture of endodontic files include cyclic and torsional fatigues. Torsional fatigue arises from partial engagement of instruments while preparing and shaping the root canal system, while the rest of the file continues to rotate. Rotation of the file in the curvature results in subjection to cyclic tension/compression stresses at area of maximum flexure, which leads to cyclic fatigue. In clinical practice, rotary files are subjected to a variety of loads, and fracture occurs due to combined application of cyclic and torsional stresses.[4]

Approximately 70% of NiTi rotary file fractures occur as the result of cyclic fatigue of rotary instruments.[5] Statistically significant differences have been found among the instrumentation times and cyclic fatigue resistance of the studied files.[6]

Technological improvements in NiTi files have resulted in novel principles of usage, various kinematics, and advanced alloys which supposedly raise the cyclic fatigue resistance (CFR) of the files.[7] NiTi rotary files containing NiTi controlled shape memory (CM) wire were developed.[8,9] The CM alloy has a much higher CFR than the routine NiTi files, due to the heat-treatment of conventional NiTi alloy-based files employing thermomechanical processes.[9] M-wire NiTi instruments were fabricated to improve flexibility and cyclic fatigue resistance. Also, surface alterations following endodontic instrumentation may occur, which are significantly lower for the M-wire NiTi instruments.[8,9]

HyFlex EDM (Coltene/Whaledent, Altstätten, Switzerland) and One Shape (OS; Micro Mega, Besancon, France) are novel single-file instruments with continuous rotation motion. Using an electrodischarge machining technology, controlled memory alloy is used to produce HyFlex EDM files. Therefore, the

mechanical characteristics of HyFlex EDM files are considerably enhanced. HyFlex EDM files (~0.25) contain three various horizontal cross-sections: quadratic in the apical region, trapezoidal in the middle region, and semi-triangular cross section in the coronal region.[3]

Neoniti (Neolix, Châtres-la-Forêt, France) is a recently developed NiTi rotary system that contains a heterogeneous rectangular cross-section and multiform tapers in a single file that contains a C1 file as orifice shaper (with size 25#, taper at the tip of 0.12 and length of 15 mm) and three A1 (with 20, #25 and #40 tip sizes) instruments¹⁰. The size of taper which is 0.08 in A1 #25 file from D0 to D5; while the taper is 0.04 in D5 to D16. These tapers are fabricated by applying a recently introduced wire cut electrical discharge machining mechanism. The manufacturer declares that the applied procedure for manufacturing of this type of product not only is incredibly accurate down to the micron-scale, but also contains no oil and is clean. Besides, the manufacturer reported that the stress is restricted to the metal surface¹¹. In addition, the generated surface is rough, leading to grinding features that speed up the preparation of root canals. Furthermore, according to the manufacturer, such instruments endure a proper heat treatment which causes increased flexibility and shape memory. Neoniti A1 has shown high CFR in a previous study.[11]

Based on the literature, no comparison has been made between Neoniti A1 and HyFlex EDM systems concerning their CFR. Thus, this study was designed to compare the CFR of these two single file systems.

Materials and Methods

This experimental study was approved by the ethic committee of Shiraz University of Medical Sciences, Shiraz, Iran (IR.SUMS.REC.1397.047). Using computer-assisted milling, artificial U-shaped cross-section grooves were formed

in 316L stainless steel blocks to simulate root canals. The diameter, gradient and curvature radius of simulated canals were 1.4 mm, 60 degrees and 5 mm, respectively. The surface was further hardened with polished chromium plating. We screwed a 4 mm-thick glass in front of the artificial canal to increase visibility of the canal and prevent slippage⁵. Instruments of each brand were evaluated for cyclic fatigue fracture in 2 experimental groups. Then, the following steps were applied:

Group 1: HyFlex EDM (~0.25).

Group 2: Neoniti A1 (25/.08).

Cyclic fatigue testing was performed on 40 files (n = 20/each group). In order to exclude defective files, all files were examined under an optical stereomicroscope at x20 magnification for visible symptoms of deformation. A low-torque motor (EndoMate; NSK, Tokyo, Japan) was applied to operate all instruments, then, following the manufacturer's instructions, they were rotated: NeoNiTi A1 with 400 rpm and 1.5 N/cm torque, and HyFlex with 400 rpm and 2.5 N/cm torque. Liquid paraffin (KimiagarToos, Mashhad, Iran) was applied on the walls of the canal by a micro-brush as a lubricant during the file rotation. The headpiece was fixed above the block to perform the cyclic fatigue test in a reproducible position. All files were used in simulated canals until fracture. A digital chronometer was used to record the fracture time. The number of cycles to failure (NCFs) was computed using the formula: $NCFs = \text{rotations per minute} \times \text{time to fracture (seconds)}/60$. In addition, length of the separated instrument was calculated to ensure the separation of the file at the curvature of the simulated canal. Normality of the data was assessed by the Kolmogorov-Smirnov and Shapiro-Wilk tests. All data demonstrated a parametric distribution. Thus, the data were compared by the Mann-Whitney test, while the statistical significance was considered at 95% ($\alpha=0.05$).

Results

The means and standard deviations of NCF, length of fractured segments, and time until fracture are shown in Table 1. The HyFlex EDM files (2984.75 ± 576.14 cycles) had a significantly higher fatigue resistance than the Neoniti A1 files (839.55 ± 305.5 cycles) ($P=0.001$).

Mean time until fracture for HyFlex EDM files was 447.8 ± 86.36 seconds which was significantly higher than the measured time for Neoniti A1 files, which was 126 ± 45.8 seconds ($P=0.001$).

The mean length of the fractured segments was also recorded and no significant difference was noted in this respect ($P=0.683$, Table 1).

Discussion

The success of root canal therapy in modern practice of endodontics, as before, requires the removal of microorganisms by cleaning and shaping of root canals and hermetic root canal obturation.[12]

Despite the optimal design and metallurgical properties of NiTi instruments in recent decades, instrument fracture is still an unpleasant occurrence in root canal treatment. This can affect the microbial control of the canal and ultimately the outcome of treatment. Instrument fracture is a multifactorial problem that is affected by instrument type, size and taper.[13]

This becomes more important when a single file system is used for canal preparation because the instrument is the first one that is introduced to the apical third and no cleaning has been done before⁵. Moreover, Kosaraju et al. reported that the rotary single file system extruded less amount of debris.[14]

A review on previous studies showed that Neoniti A1 had a higher cyclic fatigue resistance, but our comprehensive review revealed no study comparing the CFR of HyFlex EDM files and Neoniti A1.[5,11] Thus, this study aimed to compare the CFR of HyFlex

Table 1. Mean and standard deviation of cyclic fatigue (NCF), fragment length (mm) and time until fracture (seconds)

	NCF	Fragment length (mm)	Time (sec)
Hyflex EDM	2984.75 ± 576.14	7.7 ± 0.4	447.8 ± 86.36
NeoNiTi A1	839.55 ± 305.5	7.65 ± 0.42	126 ± 45.8
P-value	0.001	0.683	0.001

EDM and Neoniti A1 rotary file systems.

This study demonstrated higher cyclic fatigue resistant of HyFlex EDM instruments, with significantly greater resistance compared with Neoniti A1. The novel manufacturing technique (CM wire) of HyFlex files is believed to have an important effect on higher CFR. This is in line with the studies by Plotino et al, Pongione et al, and also Capar et al.[4,15,16]

The mean length of the fractured segments did not indicate any considerable variation in the two groups ($P=0.683$), which shows that the experimented instruments were properly located in the canal curvature induced by similar stresses.

Flexibility and cyclic life span of files depend on various factors, including metal alloy, heat therapy, frequency of threads, helical gradient, cross-sectional shape, and dimensions.[7,17]

In the present study, we observed that the HyFlex EDM files had higher NCF which may be related to the aforementioned factors. The most probable reason is different manufacturing procedure (control shape memory wire) of HyFlex EDM instruments, as mentioned by other studies.[7,15,18]

The austenite phase in the oral cavity and room temperature is the most common in NiTi alloys. At normal temperature, CM alloys can be found in both austenite and martensite phases; however, austenite is harder compared with martensite. Besides, there is a positive influence, because of increased martensite phase of files made of CM alloy.[2]

The material properties of the alloy are not the

only factors affecting the NCF of files. NCF also depends on factors such as cross-sectional geometry, fluting, and speed. According to a finite element analysis, triangular cross-sectional geometry is associated with higher levels of fatigue resistance compared with square-shaped cross-section.[7,19] Versluis and colleagues reported that rectangular and triangular models with similar center-core areas showed similar flexural hardness, while they reported higher levels of stiffness for the rectangular model (30–40%). The HyFlex EDM instruments have a triangular cross-sectional geometry, while Neoniti A1 has a rectangular cross-section.[7,20] As a result, cross-sectional geometry can be a contributing factor to higher CFR of HyFlex EDM. The speed of instrument rotation may also affect the CFR; to eliminate the effect of this parameter, the two instrument groups were operated at the same speed.[5]

There are two different modes for assessment of fatigue failure, including fixed and dynamic modes. For the latter mode, the hand-piece is used in a back-and-forth axial motion, while it moves in full rotational motion inside the trajectory. Such models better simulate the use of rotary files; however, a special device is needed to standardize the extent and pace of the axial movement. While in the dynamic mode, the fatigue resistance of rotary file is probably higher, which restraints stress in similar locations allowing distribution of stress across a larger part of the instrument.[11,21] It would be advantageous to perform another study to compare the fatigue failure of these

instruments in the dynamic mode.

To assess the CFR of NiTi instruments, various methods have been developed.[7,22-24]

Similar to the present study, many researchers have investigated CFR by rotating NiTi instruments until fracture in an artificial canal machined in a steel block.[7,22,25-28]

The main disadvantage of this method is that the results may be overestimated since the file may fit loosely in the canal resulting in more flexibility for the file at the point of maximum curvature compared with actual canals. The advantage of this method is minimizing variables that affect CFR, such as canal diameter and length.[5]

Some scholars considered the time of rotation until the fracture of files as an indicator for resistance to cyclic fatigue.[29,30] In contrast, in this study we measured NCF to assess the cyclic fatigue resistance. Application of fracture time techniques may be more applicable clinically. But since the cumulative stresses that induce microstructural alterations in the metallic alloy are the reason of cyclic fracture, CFR is best calculated by the number of cycles that an instrument endures through the fatigue test (NCF).[31] Nevertheless, by converting the NCF time, we can achieve an equitable comparison notwithstanding of the rotational pace.[7,22]

More studies are required on the therapeutic effects of negligible differences in the gradient and radius of curvature on the resistance failure (cyclic and torsional) of endodontic rotary instruments.[32]

However, regarding the differences in the used alloy, this issue is challenging. In addition, in clinical use, different irrigation solutions and applied loads can influence the CFR of the experimented instruments.[2] Finally, it should be stated that the findings of this study had some limitations in generalization to the clinical practice. For instance, using a dynamic mode increases the susceptibility to combined torsional and bending stresses while adapted

to the walls of the canal; consequently, we cannot confirm the accuracy of the fatigue resistance obtained in the present study.

Conclusion

Within the limitations of the current in vitro study, static cyclic fatigue of HyFlex EDM instruments was significantly higher than that of Neoniti A1 instruments.

Acknowledgements

The authors would like to thank the vice-chancellery of Shiraz University of Medical Sciences, for supporting this study (-13929). This manuscript was derived from a thesis by Dr. Reza Ebrahimi. Also, the authors thank Dr. Mehrdad Vossoughi from the Dental Research Development Center, for statistical analysis.

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