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CYCLIC FATIGUE RESISTANCE OF VARIOUS NICKEL-TITANIUM ROTARY ENDODONTIC INSTRUMENTS AT BODY TEMPERATURE: AN *IN VITRO* STUDY

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ABSTRACT

Introduction: The purpose of this study was to compare the cyclic fatigue of different types of nickel-titanium rotary files at body temperature.

Methods: Four types of rotary instruments with tip size 0.25 were used: HyFlex EDM (OneFile, variable taper, Colten/Whaledent), ProTaper Gold (F2, 0.08 taper, Dentsply), XP-endo Finisher (zero tapers, FKG Dentaire) and 2Shape (TS2, 0.06 taper, Micro-Mega). Ten files for each instrument were tested for cyclic fatigue at body temperature and rotated until fracture occurred in a simulated canal with an angle curvature of 60°, a radius curvature of 5 mm, and a canal width of 1.5 mm. Four groups were formed for all instruments (total number = 40). The number of cycles to fracture and the length of fractured fragment were recorded, and statistical analysis was completed using analysis of variance with significance at a (p-value < 0.05).

Results: The cyclic fatigue resistance of the HyFlex EDM OneFile was significantly greater than the other instruments, while that of the 2Shape TS2 was significantly lower (p < 0.05).

Conclusion: Within the limitations of this study, the HyFlex EDM OneFile was more resistant to cyclic fatigue than the XP-endo Finisher, ProTaper Gold F2 and 2Shape TS2 files.

KEYWORDS: Cyclic Fatigue, Files, Nickel-Titanium, Body Temperature

INTRODUCTION

Nickel-titanium (NiTi) rotary instruments exhibit high flexibility and cutting efficiency, and therefore have been commonly used to shape root canals for the past two decades [1, 2]. However, fracturing of nickel-titanium (NiTi) rotary instruments during treatment [3] remains a challenge for clinicians, where fractured NiTi files can influence the success of a root canal treatment. Fracture of NiTi files can be attributed to either cyclic fatigue or torsional fracturing [4, 5]. Cyclic fatigue occurs when the instrument rotates and is exposed to a large number of tension-compression stress cycles, which occurs especially when a curvature is present during canal preparation, where the repeated stress cycles finally lead to fracture [6, 7]. Torsional fracturing occurs when part of the instrument is locked onto the canal while the shank continues to rotate [8]. Many improvement methods have been attempted to prevent the fracture of NiTi rotary file systems, including alteration of the file cross-sections, heat treatments, and electropolishing [9].

Among the modern products of improved files, the HyFlex EDM files (Coltene/Whaledent) are a new type of nickel-titanium (NiTi) rotary instrument manufactured from controlled memory (CM) wire via electrical discharge machining (EDM) technology, which allows non-contact shaping and good control of the files to help improve their mechanical properties [10]. Also, the ProTaper Gold instruments have been advanced with metallurgy developments via heat treatments, and exhibit a two-stage specific transformation behavior and high austenite finishing temperatures [11, 12]. Recently, a novel type of nickel-titanium file called the XP-endo Finisher (FKG Dentaire, La Chaux-de-Fonds, Switzerland) has been introduced for use in the

final stage of root canal cleaning, which consists of a size-25 tip and is a no-taper rotary NiTi instrument made of a special alloy (MaxWire; Martensite-Austenite Electropolish Flex, FKG Dentaire). The XP-endo Finisher file alters its shape according to the temperature, where it is straight at room temperature owing to its martensitic phase (M-phase), but when exposed to body temperatures it enters its austenitic phase (A-phase) and assumes a spoon shape 1.5 mm deep in the final 10 mm of its length [13]. Finally, the 2Shape (TS2 ; Micro-Mega, France) file is a new-generation file system produced with a proprietary heat treatment (T-Wire) that, according to the manufacturer, improves both the flexibility and cyclic fatigue resistance of the files, where the latter improvement is claimed to be 40% [14].

Until recently, previous studies have been completed using in vitro fracture testing at room temperature [15, 16], which is much lower than body temperature. The results from these studies are thus not likely to be clinically pertinent because the NiTi instrument is used inside the root, which is surrounded by periodontium and is therefore an environment approaching body temperature. For example, de Hemptinne et al. [17] have found that the intracanal temperature during the root canal treatment is 35.1 ± 1.0°C. Further, more recent studies [18, 19, 20] have tested files in water baths and at body temperature and have consistently found a significant decrease in cyclic fatigue resistance at body temperature compared with that at room temperature.

For these reasons, body temperature was selected for the present study. However, the cyclic fatigue of these new NiTi rotary systems has not yet been compared. Therefore, the aim of this study was to compare the cyclic fatigue of different types of nickel-titanium rotary files at body temperature.

MATERIALS AND METHODS

Four brands of rotary instruments with a tip size 25 were used, including HyFlex EDM (OneFile, variable taper, Colten/Whaledent, Switzerland), ProTaper Gold (F2, 0.08 taper, Dentsply, Maillefer, Switzerland), XP-endo Finisher (zero tapers, FKG Dentaire SA, Switzerland) and 2Shape (TS2, 0.06 taper, Micro-Mega, France). Ten files of each instrument were tested for cyclic fatigue at body temperature and were rotated until fracturing occurred. Four groups were formed from all of the instruments (total number=40), with ten files in each group.

Cyclic fatigue testing was performed with the instrument rotating freely within an artificial canal that was defined by both the angle and radius of curvature, following Pruett et al. [21]. The instruments were tested within a simulated canal with an angle of curvature of 60°, a radius of curvature of 5 mm, and a canal width of 1.5 mm [20, 22]. Moreover, the center of curvature was 5.12 mm coronal to the apical ending point of the instrument, the curved segment of the canal was 5.25 mm in length and the linear segment between the tip of the instrument and the endpoint of the curvature will be approximately 2.5 mm. The canal was formed in a stainless steel block covered with a swiveling glass cover that permitted visibility of the rotating file in the canal and the removal of the broken instruments following fracture. A mark comprising permanent red ink was placed at 19 mm along the glass cover of the metal block to standardize the instrument placement [23].

A small circular hole (5 mm diameter) was drilled into the glass at the location of the simulated canal to permit the introduction of water into the canal during testing as described by Grande et al [24]. The temperature of the water in a glass container (Pyrex) was elevated to that of the human body (37°C) by placing the glass container on a digital magnetic stirrer/hotplate (SH-4C, China). The original temperature of the water was 22–25.5°C, and thus to achieve body temperature we placed the glass container on the hotplate until the water temperature stabilized at 37°C. The temperature was accurately measured in all of the experiments using the adjustable PT100 sensor rack and stainless steel rods (i.e., digital thermometer) incorporated in the hotplate according to de Vasconcelos et al [19].

For standardization of the cyclic fatigue tests, the dental hand-piece was mounted on a device that operated like a surveyor used in the dental laboratory, which allowed for accurate and simple placement of the instrument inside the artificial canal during each measurement and ensured a standardized three-dimensional alignment and positioning of the instruments to the same depth [25].

Before the static cyclic fatigue resistance test, the files were examined using a stereo

microscope (Motic, ST-39 Series, China) to ensure that no deformations were present. After each file was confirmed to be deformation-free, it was placed into the simulated canal in the metal block and the latter was submerged in the water in the glass container and mounted to a bench vise inside the glass container to ensure that the location of the hand piece in relationship to the block remained fixed (Fig. 1A). In this way, the simulated canal and the file were exposed to the water and the file could reach the experimental temperature of the water [20].

The files were rotated with an endodontic motor within the recommended range of rotational speed and torque recommended by the manufacturer. The HyFlex EDM OneFile was rotated at 500 rpm with 2.5 N/cm torque, the ProTaper Gold F2 was rotated at 300 rpm with 3 N/cm torque, the XP-endo Finisher was rotated at 800 rpm with 1 N/cm torque, and the 2Shape TS2 was rotated at 300 rpm with 2.5 N/cm torque until fracturing occurred. A video of each file rotation was recorded using a digital camera (DSLR, Nikon D5300) (Fig. 1B), whereupon the time to fracture was registered in seconds and the number of cycles to fracture (NCF) was calculated according to the following formula: NCF = revolutions per minute × time to fracture (seconds)/60. The lengths of fractured parts were measured using a digital caliper.

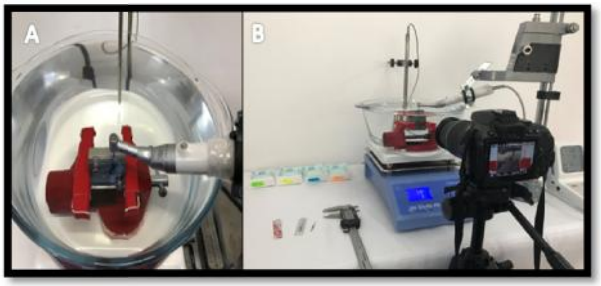

Fig. (1): Experimental setup showing (A) the metal block fixed by a bench vise and submerged in water inside the glass container and the experimental file inserted into the canal; (B) and the testing apparatus.

The data were collected and analyzed using the SPSS 22 software (IBM-SPSS Inc, Chicago, IL, USA) for statistical analysis. The data were then subjected to the Shapiro-Wilk test to analyze the normality of distribution and to the Levene test to analyze the homogeneity of variance of the variables. Analysis of variance (ANOVA) and Post-Hoc Games-Howell tests were used to determine if a statistical difference existed among the mean of the NCF values and the length of the fractured fragment for the rotary instruments herein. The level of significance was set at 0.05.

RESULTS

The mean and standard deviations of the NCF value and the length of fractured segments for the HyFlex EDM OneFile, ProTaper Gold F2, XP-endo Finisher and 2Shape TS2 files at body temperature are shown in Table 1. It is clear from Table 1 that the HyFlex EDM OneFile exhibited the highest mean NCF value of (3971.2 ± 1012.5), followed in descending order by the XP-endo Finisher (2181.7 ± 86.6), the ProTaper Gold F2 (1027.2 ± 49.7), and the 2Shape TS2 (198.8 ± 25.4).

The data exhibits a normal distribution according to the Shapiro-Wilk test ($p > 0.05$), but it is non-homogeneous according to the Levene test ($p < 0.05$). Thus, in Welch's ANOVA test (Table 1) the NCF and the length of fractured segments among the four instrument groups exhibited a highly-significant difference ($p < 0.01$). The mean of the fragment length for HyFlex EDM OneFile instruments was significantly shorter than that of other files, while XP-endo Finisher files demonstrated longest fragment length ($p < 0.05$).

Table (1). Descriptive statistics for the mean values (± Standard Deviation) of ten measurements (*N*) of the number of cycles to fracture (NCF) and the length of the fractured fragment of each instrument tested at body temperature.

Instrument	N	Number of cycles to fracture (NCF)	Fragment length (mm)
Hyflex EDM OneFile	10	3971.25 ± 1012.52[a]	2.46 ± 0.20[a]
ProTaper Gold F2	10	1027.29 ± 49.78[b]	3.24 ± 0.39[b]
XP-endo Finisher	10	2181.73 ± 86.63[c]	4.15 ± 0.21[c]
2Shape TS2	10	198.80 ± 25.45[d]	3. 08 ± 0.32[b]
Analysis of variance *P* value		< .01	< .01
Different superscript letters in the same column indicate statistically significant difference (*P*< .05)			

DISCUSSION

Recent studies have shown that the cyclic fatigue of rotary endodontic instruments is significantly reduced at body temperature compared with testing in air at room temperature [18, 19, 20]. However, these studies have used static models that eliminated the changes in temperature that a rotary instrument may experience when moving in and out of the root canal. Most NiTi files are manufactured with thermo-mechanically treated alloys and it has been showedthat the cyclic fatigue resistances of thermo-mechanically treated NiTi files were affected by ambient temperature [19, 20, 24]. Thus, the present study selected body temperatureto mimic clinical conditions and achieved this temperature by placing the measurement setup in water in a glass container on a hotplate, whereby the water temperature was stabilized [19].

In the present study, cyclic fatigue was compared between four newly-developed file brands (Hyflex EDM, ProTaper Gold, XP-endo Finisher and 2Shape) at body temperature using a metal block submerged inside water in a glass container placed on a hotplate. These instruments were chosen because each has different manufacturing process; for example, Hyflex EDM uses electric discharge machining technology, ProTaper Gold uses alloys with a gold thermal treatment, XP-endo Finisher uses MaxWire alloy, and 2Shape TS2 uses T-wire alloys. To our knowledge, there have been no studies comparing the NCF among these four rotary files at body temperature.

According to the results herein, the Hyflex EDM exhibited a higher NCF value than the XP Endo-Finisher, ProTaper Gold, and 2Shape TS2 files at body temperature, as well as a higher resistance to cyclic fatigue. Similarly, Kaval et al. [26] have reported that the cyclic fatigue resistance of Hyflex EDM was significantly higher than that of ProTaper Universal (Dentsply Maillefer) and ProTaper Gold (Dentsply Maillefer) files. In another study, Özyürek et al. [27] have reported that the cyclic fatigue resistance of Hyflex EDM was significantly higher than the 2Shape TS2 (Micro-Mega, France) file. To our knowledge, there have been no studies comparing the NCF of the Hyflex EDM and XP Endo-Finisher rotary files at body temperature. However, several studies have confirmed that Hyflex EDM exhibits a significantly increased cyclic fatigue resistance compared with the M-Wire, Hyflex CM, and conventional NiTi instruments [5, 10, 22].

The reason that Hyflex EDM files exhibit a higher cyclic fatigue resistance may be the electro-discharge machining procedure used during fabrication, though the file's manufactured alloy is not the only factor affecting the cyclic fatigue resistance of the instruments. In addition, the cross-section type, area, and usage speed of the file may influence its cyclic fatigue life [22]. Despite the results of the present study, the NiTi instruments possessing a triangular cross-sectional geometry generally exhibit a better fatigue resistance than that of a square cross-section [28].

According to the results of the present study, the XP Endo-Finisher file exhibited a higher resistance to cyclic fatigue than the ProTaper Gold and 2Shape TS2 files at body temperature. No previous study has compared the cyclic fatigue among these files, though Keskin et al. [29] have studied the XP-endo Shaper made from MaxWire alloy (cf. XP-endo Finisher) to exhibit a higher cyclic fatigue resistance than the ProTaper Gold and K3XF nickel-titanium rotary instruments at intracanal temperatures. Combining the results of that previous study with the results herein, therefore, the improved cyclic fatigue resistance may be attributable to the MaxWire alloy and the smaller taper size of

the instruments. In another study, Vaz-Garcia et al. [30] have shown that the XP-Endo Finisher exhibited a higher cyclic fatigue resistance and lower roughness than another finishing file because the XP-Endo Finisher is made with MaxWire alloy (manufactured using a proprietary and innovative thermomechanical procedure), which may provide greater flexibility and resistance than other NiTi alloys. Moreover, the XP Endo-Finisher file instrument has no taper [13] compared with the ProTaper Gold and 2Shape files. Thus, the reinforced cyclic fatigue resistance is likely caused primarily by the reduced wire dimensions of XP Endo-Finisher, although the metallurgical aspect may also have an influence.

In keeping with the results of the present study, the length of fractured segments among the four instrument groups exhibited a highly-significant difference ($p < 0.01$) and this is in agreement with previous study [26] in which alloy properties and cross-sectional design of the instruments could alteration the location of the maximum stress points, and different fragment lengths might be observed for different types of instruments because the difference in the bending moments.

CONCLUSION

Within the limitations of the present in vitro study, it was found that the cyclic fatigue resistance of the HyFlex EDM OneFile was greater than that of the XP-endo Finisher, ProTaper Gold F2 and 2Shape TS2 files.

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