Evaluation of the effect of temperature on cyclic fatigue resistance of three types of Nickel-Titanium rotary files with various alloy properties: An in vitro study

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Background and objectives: the fracturing of nickel-titanium rotary instruments during endodontic treatment because of the cyclic fatigue remains a common incidence. This study evaluated the effect of temperature on the cyclic fatigue of various nickel-titanium rotary files and compare between them.
Methods: Three 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) and 2Shape (TS2, 0.06 taper, Micro-Mega). Twenty files for each instrument were tested for cyclic fatigue at (20°C and 37°C) temperatures and rotated until fracture occurred in a simulated canal with an angle curvature of about 60°, a radius curvature of 5 mm, and a canal width of 1.5 mm. Six groups were formed for all instruments (total number = 60), with ten files in each group. The number of cycles to fracture was recorded, and statistical analysis was completed using analysis of variance and independent *t*-test with significance at a ($P<0.05$).
Results: HyFlex EDM OneFile registered no differences in fatigue life between the 2 temperatures tested ($P > .05$), whereas ProTaper Gold F2 and 2Shape TS2 showed a statistically significant reduction in fatigue life at body temperature compared with room temperature ($P <0.05$). HyFlex EDM OneFile exhibited statistically higher resistance to cyclic fatigue than ProTaper Gold F2 and 2Shape TS2 both at room and body temperatures ($P<0.05$).
Conclusions: Within the limitations of this study, body temperature influenced the cyclic fatigue resistance of ProTaper Gold F2 and 2Shape TS2 files, whereas it did not influence the fatigue life of HyFlex EDM OneFile. The HyFlex EDM OneFile was more resistant to cyclic fatigue than the ProTaper Gold F2 and 2Shape TS2 files at room and body temperatures.

Keywords: Cyclic fatigue, files, nickel-titanium, temperature

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Introduction

Nickel-titanium (NiTi) rotary instruments exhibit high flexibility and cutting efficiency, and therefore have been ordinarily 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 affect the success of a root canal treatment.

Fracture of NiTi instruments 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 take places 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 persists to rotate.[8] Many improvement methods have been attempted to prohibit the fracture of NiTi rotary file systems, including alteration of the file cross-sections, heat treatments, and electropolishing.[9]

Among the recent products of improved files, the HyFlex EDM files (Coltene/ Whaledent) are new types 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] HyFlex EDM One files with a tip size of 25 demonstrated 0.08 constant taper in the apical 4 mm of the instruments, and the taper of the instruments reduces progressively up to 0.04 in the coronal region. In addition, throughout the entire working part of the file, there are 3 different horizontal cross sections: a quadratic cross section in the apical region, a trapezoidal cross-section in the middle region, and a nearly triangular cross-section in the coronal region.[5] Also, the ProTaper Gold instruments have been advanced with metallurgy developments via heat treatments, and display a two-stage specific transformation behavior and high austenite finishing temperatures.[11,12] 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 last improvement is claimed to be 40%.[13]

Until recently, previous studies have been achieved using in vitro fracture testing at room temperature,[14,15] which is much lower than body temperature. The results from these studies are thus not likely to be clinically relevant 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.[16] have found that the intracanal temperature through the root canal treatment is 35.1 ± 1.0°C. Further, more recent studies[17-19] have tested instruments 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, room temperature (20° C) and body temperature (37°C) were selected for the present study. However, the cyclic fatigue of these new NiTi rotary systems has not yet been compared at room and body temperatures. Therefore, the aim of this study was to evaluate the effect of temperature on the cyclic fatigue of different types of nickel-titanium rotary files with various alloy properties and compare between them.

Materials and Methods

Three brands of rotary instruments with a tip size 0.25 were used, including HyFlex EDM (OneFile, variable taper, Colten/ Whaledent, Switzerland), ProTaper Gold (F2, 0.08 taper, Dentsply, Maillefer, Switzerland) and 2Shape (TS2, 0.06 taper, Micro-Mega, France). Twenty files of each instrument were tested for cyclic fatigue at (20°C and 37°C) temperatures and were rotated until fracturing occurred. Six groups were formed from all of the instruments (total number = 60), with ten files in each group.

Cyclic fatigue testing was accomplished with the instrument rotating freely within an artificial canal that was defined by both the angle and radius of curvature, following Pruett et al.[20] The files were tested within a simulated canal with an angle of curvature of about 60°, a radius of curvature of 5 mm, and a canal width of 1.5 mm. The canal was formed in a stainless steel block covered with a swiveling glass cover that allowed visibility of the rotating file in the canal and the removal of the broken instruments following a fracture. A mark comprising permanent red ink was placed at 19 mm along the glass cover of the metal block to standardize the file placement.[21]

A small circular hole (5 mm diameter) was drilled into the glass at the location of the simulated canal to allow the introduction of water into the canal during testing as described by Grande et al.[22] The original temperature of the water was 22-25.5°C, and thus to achieve the desired temperatures, Ice was placed inside the glass container (Pyrex) until the water temperature stabilizes at 20°C or placed the glass container on the hotplate until the water temperature stabilized at 37°C. The temperature was exactly 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.[18]

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 file inside the artificial canal during each measurement and ensured a standardized three-dimensional alignment and positioning of the instruments to the same depth.[23]

Before the the cyclic fatigue test, the instruments were examined using a stereomicroscope at 4× (Motic, ST-39 Series, China) to ensure that no deformations were present. After each instrument 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 vice inside the glass container to ensure that the location of the hand piece in relationship to the block remained fixed (Figure 1A). In this way, the simulated canal and the file were exposed to the water and the file could arrive at the experimental temperature of the water.[19]

The instruments 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, and the 2Shape TS2 was rotated at 300 rpm with 2.5 N/cm torque until fracturing occurred. A video of every file rotation was recorded using a digital camera (DSLR, Nikon D5300) (Figure 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.

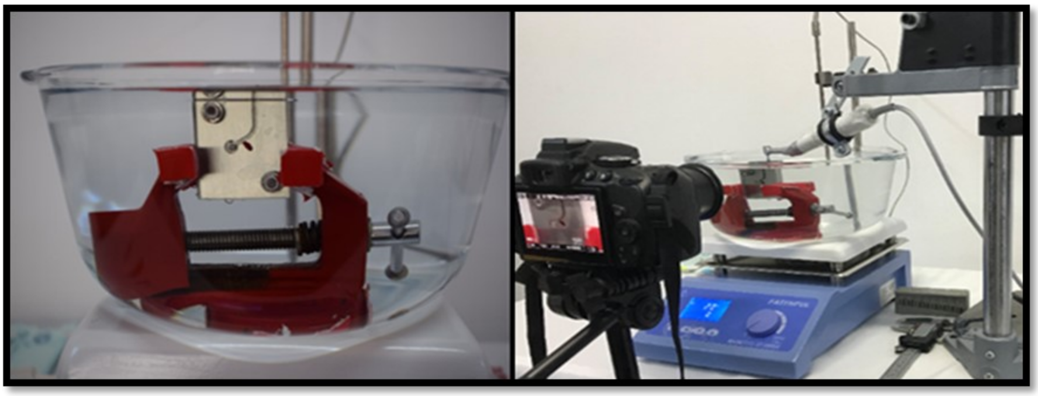

Figure 1: Experimental setup showing (A) the metal block fixed by a bench vice and submerged in water inside the glass container; (B) and the testing apparatus.

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. Welch's ANOVA and post-hoc Games-Howell tests were used to determine if a statistical difference existed among the mean of the NCF values for the rotary instruments herein at each degree of temperature, and also independent *t*-test was used between the room temperature and body temperature groups for each instrument tested. The level of significance was set at 0.05.

Results

The mean and standard deviation of the NCF for the HyFlex EDM OneFile, ProTaper Gold F2 and 2Shape TS2 files at room temperature (20°C) and body temperature (37°C) are shown in table 1. The temperature did not influence the cyclic fatigue resistance of HyFlex EDM OneFile ($P>0.05$), whereas the fatigue life of ProTaper Gold F2 and 2Shape TS2 files were significantly reduced at body temperature ($P<0.05$) (Table 2).

It is clear from tables 3 and 4 that the HyFlex EDM OneFile exhibited a statistically significant higher cyclic fatigue resistance when compared with other files at both temperatures tested (P<0.05).

Table 1: Descriptive statistics for the mean values (± Standard Deviation) of the number of cycles to fracture (NCF) of each instrument tested at room and body temperatures.

Instrument	N	Temperatures	
		Room temperature (20°C)	Body temperature (37°C)
Hyflex EDM OneFile	20	4685.34 ± 726.39[a]	3971.25 ± 1012.52[a]
ProTaper Gold F2	20	1959.4 ± 66.08[b]	1027.29 ± 49.78[d]
2Shape TS2	20	416.87 ± 23.55[c]	198.80 ± 25.45[e]
Different superscripts letters indicate a statistically significant difference (p< 0.05)			

Table 2: Independent t-test showing the effect of temperature on the mean of cycles to fracture of each instrument tested at room and body temperatures.

Groups	P value
Hyflex EDM OneFile (A1 & A2)[a]	0.087
ProTaper Gold F2 (B1 & B2)[b]	<0.001
2Shape TS2 (C1 & C2)[c]	<0.001
[a] A1: Hyflex EDM OneFile at 20°C; A2: Hyflex EDM OneFile at 37°C	
[b] B1: ProTaper Gold F2 at 20°C; B2: ProTaper Gold F2 at 37°C	
[c] C1: 2Shape TS2 at 20°C; C2: 2Shape TS2 at 37°C	

Table 3: Welch's ANOVA test for the difference the mean of cycles to fracture among all of the three instrument systems tested at room and body temperatures.

Among three instruments
At room temperature 20°C (A1,B1,C1)[a]
At body temperature 37°C (A2,B2,C2)[b]
[a] A1: Hyflex EDM OneFile at 20°C; B1: ProTaper Gold F2 at 20°C; C1: 2Shape TS2 at 20°C
[b] A2: Hyflex EDM OneFile at 37°C; B2: ProTaper Gold F2 at 37°C; C2: 2Shape TS2 at 37°C

Table 4: Games-Howell post-hoc test for the difference the mean of cycles to fracture among all of the three instrument systems tested at room and body temperatures.

Groups	Variables	Mean difference	P value
At room temperature 20°C (A1,B1,C1)[a]	A1-B1	2725.94167*	<0.001
	A1-C1	4268.47167*	<0.001
	B1-C1	1542.53000*	<0.001
At body temperature 37° C (A2,B2,C2)[b]	A2-B2	2943.96337*	<0.001
	A2-C2	3772.45337*	<0.001
	B2-C2	828.49000*	<0.001
*. The mean difference is significant at the 0.05 level.			
[a] A1: Hyflex EDM OneFile at 20°C; B1: ProTaper Gold F2 at 20°C; C1: 2Shape TS2 at 20°C			
[b] A2: Hyflex EDM OneFile at 37°C; B2: ProTaper Gold F2 at 37°C; C2: 2Shape TS2 at 37°C			

Discussion

Modern studies have shown that the cyclic fatigue of rotary endodontic instruments is significantly reduced at body temperature compared with testing in the air at room temperature.[17-19] However, these studies have used static models that eliminated the variations in temperature that a rotary instrument may experience when moving in and out of the root canal. To better coincide the environment that approaches the temperature clinically experienced by the endodontic instruments, therefore, the present study selected room and body temperature and achieved this temperature by placing the measurement setup in water in a glass container on a hotplate, whereby the water temperature was stabilized.[18]

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

Hyflex EDM is the first endodontic instrument that is fabricated by means of an electrical discharge machining (EDM) process.[10] The transformation temperatures martensite start (Ms), austenite start (As) and austenite finish (Af) for new Hyflex EDM instruments were found to be higher than for Hyflex CM indicating an altered phase composition.[24] According to the results of the present study, the Hyflex EDM OneFile showed non-significant difference between the mean of NCF at room temperature (20°C) and the body temperature (37°C) ($p > 0.05$) and that coincide with the study[25] in which no differed between room or body temperature for Hyflex EDM because the Hyflex EDM was martensitic or in R- phase at body temperature. The absence of austenite in Hyflex EDM files could be explained by its increased austenite start temperature (As ≈ 42°C) compared to Hyflex CM (As ≈ 21°C) preventing the formation of austenite at either room or body temperature.[24]

The ProTaper Gold F2 and 2Shape TS2 files showed highly significant difference between the mean of cyclic to fracture at 20°C and 37°C ($p < 0.01$) and this is in agreement with previous studies[17-19,22] in which increasing the temperature was found to decrease the number of cyclic to fracture. In one study, ProTaper Gold tested at 2 different environmental temperatures: 20°C (±2°C) for room temperature group and -20°C (±2°C) for the cooled environment group ($n = 20$), and the NCF was significantly higher for ProTaper Gold from the cooled environment than from room temperature group, so the environmental temperature drastically affects flexural fatigue resistance of ProTaper Gold.[22]

According to the results herein, the Hyflex EDM exhibited a higher NCF value than the ProTaper Gold, and 2Shape TS2 files at room and body temperature, as well as 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 file.

However, several studies have approved that Hyflex EDM exhibits a significantly increased cyclic fatigue resistance compared with the M-Wire, Hyflex CM, and conventional NiTi instruments.[5,10,28] The reason that Hyflex EDM files show 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 affect its cyclic fatigue life.[28] Despite the results of the present study, the NiTi fils possessing a triangular cross-sectional geometry generally exhibit a better fatigue resistance than that of a square cross-section.[29]

Conclusion

Within the limitations of the present in vitro study, it can be concluded that:

When a temperature increase to 37°C, simulating body temperature, substantially decreased the fracture resistance of ProTaper Gold F2 and 2Shape TS2 files, whereas it did not influence the fatigue life of HyFlex EDM OneFile between room or body temperature because the Hyflax EDM was martensitic or in R- phase at body temperature and the austenite start temperature (As ≈ 42°C).

Conflicts of interest

The authors reported no conflict of interest.

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