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CYCLIC FATIGUE AND STRUCTURAL ANALYSIS OF THREE ROTARY NICKEL TITANIUM FILES

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ABSTRACT

Nickel-titanium (NiTi) rotary shaping techniques were devised as a solution to the drawbacks associated with manual filing systems.The study was conducted to evaluate the cyclic fatigue resistance and martensitic/austenitic phase at body and room temperatures for HyFlex CM, Fanta (AH wire), Soco files.

Twenty files of each system were used. Ten of them were used at room temperature and ten were used at body temperature. Dynamic cyclic fatigue testing was performed with a specific device, which allowed the instruments to rotate freely inside a Stainless-Steel artificial canal while providing an axial movement with amplitude of 3mm up and down movement. The time was calculated until instrument fracture occurred. A Sample with weight 10 to 15 grams of each instrument was evaluated using Differential Scanning Calorimetry (DSC).The DSC analyses were conducted over a temperature range from 0°C to 60°C .

The results showed that HyFlex CM exhibited higher cyclic fatigue, followed by Fanta(AH wire), while soco showed the lowest values for both room and body temperatures. Temperature showed an effect (between body and room temperature) on cyclic fatigue resistance of some of CM wire type of instruments (Fanta and soco files).The differential scanning calorimetry confirmed the presence of the martensitic R-phase in Hyflex CM in both body and room temperatures which improved the cyclic fatigue resistance of this file, while presence of the martensitic phase only in room temperature for Fanta and Soco files not in body temperature which significantly decreases their cyclic fatigue resistance.

KEYWORDS: Cyclic fatigue ; Rotary Nickel Titanium ; Hyflex CM ; Fanta (AH wire); Soco.

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INTRODUCTION

In the last two decades, there have been numerous advancements in endodontics. A notable development involves the approach to shaping and instrumenting root canals. Enhanced materials, redesigned files, and easier techniques have streamlined canal preparation. As a result, practitioners now have a wider display of choices available for shaping root canals.

The initial transformation in root canal instrumentation occurred with the shift from carbide steel hand files to stainless steel ones. This change carried considerable importance regarding durability and sterilization procedures, leading to the widespread adoption of stainless steel hand files. Subsequently, a significant advancement emerged in the early 1990s with the introduction of NiTi rotary files.[1]

Manufacturers of NiTi rotary instruments sought to enhance flexibility and the capacity to navigate curved canals. However, the primary concern in endodontic treatment remains file separation, representing the most anticipated error. Ni-Ti, being an exotic metal, defies conventional metallurgical norms. Ni-Ti files are susceptible to two types of fractures: cyclic fatigue failure and torsional failure[2].

NiTi alloys offer high flexibility in root canal shaping instruments due to stress-induced martensitic transformation, allowing for superelasticity characterized by reversible deformation under constant stress. This behavior stems from the alloy's transition between austenitic and martensitic phases, allowing for elastic deformation until reaching the limit of strain absorption. Releasing the load before reaching the plastic deformation limit enables reversible deformation.[3]

Cyclic fatigue failure arises from the repeated tension and compression cycles experienced by instruments when flexed in the area of maximum curvature. The fatigue strength is assessed via subjecting the substance to stress under specified circumstances and measuring time until file fracture occurs. Various in-vitro testing models, employing different kinematics and designs, are utilized for cyclic fatigue assessment, yet standardization for the testing model remains elusive. While extracted teeth ideally serve as the optimal model for cyclic fatigue testing, non-tooth models are often employed due to the impracticality of standardizing natural canals for testing all files uniformly [4].

Nickel Titanium exhibits 3 distinct phases of crystalline structure: Austenitc phase, stress-induced martensitic phase (superelastic), and martensitic phase. The martensitic form of nickel titanium is somewhat soft and exhibits higher cyclic fatigue strength, making it easily deformable. Conversely, in the austenitic form, nickel titanium is inelastic, rigid, and demonstrates less cyclic fatigue strength. Additionally, nickel titnium can do transition into the R phase, that boasts much high fatigue strength than the austenitic form but less fatigue strength than the martensitic form. Phase transitions can be reversed in both directions through heating or cooling, Transitioning from the martensitic state to the R phase and then to the austenitic state when heated, and reversing this process when cooled. Differential scanning calorimetry (DSC) is utilized to analyze the impact of thermal variations on phase transitions, thereby predicting the phase of nickel titanium instruments upon specific temperatures. Peaks observed during the heating/cooling cycle signify the material's phase transformation[5,6]. This in vitro study aimed to compare three types of Ni-Ti rotary file systems in terms of cyclic fatigue resistance at room and body temperature and Structural analysis using (DSC) .

MATERIALS AND METHODS

Cyclic fatigue fracture:

60 files, each with 25 tip size, were organized into 3 main groups for each file system in vitro . Within the 3 main groups, subgroups were formed, with 1 sub-group that was tested at body-temperature of 37°C, while the 2nd subgroup is tested at room-temperature of 25°C (Figure 1).

- **20 files Hyflex CM** (Coltène/Whaledent AG, Switzerland).

- **20 files Fanta AH wire** (Fanta Dental Materials Co., Ltd, China).
- **20 files Soco** (Foshan SOCO precision Instrument CO.,Ltd, China).

A custom cyclic fatigue-testing apparatus [(7)], as shown in (Figure 1), was used for this research. An artificial simulated canal, generated using AutoCAD Autodesk as shown in Figure 2, was crafted from stainless steel with a tip size of #25, 8% taper, and a canal depth extending 0.02 cm beyond the max. diameter of the instrument. The canal featured a curvature angle of 90-degree, curvature radius of 5mm and the curvature center positioned 5mm from the canal's end. The straight segment of the canal measured 11 mm, resulting in a total canal length of 16 mm. To enable file monitoring and replacement, a segment of the canal was intentionally left open and secured with a glass piece fastened by two hand screws.

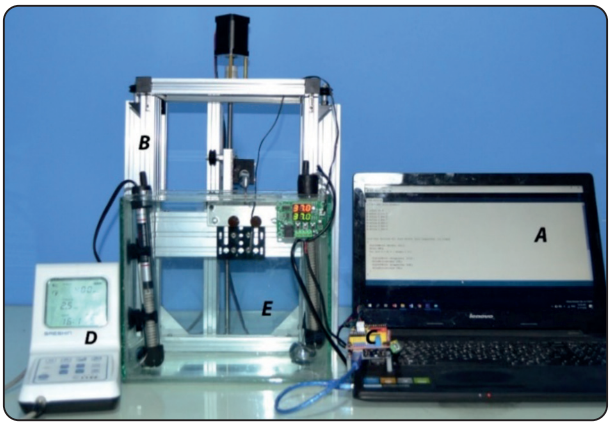

Fig. (1) Cyclic- fatigue assessment apparatus, 1: customized code, 2: Customized cyclic-fatigue device, 3: Arduino UNO & shield, 4: Endo-motor, 5: Customized water immersion bath

Fig. (2) The Simulated canal

Instruments analysis by DSC (differential-scanning calorimety):

3 brand new files from each category of the used file systems underwent assessment via DSC, encompassing scans from about 60 degree Celsius to 0 degree Celsius, to ascertain the file's phase at various thermal degrees and conversion points.

A temperature regimen, comprising 2 heating ramps and 1 cooling ramp commencing from room temperature, with a heating/cooling rate of 10°C per minute under a nitrogen atmosphere at a flow rate of 20mL/min, was implemented. The files were initially heated from 37°C (room temperature) to 60°C, then started cooling process to 0°C to generate the cooling curve, followed by reheating to 60°C to produce the heating curve. The initiation and completion points for martensitic transformation (Ms, Mf) and the reverse transformation of austenite (As, Af) were also identified.

RESULTS

Following the collection, tabulation, and statistical analysis of the data, the various tests produced the subsequent results.

Cyclic fatigue results

HyFlex CM demonstrated notably superior cyclic fatigue resistance compared to Fanta and Soco files under body & room temp. Soco files exhibited least cyclic fatigue strength in body & room temp. The analysis of cyclic fatigue was conducted by determining the time until file fracture, revealing a temp. Effect (between body & room temp.) on the cyclic fatigue strength of both Fanta and Soco files, while no clear impact of thermal changes on the cyclic fatigue strength of HyFlex CM files was observed.

TABLE (1) Effect of temperature on time to fracture:

	Room	Body	P-Value
Hyflex	39.074 ±1.234 [a]	38.464 ±1.518 [a]	0.505
Fanta	22.866 ±1.404 [a]	19.222 ±0.909 [b]	0.01
Soco	20.650 ±0.720 [a]	17.802 ±0.707 [b]	0.00

Means that don't share same letter in same column are significantly different.

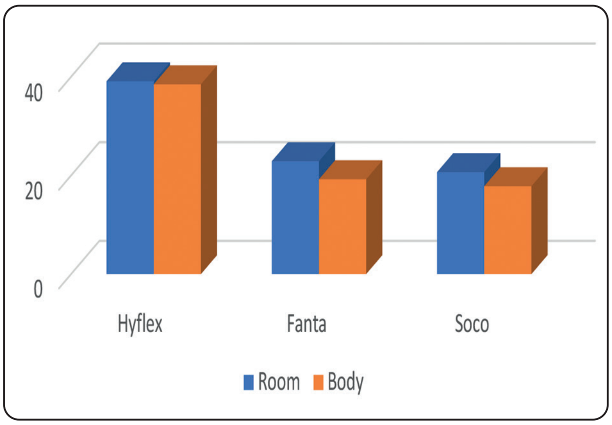

Fig. (3) Hyetography showing the effect of temperature on the Time to fracture

Differential scanning calorimetry

The DSC curves of the three rotary files exhibited a solitary endothermic peak during cooling and another during heating within the assessed temperature spectrum. Hyflex CM files displayed an Af higher than body temperature, whereas Fanta and Soco files demonstrated an Af lower than body temperature, as indicated by the average data in Table (2). The endothermic and exothermic peaks observed in Soco and Fanta files signify the transition between the martensitic and austenitic phases. Conversely, in Hyflex CM, these peaks denote the change between the R-phase and austenitic phase.

While there is a statistically significant difference between Ms of Fanta and Soco file with the higher value for Soco file, there is no statistically significant difference between Mf of both files.

For As there is no statistically significant difference between Fanta and Soco files while there is a significant difference between Hyflex CM and the other two files. With the highest value for Hyflex CM.

For Af there is a statistically significant difference between the three files with the highest value for Hyflex CM.

TABLE (2) Phase transformation temperatures

	Ms	*Mf*	*Rs*	*Rf*	*As*	*Af*
Hyflex CM	-	-	44.813 ±0.0882	35.253 ±0.237	44.393 ±0.276 [b]	53.0267 ±0.0503 [c]
Fanta	20.6 ±0.2 [a]	19.253 ±0.199 [a]	-	-	26.6633 ±0.1305 [a]	31.2233 ±0.1222 [a]
Soco	25.08 ±0.1044 [b]	19.17 ±0.0721 [a]	-	-	26.867 ±0.215 [a]	34.670 ±0.257 [b]
P-value	<0.05	0.532	-		<0.05	<0.05

Means that don't share same letter in same column are significantly different.

DISCUSSION

Chinese files are extensively utilized in our dental profession, primarily by General Practitioners due to cost-effectiveness. However, concerns regarding the quality of these files necessitate an examination of their properties and behavior. While employing files from reputable companies known for high quality is preferred, investigating the cyclic fatigue resistance and the martensitic and austenitic phases at both body & room temperature for 2 widely distributed Chinese files (Fanta and Soco files) becomes imperative. HyFlex CM serves as a benchmark due to its status as one of the ideal files regarding cyclic fatigue strength. A size 25 file from each system is selected, given its prevalence among Chinese files in use.

A model employed by Arias et al. [21] for cyclic fatigue testing, utilizing stainless-steel pins, suffers from the drawback of varying trajectories for each file. An alternative model, utilized in other studies [10][11], involves an artificial canal machined within a stainless-steel block.

In this study, aiming to replicate the clinical environment, we employed a simulated canal model. The canal was manufactured to match the size & taper of the file, ensuring an appropriate trajectory. To enable unrestricted rotation of the file within the model canal, the canal depth was designed to exceed the file's max. diameter by 0.02 cm. The canal was manufactured from stainless steel to maintain consistency and prevent wear, thus ensuring uniform trajectories for all of the files. A cover from glass atop the Stainless-Steel block allowed for visualization of the rotating instrument while maintaining precise and repeatable conditions, given glass's superior wear resistance compared to Ni-Ti files. The model featured a curvature angle of 90-degree and a curvature radius of 5mm, creating very challenging conditions for evaluating rotary files' cyclic fatigue resistance

The curvature and angle of the canal can influence the cyclic fatigue strength of rotary files [23,24]. The parameters of the model canal utilized in this research were determined utilizing the Pruett-method [8] ensuring uniformity in the trajectories of all of the files within it.While a static model may facilitate the precise confinement of instruments to an exact trajectory, a dynamic model closely mimics clinical scenarios [10,20]. Studies employing dynamic models have observed a wide range of movement amplitudes, ranging from 1mm to 5mm. While an increase in movement amplitude enhances cyclic fatigue resistance [9], clinical guidelines recommend limiting shaping to 1-3mm within the canal. So, this study used a dynamic model with a 1.5mm amplitude was employed to replicate the up&down motion typically used in the clinical situation. Files were only used in continuous rotation mode. The automatic reverse mode was disabled in order to lessen the influence of motion on cyclic-fatigue strength.

Considering that the study's thermal conditions can impact the cyclic fatigue resistance of files [12,18], so that the cyclic fatigue strength test was conducted at room & body temp. This aimed to emulate the clinical condition at body temperature, in addition to assessment of the temperature impact on all files. Two models were utilized for the test conducted at body temp. The first model utilized a temperature-controlled oven [14], while the second model, bath of water was also employed [19]. Despite the apparent precision of the oven model in maintaining testing environment temperature, the water bath model appears to closely resemble clinical conditions where instruments interact with the irrigant.

The majority of cyclic fatigue studies operators relied on a digital chronometer for time recording[11,17], yet the human element poses a significant drawback to this approach. Arias et al. devised an alternative calculation method by integrating the simulated canal and stopwatch into an electric circuit. This innovative approach ensures precise time recording as the circuit discontinues upon file fracture[21]. However, this method cannot be employed within a water bath due to water causing the electric circuit to remain closed continuously. Hence, in this study, operators utilized a digital chronometer for time recording purposes.

A specialized apparatus facilitated the dynamic cyclic fatigue test. Twenty files from each system were employed, with ten utilized at 37°C (body temp) and the remaining ten at 25°C (room temp.). Within the cyclic fatigue device, the instrument rotated freely within a st.st. simulated canal, experiencing an axial movement with a 3mm amplitude (1.5mm) up & (1.5mm) down. Duration time until file fracture was recorded.

DSC analysis involved evaluating a sample weighing between 10 to 15 grams for each instrument. The analysis encompassed a temperature range spanning from 0°C to 60°C.

The findings indicated that HyFlex CM exhibited the highest fatigue resistance, followed by Fanta Files, with Soco Files displaying the lowest resistance. Conseqently, Temperature did not influence cyclic fatigue resistance of Hyflex CM files, while there was a significant effect on Soco and Fanta Files. The results might be attributed to the presence of martensitic phase and R phase in both body and room temperature in Hyflex CM files that has been discovered after DSC test which revealed presence of AF temperature in values higher than both body and room temperatures. On the other hand Fanta and Soco files have the martensitic phase only in room temperature not in body temperature which has been revealed in DSC test reflecting lower values of AF temperature than body temperature[13,15,16,21,22].

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