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The effect of temperature change on the cyclic fatigue resistance of Three Rotary Nickel Titanium instruments with different Heat Treatment

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Abstract

Aim

This manuscript aimed to compare the cyclic fatigue resistance of the RaCe, 2Shape, and M-pro instruments at room (22°C) and body (37°C) temperatures and to investigate their phase transformation.

Materials and methods

A total of 60 files #25 .06 of the RaCe, 2Shape, and M-pro instruments were selected. A dynamic cyclic fatigue testing device with a custom-made stainless-steel canal was used that had 60° and 3mm radius of curvature. Files were divided into three groups (n=20). Each group was subdivided into 2 subgroups according to the temperature during the test: SubgroupA (room temperature 22±0.5°C) and SubgroupB (body temperature 37±0.5°C). Samples were rotated continuously in an axial motion until fracture occurred then number of cycles to fracture (NCF) was calculated. Five test specimens of each file type size 25/.06 were investigated using differential scanning calorimetry.

Results

The 2Shape file showed the highest cyclic fatigue resistance followed by the M-pro file and the least was the RaCe file. in subgroup A, there was a significant difference between the three files. in subgroup B, the 2Shape file and the RaCe file were significantly different but there was no significant difference between the 2Shape and the M-pro.

The rise in temperature was accompanied by a decrease in the cyclic fatigue resistance of the RaCe and the 2Shape files. While there was an insignificant decrease in the M-pro file.

Conclusion

The 2Shape has the highest cyclic fatigue resistance among the tested instruments. The environmental temperature plays a key role in the fatigue behavior.

Keywords Cyclic fatigue, RaCe, 2Shape, M-pro, Differential scanning calorimetry

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Introduction

The goal of biomechanical preparation of the root canal is removing all the root canal content. This is achieved by enlarging and shaping the canal to allow enough space to introduce the irrigants for cleaning the root canal with the preservation of its anatomy. During the last decade, the use of nickel-titanium (Ni-Ti) rotary instruments in the preparation of the root canals has become popular. Owed to the super-elastic behavior of Ni-Ti material, Ni-Ti instruments are highly flexible and efficient in root canal preparation following the original root canal path. The fracture of Ni-Ti files is a continuous challenge to the clinicians and usually occurs through two mechanisms: torsional failure and cyclic fatigue (1). Usually, torsional failure occurs when the stress exceeds beyond the file's elastic limit. While cyclic fatigue failure occurs due to repetitive compression and tension stresses at the point of maximum curvature in the canal (2).

Thermomechanical processing and heat treatment are essential methods to control the transformation temperatures of the Ni-Ti files that improve the flexibility and the fatigue life of the Ni-Ti instruments (3,4).

RaCe files (FKG Dentaire SA, Switzerland) a conventional super-elastic file. Electrochemical treatment of RaCe file improves resistance to torsion and metal fatigue.

2Shape files (Micro-Mega, Besancon, France) is a file system manufactured from T-wire a novel heat treatment which is declared by the manufacturer, to enhance both flexibility and cyclic fatigue resistance (5).

M-pro files (IMD, Shanghai, China) are Ni-Ti instruments made of X wire, a CM alloy with a special heat treatment to enhance strength and flexibility (6).

Cyclic fatigue has been tested at room temperature traditionally. However, these studies did not consider the novel alloys which have temperatures of transformation much higher than those presented by conventional austenitic materials (7) that may transform below or close to body temperature (4).

So, this study was conducted to evaluate the effect of temperature change on the cyclic fatigue resistance of the RaCe, 2Shape, and M-pro rotary Ni-Ti instruments. It was hypothesized that there will be difference in the cyclic fatigue resistance of the tested Ni-Ti instruments with the temperature change.

Materials and methods

Cyclic fatigue test

Total of 60 files #25 .06 of the RaCe, 2Shape and M-pro instruments were selected for the test. Cyclic fatigue testing was done using a dynamic cyclic fatigue testing device designed and described by Elwakeel (8) along with a custom made artificial stainless-steel canal that had 60° and 3mm radius of curvature submerged in a water bath filled with water. There were three groups divided according to the file type (n=20). Each group was divided into 2 subgroups regarding the temperature during the test: Subgroup A (room temperature 22 ± 0.5°C) and Subgroup B (body temperature 37 ± 0.5°C). Samples were rotated continuously in an axial motion 3mm/second until fracture in the artificial canals then number of cycles to fracture (NCF) was calculated.

Two-Way ANOVA, One-way ANOVA followed by Tukey HSD post hoc and Independent t tests were performed for the statistical analysis.

Differential Scanning Calorimetry

The DSC test was done in Yousef Jameel Science and Technology Research Center at the American University in Cairo. Five test specimens of each file type size 25 .06 were evaluated. Each file was cut into segments of approximately 3-5 mm in length. Thereafter, the file segments were sealed into 40 µl aluminum crucibles. An empty 40 µl aluminum crucible used as an inert control specimen for the DSC measurements. Both crucibles were cooled to 0°C then heated form 0°C to 50°C and subsequently cooled from 50°C to 0°C in the differential scanning calorimeter (PERKINS ELMER, USA). DSC thermogram graphs were analyzed by computer software (Universal V4.5A TA instruments) to obtain the phase transformation onset temperatures, along with the enthalpy changes (ΔH) accompanying these processes.

Results

Cyclic fatigue test

Mean and standard deviation (SD) values of different file types at two different temperatures were presented in table (1) and figure (1).

File type	RaCe	2Shape	M-pro	P-value
Temp.	Mean ± SD	Mean ± SD	Mean ± SD	
Room temp.	85.11± .66796	192.1180 ± 9.79285	127.3500± 1.73807	0.001*
Body temp.	68.4700± .27420	136.8860 ± 22.77172	115.3500± 2.64896	0.001*
P-value	0.001*	0.0001**	0.281^{NS}	

Table (1): Mean ± standard deviation (SD) of different file types at two different temperatures.

The results illustrated that in subgroup A, the NCF values of the three tested files were statistically significantly different, where the 2Shape file showed the highest fatigue resistance followed by M-pro files and the RaCe instruments had the least resistance. While in subgroup B, the statistical analysis demonstrated that NCF for the 2Shape file was significantly higher than NCF of the RaCe file. However, there was no statistical difference between the 2Shape and the M-pro file. The effect of temperature increase on each file showed that there was a statistically significant decrease in the NCF of the RaCe and the 2Shape files while the decrease in the NCF of the M-pro files was insignificant.

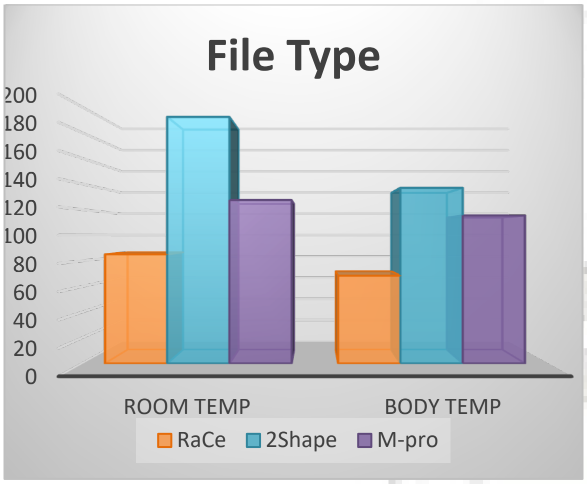

Figure (1): Bar chart showing Mean ± standard deviation (SD) of different file types at two different temperatures.

Differential scanning calorimetry

For the DSC curves (Figure 2), the RaCe and the 2Shape illustrated no phase transformation in the temperature range evaluated in this study. While M-pro revealed a single endothermic peak on the heating curve, with an onset temperature (A_s) of 35.77°C, Austenitic finish temperature (A_f) 46.52°C and an enthalpy change (ΔH) of 1.676 J/g, corresponds to the Ni-Ti martensitic/austenitic transformation.

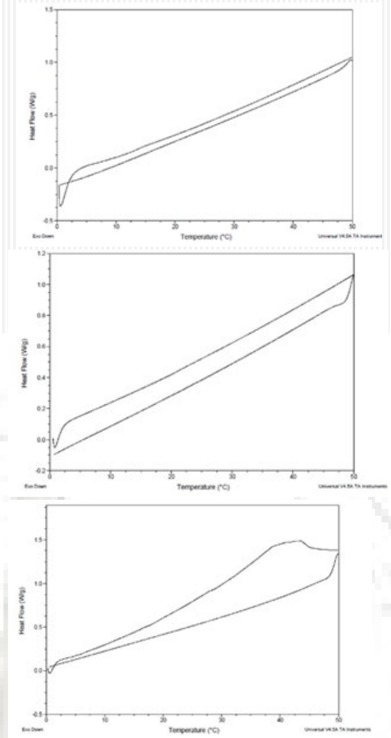

Figure (2): DSC curves for the RaCe, 2Shape and M-pro files respectively.

Discussion

Ni-Ti rotary instruments have become a fundamental mechanical preparation tool owed to their flexibility and memory shaping (9). Ni-Ti rotary files provide the operator with less time and a reduced number of instruments used. On the contrary, rotary sudden fracture with no previous signs apparent on the instrument presented as a new complication. The life span of an instrument is a major factor affecting the favorability of a system over another. Sudden breakage of Ni-Ti instruments usually occurs due to cyclic fatigue or torsional fracture or both (1,10). Cyclic fatigue happens due to alternating cycles of tension and compression on a rotating instrument when flexed in the region of the maximum curvature of the canal (11,12). Torsional fracture takes place when the instrument gets engaged in a canal while its shank continues rotating. When handpiece torque exceeds the metal's elastic limit, instrument fracture becomes unavoidable (2).

Heat treatment of rotary Ni-Ti instruments is a commonly used method for fatigue resistance enhancement. Two contemporary rotary Ni-Ti systems have been introduced to the market recently, 2Shape files produced from (T-wire) heat-treated alloy and M-pro files produced from (CM-wire). The manufacturers claimed that they have enhanced the instruments' flexibility and resistance to cyclic fatigue (5,6).

The results of the present study illustrated that generally, the newly developed 2Shape file revealed enhanced resistance to cyclic fatigue that could be related to the heat-treated alloy (T-wire) that might have improved the fatigue resistance. It had been suggested that thermal processing increased the Ni-Ti alloy austenitic transformation temperature (13) and enhanced the crystal structure arrangement improving the instrument performance (14). This is in agreement with the study of Elnaghy and Elsaka (15) which is the only article that could be found comparing the resistance to cyclic fatigue of 2Shape instruments to super-elastic Ni-Ti instruments.

The RaCe file presented the least mean NCF. This finding agreed with the previous studies (3,15–17). It could be attributed to the austenite composition of super-elastic Ni-Ti alloys during clinical use because most super-elastic Ni-Ti files possess austenite finishing temperature at or below room temperature, while the controlled memory files have austenite finishing temperature above body temperature. The austenite phase is less resistance to flexural cyclic fatigue than the martensite phase due to the decreased flexibility presented by the austenitic phase (14).

At the room temperature, the 2Shape file showed the statistically highest NCF followed by M-pro and RaCe files respectively. These results agree with those reported by El feky et al. (18) the only study available in the literature that compared the resistance to cyclic fatigue of the M-pro file and the RaCe file. As well as Shen et al. (19), Chang et al. (20), AlShwaimi (21), and Karataşlıoglu et al. (22), who reported that rotary instruments manufactured from CM-wire with thermomechanical treatment presented higher resistance to cyclic fatigue than other super-elastic instruments.

While at the body temperature the 2Shape showed the highest NCF and, it was significantly different from the RaCe files but there was no significant difference between the 2Shape and the M-pro files.
On the other hand, the effect of temperature change on the fatigue life of the three files showed that the rise in the temperature is accompanied by a decrease in the resistance to cyclic fatigue of the RaCe and the 2Shape files. While it caused insignificant decrease in the resistance to cyclic fatigue of M-pro.
This might be explained based on the metallurgical properties of the endodontic instruments. For the RaCe file the decrease in fatigue resistance can be attributed to the presence of impurities and work hardening which cause excessive pile up of dislocations and other crystal imperfections (23). While for the 2Shape and the M-pro files, martensitic instruments at room temperature are transformed to a more austenitic phase upon heating, thus decreasing their cyclic fatigue resistance (24).

Conclusion

With the limitation of the present study it was concluded that 2Shape had the highest fatigue resistance among all groups. The temperature change affected the cyclic fatigue life of the tested instruments.

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