Role of temperature on the cyclic fatigue resistance of thermally treated NiTi files

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Abstract

***Objectives*: This study aimed to evaluate the impact of body temperature on the cyclic fatigue resistance of two NiTi rotary systems; Fanta Rising (FR; Fanta Dental Materials, China) and FKG Race Evo (REV; FKG Dentaire, Switzerland).**
***Methods*: A total of 60 instruments were divided into two groups (n=30 per group) based on the instrument type REV (25/04) and FR (25/04) and then divided into two subgroups according to testing temperature (room and body temperature). The tests were performed using a custom-made stainless-steel artificial canal with a 120° angle and a 5-mm radius of curvature. Instruments were rotated continuously until fracture occurred. Time to fracture (TTF) and number of cycles to fracture (NCF) were recorded for all groups. Statistical analyses were conducted using one-way ANOVA and Tukey's post hoc tests for intergroup comparisons, and an unpaired t-test for intragroup comparisons.**
***Results*: The cyclic fatigue tests revealed that the FR exhibited significantly higher TTF and NCF values compared to the REV ($P < 0.05$). There were no significant difference in TTF and NCF at body temperature compared to room temperature ($P > 0.05$).**
***Conclusions*: The FR files demonstrated superior performance in TTF tests, likely due to its CM heat-treated wire, which enhances durability and user comfort. Body temperature did not effected TTF and NCF of tested instruments.**

Keywords: body temperature, cyclic fatigue, nickel-titanium, rising

Introduction

Nickel titanium (NiTi) instruments have become the cornerstone of modern endodontics due to their remarkable mechanical properties, which include exceptional flexibility, superelasticity, and resistance to fracture (1,2,3). These properties make NiTi instruments particularly suitable for navigating the complex and often curved anatomy of root canals, which presents significant challenges during endodontic treatment (4,5). The ability of NiTi instruments to adapt to the curvature of the canal without sacrificing mechanical integrity has revolutionized root canal therapy, reducing the likelihood of procedural errors such as canal transportation, perforation, or breakage (6). The key to this flexibility lies in the phase transformation behavior of the NiTi alloy, which undergoes a transition between two distinct phases: the austenite phase and the martensite phase. This transformation enables the instruments to exhibit superelastic behavior, allowing them to recover their original shape after being deformed, thus enhancing their performance during root canal preparation (7,8).

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The manufacturing process of NiTi instruments involves various steps, including the creation of specialized alloys designed to optimize the mechanical properties of the instrument. Over the years, different types of NiTi wires have been developed to further improve the flexibility, fatigue resistance, and torsional strength of endodontic instruments (9,10). While much of the research on cyclic fatigue resistance has been conducted at room temperature, this does not fully replicate the clinical conditions under which NiTi instruments are used (11). In vivo, the temperature inside the root canal increases during treatment, primarily due to the use of irrigants, such as sodium hypochlorite, and the exothermic reaction associated with certain endodontic materials (12). Body temperature typically ranges from 36.5°C to 37.5°C, and this rise in temperature can significantly alter the mechanical properties of NiTi instruments. Studies have shown that body temperature can influence the phase transformation behavior of NiTi alloys, potentially affecting the flexibility and fatigue resistance of the instruments (13,14). In particular, NiTi alloys are known to exhibit different characteristics when subjected to varying temperatures.

The **Fanta rising** (FR; Fanta Dental Materials, China) file system is recently launched with a special tip design that can easily create an apical stop. Thus, it aimed to create an area for general dentists to get cone fit. It has a special heat treatment and variable cross section to increase the performance of file (15). It is a rotary sytem that can shape the root canal system with sequenced files; RR(coronal flaring), R1 (glide path), R2,R3, R4 (finishing). RACE EVO (REV) (FKG Dentaire SA, La Chaux de Fonds, Switzerland) is a file system for shaping root canal system minimally. It has a triangular cross sectional design and alternating cutting edges. It is enhanced formed of the former version RaCe regarding electroplishing (16). It has high flexibly and cyclic fatigue resistance. There are studies done with RACE EVO sytem but not with new lounched Fanta AF Rising system. The FKG Race Evo system is characterized by its use of a proprietary heat treatment process that enhances the fatigue resistance and torsional strength of the instrument The aim of this study was to evaluate the effect of body temperature on the cyclic fatigue resistance of these two rotary systems. The null hypotheses of this study that there would be no differences in cyclic fatigue resistance between instruments at room and body temperatures.

Materials and methods

Cyclic fatigue testing

Sample size was calculated using G*Power v3.1 software, with a significance level (α) set at 0.05 and a power (1-β) of 0.95. Before testing total of 60 instruments (30 FR and 30 REV Files) were inspected for defects under a stereomicroscope (**Carl Zeiss ZEISS Axio Zoom.V16)** at a magnification of ×20. This step was crucial to identify any structural flaws such as bends, cracks, or any other imperfections that could influence the testing outcome. None of the instruments were discarded.

Testing conditions

Two distinct temperature conditions were implemented to simulate the temperature variability encountered during clinical endodontic procedures:

1. **Room Temperature**: The instruments were tested at 20° ± 1°C, which was maintained using **deionized cooled water**. Room temperature testing has been a standard method in previous studies on NiTi fatigue resistance, allowing for a baseline comparison of instrument performance in a controlled environment.
2. **Body Temperature**: The instruments were also subjected to body temperature, set at 37° ± 1°C water as shown in **Figure 1**. This was achieved by using an aquarium thermostat specifically designed for precise temperature control. A thermometer was used to know and adjust the temperature, ensuring stability during the entire testing period.

Each system was subjected to specific rotational parameters that reflected the manufacturer's recommendations (15,16) and typical clinical usage. These parameters were designed to replicate the rotational speed and torque that would typically be applied during root canal preparation:

- **FR**: The Fanta Rising 25/04 files were tested at a rotational speed of 450 rpm, with a torque setting of 2.5 N·cm.
- **REV**: The FKG Race Evo 25/04 files were tested at a rotational speed of 800 rpm, with a torque of 1.5 N·cm.

Both instruments were tested individually by an experienced endodontist in a **stainless-steel artificial canal** with a **60° angle of curvature** and a **5-mm radius of curvature**.

Measurement of cyclic fatigue

The **Time to fracture (TTF)** was the primary outcome measure of this study, recorded using a **digital chronometer** to ensure precise measurement of the time until each instrument fractured. The TTF represents the time each instrument took to reach failure under the cyclic stress imposed by the testing conditions. The **Number of cycles to failure (NCF)** was subsequently calculated by multiplying the TTF by the number of rotations per second (rps) for each instrument. This metric provides a standardized measure of the fatigue life of the instruments under both room and body temperature conditions.

Statistical analysis

The data analysis was conducted with non-parametric methods by SPSS software version 15 software (IBM, USA). The normality and homogeneity of variance were controlled by One- Sample Kolmogorov-Smirnov, Shapiro-Wilk and Levene's tests. The differences between groups were analysed by Mann-Whitney U or Kruskal Wallis tests for inter-group comparison at the two temperatures tested and for intra-group comparison at different temperatures. All statistical analyses were performed using a significance level of $P < 0.05$, which is commonly accepted in scientific research to determine statistical significance. This

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threshold ensures that the differences observed are unlikely to be due to chance and that the conclusions drawn are meaningful.

Results

The mean and standard deviations for TTF and NCF at both temperatures are presented in Table 1, Figure 2, and Figure 3. No significant difference was detected among the groups regarding the fractured fragment lengths ($P > 0.05$). FR demonstrated significantly higher TTF and NCF values than REV at both temperatures ($P < 0.05$). However, it was concluded that the NCF and TTF of both groups were not affected by the temperature ($P > 0.05$).

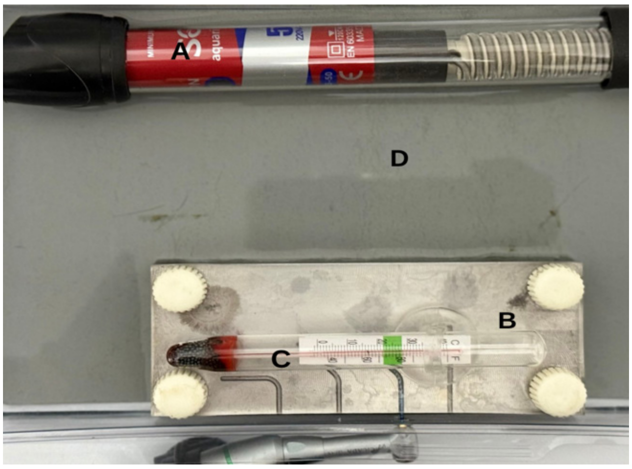

Figure 1. Test setup A) Aquarium termometer. **B)**Termometer. **C**) Stainless-steel testing device. **D)**Water.

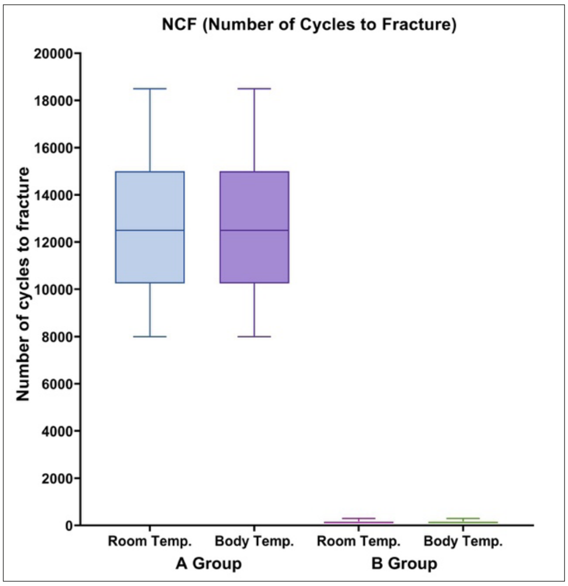

Figure 2. NCF values in different temperatures. Group A (FR files), Group B (REV Files

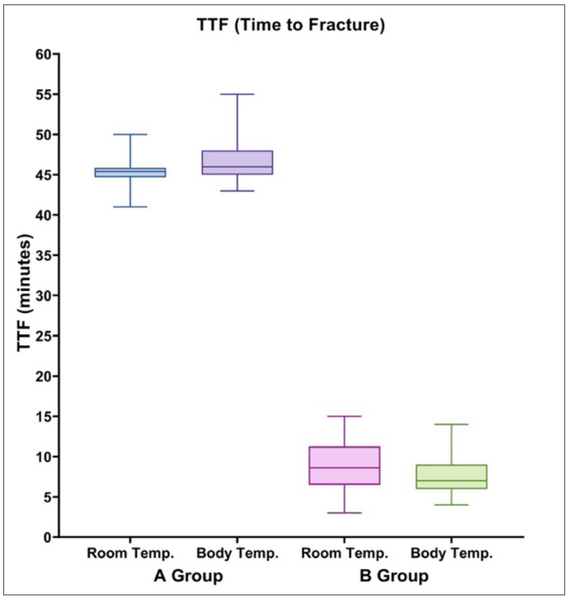

Figure 3. TTF values in different temperatures. Group A (FR files), Group B (REV Files)

Table 1. The mean and standard deviations for TTF and NCF at both temperatures

Groups	TTF				NCF			
	RoomTemp		BodyTemp		RoomTemp		BodyTemp	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
FR	45.08 ^{a,A}	1.61	46.56 ^{a,A}	2.52	12878 ^{a,A}	2943.00	12878 ^{a,A}	2943,00
REV	8.94 ^{b,A}	2.96	7.92 ^{b,A}	2.37	147.72 ^{b,A}	45.35	147.42 ^{b,A}	46.19

SD, standard deviation
Different superscript lowercase letters in columns represent significant differences among the groups ($P < 0.05$).
Different superscript uppercase letters in raw represent significant differences of the instruments in different temperatures ($P < 0.05$)

Discussion

Cyclic fatigue remains one of the most critical factors influencing the mechanical failure of nickel-titanium (NiTi) instruments in clinical practice. It occurs when an instrument is subjected to repetitive compressive and tensile stresses, particularly in curved canals, where bending stress is unavoidable (17,18). Cyclic fatigue resistance tests are done to understand the limitations of the files during clinical usage with on prepared setups. In the present study, FR had significantly higher cyclic fatigue resistance than REV files. TTF and NCF values higher than REV at both temperatures ($P < 0.05$). However, it was concluded that the NCF and TTF of both groups were not affected by temperature ($P > 0.05$).

Test set up parameters of this study were selected to closely simulate the anatomical conditions typically encountered in endodontic treatments. The use of an artificial canal is standard in fatigue testing to ensure reproducibility and control over the experimental conditions. The curvature of the canal was chosen to reflect challenging root canal anatomy, which is often present in clinical cases (17, 18, 19).

The enhanced performance of the FR instrument in time-to-fracture (TTF) tests is noteworthy and can be attributed to its Controlled Memory (CM) heat-treated wire. Heat treatment has been shown to significantly enhance the flexibility and fatigue resistance of NiTi instruments (2,3,4). CM wires exhibit a greater ability to absorb and distribute stresses due to their improved superelastic properties. This reduces the risk of microcracks and subsequent failure during prolonged use in curved canals. Additionally, this flexibility allows for safer navigation of complex canal anatomies, minimizing procedural errors such as canal transportation or ledging.

This study highlights the importance of ongoing advancements in NiTi instrument design and manufacturing. The interplay of material science, thermal processing, and geometric optimization is central to developing tools that meet the demands of modern endodontics. The use of body temperature is essential for simulating in vivo conditions that NiTi instruments experience during clinical procedures, where the root canal temperature rises due to the use of irrigants like sodium hypochlorite and the exothermic reaction of certain materials (5). This aspect shows that FR and REV file systems are safe both at body and room temperature similarly.

Several factors beyond heat treatment also contributed to the observed differences in cyclic fatigue resistance. The cross-sectional design of an instrument plays a pivotal role in stress distribution. Instruments with optimized cross-sectional geometries can better withstand cyclic loading by evenly distributing stresses across the material, reducing stress concentrations that often act as initiation sites for fractures. Similarly, taper and diameter influence the amount of metal mass present, which directly affects the flexibility and stress-handling capacity of the instrument. For these reasons the instruments with the same taper and tip (25/04) were compared in the current cyclic fatigue test. Also both instruments are working with rotation. The FR instrument appears to have an optimal combination of these features, making it more resilient to cyclic fatigue under clinical conditions. Both systems represent advanced technologies in the field of NiTi rotary instruments and are known for their superior flexibility and fatigue resistance. The REV system is characterized by its use of a proprietary heat treatment process that enhances the fatigue resistance and torsional strength of the instrument. The FR system, on the other hand, incorporates a unique thermomechanical treatment that further improves the instrument's flexibility and resistance to fracture. REV used at higher speed is characteristic of FKG's design, which aims to optimize the cutting efficiency and speed of the instrument while maintaining a balance between torque and flexibility. This setting was chosen based on the system's recommended specifications and its design, which incorporates an enhanced cutting ability with a reduced risk of instrument fracture.

Recent studies have underscored the importance of temperature in influencing the cyclic fatigue resistance of NiTi rotary instruments. For instance, Dosanjh et al. (10) investigated the effect of elevated temperatures on the cyclic fatigue behavior of NiTi instruments and found that exposure to body temperature resulted in a significant reduction in fatigue resistance compared to room temperature testing. Similarly, Jamleh et al. (12) examined the performance of NiTi instruments at different temperatures and found that the instruments showed considerable variation in their cyclic fatigue resistance, with those tested at body temperature exhibiting reduced performance. These findings suggest that the use of elevated temperatures in laboratory testing may provide a more realistic assessment of the instruments' clinical performance, as the conditions under which the instruments are exposed to cyclic stress are more closely aligned with the actual conditions in vivo (13). When NiTi instruments are exposed to higher temperatures, the phase transition between austenite and martensite may be accelerated, altering the stiffness, flexibility, and overall mechanical behavior of the instrument (14,15,16,17). On the contrary of this knowledge, in this study temperature did not statistically effected TTF and NCF values. These findings play a critical role in selecting the appropriate systems for endodontic applications. By utilizing both room and body temperature conditions, the study sought to compare the fatigue performance of the instruments in more realistic clinical scenarios, providing insights into how temperature variations affect the instruments' cyclic fatigue resistance (18) Notably, the alloys of FR and REV files are less affected by operational temperatures, as their austenitic transformation temperatures are above body temperature (19, 20). Consequently, their performance under body temperature conditions remains consistent, showing no significant difference compared to their performance at standard room temperature. These conclusions align with findings from previous studies, which demonstrated that cyclic fatigue resistance is significantly affected by both kinematics and operational temperature, especially for alloys with transformation

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temperatures below or above body temperature (21).
While the results are promising, certain limitations should be acknowledged. This study was conducted in a controlled laboratory environment, which may not fully replicate the dynamic conditions of the root canal system in vivo (22). Factors such as canal curvature, dentin hardness, and operator technique can further influence instrument performance. Future studies should aim to evaluate the behavior of NiTi instruments in simulated clinical scenarios or in vivo models to provide a more comprehensive understanding of their performance (23, 24).
Within the limitations of this study; Rising system exhibited higher TTF values compared toREV, indicating greater durability. Future studies should explore additional factors, such as cross-sectional design and rotational kinematics, to further optimize NiTi instrument performance (25,26,27).

Ethical Considerations

The study adhered to ethical guidelines for scientific research, ensuring that all procedures were performed in accordance with establish ed protocols according to Helsinki ethical declarations.

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