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The effect of cooling Reciproc instruments prior to preparation on cyclic fatigue resistance at simulated body temperature

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Purpose: This study aimed to examine the effect of cooling Reciproc endodontic files prior to preparation on their cyclic fatigue life at simulated body temperature.

Methods: Sixty-four Reciproc R40 files were randomly split into 4 groups (n = 16), as follows: control, cooling at –50°C, cooling at –16°C, and cooling at –80°C groups. The files were used in a simulated metal canal with a curvature of 90° and a radius of 3-mm. The metal block was submerged in a water tank adjusted to a temperature of 37°C. The time to file fracture and the length of the broken fragment were measured and recorded. The data were analyzed using a Kruskal–Wallis H test.

Results: The time to fracture was significantly lower in the control group compared to the cooling groups ($p< 0.05$). No differences in the time to fracture ($p> 0.05$) were observed between the cooling groups, and all groups exhibited similar length of the fractured fragments ($p> 0.05$).

Conclusion: Within the limitations of this study, it can be concluded that cooling Reciproc R40 files using different methods prior to preparation improves its cyclic fatigue resistance.

Keywords: Cooling, cyclic fatigue, Reciproc.

Introduction

File fracture during root canal treatment is a common problem encountered by dentists (1–3), with clinical incidence rates ranging between 0.9%–21% (3–6). Nickel-titanium (NiTi) endodontic files, first introduced by Walia et al. (7) in 1988, are the most popular choice among endodontists and general dentists globally (8–10) due to their favorable mechanical properties such as ease of use and super-elasticity. However, unexpected breakage of NiTi instruments still occurs, motivating manufacturers to experiment with different manufacturing methods and thermal processes to address this issue (1,2).

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The mechanical features of NiTi alloys are affected by the quantity and characteristics of its two stable austenite and martensite phases, observed at higher and lower temperatures, respectively (11). Transformation between these two phases is characterized by a change in the crystalline structure only, and no changes in the chemical content of the alloy are observed. However, the transformation temperature may vary depending on the chemical content of the alloy (11). The martensitic phase of NiTi alloys is more ductile compared to the austenitic phase as the alloy is softer at lower temperatures and more rigid at higher temperatures (12). This suggests that the application of higher or lower temperatures may change the crystal configuration of the alloy, resulting in phase transformation. The martensitic phase also improves the alloy's damping features (i.e., its resistance to cracking due to fatigue) and, therefore, extends the cyclic life of the file (13). Miyai et al. (14) showed that the phase transformation temperatures of NiTi alloys affected the mechanical properties of the endodontic files.

Cooling of NiTi instruments prior to usage may encourage transformation to the martensitic phase, thereby affecting their cyclic fatigue life. To the best of our knowledge, no studies till date have investigated the effects of cooling Reciproc files prior to usage on their cyclic fatigue life. Therefore, the current study aimed to study the effects of cooling endodontic files prior to preparation on their cyclic fatigue life using Reciproc R40 instruments at simulated body temperature. The null hypothesis was that the different cooling groups and the control group would exhibit statistically similar cyclic fatigue life.

Materials and Methods

A pilot study using 28 Reciproc R40 (VDW, Munich, Germany) instruments was carried out prior to commencement of the main study. The metal block of the custom-made device used to test cyclic fatigue was immersed in a water tank (Julabo, Seelbach, Germany) adjusted to a temperature of 37°C ± 1°C during testing (15). A canal with a radius of 3 mm and a curvature of 90° was simulated in the metal block for file application, and the temperature of the artificial canal was confirmed using a thermocouple (Fig. 1). The Reciproc files were applied using an endodontic motor (VDW Silver; VDW), and a glass was used to prevent them from slipping out of the simulated canals. The instruments were randomly split into four groups (n = 7), as follows:

Control group: R40 instruments were used without cooling.

Cooling at −50°C (cold spray) group: A dichloro-difluoromethane-based cold test (Endo-Frost, Roeko, Langenau, Germany) was sprayed on the surface of the R40 file just

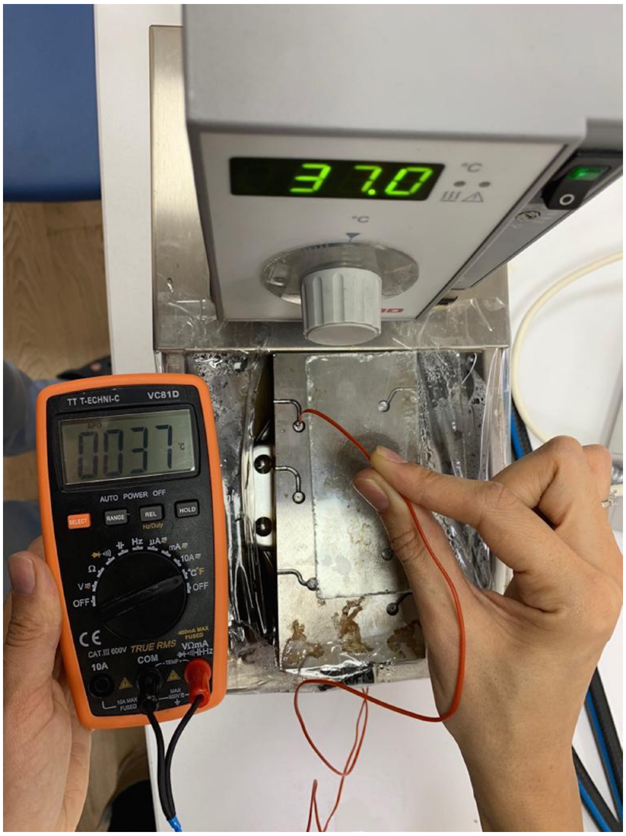

Fig. 1. Measuring the temperature of the artificial canal using a thermocouple.

prior to testing. The distance between the spray and the file was set at 10 cm.

Cooling at −16°C group: Prior to testing, the R40 instruments were stored at –16°C in a freezer overnight, and were removed one by one just before use.

Cooling at −80°C group: Prior to testing, the R40 files were stored at –80°C (New Brunswick Scientific, New Brunswick, Canada) in a freezer overnight, and were removed one by one just before use.

The time to file fracture was recorded in seconds, and the length of the broken fragment was measured in millimeters.

Analysis of the data from the pilot study showed an effect size of 7.070. The power analysis showed that a total of 8 samples would be sufficient to achieve a study power of 0.95. However, a worst-case scenario approach was adopted and the actual study sample consisted of 64 instruments (n = 16 per group), with 36 more instruments being added to the original 28 (9 instruments in each group) used in the pilot study.

Statistical Analysis

A Kruskal–Wallis H test was used to compare the groups, and all statistical analyses were performed using SPSS ver-

Table 1. The mean and standard deviation (SD) values for time to fracture and length of the fractured fragment (mm)

Groups	Time to fracture (s) ± SD	Length of the fractured fragment (mm) ± SD
Control group	20.44 ± 4.77[a]	13.09 ± 0.68[a]
Cooling at –50°C	39 ± 5.53[b]	12.65 ± 0.62[a]
Cooling at –16 °C	36.25 ± 8.84[b]	13 ± 0.75[a]
Cooling at –80 °C	35.31 ± 8.97[b]	12.68 ± 0.63[a]

SD: Standard deviation. Different superscript lowercase letters in the same column indicate a significant difference in mean ($p < 0.05$).

sion 20 (SPSS Inc., Chicago, IL, USA). The statistical significance level was set at 0.05.

Results

The time to file fracture and the length of the fractured fragments have been shown in Table 1. The time to file fracture was significantly lower in the control group compared to the cooling groups ($p < 0.05$). No differences in the time to fracture ($p > 0.05$) were observed between the cooling groups, and all groups exhibited similar length of the fractured fragments ($p > 0.05$) (Table 1).

Discussion

Cyclic fatigue failure often results in breakage of NiTi endodontic files (3, 16). Clinically, cyclic and torsional fatigue occur simultaneously, and both of these factors can lead to fracture of the instruments (17). Various advancements in instrument design and manufacturing methods have attempted to address this issue (13) by altering the flexibility, cutting ability, and fatigue resistance of the files through thermal processes. Although several studies have examined the cyclic fatigue life of various files, there is limited evidence on the effect of cooling Reciproc instruments prior to preparation on their cyclic fatigue life. The findings of the current study showed that cooling R40 files at –80°C, –16°C, and –50°C using a cold spray improved cyclic fatigue life compared to the control group ($p < 0.05$). Therefore, the null hypothesis was rejected.

These findings could be attributed to the fact that cooling of the instruments resulted in transformation of the alloy to the martensitic phase, resulting in increased flexibility. Shim et al. (18) found that the martensitic phase finishing temperature of Reciproc instruments was –13.44°C and, therefore, the current study used temperatures lower than this for cooling and to encourage transformation to the martensitic phase. Previous studies have shown that this phase is typically associated with greater flexibility and cyclic fatigue resistance (19,20). Currently, no other studies have investigated the effects of cooling files prior to preparation on their cyclic fatigue life at intra-canal temperatures, preventing direct comparison of findings. However, Grande et al. (21) examined the influence of various environmental temperatures (room temperature and a cooled environment where a tetra-fluoroethane-based cooling spray was applied directly to the file surface before and during the test) on the cyclic fatigue life of different types of files (two conventional and three heat-treated NiTi). They reported that the cooled files exhibited better outcomes compared to those at room temperature in agreement with the current study (21). However, in contrast to Grande et al. (21) who changed the environmental temperature, the current study modified the temperature of the instrument itself as this would be more applicable from a clinical perspective.

Another key finding of the current study was that all the cooling groups exhibited statistically similar results regarding the time to fracture ($p > 0.05$), despite different temperatures being used for cooling. This could likely be attributed to similar time taken for the cooled files to regain intra-canal temperature.

The length of the fractured fragments was also statistically similar between all groups ($p > 0.05$). A 90° curvature with a radius of 3-mm was used to test all groups, and the fractures were seen to mainly occur at the center of the curvature, which was approximately 13 mm from the tip of the file. This was in agreement with previous studies that file fractures typically occurred at the center of the curvature (22,23).

The current study simulated the intra-canal temperature. Vasconcelos et al. (15) examined the influence of body and room temperature on the cyclic fatigue resistance of endodontic instruments and reported dramatically decreased outcomes upon simulation of body temperature. This was further corroborated by several subsequent studies (21,24). Therefore, in order to reflect clinical conditions accurately and report results that were applicable in a clinical situation, the current study simulated body temperature by immersing the cyclic fatigue test device in water at a temperature of 37°C ± 1°C during the cyclic fatigue test.

The current study did not compare different instrument types, and instead examined the effect of cooling using the same file type in all groups. The Reciproc file was chosen as it is not completely at martensitic phase at room temperature, thus allowing us to observe the influence of cooling and subsequent martensitic phase transformation.

Conclusion

Within the limitations of this study, it can be concluded that cooling Reciproc R40 files using different methods prior to preparation improves its cyclic fatigue resistance. Further studies are necessary in order to elucidate the phase transformation behavior pattern.

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