BASIC RESEARCH – TECHNOLOGY

Effect of MT Technology of Heat Treatment on Reciproc: Comparison of Reciproc, Reciproc Blue, and Reciproc MT

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SIGNIFICANCE

New heat treatment of Memory-Triple technology could enhance the fatigue fracture resistance of the reciprocating Reciproc file made of M-wire.

ABSTRACT

Introduction: This study aimed to evaluate the effects from the memory-triple (MT) heat treatment on the fatigue resistance of the Reciproc by comparison with the file systems of same geometry. **Methods:** Reciproc files subjected to MT heat treatment technology were designated as Group RMT and were compared with the original Reciproc (Group REC) and Reciproc Blue (Group REB). Each NiTi file from 3 groups ($n = 15$) was operated reciprocally with a repetitive up-and-down movement in the curved canal with 4 mm of pecking distance inside of the simulated canal at body temperature. When each file fractured, the time until fracture was recorded. The length of the fractured fragment was measured. Fractured fragments were observed under scanning electron microscope (SEM) to evaluate the topographic features of the surface. Differential scanning calorimetry (DSC) analysis was performed to estimate phase transformation temperatures. One-way analysis of variance and Duncan post hoc comparison were applied to compare among the groups at a significance level of 95%. **Results:** RMT showed significantly higher fracture resistance ($P < .05$), whereas there was no difference in fatigue resistance between REC and REB. SEM examination showed the files from the 3 groups had similar topographic features. RMT showed a peak of austenite peak (A*p*) at a temperature (52°C) higher than body temperature, whereas REC and REB showed A*p* at 37 and 32°C, respectively. **Conclusions:** Under the condition of this study, the new heat treatment technique of MT technology could enhance the fatigue fracture resistance of the reciprocating files made of M-wire and Blue-wire. *(J Endod 2024;50:520–526.)*

KEY WORDS

Blue-wire; cyclic fatigue resistance; fracture resistance; heat treatment; M-wire; nickel-titanium file

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0099-2399/$ - see front matter

https://doi.org/10.1016/j.joen.2024.01.020

The advent of nickel-titanium (NiTi) instruments in the field of endodontics has ushered in many advantages, including expedited preparation time, enhanced cutting efficiency, and improved capacity of centering the root canal, as compared with traditional stainless-steel hand files[1]. Because of their efficient shaping ability and flexibility, root canal preparation with NiTi files has been associated with an elevated rate of treatment success[2].

Since their introduction, NiTi alloys have consistently revolutionized the field of endodontics. Advancements in NiTi instruments over the past 2 decades have led to new design and instrumentation concepts and root canal preparation techniques for each system[3,4]. Notably, the unique design characteristics of NiTi file systems, including cutting angle and tip design, exert a discernible influence on their flexibility, cutting, cleaning efficacy, and the performance of the instruments in curved and narrow root canals[1].

However, NiTi instruments are still perceived to have a fracture risk during clinical use[5,6] and may produce significant forces on root dentin during instrumentation, which may induce a dentinal defect or apical root cracks. Several factors contribute to the propensity for fracture in rotary NiTi instruments, including variations in canal anatomy, such as merging, curving, recurving, dilacerating, or dividing canals.

Furthermore, intrinsic characteristics of the instruments themselves, such as size, taper, alloy composition, manufacturing methods, flexibility, and rigidity, can also affect the fracture resistance[7].

The modes of file fracture investigated primarily encompass torsional failure and cyclic fatigue fracture[8]. Although both failure modes likely occur simultaneously in the clinical situation, cyclic fatigue appears to be more prevalent in curved root canals. In contrast, torsional failure may happen in a straight canal. Flexural or cyclic fatigue transpires as an instrument rotates within a curved canal, inducing a repetitive cycle of compressive and tensile stresses due to the motion-induced forces.

To overcome these drawbacks, manufacturers have researched and developed new manufacturing techniques to improve the physical and mechanical properties of their instruments for better clinical performance. Because the cross-sectional configuration and longitudinal shape of a file play a crucial role in determining its mechanical properties[9,10], the primary objective has been to apply alterations to the geometry of files in order to improve the mechanical properties.

Most contemporary NiTi instruments have been made with heat-treated alloys, which increases the service life of the endodontic instruments by recovering the superelastic effect[11,12]. The heat treatment process releases the internal strain of NiTi alloy and increases the phase transformation temperature of NiTi, resulting in a higher martensite phase at clinically relevant temperatures[11,12]. The NiTi files made from M-wire (Dentsply Tulsa Dental, Tulsa, OK), R-phase heat treatment (Sybron Endo, Glendora, CA), and controlled-memory (CM) wire have shown improved cyclic fatigue resistance in comparison with conventional NiTi files[9,13,14].

In 2011, reciprocating instruments with a novel kinematic movement were developed for single-file preparation, such as the Reciproc (VDW, Munich, Germany) and WaveOne systems (Dentsply Sirona, Ballaigues, Switzerland) made from M-wire NiTi alloy. The Reciproc Blue (VDW) system maintaining the same geometry and kinematics as the Reciproc has been introduced. The Reciproc Blue instrument undergoes an innovative heat treatment (Blue-wire technology by VDW) that transforms its molecular structure. This novel system exhibits higher flexibility compared with its predecessor, along with improved resistance to cyclic fatigue fractures and a reduction in surface microhardness[15].

A company recently introduced a file system (EndoRoad; Maruchi, Wonju, Korea) for minimal invasive instrumentation concept and the company applied a novel heat treatment technique called MT (memory-triple) heat treatment. There is no scientific evidence yet about the MT heat treatment and the mechanical properties of the file made of this technique.

Therefore, this study aimed to evaluate the effects from the MT heat treatment on the fatigue fracture resistance of the NiTi file systems using files with same geometries: Reciproc, Reciproc Blue, and Reciproc treated with MT technology. The null hypothesis was that these systems possess equivalent fatigue resistances.

MATERIALS AND METHODS

Heat Treatment and Group Designation

The Reciproc system was used in this study and the size R25 was selected because of its widespread clinic use. The instruments have an S-shaped cross section and feature a progressive taper. The Reciproc R25 instrument has a diameter of 0.25 mm at the tip and an 8% taper over the first 3 mm from the tip. The diameter at 16 mm from the tip (D16) is 1.05 mm.

The new Reciproc files underwent thorough examination using an operating microscope (Pico; Zeiss, Oberkochen, Germany) and then 20 files without any visible defects or distortions were sent to the company (Maruchi) for MT heat treatment.

The files that underwent heat treatment using MT technology were assigned to Group RMT. These files were compared with the original Reciproc (Group REC) and Reciproc Blue (Group REB). A meticulous inspection of all instruments in the 3 groups was conducted to identify any defects or deformities before the experiment with a dental operating microscope.

Before the main study, a preliminary test was performed under identical conditions using 4 instruments in each group. The mean values and standard deviations revealed an effect size >1.0. A markedly lower effect size of 1.072 was used for calculation using G*Power 3.1. Using the parameters of α level of 5%, β level of 20%, and the effect size, the total sample size was calculated as 12; based on this, each group was composed of 15 files in this study.

Cyclic Fatigue Resistance Test

The assessment of cyclic fatigue resistance was carried out by using a specially designed custom device (EndoC; DMJ system, Busan, Korea) (Fig. 1). In this study, a simulated canal block made of tempered steel with a 6-mm radius and 45° angle of curvature measured by the method described by Schneider was used[16]. The length of the simulated canal was 17 mm. The simulated canal block was positioned within the device and its temperature was regulated to 37°C using an electric thermal control unit.

X-Smart Plus motor (Dentsply Sirona) was connected to the device, and the Reciproc mode was used. Each NiTi file from the 3 groups was operated reciprocally with a repetitive up-and-down movement in the curved canal with a 4-mm pecking distance inside of the simulated canal. The moment at which the file tip fractured was determined audibly and visually. When each file fractured, the time (seconds) until fracture was recorded. The length of the fractured fragment was measured using a digital micro caliper (Mitutoyo, Kanagawa, Japan).

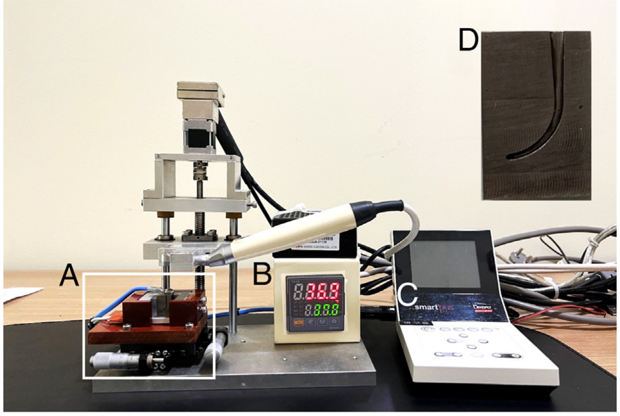

FIGURE 1 – A test device (EndoC; DMJ system, Busan, Korea) used in this study. (*A*) Heat generation pad with a simulated metal canal, (*B*) electronic heat controller, (*C*) X-Smart Plus motor (Dentsply Sirona), and (*D*) a magnified view of a simulated metal canal with a 6-mm radius and a 45° angle of curvature.

SEM Observation

After the cyclic fatigue tests, the fractured files underwent an examination via scanning electron microscopy (SEM). Before the microscopic observation, all the files were subjected to a cleaning process involving treatment with absolute alcohol and immersion in an ultrasonic bath for 180 seconds to eliminate any debris. Subsequently, the files were left to air dry at room temperature and were affixed onto metal stubs using double-sided adhesive carbon tape. The mounted samples were placed inside the SEM (JSM-7200F: JEOL, Tokyo, Japan). Finally, 4 fractured fragments from each group were observed under the SEM using a secondary electron detector, with the aim of assessing the topographic features of the surface.

Differential Scanning Calorimetry

Differential scanning calorimetry (DSC) analysis was performed to determine phase transformation temperatures. Specimens from 3 groups were analyzed (DSC Q2000 V24.4 Build 116; TA Instruments, New Castle, DE) to get the various temperature points, including martensite starting temperature (M*s*), martensite finishing temperature (M*f*), austenite starting temperature (A*s*), austenite finishing temperature (A*f*), and austenite peak (A*p*) temperature during heating and cooling curves. These peak temperatures corresponded to the distinct transformations observed in both the endothermic and exothermic curves[17].

Referring to our earlier preliminary laboratory tests, the maximum temperature during calorimetric heating was determined to be 90 °C, which was higher than the temperature required to achieve a fully austenite state for each of the studied specimens[18,19].

Statistics Analysis

The normality of the data was assessed using the Levene test. In cases of normal distribution, for data evaluation and comparison among the file groups, 1-way analysis of variance and Duncan's post hoc comparison were conducted using the statistics program SPSS (version 25.0; SPSS Inc., Chicago, IL). Statistical significance was set at 95%.

RESULTS

The findings from the cyclic fatigue tests are presented in Table 1. Group RMT (608 ± 50 s) showed significantly higher fatigue fracture resistance ($P < .05$), whereas there was no difference in fatigue fracture resistance between Group REC (358 ± 26 s) and Group REB (359 ± 33 s).

SEM examination revealed that the files from the 3 groups had similar topographic features associated with cyclic fatigue fracture, including crack initiation area(s) and fatigue fracture zone in the cross sections (Fig. 2*A*–*F*). Another typical feature known as the "overload fast fracture zone" was observed on the opposite side of the crack initiation area. In the lateral aspects (Fig. 2*G*–*O*), microcracks were shown along with the machining grooves, which are the typical aspects of cyclic fatigue fracture (Fig. 2*I*, *L*, and *O*). No specific differences were found according to the groups.

The results of the DSC analysis exhibited distinct difference in phase transformation temperatures for all groups (Fig. 3). DSC analysis showed that RMT showed a peak of austenite (A*p*) at a temperature (52°C) higher than body temperature, while REC and REB showed A*p* at 37°C and 32°C, respectively. RMT was found to predominantly contain martensite under the conditions of clinical usage.

DISCUSSION

There have been numerous attempts to improve fracture resistance by changing the file structures and applying various heat treatment methods. This study was also conducted to evaluate the effectiveness of the recently introduced MT technology as a method of heat treatment.

The cyclic fatigue resistance test has been used as a simple and reliable method for assessing the fatigue behavior of workpieces manufactured from NiTi alloy[20,21]. In addition, because reciprocating files operate without continuous rotation, the likelihood of fracture due to excessive torque is relatively low[21]. Thus, the evaluation of fatigue fragments is more important, prompting the conduction of studies on fatigue fracture resistance.

Conventional superelastic NiTi instruments predominantly remain in the austenite phase at room and body temperatures. This limited their application in severely curved canals because of the stiffness of the instrument and low fatigue resistance[12]. Heat treatment (thermal processing) is one of the most fundamental approaches for adjusting the transition temperatures of NiTi alloys and affecting the fatigue resistance of NiTi endodontic files. In recent decades, abundant effort has been devoted to introducing martensitic alloys such as M-wire and CM-wire instruments to the NiTi instruments market. Numerous studies have investigated the performance of the instruments made from M-wire, R-phase, and CM-wire, and reported more enhanced flexibility and fatigue resistance than those of conventional NiTi instruments[7,18,22]. These instruments have shown superior ductility and resistance to cyclic fatigue compared with conventional superflexible NiTi files[20,21,23,24].

Reciproc and WaveOne are representative reciprocating file systems made from M-wire. The M-wire, developed through thermomechanical processing, results from applying a series of heat treatment processes and contains 3 phases: martensite, R-phase, and austenite[23]. The presence of the martensite phase in M-wire contributes to reducing the risk of file fracture when subjected to high stress conditions. When austenite cools, it initiates a transformation into martensite at the martensite transformation start (Ms) temperature and completes the transition at the martensite transformation finish (M*f*) temperature. On the other hand, when martensitic NiTi is heated beyond the austenite transformation start temperature (A*s*), the crystal structure of the NiTi begins to shift toward austenite. Upon surpassing the higher austenite finish (A*f*) temperature, the NiTi crystal structure becomes entirely austenite[11,12].

Cyclic fatigue resistance is assessed by the "number of cycles until fracture" that an instrument withstands in a fatigue test. However, because this study involved reciprocating file systems, the "time to fracture" during operation was directly compared instead of counting the number of rotations. The cumulative number of cycles corresponds to the magnitude of microscope damage caused by the repetitive compressive and tensile stresses, which are in turn influenced by factors such as the radius of

TABLE 1 - Cyclic Fatigue Fracture Resistance (Time to Fracture) of the 3 Files With Same Geometry and the Length of Fractured Fragment

Group	Time to fracture (s)	Fragment length (mm)
REC	358.67 ± 26^{b}	4.56 ± 0.28^{a}
REB	359.40 ± 33^{b}	3.57 ± 0.21^{b}
RMT	608.00 ± 51^{a}	$4.69 \pm 0.21^{a,b}$

REC, Reciproc; REB, Reciproc Blue; RMT, Reciproc that went through the Memory-Triple Heat Treatment.
^{a,b}Different superscript letters mean significant difference between groups ($P < .05$).

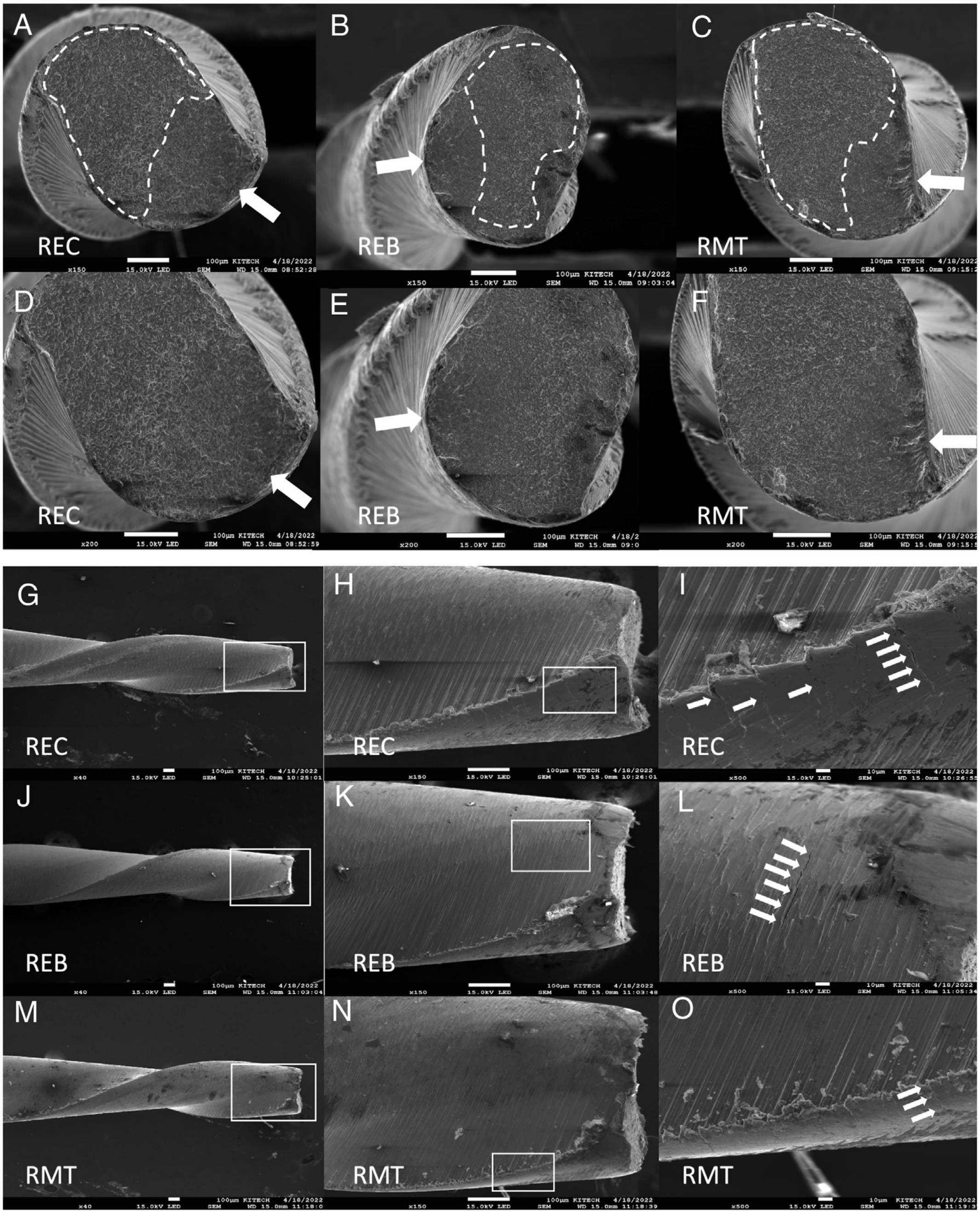

FIGURE 2 – Cross-sectional scanning electron micrographs (*A–F*) of the fracture fragments after cyclic fatigue tests. (*A*) Reciproc (REC), (*B*) Reciproc Blue (REB), and (*C*) Reciproc MT (RMT) and high magnification views of (*D*) Reciproc, (*E*) Reciproc Blue, and (*F*) Reciproc MT. No specific differences were found according to the groups. The *white arrows* indicate the crack initiation area. The areas outlined with a *dotted line* indicate the overload fast fracture zone with numerous ductile dimples. Longitudinal scanning electron micrographs (*G–O*) of the fracture fragments after cyclic fatigue tests. (*G*) Reciproc, (*J*) Reciproc Blue, and (*M*) Reciproc MT and high magnification views of (*H* and *I*) Reciproc, (*K* and *L*) Reciproc Blue, and (*N* and *O*) Reciproc MT. No specific differences by the phases. *Distinct machining grooves in the surface. The *white arrows* in the magnified view indicate microcracks near the fracture area.

curvature, arc length, instrument size, and design[25].

The Reciproc Blue, advanced from the original Reciproc, maintains the same structural shape and undergoes heat treatment to martensitic dominant Blue-wire, facilitating a comparison of the actual heat treatment effects. In addition, in this study, an original file subjected to MT heat treatment technology was included to compare the fatigue resistance among 3 groups.

The present results of the cyclic fatigue resistance test showed that the files made with MT technology exhibited significantly higher flexibility compared with the other commercially available original Reciproc and Reciproc Blue instruments. Because the sole variable distinguishing the groups was the heat treatment technique, it can be inferred that the MT heat treatment technique may potentially confer superior fatigue resistance to the instruments than the M-wire and Blue-wire instruments. It was interesting finding that the Reciproc and Reciproc Blue did not show

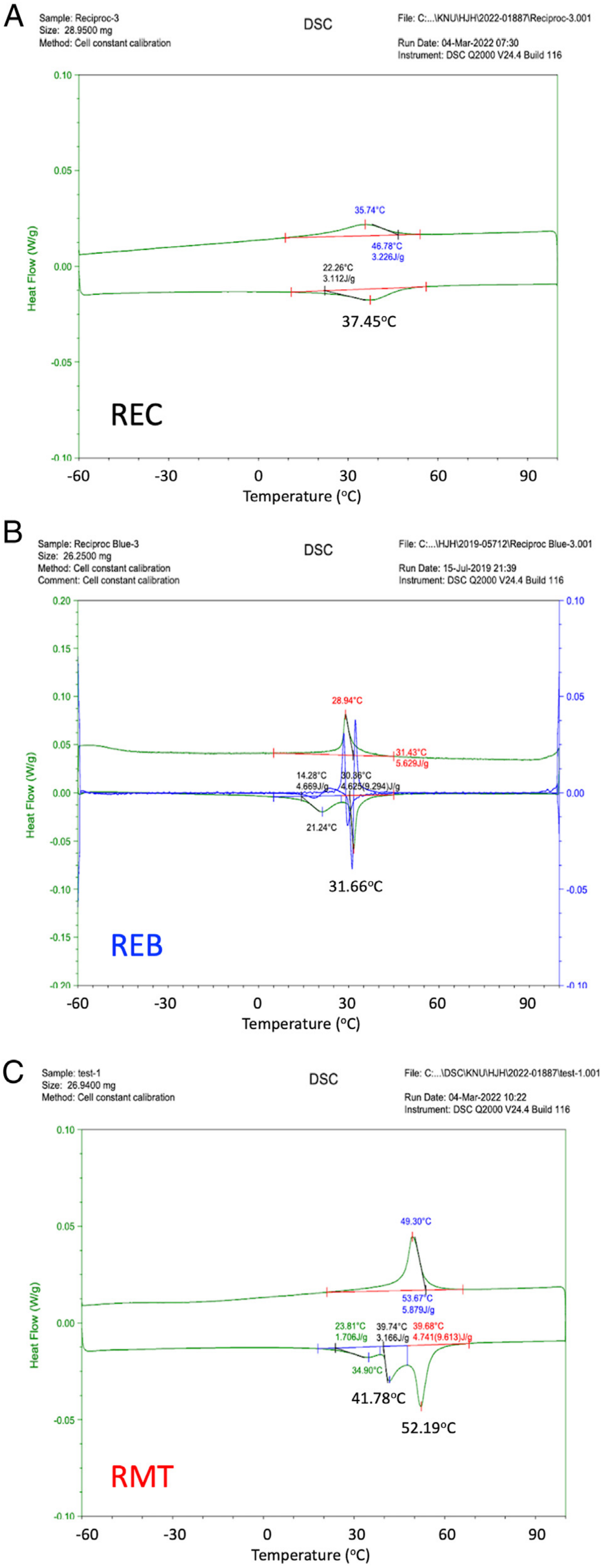

FIGURE 3 – Representative differential scanning calorimetry (DSC) graphs from each group. DSC analysis showed that (*C*) Reciproc MT showed a peak of austenite (A*p*) at a temperature (52°C) higher than body temperature, whereas (*A*) Reciproc and (*B*) Reciproc Blue showed A*p* at 37°C and 32°C, respectively. Reciproc MT has been found to contain martensite dominant at the conditions of clinical usage.

significant difference in the fatigue resistance, although the Blue-wire basically has higher flexibility from lower stiffness with the higher martensite phase[15,26]. It might result from the test condition of body temperature (37°C) using the electric thermal control and the austenite change from the martensite of the Blue-wire. This could be supported by the results of DSC, which showed that Reciproc and Reciproc Blue had the A*p* temperature at 37°C and 32°C, respectively.

The SEM analysis showed typical fractographic features associated with cyclic fatigue. After the cyclic fatigue test, these instruments showed the presence of crack initiation areas, fibrous fatigue zone, and overload fast fracture zones, exhibiting a similar appearance across all 3 tested groups. The "overload fast fracture zone" was observed on the opposite side of the crack initiation area with numerous ductile dimples (Fig. 2*A*–*C*).

CM-wire was manufactured through a proprietary thermomechanical process with the objectives of increasing flexibility, reducing shape memory, elevating transformation temperatures (A*f* to about 50°C), and achieving stable martensite at body temperature[27]. In the DSC graph (Fig. 3*C*), the file in group RMT showed A*p* at around 52°C. Thus, the alloy made from the MT heat treatment technology shares similarities with CM-wire[12,27]. This enables the instruments to be pre-curved before insertion into the root canal.

This study may be criticized with a limitation that it solely focused on cyclic fatigue resistance and did not evaluate the torsional properties. The reciprocating system changes the rotation direction periodically, and the Reciproc and Reciproc Blue systems have specific angles of rotation as 150° counterclockwise and 30° clockwise[15,21]. This periodic change of rotation does not produce higher torsional stress that might bring about torsional fracture[21,28]. Nevertheless, based on the previous studies comparing the torsional properties of NiTi files with different alloy has indicated that the torsional strengths were almost the same for the original files and heat-treated files with same geometries[22,29]. However, further study would be required to compare the torsional resistance of the files made of MT heat treatment to confirm the previous findings. Furthermore, investigating the possibility of applying MT heat treatment to instruments from different brands might lead to potential improvements in fatigue resistance.

CONCLUSION

Under the condition of this study, the new heat treatment using MT technology was found to enhance the fatigue fracture resistance of reciprocating files made from M-wire. The MT heat treatment technology would be another heat treatment technology for future endodontic NiTi instruments.

ACKNOWLEDGMENT

Zunduijamts Odgerel and Sang Won Kwak contributed equally to this work and share the first authorship. The authors deny any conflicts of interest related to this study.

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