Resistance to cyclic fatigue of Reciproc and MTwo files on continuous rotation and reciprocating movements

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ABSTRACT

Objective: The aim of present study was to evaluate the influence of alloy (conventional NiTi and M-Wire NiTi) and movement (reciprocating movement and continuous rotation) on resistance to cyclic fatigue. **Methods:** Fifteen Reciproc R25 files (VDW GmbH, Munich, Germany) were used in reciprocation motion (RM), while thirty MTwo 25/.07 files (VDW GmbH, Munich, Germany) were used either in RM (n=15) or in continuous rotation (CR) (n=15). The files were submitted to dynamic assays device moved by electric engine that allowed the reproduction of pecking motion under 300 rpm of speed. The files act simulating the instrumentation of a curved root canal with 40° and 5-mm of curvature radius. The fracture was detected by the device sensor and the time and number of cycles were obtained. Data were statistically analyzed by ANOVA and Tukeys tests ($p<0.05$). **Results:** The Reciproc R25 instruments moved by RM reached significantly higher number ($p<0.05$) of cycles before fracture (1777.68 ± 334.2 cycles) when compared with MTwo 25/.07 instruments moved by RM (610.67 ± 126.3 cycles) or CR (432.23 ± 183.2 cycles). **Conclusions:** The reciprocation motion showed significantly greater cyclic fatigue resistance and the M-Wire NiTi files showed higher cyclic fatigue resistance than conventional NiTi rotary files.

Keywords: Fatigue. Dental Instruments. Endodontics.

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Introduction

Currently, one of the major concerns in the mechanical enlargement of the root canal space is still the fracture possibility of NiTi instruments. Standing at a clinical perspective, fatigue is one of the main reasons for the NiTi rotary files fracture.[1,2] Several strategies have been adopted to improve the fatigue resistance of NiTi endodontic instruments, such as electropolishing[3], surface coatings,[4] and heat treatment[5]. Recently, a specific thermal treatment of NiTi alloy named M-Wire has been introduced to optimize the mechanical properties of this alloy,[5,6] resulting in higher fatigue resistance than conventional NiTi rotary instruments.[7]

At the same time, a new kinematics to mechanically prepare the root canal space was introduced, where only one specifically designed NiTi instrument is driven under reciprocating movement.[8] In this movement, the instrument rotates in counterclockwise (CCW) and clockwise (CW) direction with 120° of difference between both movements. Thus, for each 3 cycles, there is a whole rotation of the instrument. Reciprocation seems to reduce the cyclic fatigue[9] and consequently, the file fracture.[8,10] In a previous study, Gavini et al.[11] observed that the reciprocation movement improves significantly the resistance to cyclic fatigue of a NiTi M-Wire instrument. Nevertheless, there is little evidence on the behavior of M-Wire file and the effect of reciprocation movement on the resistance to cyclic fatigue, thus far.

Within this background, the aim of the current study was to provide a better understanding about the role of the M-Wire alloy and reciprocating movement on the instrument cyclic fatigue-life as soon to analyze the type and fracture pattern through SEM analysis.

For that, conventional NiTi alloy (MTwo, VDW GmbH, Munich, Germany) and continuous rotation (CR) movement were used as reference for comparison. Thus, two nulls hypotheses were tested: (i) Alloy does not interfere on the instrument cyclic fatigue-life and fracture pattern; and (ii) Reciprocation movement does not interfere on the instrument cyclic fatigue-life and fracture pattern.

Material and methods

A sample of fifteen Reciproc R25 instruments were used in reciprocation motion, while thirty MTwo 25 (taper 0.07) NiTi files were used either in reciprocation (n=15) or in continuous rotation movement (n=15).

Cyclic Fatigue Test

Cyclic fatigue testing was performed with a custom-made apparatus specifically designed to allow dynamic testing by simulating the pecking motion, as reported previously[11,12]. An electric motor handpiece (VDW Silver Reciproc, VDW GmbH, Munich, Germany) connected with a 20:1 contra-angle was coupled to the support arm in a parallel position to the apparatus base. Then, the file was locked into the contra-angle and the reciprocating (RM) or continuous rotation (CR) movement was performed in a standard speed of 300 rpm.

Platforms were moved using the grading rings up to reaching a position that allowed the file to be positioned 2 mm below the electronic sensor, remaining into the curved canal and free to rotate between the cylinder and the steel groove that simulates a rotary instrumentation of a canal with 40 degrees and 5 mm of radius curvature. Care was taken to ensure that the instrument was well positioned in the cylinder groove, so as to avoid file displacement.

With the file adequately engaged and positioned, the main switch was turned on and the electric motor began the pneumatic movement. This movement reproduces the pecking motion with 2 mm of amplitude that slides into the groove created on the ring made of tempered steel. With the instrument tip remaining visible throughout all cycles, the instrument penetrates 2 mm up to touch the sensor and immediately runs back and begins a new movement towards the sensor. This pecking movement was repeated at the speed of one cycle per second.

The instrument fracture was easily detected at the moment that the instrument did not touch the sensor and instantly the counter and timer were stopped. Testing time was automatically registered with a digital stopwatch (Casio Corp., Tokyo, Japan), started at the moment the motor was turned on and stopped at fracture detection. After completion of all tests, the mean time to failure observed in each group was recorded in seconds and subsequently converted into number of cycles to fracture.

SEM Analysis

To characterize and compare thetype and fracture pattern for each alloy an movement the fractured surfaces of five files from each group were examined under LEO 435 VP scanning electron microscope (Carl-Zeiss NTS GmbH, Oberkochen, Germany) to determine the morphologic characteristic of fracture patterns. Magnifications of 350X, 1,000X, 2,500X and 10,000X were used.

Statistical Analysis

Since this study included three independent sets of samples with normal distribution and equal variances, ANOVA and Tukey's test were used to assess the presence of statistically significant differences among the groups ($p<0.05$).

Results

Fatigue resistance data were assessed with regard to central tendency (means) and dispersion (standard deviation). Significant statistically difference was observed for cyclic fatigue resistance by R25 instrument driven under RM against MTwo files in either RM or CR ($p = 0.0001$). MTwo files driven under RM also showed significantly higher number of cycles to fracture when driven under CR ($p = 0.0022$), as showed in Figure 1 and Table 1.

Figure 2 shows SEM micrographs illustrating the surface morphology of Reciproc R25 (2A-D) and MTwo 25/.07 files (2E-H) both when used under reciprocation movement (RM). SEM I-L images showed surface morphology of MTwo file used under continuous rotation (CR). Generally, images reveal microvoids, spherical dimples and fatigue striations that are representative of a ductile fracture and fatigue failure, respectively. Backscattered electron detection mode - QBSD (Fig 2H and 2L) enhances striations (white arrows) and cracks (blue arrows) characterization.

Discussion

Considering the current results, both null hypotheses were rejected. Reciproc R25 files showed significantly higher resistance to cyclic fatigue than MTwo files under reciprocating movement. This fact agrees with earlier evidence,[13,14] which pointed out that the M-Wire technology enhances flexibility and resistance to cyclic fatigue.This may be explained by the results of a recent study in which instruments with

Table 1. Cycles to fracture (mean and standard deviation).

Instrument	Movement	Tip size/taper	n	Time to fracture	Cycles to fracture	
					Mean	Standard deviation
Reciproc	Reciprocation (RM)	25/08	15	355.53	1.777.68^{a}	334.2
Mtwo	Reciprocation (RM)	25/07	15	122.13	610.67^{b}	126.3
Mtwo	Continuous (CR)	25/07	15	86.44	432.23^{c}	183.2

Different superscript letters indicate statistically significant difference between means ($p < 0.05$).

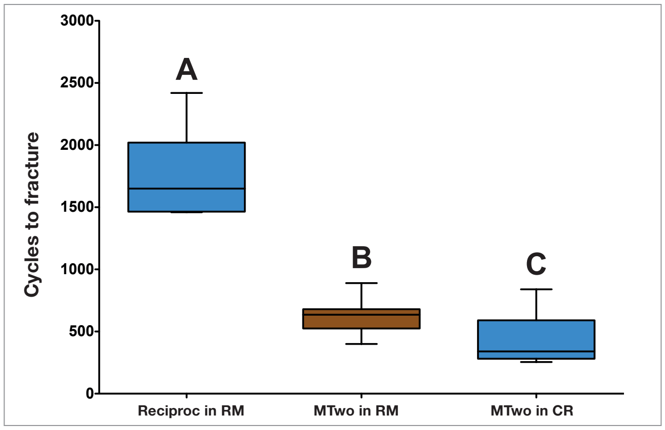

Figure 1. Box plots of the cycles of failure, illustrating the median, minimum, and maximum values, as well as the standard deviation data of each experimental group.

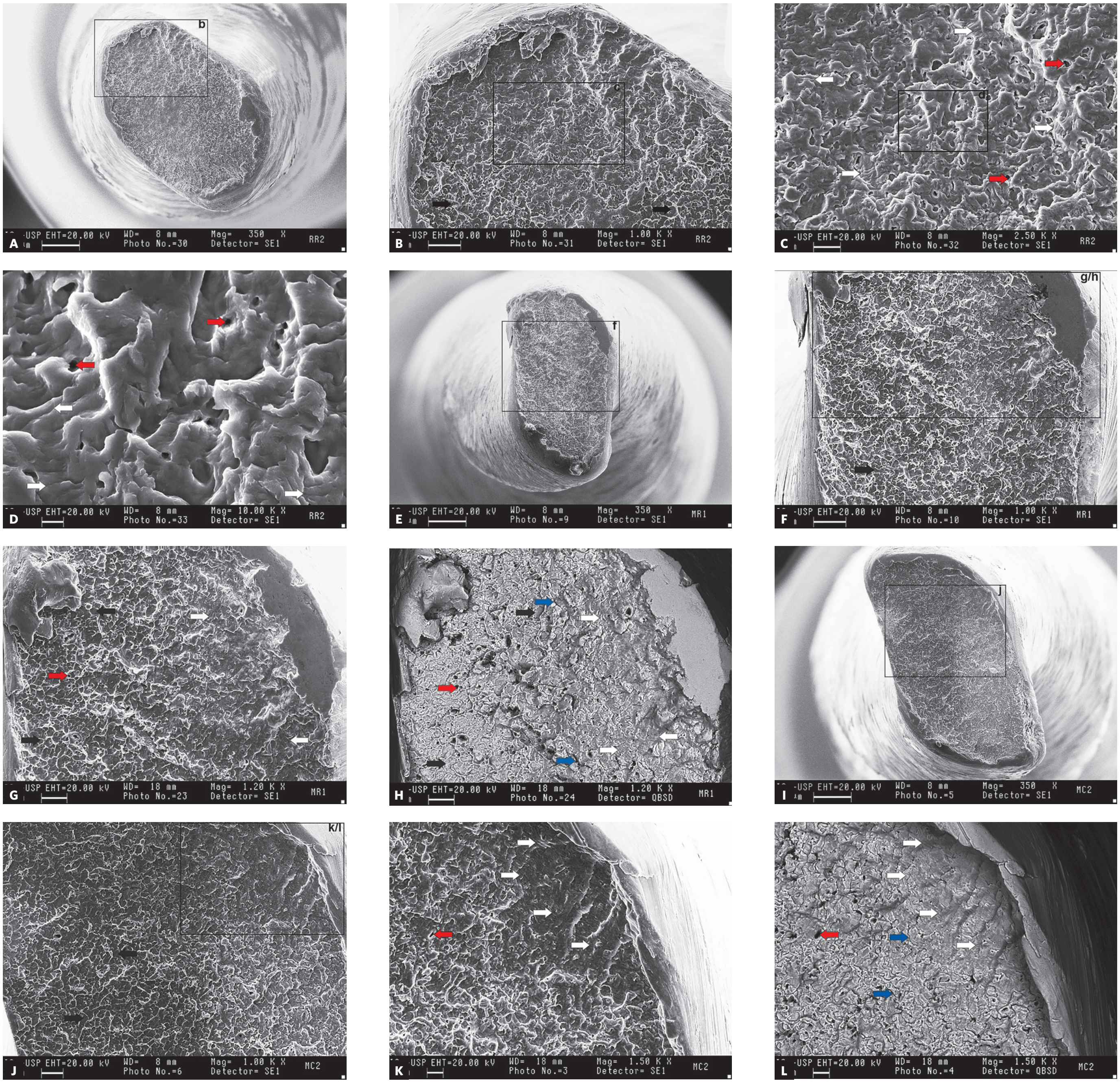

Figure 2. A) Fracture surface of Reciproc R25 instrument exhibiting plastic deformation (original magnification, 350x). **B)** Higher magnification view (1,000X) of Figure 2A, showing spherical dimples (black arrow) that indicate the occurrence of ductile failure. **C)** Fatigue striations (white arrow) and microvoids (red arrow) are shown (original magnification, 2,500x) for Reciproc R25 instrument. **D)** Fatigue striations (white arrow) and microvoids (red arrow) are shown in (original magnification, 10,000x) for Reciproc R25 instrument. **E)** Fracture surface of MTwo instrument used in reciprocating movement exhibiting plastic deformation (original magnification, 350x). **F)** Higher magnification view (1,000X) of Figure 2E, showing spherical dimples (black arrow) that indicate the occurrence of ductile failure. **G)** Original magnification (1,200x) of MTwo 25/.07 used in reciprocating movement enhances fatigue striations (white arrow), microvoids (red arrow), cracks (blue arrow) and spherical dimples (black arrow) that indicate the occurrence of ductile failure. **H)** Magnification of 1,200x under SEM backscattered electrons detection mode of MTwo 25/.07 used in reciprocating movement enhances fatigue striations (white arrow), microvoids (red arrow), cracks (blue arrow) and spherical dimples (black arrow) that indicate the occurrence of ductile failure. **I)** Fracture surface of MTwo 25/.07 instruments used in continuous rotation exhibiting plastic deformation (original magnification, 350x). **J)** Higher magnification view (1,000X) of Figure 2J, showing spherical dimples (black arrow) that indicate the occurrence of ductile failure. **K)** Original magnification (2,000x) of MTwo 25/.07 used in continuous rotation enhances fatigue striations (white arrow) and microvoids (red arrow). **L)** Original magnification (2,000x) under SEM backscattered electrons detection mode of MTwo 25/.07 used in continuous rotation enhances fatigue striations (white arrow), microvoids (red arrow) and cracks (blue arrow).

heat treatment contribute to increase the austenitic transformation temperature.[13] Moreover, it was found that the conventional superelastic NiTi file has an austenite structure[15], whereas NiTi files with thermal processing (eg, Reciproc, WaveOne and ProTaper Next) would be essentially in the martensitic condition at body temperature.[6,15] The martensitic form of NiTi alloy has remarkable fatigue resistance. The instruments constituted with this phase can be easily deformed and can recover their shape with heat above transformation temperatures. The memory NiTi Wire instrument showed significant changes in the phase transformation behavior when compared with conventional NiTi instruments. This fact allows instruments to undergo plastic deformations during the root canal preparation, reducing their influence on cyclic fatigue.

The mechanical properties of NiTi alloy are easily influenced by small changes in composition, impurities removal, and heat treatment conditions.[5] In particular, superelasticity and shape memory are strongly affected by heat treatment as part of the manufacturing processes.[5,15] M-Wire NiTi instruments are produced by a patented thermo-mechanical processing (M-Wire), which stands for an innovation in the NiTi instruments manufacturing,[13] leading to improvements in the overall physical and mechanical properties. Recently, due to their unique nano-crystalline martensitic microstructure, endodontic instruments manufactured with M-Wire are expected to have higher strength and wear resistance than counterparts made of conventional superelastic NiTi alloys.[16] Although Pedullà et al.[17] has reported no statistical significant difference between MTwo 25.06 files and Reciproc R25 under static model, in the present study, using dynamic model, Reciproc R25 presented significantly greater resistance to cyclic fatigue than MTwo 25.07, agreeing with recent results by Keifner et al.[14] In a static model, the instrument does not move axially. This creates alternate compressive and tensile stresses in a particular area of the instrument, leading to premature failure. The dynamic model incorporates cyclic axial movement, which provides a better clinical simulation and increases the lifespan of rotary files, but the amplitude, speed of pecking motion, and axial movement are purely subjective in clinical practice.[9,18]

The taper was a variable uncontrollable in the present study. MTwo 25.07 files were used due the proximity of taper of Reciproc R25 (0.08). There is a positive correlation between taper and metallic mass of instrument.[19] Therefore, a file with taper 0.07 should present a greater flexibility and resistance to cyclic fatigue than a file with taper 0.08, according to some authors.[3,9] However, in the present work, it may be observed that M-Wire NiTi alloy improves significantly the resistance of instruments, once that Reciproc R25 files have presented greater resistance to cyclic fatigue than MTwo 25.07 files, despite presenting bigger taper.

Another factor observed in the current study was that the reciprocating movement per se has also markedly influenced the resistance to cyclic fatigue. Previous studies analyzed the effect of reciprocating movement on cyclic fatigue life of the conventional NiTi files[7,8,18,20] and observed that files used under reciprocation movement showed twice more resistance to cyclic fatigue than when used under continuous rotation[11]. In addition, De-Deus et al.[9] showed that movement kinematics is a determining factor on cyclic fatigue of rotary NiTi instruments where the reciprocating movement takes more time (95 seconds) to fracture a F2 ProTaper when compared with conventional rotation (25 seconds). Therefore, recent studies also reported an improvement of cyclic fatigue when the instruments were activated in reciprocating movement.[14,17,18,21]

When analyzing the same parameter, this study demonstrated that MTwo instruments driven under reciprocating movement resisted to significantly more average cycles until separation (610.67 ±126.3 cycles) than under continuous movement (432.23 ±183.2 cycles). This result was supported by previous research as well.[11] In the reciprocating movement proposed by Yared[8], the file engages into the canal when rotating in CCW way and disengages in CW way. As the CCW rotation is greater than the CW rotation, the final result is a screwing effect,[8] which reduces the compressive forces, favoring the occurrence of elastic deformation and thus, decreasing the flexural fatigue[9,10]and the torsional fracture by taper-lock.[8,10] The present research demonstrated a positive correlation between M-Wire and reciprocating motion in significant improvement of cyclic fatigue life, agreeing with a recent study.[14]

NiTi fractured surfaces under SEM analysis (Fig 2) showed that instruments with heat treatment (M-Wire) or the reciprocating movement do not affect fracture patterns where micro-voids are produced within the metal, and nucleation, growth, and micro-void coalescence that weaken the metal[22,23] and spherical dimpling that characterizes ductile fracture. Plastic deformation because of slip, the process by which a dislocation moves in response to shear stresses, also contributes to this fracture type.[23] Images showed striations resulting from fatigue failure. These patterns are according to some previous studies.[9,11,24]

Conclusions

Considering the present results, it was observed that the reciprocation motion improved significantly the cyclic fatigue resistance and M-Wire NiTi files showed more resistance to cyclic fatigue than conventional NiTi rotary files. Thus, it may be concluded that the resistance to cyclic fatigue in NiTi instruments was influenced by the type of NiTi alloy and by the reciprocating movement. When analyzing fracture patterns, it could be demonstrated no differences when comparing movement conditions or alloy´s types.

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