Cyclic fatigue and torsional resistance of two brand new NiTi instruments used in reciprocation motion: Reciproc vs. WaveOne.

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Abstract

The use of reciprocating movement (RM) was claimed to increase the resistance of nickel-titanium (NiTi) file to fatigue in comparison to continuous rotation (CR). Recently two new brands of NiTi file have been marketed for use in a RM mode. The purpose of this study was to compare the cyclic fatigue resistance and torsional resistance of these two files; Reciproc and WaveOne. Cyclic fatigue test with a simultaneous pecking motion was performed with the instrument (n = 10 each) operating in the recommended reciprocation motion until fracture for th Reciproc R25 and WaveOne Primary files. ProTaper F2 was tested in continuous rotation to serve as a control for comparison. The number of cycles to fracture (NCF) was determined by measuring the time to fracture. The length of the fragment was measured and the fracture surface examined using SEM. Torsional strength was measured using a torsiometer after fixing the apical 5 mm of the instrument rigidly. Statistical analysis was performed using one-way ANOVA. The results showed that Reciproc had a higher NCF, and WaveOne had a higher torsional resistance, than the others. Both reciporcating files demonstrated a significantly higher cyclic fatigue and torsional resistances than ProTaper ($P < .05$). The fractographic analysis showed specific features of cyclic fatigue and torsional resistance for all instruments. The two brands of NiTi file for use with a reciprocation motion seem to have superior mechanical properties.

Key words: Nickel-Titanium rotary file; reciprocating; torsional resistance; cyclic fatigue resistance; cross-section

Introduction

Nickel-titanium (NiTi) rotary instruments are commonly used for endodontic practice nowadays. These instruments offer many advantages over conventional stainless steel files, are more flexible and with increased cutting efficiency. The superelasticity of NiTi rotary files allows the clinicians to produce the desirable, tapered root canal form with a reduced tendency to canal transportation (1-3). Despite these advantages, NiTi instruments appear to have a high risk of separation (4, 5).

The fracture modes of rotary NiTi files could be broadly classified into 2 types: flexural (cyclic) fatigue and torsional failure (5). Flexural fatigue fracture of the file occurs because of repeated compressive and tensile stresses accumulated at the point of maximum flexure in a curved canal. On the other hand, torsional failure occurs when the tip or some part of the file binds in the root canal while the handpiece that holds the shank of the file continues to rotate (5, 6).

In late 2000's, a new preparation technique using only one ProTaper F2 instrument in a reciprocating motion was proposed by Yared (7). The use of reciprocating motion was shown to extend the lifespan of a NiTi instrument, hence resistance to fatigue, in comparison to continuous rotation (8, 9). Recently, two brands of NiTi instrument were introduced to the market that advocated the reciprocation concept: Reciproc (VDW, Munich, Germany) and WaveOne (Dentsply Maillefer, Ballaigues, Switzerland). These manufacturers claim that the reciprocal motion would reduce the torsional stress by periodically reversing the rotation (30-degree clockwise, then 150-degree counterclockwise rotation) of the file. This reciprocating movement is believed ultimately increase the lifespan of the instrument (9, 10).

There is only limited information about the behaviour of files using reciprocation motion. In particular, no data was reported about the fatigue behavior of these newly developed, reciprocating files. Therefore, the purpose of this study was to compare the cyclic fatigue and torsional resistances of two brands of NiTi file (Reciproc and WaveOne) using reciprocating motion..

Materials and Methods

Two brands of NiTi files marketed for use in a reciprocating motion were tested: Reciproc with an S-shaped cross-section, and WaveOne with a convex triangular cross-section. The Reciproc R25 instrument and WaveOne Primary file, both of which had an ISO size 25 at the tip and a taper of .08 in the apical 3 millimeters, were selected. Another instrument, ProTaper F2 (Dentsply Maillefer) which has a convex triangular cross-section with same apical tip size and apical taper, was also tested as a control. All files used in this experiment was 25 mm long, with 10 instruments each consumed in a cyclic fatigue and a torsional resistance test. Every instrument was inspected for defects or deformities prior to the experiment with a dental operating microscope (Pico; Zeiss, Oberkochen, Germany).

The cyclic fatigue test was conducted in a custom made device which allowed a reproducible simulation of an instrument confined in a curved canal, similar to that described by Gambarini (11) and Lee et al (12). In brief, an artificial canal block made of tempered steel with 0.6 mm apical diameter, 6.06 mm radius and 45° angle of curvature, measured according to the Schneider method (13), were incorporated into the blocks. A continuous up-and-down (4 mm in each direction at 0.5 Hz) pecking movement was incorporated to simulate the pecking motion in a real clinical situation. The files were operated in the VDW.SILVER motor (VDW) with each recommended setting; Reciproc files with the "Reciproc" mode, and WaveOne with the "WaveOne" mode. The ProTaper F2 was rotated with full clockwise rotation at a rate of 300 rpm. To reduce friction between the instrument and the metal canal walls, a synthetic oil (WD-40; WD-40 Company, San Diego, CA) was sprayed into the simulated canal. The instrument was allowed to rotate/reciprocate with spontaneous pecking movement until fracture. Timing was stopped as fracture was detected visually and/or audibly. The number of cycles to failure (NCF) for each instrument was calculated by multiplying the time (seconds) to failure by the number of rotations or cycles per second, regardless of the rotation direction (Note: The manufacturers claim that the Reciproc mode has 300 rpm and WaveOne mode has 350 rpm). The length of the fractured file tip was measured using a digital microcaliper (Mitutoyo, Kawasaki, Japan).

To evaluate the torsional resistance the experiment was done using an experimental design described by Park et al (14) and Yum et al (15). Briefly, a metal block with a cubical hole (5 X 5 X 5 mm) was constructed in which 5 mm of the tip of each file was rigidly held in place by filling the mold with a resin composite and light-cured. To compare the mechanical property of the instrument under torsion, a uniform rotation at 2 rpm was applied to the file in a straight state using a torsion tester (Osstem, Busan, Korea). The torque was applied in counterclockwise direction for Reciproc and WaveOne (due to the direction of the spiraling flutes), and in clockwise direction for the ProTaper. The maximum torsional load (N·cm) was recorded during loading until the file succumbed to the torsional load.

The broken fragments were evaluated under the scanning electron microscope (SEM) (S-4800 II; Hitachi High Technologies, Pleasanton, CA) for topographic features of the fracture surfaces and in lateral view at various magnifications.

The NCF and ultimate torsional load were analyzed by using the one-way analysis of variance in software (PASW Statistics 18; SPSS Inc, Chicago, IL). Duncan post hoc test was applied to identify the group(s) that were different from each other. Statistical significance was set at a confidence level of 95%.

Results

The NCF and ultimate torsional strength for the each files are presented in Table 1. Reciproc had the best fatigue resistance between groups ($p < .05$), and WaveOne significantly higher NCF than ProTaper ($p < .05$). The mean lengths of the fracture fragment of three brands showed no difference statistically ($p > .05$).

The ultimate torsional strength was the highest for WaveOne, followed by Reciproc and ProTaper in that order (Table 1). The differences were significant between groups ($p < .05$).

SEM of the fracture surface showed similar and typical features of cyclic fatigue and torsional failure for the three brands. Crack initiation area and overload fast fracture zone for cyclic fatigue fractures, and concentric abrasion marks and the fibrous dimple marks at the center of rotation (Figure 1).

Discussion

Effective cleaning and shaping of the root canal system is the most important factor for achieving the biological and mechanical objectives of root canal treatment. Over the years, various instrumentation techniques and flexible instruments have been introduced for this purpose (1, 4, 7, 10).

Recently, new systems using reciprocation motion were introduced to the market with the claim to shape root canals with only one file. As a result of technique simplification, according to their claims, clinicians can save time and cost for endodontic treatment. However, to shape root canals with only one file, the instrument will be subject to a great deal of stresses, both torsional and cyclic (bending) fatigue. It should have a good resistance to fracture. ProTaper is a common brand used worldwide and its F2 instrument was the file that was initially tested for use in a reciprocating motion by Yared (7). Therefore, the purpose of this study was to compare the cyclic fatigue and torsional resistance of Reciproc and WaveOne, with ProTaper serving as a control.

In this research, the reciprocating rotations were delivered using the preset modes in the specially designed endodontic motor (VDW.SILVER) with the advertised rotation rates of 300 and 350 rpm for the Reciproc and WaveOne, respectively. It is probable that the rotation rate can affect on the fatigue resistance, especially when the usage time is concerned. For that, we had done a pilot study to compare the two operation modes for the effect on fatigue life. That is, experiment was performed by operating the Reciproc with the “WaveOne” mode and WaveOne with “Recipro” mode ($n = 10$ for each system) in the same canal conditions. Two-way ANOVA verified that the rotation rate (mode) did not have any influence on the cyclic fatigue failure ($p > .05$).

The tip size (diameter at D0) and apical taper of Reciproc R25, WaveOne primary and ProTaper F2 were same with each others. The two reciprocating file systems are made of the same alloy (M-wire) but have different cross-sections, S-shape and concave triangular shape for Reciproc and WaveOne, respectively. It was reported that the larger cross-sectional area would have a higher flexural and torsional stiffness (16, 17) and thus the file design (cross-sectional shape, diameters of core, and so on) would have a significant influence on the torsional and bending (hence, fatigue) resistance (17). From our experimental results, the Reciproc showed a higher cyclic fatigue but a lower torsional resistance than WaveOne. It implies that the Reciproc possesses a lower flexural stiffness and a smaller polar moment of inertia than the WaveOne. In other words, the WaveOne had a higher torsional stiffness than Reciproc (14-18).

In a supplementary examination, we captured the cross-sectional configuration of each instrument at D5 under SEM and measured the area in software (AutoCAD; Autodesk Inc., San Rafael, CA, USA). WaveOne was found to have the biggest area (up to about 323,000 μm^2) and Reciproc the smallest area (about 275,000 μm^2). The NCF and polar moment of inertia seemed to follow the order of cross-sectional area and in reverse order for torsional stiffness. However, the ProTaper F2 had a similar cross-sectional area (about 318,000 μm^2), compared with the WaveOne, but succumbed at a lower NCF and with a lower torsional strength. This may be related to the mechanical characteristics of the NiTi alloy. The two new brands of reciprocation file were made from “M-wire” NiTi while ProTaper files were from the traditional NiTi alloy. Instruments made from M-wire or R-phase NiTi were reported to offer greater flexibility and resistance to cyclic fatigue than the files from traditional alloys (8, 14, 15, 19-21). This would explain why WaveOne exhibited a higher fatigue resistance despite its cross-sectional shape and area both being similar to ProTaper. In addition, ProTaper had a greater number of spiraling flutes (i.e. smaller pitch) than the two reciprocation brands. This would have an effect of increasing the stiffness along the shaft and, consequently, making stress concentration at those areas fixed by resin embedding resulting in a lower value of measured torsional strength (15, 16). Although the present study measured the ultimate torsional strength by single-direction rotation at a constant but slow speed, it is obvious that an instrument with a higher torsional strength would have better durability against the repetitive torsional stresses. An extended lifespan was recorded for NiTi instruments used in reciprocating motion. The increased fatigue resistance has been postulated to be due to the release of reaction stresses built up in the material by reversing the rotational direction (7-9).

The SEM analysis showed typical fractographic appearances of cyclic fatigue and torsional fractures. Those instruments after the cyclic fatigue test showed the presence of crack initiation areas and overload fast fracture zones, which appearance was similar among the three brands. That is, the reciprocating motion did not prevent, but has delayed the onset of catastrophic failure (unstable and fast crack growth) of the material. Those fragments after torsional test demonstrated the typical fractographic appearances of shear failure, including concentric abrasion marks and fibrous microscopic dimples at the center of rotation (6, 14, 15, 22).

The new concept of reciprocating instrument and the use of only one instrument to enlarge the canal, regardless of the pre-existing canal condition (such as dimension and curvature), into a final size and taper seems to go against the current instrumentation protocol which requires the gradual enlargement of the canal with a series of instruments until the desired shape is obtained. However, this new concept of using a single (reciprocating) instrument is cost effective and can shorten the learning curve for practitioners to adopt the new technique (7, 9).

Based on the results in this study, of the two makes of NiTi reciprocating instrument should be recommended for selective applications, according to the canal conditions. For instance, Reciproc may be more suited for preparing canals with more abrupt curvature due to its good fatigue resistance, and WaveOne for the constricted canal that may induce higher torsional stresses. Further researches, ex-vivo or clinical, are highly recommended to verify the clinical efficacy of these instruments for shaping the root canal and for ways to minimize the risk of fracture. In conclusion, both Reciproc and WaveOne files showed a significantly higher fracture resistance than ProTaper. The Reciproc outclassed WaveOne in cyclic fatigue resistance, but vice versa for torsional strength.

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Table1. Cyclic fatigue and torsional resistance tests' results (Mean ± SD)

	Reciproc	WaveOne	ProTaper
Number of cycles to failure (NCF)	2069.50 ± 371.40 ^{a}	1766.92 ± 318.92 ^{b}	595.00 ± 104.67 ^{c}
Length of fractured fragment after cyclic fatigue tests (mm)*	3.89 ± 1.28	4.23 ± 0.82	4.75 ± 0.52
Ultimate torsional strength (N·cm)	2.95 ± 0.18 ^{b}	3.55 ± 0.16 ^{a}	2.51 ± 0.21 ^{c}

^{a,b,c}; Different superscripts means significant differences between groups in horizontal row ($p < .05$).

* There was no significant difference in the length of fracture fragment between files ($p > .05$).

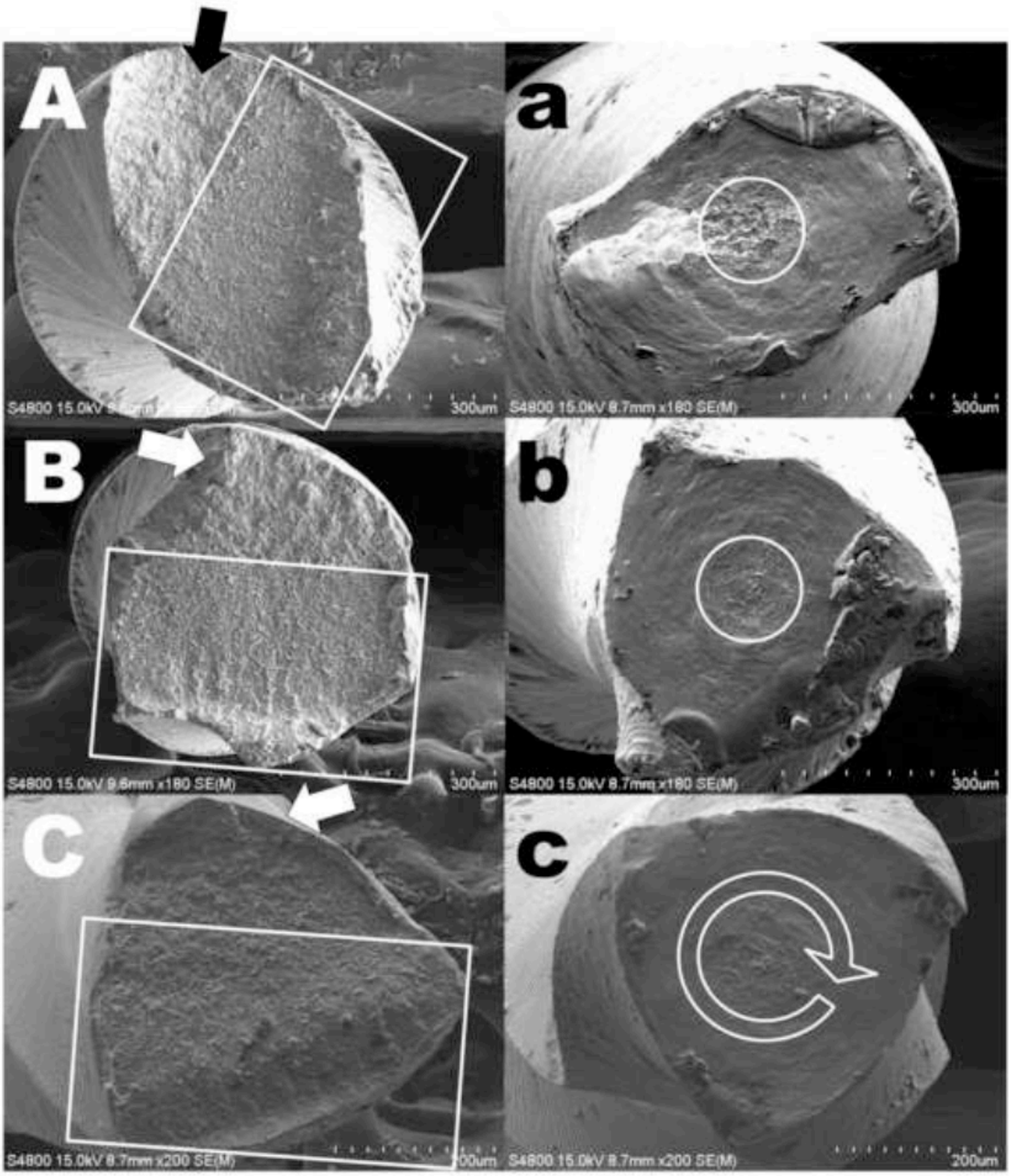

Figure 1. Scanning electron micrographs of the fracture surface of the separated fragments (first row: A,a = Reciproc; second row: B,b = WaveOne; bottom row: C,c = ProTaper). Left column (A, B and C) showed images after cyclic fatigue test with arrows indicating the crack initiation origin, and the rectangular box indicating the area of overload fast fracture zone. Right column (a, b, and c) showed the images after torsion test with the round arrow (omitted in a and b) indicating the concentric abrasion mark and the circle (omitted in c) showing the fibrous dimples.