

Influence of Continuous or Reciprocating Optimum Torque Reverse Motion on Cyclic Fatigue Resistance of Two Single-File Nickel-Titanium Rotary Instruments

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ABSTRACT

Objective: Different single-file instruments and kinematics have been introduced on the market. It is important to know the cyclic fatigue performance of these instruments in these new kinematics such as reciprocation of Optimum Torque Reverse (OTR) motion. The aim of this study was to evaluate the resistance to cyclic fatigue of F6 SkyTaper and OneShape used in continuous rotation (proper rotation) or in reciprocating OTR motion.

Methods: A total of forty-eight nickel-titanium files were tested. Twenty-four instruments of both brands were divided into two groups (n=12) on the basis of the motion tested: continuous rotation (group 1) or reciprocating OTR motion (group 2). Resistance to cyclic fatigue was determined by recording time to fracture (TtF) in a stainless steel artificial canal with a 60° angle of curvature and 5 mm radius of curvature. Data were analysed by two-way analysis of variance and post-hoc Bonferroni tests for multiple comparisons with P<0.05 as the level of significance.

Results: F6 SkyTaper showed higher TtF compared with OneShape, both in continuous and in OTR motion (P<0.0001). The two tested instruments showed higher cyclic fatigue resistance in reciprocating OTR motion than continuous rotation (P<0.0001).

Conclusions: OTR motion significantly improves cyclic fatigue resistance of the tested instruments. In addition, F6 SkyTaper showed higher cyclic fatigue resistance than OneShape in both motions.

Keywords: continuous rotation, cyclic fatigue resistance, F6 SkyTaper, OneShape, OTR motion.

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HIGHLIGHTS

- OTR motion is a kinematic recently introduced to improve clinical performance of NiTi rotary files.
- Cyclic fatigue resistance of F6 SkyTaper and OneShape used in reciprocating OTR motion or in continuous rotation was evaluated.
- Reciprocating OTR motion improved cyclic fatigue resistance of all tested files. F6 SkyTaper showed higher cyclic fatigue resistance than OneShape in both motions.

INTRODUCTION

Endodontic rotary files made from nickel-titanium (NiTi) alloy are more elastic than stainless steel instruments (1). Despite their increased strength and flexibility, NiTi rotary files are subjected to fracture without any visible signs of deformation (2). Fracture of NiTi instruments depends on torsional or cyclic fatigue (3, 4). Torsional fatigue occurs when the tip of the instrument binds in the canal while the shank continues to rotate (4, 5). Cyclic fatigue occurs when the instrument continues to rotate freely in a curvature

and tension/compression cycles are generated until fracture occurs (4). Manufacturers have developed new concepts of use and different cross-sectional designs, as well as different kinematics, that increase the cyclic fatigue resistance of the NiTi rotary files (6).

F6 SkyTaper (Komet Brasseler, Lemgo, Germany) and OneShape NiTi rotary instruments (Micro Mega, Besançon, France) are both two-size 25/.06 endodontic single-files made to be used in continuous clockwise (CW) rotation. F6 SkyTaper instruments present two sharp cutting edges

in a double-S cross-section design (7). OneShape instruments have a triangular cutting edge in the apical part, two cutting edges in the coronal part, and a cross section that progressively changes from three to two cutting edges between the apical and coronal parts, and this design contributes to an optimal cutting action (8).

Studies have reported that a reciprocating motion might extend the lifespan of a NiTi instrument, and thus resistance to fatigue, with respect to continuous rotation (9-12). However, it has also been reported that a reciprocating motion presents some limitations such as major debris transportation toward the apex (13). Consequently, manufacturers have tried to develop new kinematics to exploit reciprocation's benefits and minimize its disadvantages (13). One of these new kinematics is Optimum Torque Reverse (OTR). In OTR motion, the torque is automatically measured during file continuous rotation, and if the torque is less than the set value, the file rotation in CW direction continues, but if the torque has reached the set value, the file reverses rotation in a counterclockwise direction by 90° and then continues in the cutting direction (CW) for 180° until the torque becomes less than the set value. Thus, the reciprocating OTR motion is a partial reciprocation with CW rotational effect and therefore it can be used with instruments that cut in the CW direction such as F6 SkyTaper and OneShape. According to the manufacturer (J. Morita, Tokyo, Japan), OTR reduces file fatigue as well as the possibility of file separation (14).

There is only limited information about OTR motion. In particular, no data are available about the cyclic fatigue resistance of NiTi single-files in reciprocating OTR motion. Thus, the aim of this study was to compare the cyclic fatigue resistance of two single-file NiTi instruments (F6 SkyTaper and OneShape) used in continuous (proper) rotation or in reciprocating OTR motion.

METHODS

Two NiTi rotary single-files (F6 SkyTaper size 25, 0.06 and OneShape size 25, 0.06) were used in this study. All fourth-eight files used were 25-mm long. Twenty-four examples of both types of instrument were divided into two groups (n=12) on the basis of the motion tested-group 1 in continuous rotation and group 2 in reciprocating OTR motion.

Every instrument was inspected for defects or deformities before the experiment under a stereomicroscope (SZR-10; Optika, Bergamo, Italy), and none were discarded.

A static model for cyclic fatigue testing was conducted in a custom-made device that allows reproducible simulation of an instrument confined in a curved canal, similar to that previously described (15, 16). The device consists of a 36.8 mm×25.4 mm×9.5 mm metal block with a suitable simulated canal with 60° angle of curvature and a 5-mm radius of curvature to the

centre of the 1.5-mm wide canal. It ensures three-dimensional alignment and positioning of all instruments at a depth of 19 mm. The radius was measured to the central axis of the curvature according to the method of Schneider (17). The centre of the curvature was 5 mm from the tip of the instrument (18). The apparatus enabled the instrument to rotate freely within a stainless steel artificial canal at a constant pressure.

To reduce friction between the instrument and the metal canal walls, synthetic oil (WD-40; WD-40 Company, San Diego, CA) was sprayed into the simulated canal (19).

The file tip was positioned at 19 mm, and then rotation began synchronised with the timing by a digital stopwatch (Timex, Middlebury, CT) to the thousandth of a second.

In both groups, the instruments were activated by the torque-controlled motor DentaPort ZX with its specific 1:1 contra-angle handpiece (J. Morita, Kyoto, Japan).

In group 1, files were activated in continuous rotation at a constant speed of 300 rpm setting the minimum torque value and by disabling the auto-reverse and auto-stop functions.

In group 2, OTR motion was performed setting the OTR function at 300 rpm and adjusting the torque limit at the minimum level in order to generate a reciprocating OTR motion without any phase of continuous rotation. The contact between the artificial canal and the instrument tested produced a constant torque value that exceeded the one set on the endodontic motor so that the instrument rotated only in OTR reciprocating motion from the beginning of the test until final fracture of the instrument.

For each instrument, the time to fracture (TtF) in seconds from the start of the test until the moment of breakage was detected visually and/or audibly. To obviate human error, video recording was carried out simultaneously, and the recordings were observed to cross-check the time of file separation.

The length of the fractured file tip was measured with a digital microcaliper (Mitutoyo Italiana srl, Lainate, Italy), and the broken fragments were evaluated under a scanning electron microscope (SEM) (S-4800 II; Hitachi High Technologies, Pleasanton, CA) for topographic features of the fracture surfaces. The TtF data were analysed by using two-way analysis of variance (ANOVA) and Bonferroni post-hoc tests at a significance level of 0.05 (Prism 5.0; GraphPad Software, Inc, La Jolla, CA, USA). The TtF was the dependent variable, and the brand of files and the type of motion were independent measurements.

RESULTS

The mean TtF and length of the fractured fragments as well as their standard deviations after the cyclic fatigue test in continuous and in reciprocating OTR motion are presented in Table 1.

TABLE 1. Mean and standard deviation of time to fracture (TtF) in seconds and length of fractured fragments (mm) of the instruments subjected to static test in continuous rotation or reciprocating OTR motion.

Instrument	Cyclic Fatigue (TtF)*				Fractured fragment length (mm)*			
	Continuous rotation (Group 1)		Reciprocating Optimum Torque Reverse motion (Group 2)		Continuous rotation (Group 1)		Reciprocating Optimum Torque Reverse motion (Group 2)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
F6 SkyTaper	151 ^{a1}	18	317 ^{b1}	29	5.07 ^{a1}	0.19	5.10 ^{a1}	0.17
OneShape	61 ^{a2}	21	126 ^{b2}	25	5.09 ^{a1}	0.17	5.12 ^{a1}	0.21

The same letters show differences that are not statistically significant ($P > .05$) in comparison with different groups of the same brand; the same numbers show differences not that are not statistically significant ($P > .05$) in comparison with the same group of different brands.

* Two-Way ANOVA analysis interaction, $P > 0.0001$
SD, standard deviation

The inferential analysis revealed statistically significant differences between the instruments tested considering the type of motion as the independent variable (two-way ANOVA, $P < 0.0001$; interaction < 0.0001). Moreover, there were statistically significant differences between the continuous rotation and reciprocating OTR motion considering the type of instrument as the independent variable (two-way ANOVA, $P < 0.0001$). Post-hoc analysis revealed a significantly higher cyclic fatigue resistance of F6 SkyTaper compared to OneShape in both motions ($P < 0.0001$).

The significant interaction in the statistical analysis suggested that both of the variables (type of motion and instrument) had a relevant impact on the cyclic fatigue resistance.

The two tested instruments showed higher cyclic fatigue resistance in reciprocating OTR motion than in continuous rotation ($P < 0.0001$).

The mean length of the fractured fragments (5.0 mm) was not significantly different for any of the instruments tested ($P > 0.05$), and SEM of the fracture surface showed similar and typical features of cyclic fatigue failure for the two instruments. The crack initiation area and the overload fast fracture zone for cyclic fatigue fractures are shown in Figure 1.

DISCUSSION

Flexural fatigue is one of the main reasons for NiTi file fracture during root canal preparation (7). The present study compares the resistance to cyclic fatigue of F6 SkyTaper and OneShape used in continuous (proper) rotation or in reciprocating OTR motion.

OTR motion was investigated because it is a new kinematic recently introduced in the market, and thus no data are reported in the literature about cyclic fatigue resistance of NiTi rotary instruments used in reciprocating OTR motion compared to continuous rotation. In particular, we tested instruments developed to be used in CW continuous rotation because OTR motion is a CW continuous rotation that changes in a partial reciprocation with the CW rotational effect if the torque limit is exceeded. This kinematics was proposed in order to have

the reciprocating movement only when needed, thus reducing the possible disadvantages of reciprocation such as apical debris compaction and extrusion.

In our study, the torque limit was set at the minimum value to generate a reciprocating OTR motion without any phase of continuous rotation. A setting of a torque limit higher than the minimum one could have prevented the activation of the reciprocating OTR motion because the torque generated during a cyclic fatigue test is very low. In that case, the movement of the instruments would have been a continuous rotation, which we already tested in group 1, or it would have changed unpredictably during the test, making standardisation impossible.

In addition, we tested only reciprocating OTR motion because if we had tested the OTR motion as we tried in our previous methodological trial, the reciprocating OTR motion would begin at different times for each file making the data not directly comparable (20).

Moreover, F6 SkyTaper and OneShape were used in this study because there are few data on the cyclic fatigue resistance of these files.

According to Yao et al. (21), the use of standardised artificial canals minimises the other variables in a cyclic fatigue test. Gavini *et al.* (22) explained the importance of properly selecting the type of test (static or dynamic) for the experiment. In this study, it was decided to evaluate cyclic fatigue resistance in a static test because a dynamic model has some limitations. 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. The ability to constrain the files in a precise trajectory is also difficult in dynamic testing (23). In addition, cyclic fatigue was tested in an artificial canal with 60° of curvature and a 5-mm radius of curvature as reported in most of the previous studies (15, 18, 24, 25). According to previous literature, fatigue life of the instruments was evaluated by TtF and not by the number of cycles to fracture (NCF) (26, 27). Indeed, the TtF is easier to

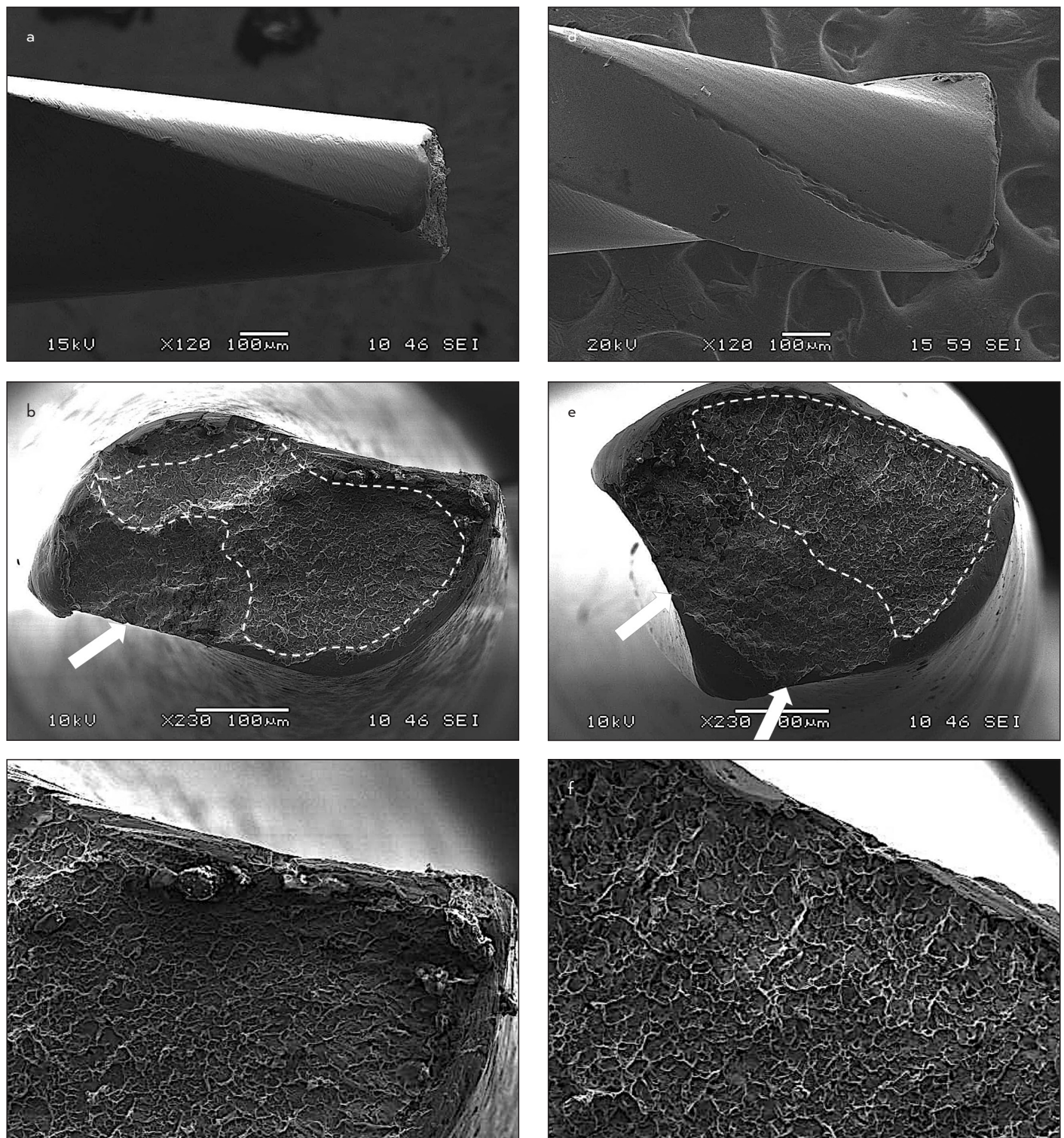


Figure 1. a-f. Scanning electron micrographs of the fracture surfaces of separated fragments after cyclic fatigue test in reciprocating OTR motion (left column: a, b, c = F6 SkyTaper; right column d, e, f = OneShape). The first row shows images in lateral view (a, d), while the central and bottom ones are in axial view (b, e; c, f). The white arrows indicate the origin crack initiation area, while the white area (dotted line) indicates the final fast fracture zone. Particulars of the fast fracture zone edge are visible in the bottom row (c, f). The surface pattern shows fibrous dimples and cones in the same fracture plane.”

control for the operator than NCF and consequently presents more clinically relevant information (26, 28).

In the present study, the tested instruments showed higher cyclic fatigue resistance in reciprocating OTR motion than continuous rotation.

In group 2, instruments were tested using only reciprocating OTR motion to prevent any phase of continuous rotation, which was already tested in group 1. Consequently, the reciprocating motion used could explain the higher cyclic fatigue resistance results observed for both instruments tested in reciprocating OTR than continuous rotation. In agreement

with the present results, it was reported that reciprocation improves cyclic fatigue resistance of NiTi files compared to continuous rotation (9-12, 29).

In this study, F6 SkyTaper showed significantly higher cyclic fatigue resistance than OneShape in both motions. F6 SkyTaper instruments have two sharp cutting edges in a double-S cross-section design while OneShape instruments have three variable cross-section zones, which change from three cutting edges near the tip region to two cutting edges at the end of the working part (7). In addition, the asymmetric portion of the OneShape instrument is only in the final 2 mm of the tip (8).

According to Grande et al. (30) and Plotino et al. (24), cross-sectional design influences the cyclic fatigue resistance. In particular, it was reported that there is an inverse correlation between the cyclic fatigue resistance and the amount of the cross-sectional metal mass of the NiTi files. In a supplementary examination, F6 SkyTaper was found to have a smaller area with respect to OneShape (F6 SkyTaper=91.413 μm^2 and OneShape=112.448 μm^2) when measuring the cross-sectional configuration of each instrument at 5 mm from the tip (D5, file diameter at 5 mm) under a scanning electron microscopy and using the AutoCAD software (Autodesk Inc, San Rafael, CA). Therefore, the higher cyclic fatigue resistance of F6 SkyTaper could be attributed to the reduced cross-sectional area associated with the S-shaped cross-sectional design (7).

Moreover, the significant interaction ($P < 0.0001$) between the two variables tested (type of movement and instrument) confirmed that the cyclic fatigue results were due to differences in both the type of movement and the type of instrument. These results are in agreement with a previous study (7). Nevertheless, in that study, F6 SkyTaper was compared to the New Generation OneShape, while in our study we tested conventional OneShape. Differently from conventional OneShape files, New Generation OneShape instruments have an off-centered cross-sectional design feature that generates a swaggering motion. Moreover, the number of threads has been reduced to increase the instrument's flexibility and therefore its cyclic fatigue resistance (7). However, F6 SkyTaper showed higher cyclic fatigue resistance than New Generation OneShape. Therefore, it is reasonable to think that F6 SkyTaper cyclic fatigue resistance is also higher than the traditional OneShape, as reported in the present study.

On the basis of the present results, reciprocating OTR motion associated with single-file systems, limited to the tested instruments, should be recommended for clinical situations in which the flexural fatigue is high (e.g. in curved canals).

CONCLUSION

Under these experimental conditions and in-vitro experimental limitations, reciprocating OTR motion improves cyclic fatigue resistance compared to continuous rotation for both F6

SkyTaper and OneShape. F6 SkyTaper showed higher cyclic fatigue resistance than OneShape files in both movements tested. Further research is necessary to evaluate the clinical performance of this new kinematic for shaping root canals and minimizing the risk of fracture.

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