Influence of continuous rotation or reciprocation of Optimum Torque Reverse motion on cyclic fatigue resistance of nickel-titanium rotary instruments

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Influence of continuous rotation or reciprocation of Optimum Torque Reverse motion on cyclic fatigue resistance of nickel-titanium rotary instruments

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Running head: OTR motion and cyclic fatigue of NiTi files

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Abstract

Aim To evaluate the resistance to cyclic fatigue of ProTaper Next (PTN; Dentsply Sirona, Ballaigues, Switzerland), Revo-S (Micro-Mega, Besançon, France), Mtwo (Sweden & Martina, Padova, Italy), Twisted Files (TF, SybronEndo, Orange, CA, USA) and EndoWave (J Morita Corporation, Osaka, Japan) used in continuous rotation or in reciprocation of Optimum Torque Reverse motion (OTR).

Methodology A total of 120 nickel-titanium files were tested. Twenty-four instruments for each brand were divided into 2 groups (n = 12) on the basis of the motion tested: continuous rotation (Group 1) or reciprocation of 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. The TtF data were analysed by using the two-way analysis of variance (ANOVA) and Bonferroni post-hoc tests at 0.05.

Results Mtwo and TF had significantly higher TtF when compared with all other instruments, both in continuous rotation and reciprocation of OTR motion ($P < 0.0001$ and $P < 0.05$, respectively). No difference was observed between Mtwo and TF ($P > 0.05$), in both motions. PTN was associated with higher cyclic fatigue resistance than Revo-S and EndoWave, both in continuous rotation and reciprocation of OTR motions ($P < 0.0001$). No difference was observed between Revo-S and EndoWave, in both motions ($P > 0.05$). Reciprocating OTR motion improved TtF of all instruments ($P < 0.0001$).

Conclusions Reciprocation of OTR motion improved significantly cyclic fatigue resistance of all instruments tested compared with continuous rotation. Mtwo and TF had significantly higher cyclic fatigue than the other instruments, in both continuous rotation and reciprocation of OTR motion.

Introduction

Nickel-titanium (NiTi) rotary files have become popular instruments to shape root canals (Bird *et al.* 2009) because of their elasticity, efficiency (Glossen *et al*. 1995, Short *et al.* 1997), and cutting capacity (Peters *et al.* 2014). However, there is a general perception that NiTi instruments have a high risk of fracture during their use. Clinically, there is a real potential for rotary NiTi instruments to fracture inside the canal; even new instruments might demonstrate unexpected breakage on first use

(Arens *et al.* 2003). Although excess torsion and cyclic fatigue have both been implicated as a reason for file fracture, the latter is probably the more prevalent cause of the ‘‘unexpected’’ breakages that occur (Shen *et al.* 2006, Cheung 2009). Cyclic fatigue occurs as a result of the alternating tension-compression cycles to which the NiTi files are subjected when flexed in the region of maximum curvature of the canal (Sattapan *et al.* 2000).

Various manufacturing strategies for NiTi rotary endodontic files have been developed to improve flexibility and resistance to fatigue fracture, including different cross-sectional designs, use of new alloys that provide superior mechanical properties and improvement in the manufacturing processes (Gambarini *et al.* 2008).

ProTaper Next (PTN; Dentsply Sirona, Ballaigues, Switzerland) files are made of M-wire, a NiTi alloy manufactured by a thermal treatment process that reportedly increases flexibility and resistance to cyclic fatigue (Gao *et al*. 2012, Ye *et al.* 2012). Its design features include variable tapers and an off-centered rectangular cross-section.

Revo-S (Micro-Mega, Besançon, France) is a traditional NiTi file system with an off-centred design that generates travelling waves of motion along the active part of the file (Capar *et al.* 2015).

Mtwo rotary files (Sweden & Martina, Padova, Italy) are made of traditional NiTi with a S-shaped cross-section; Twisted Files (TF, SybronEndo, Orange, CA, USA) are made of R-Phase treated NiTi with an equilateral triangular cross-section (Yang *et al.* 2011). The manufacturing process of Twisted Files (TF) as well as electropolishing treatment has been reported to increase their cyclic fatigue resistance (Kim *et al*. 2010, Oh *et al.* 2010).

EndoWave (J Morita Corporation, Osaka, Japan) are traditional NiTi rotary files with triangular cross sections developed to increase the safety factor and cutting efficiency with a ‘continuous wave’ design of instrument (J Morita Corporation 2015). EndoWave instruments are electropolished (Anderson *et al.* 2007), which may enhance the fatigue life of instruments by removing surface irregolarities, cracks, and residual stresses (Kuhn *et al.* 2001).

An alternative method of increasing cyclic fatigue resistance is the use of rotary NiTi instruments in reciprocating motion (Yared 2008). Reciprocating NiTi files have a higher cyclic fatigue resistance when compared with that of continuous rotary NiTi files (Pedullà *et al.* 2013).

The new Optimum Torque Reverse (OTR) kinematic has been recently developed to exploit the benefits of reciprocation and minimize its disadvantages (Plotino *et al.* 2015). During continuous rotation, the torque is automatically measured: if the torque is less than the set value, the file rotation in Clockwise direction (CW) continues, but if the torque has reached the set value, the file reverses rotation in Counterclockwise direction (CCW) by 90° and then continues in the cutting direction (CW) for 180° until the torque becomes less than the set value (J Morita Corporation 2016). Thus, the reciprocation of OTR motion is a partial reciprocation with CW rotational effect and therefore it can be used with instruments that cut in a CW direction such as the PTN, Revo S, Mtwo, TF and EndoWave (these instruments are made to cut in continuous CW rotation). According to the manufacturer, OTR reduces file fatigue as well as the possibility of file breakage (J Morita Corporation 2016).

Therefore the aim of this study was to compare the cyclic fatigue resistance of five NiTi instruments (PTN, Revo- S, Mtwo, TF and EndoWave) used in continuous rotation or in reciprocation of OTR motion. The null hypothesis was that reciprocation of OTR motion has no influence on cyclic fatigue resistance of the tested instruments.

Materials and Methods

Files from five NiTi rotary brands (PTN X2 size 25, .06 taper, Revo-S SU size 25, .06 taper, M-two size 25, .06 taper, TF size 25, .06 taper and EndoWave size 25, .06 taper) were used.

A total of one- hundred and twenty instruments (25-mm long), twenty-four for each brand were divided into 2 groups (n=12) on the basis of the motion tested: Group 1 in continuous rotation and Group 2 in reciprocation of OTR motion.

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

Cyclic fatigue resistance test

Static cyclic fatigue tests were conducted in a custom-made device that allowed a reproducible simulation of an instrument confined in a curved canal, similar to that described in other studies (Larsen *et al.* 2009, Gambarini *et al.* 2012). It consists of a 36.8 mm x 25.4 mm x 9.5 mm metal block with a suitable artificial canal with 60° angle of curvature and a 5-mm radius of curvature to the centre of the 1.5-mm wide canal. It ensured three-dimensional alignment and positioning of all instruments at 19 mm in depth. Radius was measured to the central axis of the curvature according to the method of Schneider (Schneider 1971). The centre of the curvature was 5 mm from the tip of the instrument. 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, USA) was sprayed into the artificial canal (Kim *et al.* 2012).

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

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

In a previous methodological trial, we had tested the OTR motion (not only the reciprocating movement) but the reciprocation of OTR motion started unpredictably. Consequently, only the reciprocation of OTR motion was tested.

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, reciprocation of OTR motion was performed setting the OTR function at 300 rpm and adjusting the torque limit at minimum level in order to generate an OTR reciprocating motion without any phase of continuous rotation. The contact between the artificial canal and the instrument tested produced a constant low torque value that exceed 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, Time to Fracture (TtF) in seconds from the start of the test until the moment of breakage (detected visually and/or audibly) was recorded. To obviate human error, video recording was carried out simultaneously, and the recordings were observed to cross-check the time of file fracture.

SEM analysis

The length of the fractured file tip was measured using a digital microcaliper (Mitutoyo Italiana srl, Lainate, Italy). The broken fragments were evaluated under scanning electron microscope (SEM) (S-4800 II; Hitachi High Technologies, Pleasanton, CA, USA) for topographic features of the fracture surfaces with a magnification of 120x or 150x for the lateral views and 190x or 250x for the axial views in order to obtain the best visualization as possible for all instruments.

Statistical analysis

The log-transformed TtF data were analysed statistically using two-way analysis of variance (ANOVA) and Bonferroni post-hoc tests for multiple comparisons at 0.05 level of significance (Prism 5.0; GraphPad Software, Inc, La Jolla, CA, USA) to ensure that the assumptions of the analysis were fulfilled. The TtF was variable dependent, whereas the brand of files and the type of motion were independent variables.

Results

Mean cyclic fatigue resistance for each instrument in continuous rotation and in OTR reciprocating motion as well as length of the fractured fragments and their standard deviations are presented in **Table 1**.

The inferential analysis revealed 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 significant differences between the continuous rotation and OTR reciprocating motion considering the brand as the independent variable (two-way ANOVA, $P < 0.0001$). Post-hoc analysis revealed a significantly higher cyclic fatigue resistance of Mtwo and TF when compared with all other instruments, both in continuous rotation ($P < 0.0001$) and reciprocation of OTR motion (P <

0.001). No difference was founded between Mtwo and TF, in both motions ($P > 0.05$). PTN was associated with higher TtF values than Revo-S and EndoWave, both in continuous rotation and reciprocation of OTR motions ($P<0.0001$). No difference was observed between Revo-S and EndoWave, in both motions ($P>0.05$).

All of the tested instruments had higher cyclic fatigue resistance when used with reciprocating OTR motion than continuous rotation ($P < 0.0001$).

The mean length of the fractured fragment (5.0 mm) was not significantly different between the instruments tested ($P > 0 .05$).

SEM images of the fracture surface revealed mechanical damage due to cyclic fatigue failure in all of the groups tested both in OTR reciprocating motion and continuous rotation with dimpling and cone formations from the ductile rupturing (**Fig. 1**).

Discussion

Several factors are responsible for file fracture; however, cyclic fatigue has been reported to be a significant cause when rotary files are used in curved root canals (Sattapan *et al.* 2000). This study compared the resistance to cyclic fatigue of PTN, Revo S, Mtwo, TF and EndoWave used in continuous rotation or in reciprocation of OTR motion.

On the basis of the results, the null hypothesis that reciprocation of OTR motion has no influence on cyclic fatigue resistance of the tested instruments was rejected.

OTR motion was investigated because it is a new kinematic and no data is available on cyclic fatigue resistance of NiTi files used in OTR reciprocating motion. In this study, instruments designed for CW continuous rotation were tested because OTR motion is a CW continuous rotation that changes to a partial reciprocation with CW rotational effect if the set torque limit is exceeded. Cyclic fatigue tests were performed in continuous rotation (Group 1) and reciprocation of the OTR motion (Group 2) separately. When reciprocation of OTR motion was tested (Group 2) the torque limit was set at the minimum level in order to generate an OTR reciprocating motion without any phase of continuous rotation.

In cyclic fatigue tests, the torque generated is very low, therefore the setting of a torque limit higher than the minimum one could have prevented the activation of the reciprocation of OTR motion. In that case, the movement of instruments would have been a continuous rotation or it would have changed unpredictably during the test, making standardization impossible.

When continuous rotation was tested (Group 1) the torque limit was set at the minimum level without auto reverse and auto stop functions in order to use the same torque level set for instruments activated by OTR reciprocating motion (Group 2) and to avoid reverse or stopping of rotation during the test.

Moreover, only reciprocation of OTR motion was tested because if the OTR motion would be tested, as in previous methodological trials, the reciprocation of OTR motion would begin at different times for each file of the same brand and also different brands. Therefore, the standardisation of the tests under the same conditions would have been impossible and data would not been directly comparable.

The instruments tested were selected because they are the last instrument of systems that use a sequence of NiTi files in a single-length technique. Moreover, these endodontic instruments are made using several NiTi alloys (M-wire for PTN, R-phase for TF and traditional NiTi for Mtwo, Revo-S and EndoWave).

According to Yao *et al.* (2006), the use of standardized artificial canals minimizes the other variables in cyclic fatigue tests. In this study, a static model for cyclic fatigue tests was preferred to the dynamic one in order to rule out confounding causes by other mechanisms of instrument fracture apart from cyclic fatigue (Pedullà *et al.* 2015). Moreover, the ability to constrain the files in a precise trajectory is also difficult in dynamic tests (Li *et al.* 2002).

In the present study, Mtwo and TF had significantly higher cyclic fatigue resistance than all other instruments, in both motions. No difference was observed between TF and Mtwo, in both motions.

These results are in agreement with previous reports (Kim *et al.* 2010, Pedullà *et al.* 2012, Elnaghy 2014).

Several factors, including the type of metal alloy (Gao *et al.* 2012), the heat-treatment of NiTi (Arias *et al.* 2014), the cross-sectional shape (Versluis *et al.* 2012) and the dimensions (Parashos *et al.* 2004), affect the flexibility and cyclic lifespan of endodontic files.

The high cyclic fatigue resistance observed for TF files is probably due to the synergistic effect of the manufacturing process including twisting, surface treatment and the R-Phase of their NiTi alloy

(Gambarini *et al.* 2008, Kim *et al.* 2010, Pedullà *et al.* 2012).

Although produced by a traditional grinding process, Mtwo instruments were not significantly different than Twisted Files in terms of cyclic fatigue resistance. This is probably due to the lower flexural rigidity for the cross-section of Mtwo (Pedullà *et al.* 2012).

In a recent study, Pedullà *et al.* (2016) reported that the cross sectional area of ProTaper Next X2 5mm from the tip (D5) was greater than Mtwo size 25, .06 taper. This could explain the greater resistance to cyclic fatigue of Mtwo compared with PTN according to previous findings that suggested lower cyclic fatigue resistance for instruments with a greater cross-sectional area (Melo *et al.* 2002, Grande *et al.* 2006).

Regarding the other tested instruments, PTN had higher cyclic fatigue resistance than Revo-S and EndoWave, both in continuous and reciprocating OTR motion. These findings are in agreement with a previous study (Capar et al. 2015). The results could be attributed to the manufacturing process including the M-Wire technology and the rectangular cross-section design of PTN (Gao et al. 2012, Elnaghy 2014).

No difference was observed between Revo-S and Endowave, in both motions.

Data for direct comparison between the EndoWave and other rotary instruments used in this investigation are currently unavailable. It is believed that electropolishing may result in improved cyclic fatigue resistance (Pohl *et al.* 2004). However, the present results are in agreement with previous studies that reported no increase of cyclic fatigue in electropolished instruments (Bui *et al.* 2008, Oh *et al.* 2010). This difference might be because electropolishing is very sensitive and may have a range of effects on mechanical properties depending on the type of electropolishing process used (Oh *et al.* 2010).

All tested instruments had higher cyclic fatigue in reciprocation of OTR motion than continuous rotation. Files were tested using OTR kinematic only in reciprocating motion without any phase of continuous rotation. Consequently, the reciprocating motion used could explain the higher cyclic fatigue resistance observed for all of the instruments tested in reciprocating OTR motion than in continuous rotation. In fact, several studies reported that reciprocating motion improves cyclic fatigue resistance compared with continuous rotation (Gavini *et al.* 2012, Pedullà *et al.* 2013, Elnaghy &

Elsaka 2015).

There was no significant difference in the mean lengths of the fractured fragments of any of the files tested. The fractured length of each file was at the centre of the curvature (approximately at 5 mm from the tip of the instrument) and this confirmed the positioning of the instruments in a precise trajectory (Özyürek 2016).

SEM analysis revealed typical fractographic appearances of cyclic fatigue fractures that were similar amongst the five brands tested. Cyclic fatigue fracture is characterized by dimples on the entire fracture surface (Parashos & Messer 2006, Campbell et al. 2014).

Conclusions

Within the limitations of this study, the instruments tested were associated with greater cyclic fatigue resistance in reciprocation of OTR motion than continuous rotation. Mtwo and TF files had the greatest cyclic fatigue resistance, in both motions. PTN instruments displayed greater cyclic fatigue resistance than Revo-S and EndoWave, both in continuous and in OTR reciprocating motion. No difference was observed between Revo-S and EndoWave, in both movements.

Conflict of Interest statement

The authors have stated explicitly that there are no conflicts of interest in connection with this article.

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Figure Legend

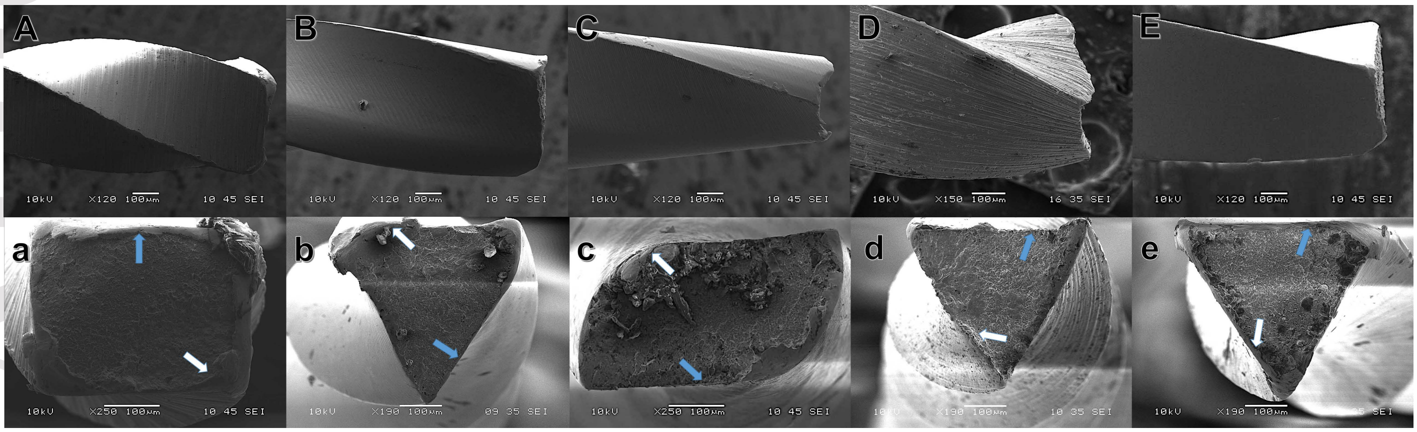
Figure 1 Scanning electron micrographs of fracture surface of instruments size 25, .06 taper after the cyclic fatigue test using reciprocating OTR motion (A, a = ProTaper Next X2; B, b = Revo S SU; C, c Mtwo; D, d Twisted File; E, e EndoWave. (A-E) The first row shows the images in lateral view while (a-e) the second row is an axial visualization of the fractured surface. The blue arrows indicate the origin of the crack while the white ones indicate the final abrupt breakage. The surface pattern shows dimples and cones observed in the same fracture plane due to cyclic fatigue failure.

Table 1 Time to fracture (TtF) (s) and length of fractured fragments (mm) of ProTaper Next, Revo-S, Mtwo, Twisted File and EndoWave files tested in continuous rotation or reciprocation of OTR motion.

Instrument	Cyclic Fatigue (TtF)				Fractured fragment length (mm)			
	Continuous rotation (Group 1)		Optimum Torque Reverse motion (Group 2)		Continuous rotation (Group 1)		Optimum Torque Reverse motion (Group 2)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
ProTaper Next	51[a1]	6	118[b1]	17	5.03[a1]	0.16	5.06[a1]	0.18
Revo-S	41[a2]	9	86[b2]	9	5.05[a1]	0.19	5.09[a1]	0.17
M-two	108[a3]	24	159[b3]	23	5.08[a1]	0.19	5.07[a1]	0.16
Twisted Files	122[a3]	16	165[b3]	26	5.10[a1]	0.17	5.11[a1]	0.18
EndoWave	37[a2]	5	68[b2]	12	5.04[a1]	0.18	5.08[a1]	0.17

For cyclic fatigue, means and standard deviations were analysed using log-transformed TtF data to reduce the influence of different standard deviations and to fulfill the assumptions of the analysis. The same letters show differences not statistically significant ($P > .05$) in comparison with different groups of the same brand; the same number show differences not statistically significant ($P > .05$) in comparison with the same group of different brands.

SD, standard deviation.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