Effect from Cyclic Fatigue of Nickel-Titanium Rotary Files on Torsional Resistance

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Abstract

Introduction: The aim of this study was to evaluate the effect of cyclic fatigue on the torsional resistance of nickel-titanium (NiTi) rotary instruments. **Methods:** ProFile (#25/0.06; Dentsply Maillefer, Ballaigues, Switzerland) and ProTaper (F1, Dentsply Maillefer), both of which have the same external diameter at D5, were tested using a fatigue testing machine for the mean number of cycles of failure (mNCF). Then, new files were cyclic precycled to 4 conditions (ie, 0%, 25%, 50%, and 75% of the mNCF) before the torsional resistance test was performed on these cyclic preloaded files. A uniform clockwise rotation was applied to the file in a straight state in a torsion tester. The torsional load and distortion angle were recorded during rotation until the file succumbed to the torque. The toughness was computed. The results were analyzed statistically using one-way analysis of variance and the Duncan post hoc comparison to find any differences between groups at a significance level of 95%. **Results:** In both ProFile and ProTaper groups, the 75% preloading groups had significantly lower torsional strength than other preloaded files. In the ProFile group, the 50% and 75% preloading groups had a smaller distortion angle until fracture than the 25% and no preloading groups. The 75% preloading group showed a lower toughness value than the 25% and no preloading groups. In the ProTaper group, all preloading groups had less distortion and toughness than the no preloading group. Fractographic examinations revealed the 75% preloaded files showed less amount of reverse-wound flute than other preloading groups. **Conclusions:** Within the limitations of the methodology, it could be concluded that approximate 75% cyclic fatigue may reduce the torsional resistance of NiTi rotary instruments significantly. *(J Endod 2012;38:527–530)*

Key Words

Correlation, cross-section, cyclic fatigue, nickel-titanium rotary file, preloading, torsional resistance

Nickel-titanium (NiTi) rotary instruments are commonly used for endodontic treatment. Root canal preparation with NiTi rotary files is not only easier and faster but also more likely to lead to an improved success rate than with hand instruments (1). Despite the increased flexibility and strength, compared with stainless-steel instruments (2), NiTi rotary instruments still seem to have a risk of fracture in the clinical situation (3–5).

The failure modes of NiTi instrument have been studied fairly extensively (4–9). Although cyclic fatigue is caused by repetitive compressive and tensile stresses acting on outer fibers of a file rotating in a curved canal, torsional failure occurs when the tip of the instrument binds but the shank of the file (driven by the handpiece) continues to rotate (5). Shear fracture of the material then occurs when the maximum strength of the material is exceeded (6). Clinically, cyclic fatigue seems to be more prevalent in curved root canals, whereas torsional failure might happen even in a straight canal (4, 7). Although both failure modes probably occur simultaneously in the clinical situation, most studies of fracture simulation of NiTi files had been performed separately for cyclic fatigue or torsional failure test (4, 6, 7), and it has been rarely studied to correlate these 2 factors of fracture. The purpose of this study was to evaluate the effect of cyclic fatigue on torsional failure of NiTi rotary instruments.

Materials and Methods

Two NiTi rotary systems, ProFile (Dentsply Maillefer, Ballaigues, Switzerland) and ProTaper (Dentsply Maillefer), were selected for this study because they were reported to have unequal cyclic fatigue fracture characteristics (8). The size of the ProFile was #25/0.06 taper and that of the ProTaper was F1 (#20 tip size with 7% taper at apical a few millimeters). They were selected because they possess the similar diameter (0.52∼0.55 mm) at D5 (ie, 5 mm from the file tip and, thus, a similar cross-sectional area roughly at that length).

To evaluate the effect of cyclic fatigue on torsional resistance, we preloaded 4 conditions of cyclic fatigue to the NiTi rotary file before the torsional failure test. The number of cycles of failure (NCF) was counted for each instrument using a custom-made device that allowed a reproducible simulation of rotary instrumentation confined within a curved canal. In the present study, a simulated canal with a radius of 7.8 mm, a 35° curvature, and apical diameter of 0.6 mm was used in an attempt to eliminate variations of canal anatomy.

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0099-2399/$ - see front matter

doi:10.1016/j.joen.2011.12.018

To determine the mean fatigue life (mNCF) of the 2 systems, 10 new files from each brand were rotated until fracture and then calculated using the rotation time (seconds) and the rotations per minute. The mNCFs of ProFile and ProTaper were 896 and 422, respectively. Using the mNCFs, 4 cyclically preloaded conditions (ie, 0% or no preloading, 25%, 50%, and 75% of mNCFs) were each applied to 10 new instruments of both brands.

After cyclic preloading to various extents, torsional loading tests were performed in a torsion tester (Osstem, Busan, Korea) for each brand with a method described by Yum et al (7). Briefly, a metal block with a cubic hole (5 × 5 × 5 mm) was constructed in which 5 mm of the tip of the file was rigidly held in place by filling the mold with a resin composite. To evaluate the mechanical behavior under torsional load and exclude the influence of flexural fatigue, a uniform clockwise rotation at a rate of 2 rotations per minute was applied to the file in a straight state. The torsional load and distortion angle were recorded until the file broke. Seven files of each brand preloaded to various percentages of the value (n = 10) were tested. The toughness was computed from the area under the plot for each file. The results were analyzed statistically using one-way analysis of variance and the Duncan post hoc comparison for any difference between groups at a significance level of 95%.

The fracture surfaces of all fragments after the torsion test were evaluated under the scanning electron microscope (S-4800 II; Hitachi High Technologies, Pleasanton, CA) for topographic features. The 3 files from each group that were not used for the torsional test were examined longitudinally for the specific features after cyclic loading for various amounts.

Results

The maximum torsional strength, distortion (fracture) angle, and the computed toughness of each group are presented in Table 1, and the torque and distortion angle are depicted in Figure 1. In both the ProFile and ProTaper groups, the 75% preloading groups had significantly lower torsional strength than others ($P < .05$), and there was no difference among the 0%, 25%, and 50% preloaded groups ($P > .05$). In the ProFile group, the 50% and 75% preloading groups had a smaller distortion angle until failure than the 25% and no preloading groups. The 75% preloading group had less toughness than the 25% and no preloaded groups ($P < .05$). In the ProTaper group, all of the preloading (ie, 25%, 50%, and 75%) groups had less of a distortion angle until fracture and less toughness than the no preloading group. The 75% preloading group had the least toughness ($P < .05$).

There was no specific finding or difference of the scanning electron microscopes in the lateral view for various cyclically preloaded files. The appearances of the fracture surface after the torsion test all exhibited the typical pattern of torsional fracture characterized by circular abrasion marks and skewed dimples near the center of rotation (Fig. 2*E* and *F*). The 75% preloaded files from both brands showed a smaller amount of reverse-wound flute (Table 1) than other cyclically preloaded groups (Fig. 2). Some specimens from the 75% preloading groups showed prominent microcracks near the torsional fracture plane (Fig. 2*D* and *H*).

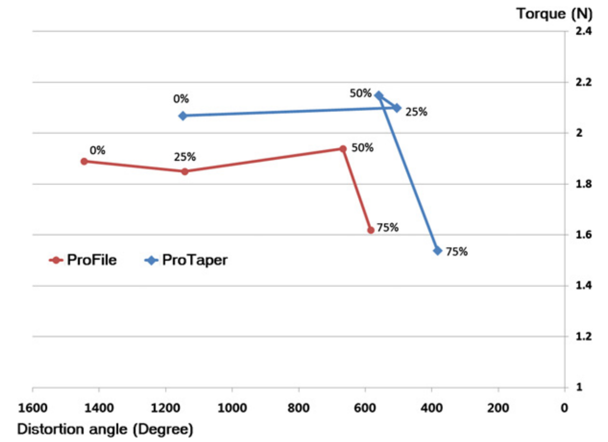

Figure 1. The maximum torsional strength (torque) and distortion angle according to the preloaded cyclic fatigues.

Discussion

The mechanism of rotary instrument fracture was reported as torsional (a special form of shear) failure and cyclic fatigue fracture (5). Cyclic fatigue resistance is measured by the number of cycles that an instrument endures in a fatigue test. The number of cycles is cumulative and related to the extent of (microscope) damage caused by the repeated compressive and tensile stresses that, in turn, are related to the radius of curvature, arc length, and instrument size and design (9–12). According to Tobushi et al (13), the cyclic fatigue test is a simple and reliable approach to determine the fatigue behavior of workpieces manufactured from NiTi alloy.

Torsional failure occurs when the tip or some part of the instrument is "locked" or jammed in the canal, but the shank of the file (driven by the handpiece) continues to rotate. It is difficult to reproduce the environment of torsional failure occurs, and there is no specification or international standard to test the torsional resistance of rotary NiTi instruments. The measurement of torsional strength of root canal instruments is usually performed in a torsiometer, as is stipulated by the American Dental Association specification number 28 that was meant for the stainless-steel instruments (14). Data obtained using this

TABLE 1. Ultimate Strength (N), Fracture Angle (degree), and Toughness (N · degree) from Torsional Resistance Tests (mean ± standard deviation) after Cyclic Preloading of the mNCF

	Cyclic preloading of the mNCF			
	0%	25%	50%	75%
ProFile				
Ultimate strength	1.89 ± 0.15^{a}	1.85 ± 0.25^{a}	1.94 ± 0.20^{a}	1.62 ± 0.20^{b}
Fracture angle	$1{,}446 \pm 864^{a}$	$1{,}143 \pm 579^{ab}$	668 ± 178^{b}	583 ± 200^{b}
Toughness	$2{,}000 \pm 1168^{a}$	$1{,}469 \pm 646^{ab}$	850 ± 325^{bc}	636 ± 305^{c}
ProTaper				
Ultimate strength	2.07 ± 0.40^{a}	2.10 ± 0.10^{a}	2.15 ± 0.18^{a}	1.54 ± 0.11^{b}
Fracture angle	$1{,}148 \pm 642^{a}$	506 ± 110^{b}	559 ± 142^{b}	384 ± 55^{b}
Toughness	$1{,}575 \pm 749^{a}$	782 ± 199^{bc}	$1{,}004 \pm 607^{b}$	390 ± 77^{c}

Different superscripts mean significant differences between groups in the horizontal row ($P < .05$).