Effect of Torsional Loading of Nickel-Titanium Instruments on Cyclic Fatigue Resistance

Gary Shun-Pan Cheung, BDS, MDS, PhD, Seung-Hei Oh, DDS, MS,† Jung-Hong Ha, DDS, MS,‡ Sung Kyo Kim, DDS, MS, PhD,‡ Se-Hee Park, DDS, MS, PhD,§ and Hyeon-Cheol Kim, DDS, MS, PhD†*

Abstract

Introduction: The aim of this study was to evaluate the effect of torsional preload on the cyclic fatigue life of nickel-titanium rotary instruments. **Methods:** ProFile (#25/0.06) (Dentsply Maillefer, Ballaigues, Switzerland) and ProTaper (F1; Dentsply Maillefer) were used. Each file was preloaded at 4 conditions (ie, no preloading and 25%, 50%, and 75% of mean ultimate torsional strength) of torsional prestress before the fatigue test. The torsional preloads were applied by securing 5 mm of the file tip while keeping the file straight, rotating it clockwise until the preset torque, and then returning to the original position. This motion was repeated until a preset number (10, 30, or 50) of repetitions were reached (n = 12). After torsional preloading, the number of cycles to failure was evaluated in a simulated canal. Data were analyzed using 2-way analysis of variance and the Duncan post hoc comparison. The fractured fragment surfaces were examined under a scanning electron microscope for the topographic features of fractured instruments. **Results:** For both instruments, there was a significant effect because of the extent of torsional preloads. The 50% and 75% torsionally preloaded ProFile and all ProTaper preloading groups had a higher number of cycles to failure than the other group(s). There was little difference in the lateral view appearance between new and torsionally preloaded files. After cyclic fatigue testing, all preloaded instruments showed numerous microcracks adjacent to the fracture site on lateral view examination. The microcracks did not seem to follow the machining grooves on the instrument surface but rather ran irregularly. **Conclusions:** The torsional preloads within the superelastic limit of the material may improve the cyclic fatigue resistance of nickel-titanium rotary instruments. *(J Endod 2013;39:1593–1597)*

Key Words

Cyclic fatigue resistance, nickel-titanium rotary file, preloading, superelasticity, torsional load

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 seem to be vulnerable to fracture in clinical situations (3–6).

The separation of NiTi instruments has been studied extensively (6–10). Flexural or cyclic fatigue occurs when an instrument rotates in a curved canal, which causes motion-induced repeated compressive and tensile stresses. Torsional failure occurs when the tip of the instrument binds in the canal, but the motor continues to rotate (6). Clinically, cyclic fatigue seems to be more prevalent in curved root canals, whereas torsional failure might happen even in a straight canal (6, 7). Although both failure modes probably occur simultaneously in the clinical situation, most fracture simulation studies of NiTi files have been conducted separately for a cyclic fatigue or torsional failure test (6–10). There are very few studies that correlated these 2 factors of fracture.

Some reports (11, 12) were available indicating that the cyclic preloading (preuse) of NiTi rotary files would reduce the torsional resistance significantly. However, to date, a rare study has investigated the potential effect on cyclic fatigue resistance by torsional preloading. In the clinical situation, as a result of the diversity of canal dimensions, NiTi rotary instruments may be subject to torsional stress of various degrees during root canal preparation, especially in the early stage of canal enlargement. The aim of this study was to evaluate the effect of torsional preload on the cyclic fatigue life of selected NiTi rotary instruments.

Materials and Methods

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

To evaluate the effect of torsional stress on cyclic fatigue life, each file was preloaded at 4 conditions of torsional prestress before the fatigue test. Before that experiment, the maximum torsional load (Ncm) until fracture was estimated for the 2 brands of instruments (n = 10 each) using a custom-made device (AEndoS; DMJ System, Busan, Korea) (Fig. 1A) for a mean ultimate torsional strength. The values for ProFile and ProTaper

From the *Area of Endodontics, Faculty of Dentistry, the University of Hong Kong, Hong Kong SAR, China; †Department of Conservative Dentistry, School of Dentistry, Pusan National University, Dental Research Institute, Yangsan, Korea; ‡Department of Conservative Dentistry, School of Dentistry, Kyungpook National University, Daegu, Korea; and §Department of Conservative Dentistry, College of Dentistry, Gangneung-Wonju National University, Gangneung, Korea.

Gary Shun-Pan Cheung, Seung-Hei Oh, and Jung-Hong Ha contributed equally to this study.

Address requests for reprints to Dr Hyeon-Cheol Kim, Department of Conservative Dentistry, School of Dentistry, Pusan National University, 20, Geumo-ro, Mulgeum, Yangsan, Gyeongnam 626-810, Korea. E-mail address: golddent@pusan.ac.kr

0099-2399/$ - see front matter

http://dx.doi.org/10.1016/j.joen.2013.07.032

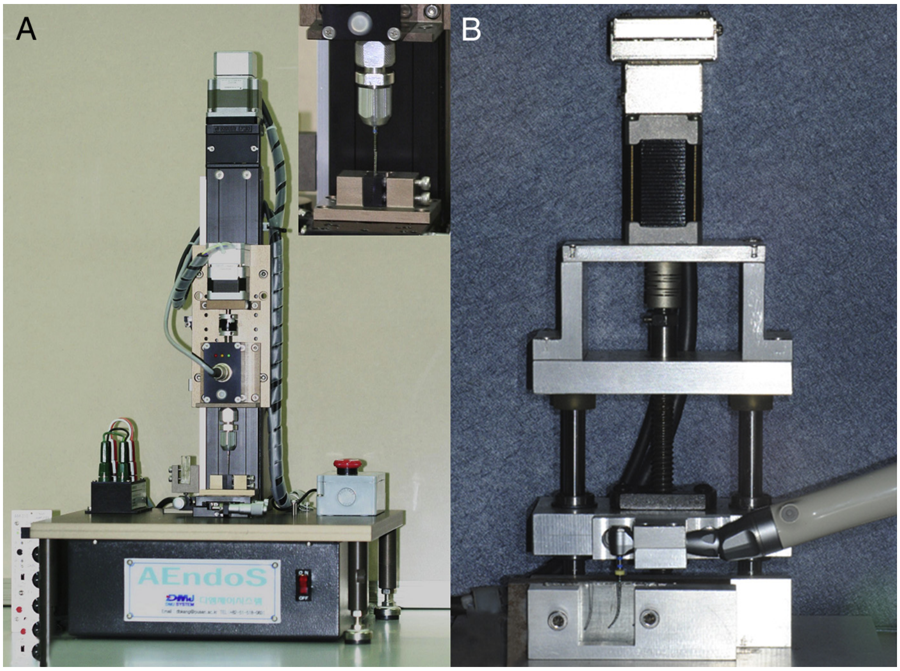

Figure 1. (*A*) Device (AEndos) for applying torsional (pre)loads and (*B*) customized cyclic fatigue tester with a simulated artificial canal.

were 1.83 Ncm and 1.84 Ncm at the D5 level. Four torsional preloading conditions were applied ($N = 118$): 0% or no preloading and 25%, 50%, and 75% of the mean ultimate torsional strength. The torsional preloads were applied using the same device (AEndoS) by securing 5 mm of the file tip between polycarbonate blocks and, while keeping the file straight, rotating it clockwise at a constant rate of 2 rpm until the preset torque value (25%, 50%, and 75%) and then returning to the original position (ie, strain = 0). This motion was repeated until a preset number of repetitions were reached; 12 new instruments of each brand were preloaded for 10, 30, or 50 repetitions.

After torsional preloading, cyclic fatigue resistance was evaluated in a custom-made device (Fig. 1*B*) that was a reproducible simulation of a curved canal to confine the rotating instrument. This artificial canal block was made of tempered steel with a 7.8-mm radius and 35° angle of curvature measured using the Schneider method (13). Synthetic oil (WD-40; WD-40 Company, San Diego, CA) was sprayed into the metal canal space to reduce friction between the instrument and the walls of the metal canal. The instruments ($n = 10$ from each subgroup) were freely rotated at 300 rpm in a "static" mode (ie, without any pecking movement). Instrument fracture was detected visually and audibly, and the time for fracture was recorded with a chronometer. The number of cycles to failure (NCF) for each instrument was calculated by multiplying the total time (seconds) to failure by the rotation rate (5 revolutions per second, 300 rpm). The length of the fractured file tip was measured using a digital microcaliper (Mitutoyo, Kawasaki, Japan) at 10× magnification under a dental operating microscope (Zeiss Pico; Carl Zeiss MediTec, Dublin, CA).

Data were first examined using the Shapiro-Wilk test for normality of distribution. The results were analyzed using 2-way analysis of variance and Duncan post hoc comparison for any difference between groups at a significance level of 95% (SPSS v19.0; IBM Corp, Somers, NY). For each brand, 2 independent variables were evaluated: torsional preload value and the number of repetitions of torsional preloads.

The fracture surfaces of all fragments after the fatigue test were examined under the scanning electron microscope (S-4800 II; Hitachi High Technologies, Pleasanton, CA) for the topographic features of the fractured instruments. Two files from each subgroup, which were not tested for cyclic fatigue, were examined longitudinally for any specific features after torsional preloading for various extents.

Results

The NCFs for each group are presented in Table 1. The Shapiro-Wilk test showed a normal distribution of data for the fatigue resistance test and the length of fractured fragments. For both brands of instrument, there was a significant effect because of the extent (or value) of torsional preloads but no significant influence by the number of preload repetitions (Table 1).

For the ProFile brand, the 75% and 50% torsionally preloaded groups showed significantly higher NCFs than the nonpreloaded (0%) group ($P < .05$). The length of the fracture fragment ranged from 3.57–4.73 mm (average = 3.94 mm).

For the ProTaper brand, all preloading (25%, 50%, and 75%) groups had higher NCFs than the nonpreloaded group ($P < .05$). The 75% and 50% torsionally preloaded groups showed significantly higher NCF values than the 25% preloaded group ($P < .05$). The fracture length ranged from 3.69–5.15 mm (mean = 4.09 mm).

The scanning electron microscopic topographic appearance of the fracture surfaces showed typical features of cyclic fatigue, including 1 or more crack initiation area(s) and the presence of fatigue striations (Fig. 2*A* and *B*) and a fast fracture zone with dimples and microporosities (Fig. 2*C*). There was little difference in the longitudinal or lateral view appearance between new and torsionally preloaded files; indeed, the lateral aspect of the preloaded file did not show any specific topographic features even after loading to 75% of the ultimate torsional strength for up to 50 repetitions (Fig. 2*D*). After cyclic fatigue testing and on lateral view examination, all preloaded instruments showed numerous microcracks adjacent to the fracture site (Fig. 2*E–H*). Of particular interest, the microcracks did not seem to follow the machining grooves on the instrument surface, but rather