Influence of Cyclic Flexural Deformation on the Torsional Resistance of Controlled Memory and Conventional Nickel-titanium Instruments

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Abstract

Introduction: The aim of this study was to evaluate the influence of cyclic deformation on the torsional resistance of controlled memory (CM) nickel-titanium files in comparison with superelastic (SE) instruments with similar geometric and dimensional characteristics. **Methods:** New 30/.06 HyFlex (HF; Coltene/Whaledent, Inc, Cuyahoga Falls, OH), Typhoon (Clinician's Choice Dental Products, New Milford, CT), RaCe (FKG, La-Chaux De Fonds, Switzerland), and ProTaper Universal F2 instruments (F2; Dentsply Maillefer, Ballaigues, Switzerland) were assessed. The diameter and pitch length were measured along the active part of the instruments. The number of cycles to failure (Nf) in flexural fatigue and the torsional resistance were evaluated for new files ($n = 10$). Ten new instruments of each type were fatigued to 3/4 of their fatigue life and then submitted to torsion until rupture. Data were analyzed using 1-way analysis of variance ($\alpha = .05$). **Results:** New CM files had a significantly higher Nf when compared with SE instruments; HF exhibited the highest value ($P = .001$). The mean torque value for F2 was the highest ($P = .001$). CM files precycled to 3/4 Nf had a significantly lower torque than the new files (HF: $P = .003$, Typhoon: $P = .001$), whereas the SE instruments displayed no significant differences (F2: $P = .059$, RaCe: $P = .079$). **Conclusions:** Cyclic flexural loading significantly reduced the torsional resistance of CM instruments. *(J Endod 2016;■:1–6)*

Key Words

Controlled memory, fatigue resistance, nickel-titanium, rotary endodontic instruments, torsional resistance

Significance

The results of the present study indicate that clinicians should consider the decrease in torsional resistance after multiple use in curved canals when NiTi rotary endodontic instruments manufactured by the controlled memory technology are used.

The endodontic field encountered an important breakthrough with the introduction of the nitinol alloy. It offers special mechanical properties like a shape memory effect and superelasticity (1). Notwithstanding the particular properties of NiTi instruments, they could suffer unexpected fractures during root canal preparation.

The performance of endodontic NiTi instruments under cyclic loading relies on material strength, microstructure, surface quality, and type of loading. It is associated with structural and functional fatigue, which are damages generated either to the microstructure or the functional properties of the material, respectively (2).

According to some researchers, flexural fatigue is probably the most prevalent cause of unexpected fracture encountered clinically (3, 4). However, Sattapan et al (5) reported a higher prevalence of torsional fracture for multiple use of NiTi rotary files. Despite these remarks, it is difficult to avoid the fact that both flexural and torsional stresses occur concomitantly, but until now just a few reports have associated them with each other. It has been reported that cyclic flexural straining significantly reduced torsional resistance, particularly of the instruments preloaded at three fourths of their life span (6–8).

To improve the resistance of NiTi files, different thermomechanical treatments have been applied to the NiTi alloy to enhance their endurance (9–12). Heat treatment is 1 of the most fundamental approaches favoring the adjustment of the transition temperatures, with the purpose of controlling the alloy microstructure and consequently improving its mechanical behavior (13).

Among the first thermomechanical treatments applied to the conventional NiTi alloy was the M-Wire introduced in 2007 by Berendt (14). The 508 nitinol wire (Nitinol Devices & Components, Inc, Fremont, CA) is cold drawn and submitted to different thermomechanical treatments resulting in a material that includes some amount of the R-phase and B19′ martensite (15), thus improving the flexibility and fatigue resistance of the instruments (9, 10, 16). The accumulation of lattice defects is considerably lower because of a more competent superelastic (SE) behavior (15). Later, in 2010, NiTi

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rotary instruments made from an NiTi wire were subjected to a particular proprietary thermal processing named the controlled memory (CM) technology (CM Wire; DS Dental, Johnson City, TN). Studies have shown that instruments made with the CM technology have superior flexibility and fatigue resistance compared with instruments made of conventional NiTi (17–19). Thus, the aim of this *in vitro* study was to assess the influence of flexural fatigue loading on the torsional resistance of CM rotary files when compared with conventional NiTi files with similar dimensions and geometries.

Materials and Methods

New 30/.06 instruments including Typhoon (TYP; Clinician's Choice Dental Products, New Milford, CT) and HyFlex CM (HF; ColteneEndo/Whaledent, Cuyahoga Falls, OH) along with RaCe (RC; FKG Dentaire, La-Chaux de Fonds, Switzerland) and ProTaper Universal F2 (F2; Dentsply Maillefer, Ballaigues, Switzerland), which are made of conventional NiTi, were analyzed. These instruments were chosen because of their similar geometric design (RC and HF with triangular cross sections and F2 and TYP with convex triangular cross sections).

A total of 120 files were used in this study. The instruments were divided into 3 groups:

1. Control group 1, which was composed of 10 new instruments of each system that were fatigued until fracture to determine the number of cycles to failure (Nf)
2. Control group 2 (CG2) (n = 10 each system), which was submitted to torsion tests to failure to determine the maximum torque
3. An experimental group (EG) in which new instruments (n = 10 each system) were fatigued to three fourths of their Nf and then submitted to torsion tests to failure

To assess the dimensional characteristics based on the American National Standards Institute/American Dental Association Specification No. 101, 10 instruments of each system were photographed using a high-resolution digital camera (20D; Canon, Tokyo, Japan). Lines were drawn on the instrument images, and the outermost diameter at each millimeter from the tip and the distance between each pitch were determined using ImageJ 1.49 V (National Institutes of Health, Bethesda, MD).

Ten instruments (n = 10) of each system were tested in fatigue until failure at room temperature using a bench device with an artificial canal made of quenched steel. This device consists of an arch with a curvature radius of 5 mm and an angle of 45° in a guide cylinder of 10 mm in diameter, all of them made of the same material (20). The chosen geometry placed the area of maximum tensile strain amplitude at about 3 mm from the tip of the instrument. The instruments, attached to a handpiece with a reduction of 16:1 and a torque of 4 Ncm, were allowed to rotate freely until fracture inside of the artificial canal, aligned between the arch and the guide cylinder, and the Nf was obtained by multiplying the rotation speed (300 rpm) by the test time registered using a digital chronometer. The point of fracture relative to the tip of the instrument was estimated by measuring the fractured file with an endodontic ruler. Once the mean Nf was determined, new files (n = 10) were tested in the fatigue test bench up to 3/4 of their previously determined fatigue life and subsequently tested in torsion to fracture, corresponding to the experimental group for each system. This precycling condition was chosen aiming to reach a highly fatigue-damaged condition within the 25% safety margin of average Nf values. Nevertheless, 1 PTU F2 instrument and 2 TYP instruments failed before reaching 3/4 of their average fatigue life. No HF nor RC instrument failed before reaching this condition. The failed instruments were replaced, and the files were tested as before.

Torsion tests were performed according to ISO 3630-1 in a bench machine (AN8050; Analógica, Belo Horizonte, MG, Brazil). The rotation speed was set clockwise to 2 rpm. The end of the shaft was clamped into a chuck connected to a reversible geared motor. Three millimeters of the instrument's tip were clamped in another chuck with soft brass jaws to prevent sliding. Continuous recording of torque and angular deflection was provided by a specifically designed computer program. The statistical significance of the differences of the measurements among the 4 types of files was assessed by 1-way analysis of variance and the post hoc Tukey test at a significance level of $P > .05$.

The fracture surfaces of 3 randomly selected instruments of each system were examined under a scanning electron microscope (SEM-FEI Inspect S50; FEI Co, Hillsboro, OR) to access the main characteristics of the fracture process.

Results

The mean values and standard deviation of the diameter at 3 millimeters from the tip (D3) for the instruments exhibiting a triangular cross section revealed similar values (HF: .48 ± .01 mm and RC: .49 ± .01 mm), with no statistical significant differences between them (P = .180). On the other hand, D3 values for instruments with a convex triangular cross section (TYP: .48 ± .01 mm and PTU F2: .50 ± .01 mm) displayed PTU F2 instruments with a significantly larger D3 (P = .002).

The main geometric characteristics and the mechanical properties of the new files are summarized in Figure 1. PTU F2 instruments exhibited smaller values (1.04 ± .02 mm) of the pitch lengths of all instruments evaluated (Fig. 1*A*) followed by TYP (1.26 ± .04 mm), HF (1.52 ± .02 mm), and RC (1.66 ± .14 mm) instruments. The pitch lengths increased along the active part for all of the instruments, except for HF instruments, which exhibited a constant value of this geometric parameter. The RC instruments exhibited the largest pitch lengths among all of the instruments evaluated. The mean values of the Nf obtained in the fatigue tests of new instruments (control group 1) are shown in Figure 1*B* (standard deviations shown as error bars). The results indicated that HF instruments presented a significantly higher Nf compared with RC instruments (P = .001). The same pattern was observed for TYP and PTU F2 instruments; TYP showed significantly higher mean Nf values (P = .001), confirming the higher fatigue resistance of CM instruments. Among all of the instruments, the mean point of fracture from the tip was 3.0 mm (±.01 mm).

The average torsion curves for the new instruments (CG2) are shown in Figure 1*C*. The results indicated that instruments with a triangular convex cross section (TYP and PTU F2) exhibited higher mean torque values in comparison with instruments with a triangular cross section (HF and RC). Statistical analysis showed that the maximum torque of PTU F2 was significantly higher than TYP files (P = .002), with similar cross-sectional geometry. In contrast, HF and RC presented similar results for the maximum torque (P = .200). Moreover, PTU F2 presented the highest torsional resistance among all of the instruments evaluated (P = .001).

The mean values of maximum torque and angular deflection of the new instruments (CG2) and those previously fatigued to 3/4 of their fatigue life and then tested in torsion to rupture (EG) are shown in Figure 2*A* and *B*. Cyclic flexural preloading caused a statistically significant reduction of maximum torque for the CM instruments of up to 25% (HF: P = .003 and TYP: P = .001). However, no such difference was noticed between CG2 and EG SE instruments (PTU F2: P = .059 and RC: P = .079). The mean values of maximum angular deflection (Fig. 2*B*) showed the same tendency as the torque, with a significant