Effect of Torsional and Fatigue Preloading on HyFlex EDM Files

Ya Shen, DDS, PhD,[*†] *Charles Tra, DMD,*[*] *Ahmed Hieawy, DDS, PhD,*[*] *Zhejun Wang, DDS, PhD,*[*] *and Markus Haapasalo, DDS, PhD*[*]

Abstract

Introduction: The purpose of this study was to evaluate the effect of a low amount of torsional preloading on the fatigue life and different degrees of cyclic fatigue on torsional failure of HyFlex EDM (EDM; Coltene-Whaledent, Allstetten, Switzerland) and HyFlex CM (CM; Coltene-Whaledent) instruments. **Methods:** EDM and CM files were used. The fatigue resistance was examined in a 5-mm radius and 60° single curve, and the mean number of cycles to failure (N_f) was recorded. The torque and rotation angles at failure of the instruments were measured according to ISO 3630-1. New files were precycled to 0%, 50%, and 75% of the N_f, and torsional tests were then performed. Other new files were preloaded at 5%, 15%, 25%, and 50% of the mean rotation angles before the fatigue test. The fracture surfaces of the fragments were examined under a scanning electron microscope. **Results:** The fatigue resistance of EDM instruments was higher than that of CM instruments ($P < .05$). The torque and angle of rotation at fracture of the files were similar. Torsional preloading lowered the N_f of EDM at 15% preloading ($P < .05$) and the N_f of CM at 50% preloading ($P < .05$). However, the N_f of EDM files even with 50% torsional preloading was significantly higher than unused CM files ($P < .05$). Fatigue prestressing even at 75% had no negative effect on the torque and rotation angle of the EDM files. Moderate precycling (50%) of EDM files increased their torsional resistance. The fractographic patterns corresponded to the pattern defined by the last stage test. **Conclusions:** A low amount (15%) of torsional preloading reduced the fatigue resistance of EDM files, whereas even extensive (75%) precyclic fatigue was not detrimental to their torsional resistance. *(J Endod 2017;■:1–5)*

Key Words

Endodontic, fatigue, fracture, HyFlex CM, HyFlex EDM, preloading, torsion

Significance

The torsional and fatigue profiles presented in this study serve as a basis for safer instrumentation. The fatigue resistance of NiTi files may be reduced at a low amount of torsional preloading.

Nickel-titanium (NiTi) instruments are continuously improved with new designs and metallurgical innovations to facilitate safe and effective root canal preparation. Clinically, it is important that the instruments do not unexpectedly fracture, which may happen by 1 or a combination of 2 different ways: cyclic fatigue and/or torsional failure (1, 2). Cyclic fatigue is caused by the alternating tension-compression cycles to which they are subjected when flexed in the maximum curvature of the canal during rotation (1, 3). Torsional fracture occurs when the torque resulting from the contact between the instrument and the canal wall exceeds the torsional strength of the instrument or when the instrument tip is locked in a canal while the rest of the file continues to rotate (1, 4).

Thermal treatment of NiTi alloys or files has been used to optimize the mechanical properties of the files (5–11). HyFlex CM (CM) rotary files (Coltene-Whaledent, Allstetten, Switzerland) are made from NiTi wire that has been subjected to proprietary thermomechanical processing. Recently, HyFlex EDM (EDM) (Coltene-Whaledent) files were introduced. They are manufactured from the same wire as CM files but are produced via electrodischarge machining, a noncontact thermal erosion process that partially melts and evaporates the wire by high-frequency spark discharges (12). During this procedure, the shape of a work piece is changed by building a potential between the NiTi metal and the tools. The sparks initiated in this process are melting and vaporizing the material of the work piece in its surface layer (13). One study (14) found an increase of fatigue resistance for up to 700% of the EDM compared with CM (size 40/.04) in a 70° curvature with a 5-mm radius. In clinical use, it is likely that torsional and fatigue forces happen simultaneously during root canal preparation. A recent study (15) showed that a low amount (25%) of torsional preloading reduced the fatigue resistance of K3XF (heat-treated) (SybronEndo, Orange, CA) instruments. Another study (16) also found that 25% torsional preloads significantly reduced the cyclic fatigue of Typhoon CM files (Clinician's Choice Dental Products, New Milford, CT) (size 25/.06). Therefore, the purpose of this study was to evaluate the effect of a low amount (up to 5%) of torsional preloading on the cyclic fatigue life and various degrees of cyclic fatigue on torsional failure of EDM and CM files.

Materials and Methods

Size 40/.04 EDM and CM rotary NiTi files were selected for the study because this was the only size and taper shared by both instruments. The files were subjected

From the *Division of Endodontics, Department of Oral Biological and Medical Sciences, Faculty of Dentistry, and †Department of Materials Engineering, The University of British Columbia, Vancouver, Canada.

Address requests for reprints to Prof Markus Haapasalo, Division of Endodontics, Department of Oral Biological and Medical Sciences, UBC Faculty of Dentistry, 2199 Wesbrook Mall, Vancouver, BC, Canada V6T 1Z3. E-mail address: markush@dentistry.ubc.ca

0099-2399/$ - see front matter

https://doi.org/10.1016/j.joen.2017.12.002

to fatigue tests inside a custom-made artificial canal in stainless steel at a curvature of 60° with a 5-mm radius (with size 40/.06) in the laboratory (17). The instruments were rotated at 500 rpm (as recommended by the manufacturer) until fracture. The fatigue life, or the total number of revolutions to failure (N_f), was recorded. The torsion tests were performed according to ISO 3630-1 using a torsion machine; 3 mm of the instrument tip was secured firmly in a specifically designed soft brass holder to prevent sliding (4, 18). The apparatus was composed of a torque sensor (Futek Model TFF 400; Futek, Irvine, CA) and a low-speed rotating motor. The rotation speed was set clockwise to 2 rpm until fracture occurred (18). The torsional load and rotation angle were recorded until the instrument broke (15, 18).

The effect that cyclic fatigue had on torsion was evaluated as follows: cyclic preloading was first performed on the files under 3 conditions. Twelve unused instruments in each group were exposed to 0%, 50%, or 75% of their respective mean N_f (Table 1). After cyclic preloading, torsional loading tests were performed in a torsion tester until fracture to establish the mean values of torque to failure and the maximum angular rotation of the instruments. In the torsional preloading groups, 12 new instruments in each group were preloaded to 0%, 5%, 15%, 25%, or 50% of their respective mean distortion (rotation) angle at torsional fracture (Table 2). After torsional preloading, cyclic fatigue resistance was examined in the artificial canal.

After instrument fracture, 3 files in each group were examined longitudinally under a scanning electron microscope (Stereoscan 260; Cambridge Instruments, Cambridge, UK). The fracture surfaces of the fragments were also examined with the scanning electron microscope at 5 kV. The results were analyzed using 2-way analysis of variance and the post hoc Tukey test (SPSS for Windows 11.0; SPSS, Chicago, IL) when necessary at a significance level of $P < .05$.

Results

EDM instruments subjected to fatigue testing had a significantly higher N_f when compared with CM instruments (Table 1) ($P < .05$). However, the torque and angle of rotation at fracture of the EDM files were similar to those of CM instruments (Table 2 and Fig. 1). The corresponding torque of files that were preloaded to 5% of the mean of the rotation angle reached almost 10% of the torque at fracture (Table 2).

In the torsional preloading groups, a low amount of preloading (15% of the mean of the rotation angles) significantly reduced the mean N_f of EDM instruments (Fig. 1*A*) ($P < .05$) in cyclic fatigue testing, whereas a moderate amount of 50% torsional preloading significantly lowered the N_f of CM files ($P < .05$). The N_f of EDM files even with 50% torsional preloading was significantly higher than that of CM files without any torsional preloading ($P < .05$).

In the EDM fatigue prestressed groups, there was no difference in the torque value and rotation angle between the groups without prestress and even with 75% prestress. The CM files had significantly lower rotation angles after 50% fatigue stress and torque value after 75% fatigue stress compared with the files without fatigue prestress ($P < .05$).

TABLE 1. Baseline Data for HyFlex EDM (EDM) and HyFlex CM (CM) Instruments, Size 40/.04: Fatigue Life Span (Number of Revolutions [Nf]) and Precyclic Nf

	N_f	50% N_f	75% N_f
EDM	2490 ± 306	1245	1868
CM	1029 ± 158	515	772

A close-up scanning electron microscopic view of the EDM and CM files showed the presence of a peculiar irregular surface texture derived from the manufacturing process (Fig. 2). High-magnification micrographs disclosed a nonuniform structure in which pits, pores, and voids were observed on a "rough spark-machined" surface (Fig. 2*A*). After 15% torsional preloading, both EDM and CM files showed microcracks in the plastic deformation area about 3–4 mm away from the tip. Although the machining grooves of the EDM files were removed during the manufacturing process, the microcracks ran irregularly perpendicular to the longitudinal axis of the files close to the fractured area (Fig. 2*E*). The length of the fractured piece was 3.8 ± 0.8 mm after fatigue failure.

Fractographically, when the instruments failed by fatigue only (Fig. 2*B*) or by fatigue after torsional preloading (Fig. 2*E* and *H*), the crack origins and areas showing microscopic fatigue striations and dimple rupture could be identified on all fracture surfaces. Most of the EDM and CM files had multiple crack origins, which were usually located at the cutting edge or flat edge (Fig. 2*C*). In both instruments in which the torsional test was applied without fatigue preloading (Fig. 2*J–L*) or after fatigue preloading (Fig. 2*M–O*), the fractography corresponded to the torsional fracture pattern with circular abrasion marks and skewed dimples near the center of rotation.

Discussion

The present study found that both of the preloading conditions, torsional preloading and fatigue prestress, may affect fatigue and torsional resistance of heat-treated NiTi files. Although the determination of fatigue resistance and the ultimate torque of unused instruments in separate sets of experiments can be helpful for comparison or screening purposes, an understanding of the impact of preloading on the behavior of NiTi instruments (15, 19) would be important in teeth with several challenging root canals and for dentists who may clinically reuse their instruments.

Our results showed that EDM files had fatigue resistance superior to CM files, which may be related to the relative proportions and characteristics of the NiTi microstructural phases of an NiTi alloy (5, 20). X-ray diffraction analysis on EDM has revealed the presence of martensite and R-phase, whereas a mixture of martensite and austenite structures was identified in CM files (7, 21). Differential scanning calorimetry analysis has also found higher austenite finish temperatures for EDM files (51°C–54°C) than for CM files (32°C–37°C) (7). The martensitic phase has excellent damping characteristics because of the energy absorption characteristics of its twinned phase structure. In addition, the martensitic form of NiTi has remarkable fatigue resistance. The R-phase is usually considered an intermediate phase between martensite and austenite and has a different crystal structure (13). Recently, 1 study (14) showed that EDM, containing large amounts of R-phase, exhibited better mechanical fatigue resistance than CM, primarily consisting of austenite and martensite. Therefore, their findings support our results that the fatigue resistance of EDM files was 1 time higher than CM files. However, Pirani et al (14) found that the fatigue life of EDM files was up to 6 times higher than CM files. The difference between the present study and the published study (14) may be caused by the different fatigue modes (ie, a customized canal [size 40/.06] vs a heat-bent 16-G stainless steel needle) (14).

The effect of torsional loading on fatigue resistance has been studied in conventional superelastic NiTi files and heat-treated NiTi files (15, 16, 22–25). Previous studies showed that torsional