Torsional and Cyclic Fatigue Resistance of a New Nickel-Titanium Instrument Manufactured by Electrical Discharge Machining

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Abstract

Introduction: The purpose of this study was to evaluate the torsional and cyclic fatigue resistance of the new Hyflex EDM OneFile (Coltene/Whaledent AG, Altstatten, Switzerland) manufactured by electrical discharge machining and compare the findings with the ones of Reciproc R25 (VDW, Munich, Germany) and WaveOne Primary (Dentsply Maillefer, Ballaigues, Switzerland). **Methods:** One hundred-twenty new Hyflex EDM OneFile (#25/0.08), Reciproc R25, and WaveOne Primary files were used. Torque and angle of rotation at failure of new instruments (n = 20) were measured according to ISO 3630-1 for each brand. Cyclic fatigue resistance was tested measuring the number of cycles to failure in an artificial stainless steel canal with a 60° angle and a 3-mm radius of curvature. Data were analyzed using the analysis of variance test and the Student-Newman-Keuls test for multiple comparisons. The fracture surface of each fragment was examined with a scanning electron microscope. **Results:** The cyclic fatigue of Hyflex EDM was significantly higher than the one of Reciproc R25 and WaveOne Primary ($P < .05$ and $P < .001$, respectively). Hyflex EDM showed a lower maximum torque load ($P < .05$) but a significantly higher angular rotation ($P < .0001$) to fracture than Reciproc R25 and WaveOne Primary. No significant difference was found comparing the maximum torque load, angular rotation, and cyclic fatigue of Reciproc R25 and WaveOne Primary ($P > .05$). **Conclusions:** The new Hyflex EDM instruments (controlled memory wire) have higher cyclic fatigue resistance and angle of rotation to fracture but lower torque to failure than Reciproc R25 and WaveOne Primary files (M-wire for both files). *(J Endod 2016;42:156–159)*

Key Words

Cyclic fatigue, electrical discharge machining, Hyflex EDM, M-wire, torsional resistance

Nickel-titanium (NiTi) endodontic files have increased flexibility and strength compared with stainless steel instruments, but they seem to be vulnerable to fracture in clinical situations (1–5). One study found that NiTi files fractured 7 times more often than stainless steel files (6). Other studies found a file fracture rate of approximately 5% in clinical practice (7, 8). Many variables might contribute to file separation, but the 2 main causes are cyclic fatigue and torsional stress (9).

Cyclic fatigue results in the failure of the file when repeated cycles of tension and compression occur when bending is sufficient to cause structural breakdown and eventual fracture. Clinically, this often happens in curved canals (10).

Torsional stress is generated by the twisting of a file about its longitudinal axis at 1 end while the other end is fixed. This can happen in straight or curved canals if the tip binds (11), especially in the preparation of narrow and constricted canals when the file is susceptible to high torsional loads (12). Torsional failure is characterized by a maximum torsional load and angle of rotation. This last property reveals the capability of the file to twist before fracture (13). Because of this, file manufacturers have tried to develop new designs, manufacturing processes, and kinematics to minimize fracture occurrence and create easier and faster techniques that maintain the original canal shape with considerably less iatrogenic error (14, 15).

The Hyflex EDM OneFile (HEDM; Coltene/Whaledent AG, Altstatten, Switzerland) is a novel instrument designed and marketed to shape root canals using a single-file technique in continuous rotation (16). Reciproc R25 (Rec; VDW, Munich, Germany) and WaveOne Primary (WO; Dentsply Maillefer, Ballaigues, Switzerland) are 2 well-known single-file instruments designed and marketed to shape root canals using a single-file technique in reciprocating motion (17).

HEDM is manufactured using the technique of electrical discharge machining (EDM). EDM can be used to manufacture all types of conductive materials (eg, metals, alloys, graphite, ceramics, and so on) of any hardness with high precision (18). During this procedure, the shape of a work piece is changed by building a potential between the work piece and the tools. The sparks initiated in this process are melting and vaporizing the material of the work piece in its top layer (16).

HEDM files are produced with the well-known controlled memory (CM) treatment just like HyFlex CM files (Coltene/Whaledent AG). The EDM process creates a rough and hard surface that could improve the cutting efficiency of these files (16, 18).

HEDM files have a tip size of 25 with a 0.08 taper. The taper is a constant 0.08 in the apical 4 mm of the instruments but reduces progressively up to 0.04 in the coronal portion of the instrument. This new file has 3 different cross-sectional zones over the entire length of the working part (rectangular in the apical part and 2 different

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trapezoidal cross sections in the middle and coronal part of the instrument working portion) to increase its fracture resistance and cutting efficiency (16).

Rec and WO have the same nominal size (tip size of 25 with a 0.08 taper). The taper is constant in the apical 3 mm of the instruments, but it is reduced in the middle and coronal portion of the working part of the instrument (19).

Rec instruments have a constant S-shaped cross section with 2 cutting blades; WO instruments have a modified convex triangular cross section at the tip and a convex triangular cross section in the middle and coronal portion of the instrument (10, 20). Additionally, Rec and WO are manufactured using M-wire NiTi to enhance the flexibility and fatigue resistance of the instrument (13).

To date, no data are available on mechanical properties such as torsional stress and cyclic fatigue resistance of the new Hyflex EDM because it seems to be the first NiTi instrument manufactured using the EDM process. Hence, the aim of this work was to investigate the cyclic fatigue, maximum torque load, and angular rotation of HEDM and to compare the findings with the ones of Rec and WO files.

Materials and Methods

Three NiTi rotary systems (HEDM size #25, 0.08 taper and Rec and WO size #25, 0.08 taper) were used in this study. All files used were 25-mm long, with 20 instruments each consumed in cyclic fatigue and torsional resistance tests. Every instrument was inspected for defects or deformities before the experiment under a stereomicroscope (SZR- 10; Optika, Bergamo, Italy); none were discarded. The torsional load was applied until fracture to estimate the mean ultimate torsional strength and angle of rotation of the instruments tested using a custom-made device produced following ISO 3630-1 (9).

Each file was clamped at 3 mm from the tip using a chuck connected to a torque-sensing load cell; after which, the shaft of the file was fastened into an opposing chuck able to be rotated with a stepper motor. The HEDM shaft was rotated in the clockwise direction, whereas the other ones of Rec and WO were rotated in the counterclockwise direction at a speed of 2 revolutions per minute until file separation. The torque load (Ncm) and angular rotation (°) were monitored continuously using a torsiometer (Sabri Dental Enterprises, Downers Grove, IL) at room temperature (21°C $\pm$ 1°C), and the ultimate torsional strength and angle of rotation at failure were recorded.

The cyclic fatigue tests were performed using a custom-made device that allowed a reproducible simulation of an instrument confined in an artificial curved canal as described previously (21, 22). The artificial canal was manufactured by reproducing the instrument size and taper, thus providing the instrument with a suitable trajectory with a 60° angle of curvature and a 3-mm radius of curvature. The instruments were activated by using a 6:1 reduction handpiece (Sirona Dental Systems GmbH, Bensheim, Germany) powered by a torque-controlled motor (Silver Reciproc, VDW) using the preset programs "Reciproc ALL" and "WaveOne ALL" to activate Rec and WO, respectively. HEDM instruments were tested using a continuous rotation at 500 rpm as recommended by the manufacturer. To reduce the friction of the file as it contacted the artificial canal walls, special high-flow synthetic oil designed for lubrication of mechanical parts (Super Oil; Singer Co Ltd, Elizabethport, NJ) was applied. All instruments were rotated until fracture occurred. The number of cycles to failure for each instrument was calculated by multiplying the time (seconds) to failure by the number of rotations or cycles per second regardless of the rotation direction. (It was reported that the "Reciproc ALL" mode runs at 300 rpm, and the "WaveOne ALL" mode runs at 350 rpm [23–25]). The length of the fractured file tip was measured by using a digital microcaliper (Mitutoyo, Kawasaki, Japan). The fracture surfaces of all fragments were examined under a scanning electron microscope (ZEISS Supra 35VP; Oberkochen, GmbH, Germany) to look for topographic features of the fractured instruments.

The data were first verified with the Kolmogorov-Smirnov test for the normality of the distribution and the Levene test for the homogeneity of variances. Thus, data were statistically evaluated by the analysis of variance test and the Student-Newman-Keuls test for multiple comparisons (Prism 5.0; GraphPad Software, Inc, La Jolla, CA) with the significance level established at 5% ($P < .05$).

Results

The mean and standard deviations of the cyclic fatigue resistance, torque maximum load, and angle of rotation until fracture for each instrument are presented in Table 1. HEDM showed a higher cyclic fatigue resistance than Rec ($P < .01$) and WO ($P < .001$). No difference was found in the cyclic fatigue of Rec and WO.

The maximum torsional strength of HEDM was lower than Rec and WO ($P < .05$), whereas no significant difference was found comparing these reciprocating instruments. HEDM showed significantly higher angular rotation to fracture (and therefore significantly higher time before torsional fracture) than Rec and WO ($P < .0001$), whereas these last 2 files showed no difference on this mechanical property ($P > .05$).

The mean length of the fractured fragment (3.0 mm) was not significantly different for all of the instruments tested ($P > .05$). Scanning electron microscopy of the fracture surface showed similar and typical features of cyclic fatigue and torsional failure for the 3 brands. The crack initiation area and overload fast fracture zone for cyclic fatigue fractures and concentric abrasion marks and the fibrous dimple marks at the center of rotation for torsional failure are shown in Figure 1.

Discussion

Several variables such as instrument size, taper, cross-sectional design, and manufacturing techniques affect the clinical performance of endodontic files and their resistance to fracture by torsion and/or cyclic fatigue (26, 27). Manufacturers have developed patented heat treatments for NiTi endodontic instruments to improve their mechanical properties and clinical performance (28). M-wire, the alloy used to manufacture Rec and WO, and CM-wire, the alloy used to make Hyflex CM and the new HEDM, are 2 types of heat-treated NiTi (16, 28).

TABLE 1. Mean Cyclic Fatigue (NCF), Torque (Ncm), and Angle of Rotation (°) of Instruments Tested

Instrument	Cyclic fatigue (NCF)				Torque (Ncm)				Angle of rotation (°)			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Hyflex EDM OneFile	973[a]	152	792	1186	1.33[a]	0.05	1.24	1.44	536.20[c]	96.70	435	680
Reciproc R25	525[b]	58	404	602	1.57[b]	0.15	1.38	1.70	215.20[d]	35.89	181	275
WaveOne Primary	407[b]	51	330	490	1.74[b]	0.11	1.60	1.96	211.70[d]	31.37	172	260

Max, maximum; Min, minimum; NCF, number of cycles to failure; SD, standard deviation.

Different superscript letters in the same column indicate statistic differences among groups ($P < .05$).