Impact of Heat Treatments on the Fatigue Resistance of Different Rotary Nickel-titanium Instruments

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Abstract

Introduction: The aim of this study was to assess the influence of M-Wire (Dentsply Tulsa Dental Specialties, Tulsa, OK) and controlled memory technologies on the fatigue resistance of rotary nickel-titanium (NiTi) files by comparing files made using these 2 technologies with conventional NiTi files. **Methods:** Files with a similar cross-sectional design and diameter were chosen for the study: new 30/.06 files of the EndoWave (EW; J. Morita Corp, Osaka, Japan), HyFlex (HF; Coltene/Whaledent, Inc, Cuyahoga Falls, OH), ProFile Vortex (PV; Dentsply Tulsa Dental Specialties, Tulsa, OK), and Typhoon (TYP; Clinician's Choice Dental Products, New Milford, CT) systems together with ProTaper Universal F2 instruments (PTU F2; Dentsply Maillefer, Ballaigues, Switzerland). The compositions and transformation temperatures of the instruments were analyzed using x-ray energy-dispersive spectroscopy and differential scanning calorimetry, whereas the mean file diameter values at 3 mm from the tip (D3) were measured using image analysis software. The average number of cycles to failure was determined using a fatigue test device. **Results:** X-ray energy-dispersive spectroscopy analysis showed that, on average, all the instruments exhibited the same chemical composition, namely, 51% Ni–49% Ti. The PV, TYP, and HF files exhibited increased transformation temperatures. The PTU F2, PV, and TYP files had similar D3 values, which were less than those of the EW and HF files. The average number of cycles to failure values were 150% higher for the TYP files compared with the PV files and 390% higher for the HF files compared with the EW files. **Conclusions:** M-Wire and controlled memory technologies increase the fatigue resistance of rotary NiTi files. *(J Endod 2014;40:1494–1497)*

Key Words

Controlled memory, fatigue resistance, heat treatment, M-Wire, nickel-titanium endodontic instruments, transformation temperatures

Because of their mechanical properties, rotary instruments made of nickel-titanium (NiTi) alloys are commonly used in endodontic treatments to facilitate the shaping of root canals that exhibit complex anatomies (1). Despite the favorable properties of these alloys, a high risk of fracture continues to be a problem during endodontic therapy; metal fatigue represents a predominant reason for file separation (2). Flexural fatigue fractures occur as a result of repeated compressive and tensile stresses that accumulate at the point of maximum flexure when instrument rotates within a curved canal (3, 4). The strain levels attained by rotary endodontic instruments during clinical use depend on the root canal geometry and the applied loads that are concentrated on the region of maximum curvature within the root canal, which can vary with the instrument diameter (3, 5).

Increasing resistance to instrument fracture has been a focus in the advancement of rotary NiTi instrument technology. Over the past 10 years, significant improvements in instrument design, control of raw material properties, and manufacturing processes have been achieved (6, 7). An example of a recent advancement involving the improvement of raw material properties is the proprietary thermomechanical processing procedure that is applied to conventional NiTi wire (8), which led to the development of the M-Wire (MW) (Dentsply Tulsa Dental Specialties, Tulsa, OK) that is used in the ProFile Vortex (PV) and GTX instruments (Dentsply Tulsa Dental Specialties). This material exhibits a more efficient superelastic behavior with reduced generation and accumulation of lattice defects during each load-unload cycle (9), increasing the fatigue resistance of these instruments (10). Another example is controlled memory (CM) technology in which endodontic instruments are subjected to a special thermal process after being machined from conventional NiTi wire to increase their fatigue resistance (11). The HyFlex (HF; Coltene/Whaledent, Inc, Cuyahoga Falls, OH) and Typhoon (TYP; Clinician's Choice Dental Products, New Milford, CT) files were recently developed using CM technology.

Accurate information concerning the fatigue behavior of these new NiTi rotary instruments remains limited, particularly because instrument dimensions and cross-sectional designs must be considered when comparing fatigue properties. The aim of this study was to evaluate the effects of these new technologies on the physical properties and fatigue behavior of rotary NiTi instruments. Care was taken in choosing similar file dimensions and geometries. The representative technologies investigated to identify potential advantages and limitations were conventional NiTi (C-NiTi), MW, and CM.

Materials and Methods

We evaluated new 30/.06 files of the EndoWave (EW; J. Morita Corp, Osaka, Japan), HF, PV, and TYP systems together with ProTaper Universal F2 instruments (PTU F2; Dentsply Maillefer, Ballaigues, Switzerland). These instruments were chosen

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because they have similar geometric designs; EW and HF exhibit triangular cross-sections, whereas PTU F2, PV, and TYP exhibit convex triangular cross-sections. However, these instruments use the following different technologies: EW and F2 are made of C-NiTi, PV is made with MW, and HF and TYP are CM files.

X-ray energy-dispersive spectroscopy (Noran TN-M3055, Middleton, WI) was used to determine the average amounts of nickel and titanium contained within the files. Five small areas were analyzed within each type of system. The HF and TYP instruments were analyzed before and after removal of their oxide surface layer by grinding. Transformation temperatures were determined as the beginning and end of exothermic/endothermic peaks on the heating and cooling curves recorded by differential scanning calorimetry (DSC; Shimadzu DSC 60, Kyoto, Japan). Three tests were performed using the different samples of each system; in each test, the sample was heated to 80°C and then cooled to −80°C at a rate of 10°C/min.

Ten instruments of each system were photographed using a high-resolution digital camera (20D; Canon, Tokyo, Japan) to assess their dimensional characteristics based on the criteria of American National Standards Institute/American Dental Association Specification No. 101. Lines were drawn on either side of the images, and the outermost diameters at each millimeter from the tip were measured using Image Pro Plus 6.0 (Media Cybernetics, Silver Spring, MD).

The instruments (N = 10) were then fatigue tested at room temperature using a bench device with an artificial canal that was made of quenched tool steel consisting of an arch with a radius of 5 mm, an angle of curvature of 45°, and a guide cylinder 10 mm in diameter made of the same material. The device was described in detail elsewhere (12). The chosen geometry placed the area of maximum canal curvature at 3 mm from the tip of the instruments. The instruments were allowed to rotate freely until breakage inside the artificial canal aligned between the arch and the guide cylinder, and the number of cycles to failure (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 determined by measuring the fractured file using an endodontic ruler. The fracture surfaces of 3 randomly selected instruments of each system were observed using a scanning electron microscope (JSM 6360; JEOL, Tokyo, Japan) to evaluate the features associated with the failure process.

The statistical significance of the differences in the measured parameters among the different types of instruments was assessed by using 1-way analysis of variance at 95% confidence level.

Results

The results of the semiquantitative x-ray energy-dispersive spectroscopy analysis showed that, on average, all of the instruments exhibited the same chemical composition, namely, 51% Ni–49% Ti. High amounts of oxygen were initially found on the HF and TYP files because of their thick oxide surface layers. When this layer was properly ground and the analysis was repeated, the average values of Ni and Ti were the same as those of the other instruments.

The transformation temperatures determined by DSC are shown in Table 1 along with the mean diameter values at 3 mm from the tip (D3). The Ms and Mf temperatures correspond to the start and finishing of the formation of martensite during cooling, whereas As and Af represent the corresponding temperatures for the reverse transformation that occurred upon heating. The value of the material's Af temperature in relation to test or clinical use temperatures is important to define the phases present in that condition. For EW and PTU F2 files, Af temperatures were close to room temperature; in the other systems, Af was well above room temperature, with the TYP instruments exhibiting the highest Af value, indicating that a reasonable amount of martensite should be present in these instruments at the test temperature. On the other hand, the cooling curve of the HF files, in contrast to the others, revealed that those instruments first transformed to the R-phase and then to B19′ martensite, thus presenting 2 peaks, Rs and Ms (Table 1).

TABLE 1. Mean Values of Martensitic and Reverse Transformation Temperatures (standard deviations <3°C) and Diameter at 3 mm from the Tip (D3) (standard deviations <0.02 mm) of the Instruments Studied

	Transformation temperatures						
Instruments	Rs	Rf	Ms	Mf	As	Af	D3 (mm)
EW	—	—	15.3	−16.0	−7.3	23.3	0.53
HF	14.3	3.3	−22.0	−47.3	15.8	31.3	0.52
PV	—	—	36.3	24.1	29.0	43.4	0.51
TYP	—	—	22.2	4.0	16.8	43.8	0.50
PTU F2	—	—	18.8	−11.0	−3.7	26.4	0.50

Af, austenite finishing temperature; As, austenite start temperature; EW, EndoWave; HF, HyFlex; Mf, martensite finishing temperature; Ms, martensite start temperature ; PTU F2, ProTaper Universal F2 instruments; PV, ProFile Vortex; Rf, R-phase finishing temperature; Rs, R-phase start temperature; TYP, Typhoon.

Statistical analysis of the D3 values revealed that the instruments with triangular cross-sections (ie, HF and EW) exhibited similar diameters at 3 mm from the tip (P = .426) as those with convex triangular cross-sections (ie, PTU F2, PV, and TYP [P>.050]). On the other hand, the D3 values of PTU F2 and TYP were significantly smaller than those of HF and EW (P<.05). However, although they were different from EW (P = .027), the PV instruments exhibited no statistically significant difference in D3 compared with HF (P = .133).

The results of the fatigue tests are summarized in Figure 1. The Nf values exhibited statistically significant differences (P<.001) among all of the instruments, with higher values for CM instruments. The average Nf value for the HF instruments was significantly increased compared with that of all of the other systems. For all of the instruments, the average point of fracture was 3.0 mm from the tip with a standard deviation of 0.2 mm.

The fracture surfaces of fatigue-tested instruments observed by scanning electron microscopy exhibited the typical features of this fracture mode. The secondary electron images in Figure 2 exemplify the larger areas of nucleation and slow crack propagation found in the CM instruments compared with the other instruments. Fatigue striations and secondary cracks were observed within the smooth regions of the

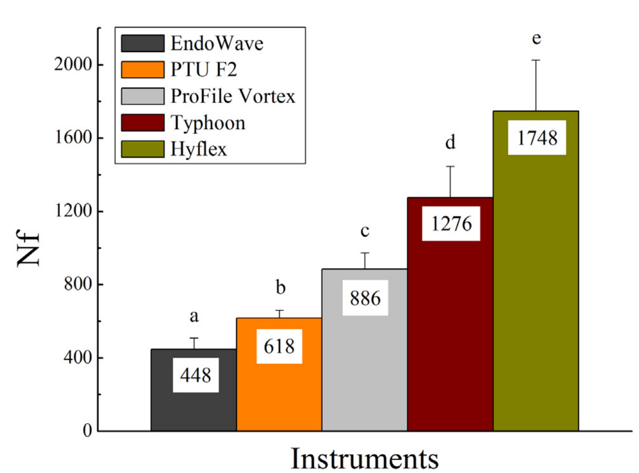

Figure 1. The mean values of Nf measured in the flexural fatigue tests. Bar values marked with different letters were statistically different (P≤.05).