Mechanical Properties of Various Heat-treated Nickel-Titanium Rotary Instruments

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Abstract

Aim: The purpose of this study was to compare the bending stiffness, cyclic fatigue, and torsional fracture resistances of heat-treated and conventional nickel-titanium rotary instruments. **Methods:** V-Taper 2 (VT2; #25/.08), V-Taper 2H (V2H; #25/.06), Hyflex CM (HCM; #25/.06), HyFlex EDM (HDM; #25/variable taper), and ProTaper Next X2 (PTN; #25/variable taper) were tested. The bending stiffness was measured with the customized device (AEndoS), and the files (n = 15) were fixed at 3 mm from the tip and bent at 45° with respect to their long axis. Cyclic fatigue resistance was tested by pecking and rotating instruments (n = 15) in artificial canal with a 7.8-mm radius and 35° angle of curvature until fracture. The ultimate torsional strength and toughness were estimated by using AEndoS. The file tip of 5 mm was fixed between resin blocks and driven clockwise at 20 rpm until fracture. The results were analyzed by using one-way analysis of variance and Duncan post hoc comparison. The fracture surfaces and longitudinal aspect of each group were examined under the scanning electron microscope. **Results:** CM-wire instruments had lower bending stiffness than others. HDM showed the highest cyclic fatigue resistance, followed by VTH and HCM ($P < .05$). VT2 showed the highest ultimate strength, followed by HDM, VTH-PTN, and HCM. HDM and VT2 showed significantly higher toughness than VTH, HCM, and PTN ($P < .05$). Scanning electron microscope analysis showed typical fractographic features of cyclic fatigue and torsional fractures. **Conclusions:** CM-wire instruments showed higher flexibility and cyclic fatigue resistance than M-wire and conventional nickel-titanium instruments. Large cross-sectional area and conventional nickel-titanium showed high torsional resistance. *(J Endod 2017;■:1–6)*

Key Words

Bending stiffness, CM-wire, cyclic fatigue, electro discharge machining, NiTi rotary file, torsional fracture resistance

Significance

CM-wire instruments showed higher flexibility and cyclic fatigue resistance than M-wire and conventional NiTi instruments. These characteristics of CM-wire instruments may improve the quality of root canal preparations.

Nickel-titanium (NiTi) files have advantages such as higher flexibility, fewer canal deviations, and shorter procedural time than stainless steel files (1). However, NiTi files are likely to be vulnerable to fracture in clinical use. Instrument separation is the major problem with NiTi rotary instrumentation techniques. Cyclic and torsional fatigues are 2 main mechanisms that may lead to instrument separation (2). When the instrument rotates in a curved canal, it generates repetitive tension/compression cycles in the region of maximum flexure; then cyclic fatigue occurs (2). During root canal shaping procedures, a part of the instrument binds to the dentin, and the rest of the file continues to rotate, resulting in torsional fracture (3).

To overcome these drawbacks, manufacturers have been trying to make NiTi files of superior mechanical properties by using heat treatments, different cross-sectional designs, and new manufacturing processes (4–6). There are 3 kinds of heat-treated NiTi alloys used for endodontic instruments: M-wire, R-phase, and CM-wire.

M-wire has been developed through thermomechanical processing and contains 3 crystalline phases, including deformed and micro-twinned martensite, R-phase, and austenite (7, 8). M-wire showed contrasting findings about cyclic fatigue in the literature. Some articles reported significantly improved cyclic fatigue resistance of M-wire files such as ProTaper Next (Dentsply Sirona, Ballaigues, Switzerland) in comparison with conventional NiTi instruments (7, 9); instead, other literature showed no difference in cyclic fatigue of M-wire and conventional NiTi files (10, 11).

R-phase instrument has greater flexibility and increased resistance to cyclic fatigue than conventional NiTi files (12). However, R-phase instrument was reported to have a lower torsional strength than conventional NiTi files (13, 14).

Recently, brand-new NiTi rotary instruments made from a controlled memory wire (CM-wire; DS Dental, Johnson City, TN) have been introduced. When the conventional NiTi alloy gets a certain range of mechanical load, austenite is transformed to stress-induced martensite (15). Martensite phase is unstable at temperatures above austenite finishing temperature (Af) and returns to austenite by a reverse transformation when the load is

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removed. Therefore, the Af should be below working temperature for conventional superelastic NiTi files. However, by using the CM-wire technology, NiTi files do not have the rebound effect after unloading, and their original shape is restored after heat application or autoclaving procedure. The behavior of these files may be explained by the presence of stable martensite phase, meaning that Af is above the working temperature (16).

The manufacturer and previous studies claim that CM-wire instruments have superior flexibility and cyclic fatigue resistance than conventional NiTi files (5, 6, 17). On the other hand, a study reported that ultimate tensile strength of the CM-wire instruments was lower than those of conventional superelastic NiTi wires (18).

Hyflex CM (Coltene/Whaledent, Altstätten, Switzerland) and HyFlex EDM (Coltene/Whaledent) are manufactured from the same controlled memory wire; however, HyFlex EDM instruments are produced via electrical discharge machining (EDM), a non-contact thermal erosion process that partially melts and evaporates the wire by high-frequency spark discharges (17, 19).

The V-Taper 2H (SS White, Lakewood, NJ) are other CM-wire files with same variable taper, cross section, and designs of V-Taper 2 (SS White), which are traditional NiTi instruments (20).

It is well-known that the nature of the alloy and the manufacturing process greatly affect the instruments' mechanical behavior (21). However, there are few scientific data about mechanical properties of heat-treated (as CM-wire and M-wire) NiTi files, especially about their bending stiffness as well as the amount of rebound effect, after unloading of instruments made by M-wire or conventional NiTi was not reported in the literature.

Therefore, the purpose of this study was to compare the bending stiffness (including residual angle), cyclic fatigue, and torsional fracture resistances of heat-treated and conventional NiTi rotary instruments.

Materials and Methods

Five NiTi rotary systems were used in this study: V-Taper 2 (VT2; #25/.08), V-Taper 2H (V2H; #25/.06), Hyflex CM (HCM; #25/.06), HyFlex EDM (HDM; #25/variable taper), and ProTaper Next X2 (PTN; #25/variable taper). All files used were 25 mm long. Every instrument was inspected for defects or deformities before the experiment under a dental operating microscope (Zeiss Pico; Carl Zeiss MediTec, Dublin, CA); none were discarded.

Bending Stiffness

The bending stiffness was measured with the customized device (AEndoS; DMJ System, Busan, Korea) following the American National Standard/American Dental Association specification no. 28 and ISO specification 3630-1:2008 (22, 23). The files (n = 15) were fixed at 3 mm from the tip and then were bent at 45° with respect to their long axis, and the bending moment was recorded by a load cell of the same device. If the file, which was bent at 45°, does not go back to the original position where it was, the angle between the bent file and the first position was defined as the residual angle. The value "a" was fixed. The value "b" was measured with microcaliper. "Tan θ" was calculated by b/a. A residual angle (θ) was calculated by "Arctan (b/a)" [$\theta = \tan^{-1}(b/a)$, residual angle].

Cyclic Fatigue Resistance

Cyclic fatigue resistance was evaluated in a custom-made device. It was a repeatable simulation in curved canal to confine the rotating instrument. This artificial canal block was made of tempered steel with 7.8-mm radius and 35° angle of curvature measured by the method of Schneider (24). 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 from each subgroup (n = 15) were rotated at 300 rpm in pecking movement. Because the rotation speed and number of cycles to failure (NCF) are mathematically proportioned and/or the speed may have an influence on the NCF (16), the fatigue condition was given with the minimum recommendation speed of the tested file systems to make a fair condition. Once the instrument fracture was detected visually and audibly, the time for fracture was recorded with a chronometer. The NCF for each instrument was calculated by multiplying the total time (seconds) to fracture by the rotation rate (5 revolutions per second, 300 rpm). The length of the fractured file tip was measured by using a digital microcaliper (Mitutoyo, Kawasaki, Japan) at ×10 magnification under the dental operating microscope.

Torsional Resistance

The ultimate torsional strength and toughness were estimated for the 5 brands of instruments (n = 15 each) by using the custom-made device (AEndoS) for maximum torsional load (Ncm) until fracture. The file tip of 5 mm apical part was rigidly fixed between 2 resin blocks. Each file was driven clockwise at 20 rpm until file fracture occurred. During the file rotation, the torsional load (Ncm) and distortion angle (°) were recorded at the rate of 50 Hz. The toughness until fracture was computed from the area under the plot presenting distortion angle (X axis) and torsional load (Y axis) by using Origin v6.0 Professional (Microcal Software Inc, Northampton, MA).

After cyclic fatigue and torsional tests, all fractured fragments were observed under the scanning electron microscope (SEM) (S-4800 II; Hitachi High Technologies, Pleasanton, CA) to evaluate topographic features of the fractured surfaces.

Statistical Analysis

Data were first examined by using the Shapiro-Wilk test for normality of distribution. The results were analyzed by using one-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).

TABLE 1. Bending Stiffness, Cyclic Fatigue Resistance, and Torsional Resistances of Each Tested Groups (Mean ± Standard Deviation)

	Bending stiffness		Cyclic fatigue resistance		Torsional resistance		
Group	Residual angle (°)	Bending stiffness (Ncm)	NCF	Fracture fragment length (mm)	Ultimate strength (Ncm)	Distortion angle (°)	Toughness (° Ncm)
VT2	0^a	1.73 ± 0.15^e	1140 ± 105^a	1.96 ± 0.18^a	3.22 ± 0.45^d	979 ± 45^b	2147.79 ± 318^d
VTH	36.81 ± 3.83^c	0.43 ± 0.03^b	$10,696 \pm 2452^c$	4.38 ± 1.3^d	1.79 ± 0.14^b	1192 ± 34^c	1345.57 ± 089^c
HCM	42.66 ± 1.82^d	0.30 ± 0.04^a	6613 ± 1119^b	3.67 ± 0.37^c	1.44 ± 0.15^a	960 ± 42^b	773.55 ± 109^b
HDM	41.76 ± 1.20^d	0.51 ± 0.09^c	$15,212 \pm 2579^d$	2.64 ± 0.60^b	2.79 ± 0.31^c	1161 ± 117^c	2029.76 ± 360^d
PTN	06.52 ± 0.49^b	0.65 ± 0.05^d	2601 ± 420^a	3.02 ± 0.31^b	1.79 ± 0.10^b	459 ± 60^a	483.42 ± 062^a

[a,b,c,d]Different superscript letters indicate statistical differences between groups in vertical column (P < .05).