Comparison of the Mechanical Properties of Rotary Instruments Made of Conventional Nickel-Titanium Wire, M-Wire, or Nickel-Titanium Alloy in R-Phase

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Abstract

Introduction: This study compared the mechanical properties of endodontic instruments made of conventional nickel-titanium (NiTi) wire (K^3 and Revo-S SU), M-Wire (ProFile Vortex), or NiTi alloy in R-phase (K^3XF). **Methods:** The test instruments were subjected to mechanical tests to evaluate resistance to bending (flexibility), cyclic fatigue, and torsional load in clockwise rotation. Data were statistically evaluated by the analysis of variance test and the Student-Newman-Keuls test for multiple comparisons. **Results:** In the bending resistance test, flexibility decreased in the following order: K^3XF > Revo-S SU > ProFile Vortex > K^3. The ranking in the fatigue resistance test was the following: K^3XF > K^3 > ProFile Vortex > Revo-S SU. In the torsional assay, the angular deflection at failure decreased in the following order: K^3XF > Revo-S SU > K^3 > ProFile Vortex. For the maximum torque values, the ranking was K^3 > K^3XF > ProFile Vortex > Revo-S SU. **Conclusions:** The results showed that the K^3XF instrument, which is made of NiTi alloy in R-phase, had the overall best performance in terms of flexibility, angular deflection at failure, and cyclic fatigue resistance. In addition to the alloy from which the instrument is manufactured, the design and dimensions are important determinants of the mechanical performance of endodontic instruments. *(J Endod 2013;39:516–520)*

Key Words

Cyclic fatigue, endodontic instruments, flexibility, M-wire, nickel-titanium alloy, R-phase, torsional resistance

Proper and safe cleaning and shaping of root canals depend on the mechanical behavior of endodontic instruments. Insufficient knowledge of instrument characteristics may lead to procedural errors (ledge and transportation) and/or fracture of the instrument in the canal. Important mechanical properties of instruments that influence their performance during instrumentation of curved canals include flexibility and resistance to fracture.

Flexibility can be defined as the elastic bending of an endodontic instrument when subject to a load applied at its extremity in the direction that is perpendicular to its long axis (1). Flexibility of an endodontic instrument is influenced by composition and thermomechanical treatment of the metallic alloy as well as the instrument geometry, including size and cross-sectional design (2–6). Flexibility may influence the instrument's ability to properly shape curved root canals. Several studies showed that more flexible instruments produce more centered preparations (7–9). Changes to improve flexibility and resistance to fatigue fracture of endodontic instruments have been proposed, including different thermomechanical treatments and modified chemical composition of the nickel-titanium (NiTi) alloy, different cross-sectional designs, and changes in the manufacturing process. Two important modifications in the NiTi alloy include the M-Wire alloy (10, 11) and the NiTi alloy in a different phase of crystalline structure (R-phase) (12).

Fracture of NiTi rotary instruments occurs by torsional stress or cyclic flexural fatigue (13). Cyclic fatigue occurs when the instrument, within its elastic limit, rotates in a curved canal. As the instrument rotates along the curvature, cycles of tension/compression are repeatedly generated at the point of maximum flexure until fracture occurs (14–17). Fracture by cyclic fatigue is a great reason of concern because it can develop unannounced. Torsional fracture occurs when the tip of the instrument is locked in the canal, while the shaft continues rotating (18, 19). A study (20) reported that the incidence of fracture of NiTi rotary instruments was around 5%. Of these, 70% were caused by cyclic fatigue, and the other 30% were due to torsional stress. Fatigue fracture of NiTi rotary instruments has been extensively studied (21, 22), but there is little information available about torsional fracture resistance (19, 23, 24).

Although knowledge of the mechanical behavior of endodontic instruments is very important for clinicians to predict clinical performance, manufacturers do not make this information available. The present study was intended to compare the resistance to bending (flexibility), cyclic fatigue, and torsional load of endodontic instruments

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made of conventional NiTi wire, M-Wire, or NiTi alloy in R-phase. The hypothesis is that the new generation of instruments made of modified NiTi alloys present improved mechanical behavior when compared with instruments made of the conventional NiTi alloy.

Materials and Methods

The following rotary NiTi instruments were used in this experiment: K^3 (SybronEndo, Orange, CA), K^3XF (SybronEndo), ProFile Vortex (Dentsply Tulsa Dental, Tulsa, OK), and Revo-S SU (Micro-Mega, Besançon, France). All instruments were 25 mm long, size 25, and 0.06 mm/mm in taper. Ten instruments from each brand were evaluated per test. K^3 and Revo-S SU instruments are made of conventional NiTi alloy, K^3XF of NiTi alloy in R-phase, and ProFile Vortex of M-Wire alloy.

Instrument Geometry

The test instruments were examined under a stereomicroscope (Pantec; Panamba, Cambuci, SP, Brazil) to determine their diameters at D_3 and D_{13} as well as the number of spirals in the working portion. The taper of the working portion was calculated by subtracting the diameters at D_3 and D_{13} as described by Stenman and Spangberg (25) by using the following equation: Taper (T) = $D_{13} - D_3/10$. The diameter at D_0 was calculated on the basis of the values of D_3 and T by using the following equation: $D_0 = D_3 - (T \times 3)$. The number of spirals per millimeter was obtained by dividing the number of spirals by the length of the working portion. Two instruments of each brand were embedded in acrylic resin and prepared for scanning electron microscopic (SEM) analysis of their cross sections (JSM 5800; JEOL, Tokyo, Japan).

Bending Resistance Test

The bending resistance of the instruments was evaluated by the cantilever-bending test, as described by Serene et al (1) and modified by Lopes et al (26). Briefly, a universal testing machine (Emic, DL 10.000, São José dos Pinhais, PR, Brazil) was used. Load was applied by means of a flexible stainless steel wire (with length of 30 cm and diameter of 0.34 mm), with one of the extremities fastened to the testing machine head and the other end 3 mm away from the instrument tip. The useful length of all test instruments was adjusted to 22 mm. The bending test was conducted until the tip of each specimen underwent an elastic displacement of 45°. The test speed was 15 mm/min, and the load cell used was 20 N.

Cyclic Fatigue Resistance Test

An artificial canal was made out of a cylindrical tube of stainless steel with the inner diameter of 1.4 mm, total length of 19 mm, arc located between the 2 straight segments of the canal, and curvature radius of 6 mm. The arc measured 9 mm, the longest straight part was 7 mm, and the shortest straight part was 3 mm. The apparatus used in the cyclic fatigue test was described previously (26). The tested instruments were rotated clockwise at 310 rpm until fracture. The time of fracture was recorded by the same operator by using a digital stopwatch (Technos, Manaus, AM, Brazil) and was established when there was visual observation of the instrument fracture. The number of cycles to failure (NCF) was obtained by multiplying the rotational speed by the time (in seconds) until fracture occurred. During the test, the artificial canal was filled with glycerin to reduce the friction of the instrument against the canal wall and to minimize the release of heat.

Torsional Resistance Test

The torsional test in clockwise rotation was performed in a universal testing machine (Emic, DL 10.000) as described elsewhere (27–29). Briefly, torsion without axial load was applied by a device attached to the crosshead of the universal testing machine. By this approach, a known torque was applied to the instruments, and at the same time, rotation was monitored. The instruments were clamped 3 mm from the tip by immobile brass jaws and the handle grasped with triple set screws on the rotating shaft. A 0.3-mm-wide cord wrapped around the rotating shaft was connected to a load cell of 20 N coupled to the crosshead of the universal testing machine. Rotation occurred as the crosshead was raised and calculated to be 2 rpm. Load and deformation at failure were continuously recorded by a microcomputer coupled to the universal testing machine. The deformation at failure was converted to angular deflection (rotations or degrees). The maximum load was converted to maximum torque (19, 27).

SEM Analysis

The fracture surface and helical shaft of fractured instruments were analyzed by using SEM (JEOL JSM 5800) to determine the type of fracture and evaluate the presence of plastic deformation in the shaft.

Statistical Analysis

In all 4 tests, data were statistically evaluated by the analysis of variance test and the Student-Newman-Keuls test for multiple comparisons, with the significance level established at 5% ($P < .05$).

Results

Instrument Geometry

The mean length of the working portion, the diameter at D_0, the total number of spirals, and the number of spirals per millimeter in the working portion of the instruments are shown in Table 1. SEM analyses showed that the tested instruments had different cross-sectional designs, except for K^3XF and K^3 instruments (Fig. 1). Both K^3XF and K^3 showed a U-shaped cross section with 3 cutting blades, 3 flutes with sinuous profiles (concave and convex walls), and 3 radial lands. ProFile Vortex instruments had convex triangular cross section also with 3 blade-cutting surfaces and 3 flutes with convex profiles. Revo-S SU instruments showed asymmetric triangular cross section with 3 different radius lengths, 3 cutting blades, and 3 flutes with sinuous profiles (concave and convex walls).

Bending Resistance Test

The mean bending resistance, represented by the maximum load (in degrees) to bend the instruments, is shown in Table 2. Significant

TABLE 1. Mean Values for the Diameter at D_0, Taper, Length of the Working Portion, Total Number of Spirals, and Number of Spirals per Millimeter in the Working Portion of the Test Instruments

Instrument	D_0 (mm)	Taper (mm)	Length of the working portion (mm)	Total number of spirals	Spirals per mm
K^3XF	0.23	0.06	16	17	1.07
K^3	0.23	0.06	16	18	1.12
Profile Vortex	0.24	0.06	16.75	10	0.6
Revo-S SU	0.22	0.06	20.50	10	0.5