Assessment of the Mechanical Properties of ProTaper Next Nickel-Titanium Rotary Files

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Abstract

Introduction: The purpose of this study was to compare the torsional resistance, flexibility, and surface microhardness of ProTaper Next files (PTN) with Twisted Files (TF) and RaCe (RC). **Methods:** A metal block with a cubical hole was used to evaluate the torsional resistance. Five millimeters of the tip of each file was securely held in place by filling the mold with a resin composite, and the files were driven clockwise at 300 rpm. The number of load applications before fracture was recorded for each file. A scanning electron microscope was used to characterize the topographic features of the fracture surfaces of the broken files. The files were tested for bending resistance by using cantilever-bending test. Vickers microhardness was measured on the cross section of instruments with 300-g load and 15-second dwell time. Torsional resistance data were analyzed by using the nonparametric Kruskal-Wallis and Mann-Whitney *U* tests. Bending resistance and microhardness data were analyzed by using analysis of variance and Tukey tests. **Results:** PTN showed the highest torsional resistance and microhardness, followed by RC ($P < .05$). The fracture cross sections of all brands showed dimpling near the center of fracture surface. The ranking in the bending resistance values was as follows: RC > PTN > TF. **Conclusions:** PTN improved its resistance to torsional stresses and wear compared with TF and RC. TF showed improved flexibility compared with other tested brands. *(J Endod 2014;40:1830–1834)*

Key Words

Flexibility, microhardness, nickel-titanium files, ProTaper Next, torsional resistance

In recent years, there have been considerable improvements in the design and the raw materials for nickel-titanium (NiTi) rotary endodontic files by enhancing the manufacturing process, microstructures, and material properties (1–4). Despite the improved flexibility and strength of the NiTi rotary files compared with stainless steel files, they seem to have a higher possibility of separation (5, 6).

Fracture resistance and flexibility are significant mechanical properties that affect the performance of NiTi rotary files throughout instrumentation of curved canals (4). It has been reported in one study that failure that is due to torsional overload is the most frequent cause of fracture of NiTi rotary files (7). Torsional stress is formed by twisting the file through its longitudinal axis at one end, whereas the other end is fixed, and this can take place in straight or curved canals if the tip binds (8, 9). Once the elastic limit of the metal is surpassed, the rotary file undergoes plastic deformation, which can be followed by fracture if the load is adequately high (10).

Endodontic files with enhanced flexibility will decrease iatrogenic errors caused by canal transportation and improve the effectiveness and safety of root canal preparation (11). Factors that influence the flexibility of NiTi rotary files are instrument geometry as well as the composition and thermomechanical treatment of the metallic alloy (1, 4, 12). It has been reported that files with high flexibility produce more centered preparations (13, 14). Various manufacturing strategies for NiTi rotary endodontic files have been developed to enhance flexibility and resistance to fracture (2, 4, 8), including improvement of the surface of the file via electropolishing (eg, RaCe [RC]; FKG Dentaire, La Chaux-de-Fonds, Switzerland), the use of new alloys that provide superior mechanical properties (eg, Twisted Files [TF]; SybronEndo, Orange, CA), and the use of different cross-sectional designs (8, 15, 16).

Recently, ProTaper Next files (PTN) (Dentsply Maillefer, Ballaigues, Switzerland) have been launched in the dental market. PTN files exhibit a rectangular cross-section design for superior strength and an exceptional asymmetric rotary motion that improves canal shaping effectiveness as assumed by the manufacturer. They are manufactured by using M-Wire NiTi to enhance flexibility and cyclic fatigue resistance of the files (2, 17). In a recent study, PTN files appeared to enhance the resistance to cyclic fatigue compared with ProTaper Universal (Dentsply Maillefer) and HyFlex CM (ColténeEndo/Whaledent, Inc, Cuyahoga Falls, OH) but not TF (2).

Understanding the mechanical properties of innovative NiTi endodontic files and their effect on instrument performance has become crucial for the clinician to select the instrument that accomplishes the perfect clinical outcome (1). Consequently, the aim of this study was to compare the mechanical properties of the PTN files with other files tested including TF and RC.

Materials and Methods

Three NiTi rotary file systems (PTN, TF, and RC) of size #25, 0.06 taper were included in this study. The length of the files was 25 mm, except that TF was 23 mm

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0099-2399/$ - see front matter

http://dx.doi.org/10.1016/j.joen.2014.06.011

in length. Each file was examined for defects before the test with a dental operating microscope (Global Surgical, St Louis, MO). Twenty files from each brand were evaluated per test.

Torsional Resistance

The torsional resistances of the files were evaluated as described by Park et al (8). Briefly, repetitive torsional stress was applied to the file without bending (ie, in a straight state) to assess the pure torsional resistance and eliminate the influence of flexural fatigue. Torsional resistance was evaluated by using a custom-made metal block with a cubical hole (5 × 5 × 5 mm). Five millimeters of the tip of each file was securely held in place by filling the mold with a resin composite (Filtek P60; 3M ESPE, St Paul, MN) and light-cured with Elipar S10 unit (3M ESPE; light output, 1200 mW/cm^2) for 80 seconds.

The files were driven clockwise at 300 rpm by using an endodontic torque-controlled motor (X-Smart; Dentsply Maillefer), with the auto-stop mode engaged until the preset torque was reached (1.0 N.cm) and the engine stopped automatically. This was counted as one start-stop loading cycle. The engine was allowed to start again, and the process was repeated. The number of such load applications before fracture was recorded for each file. A scanning electron microscope (SEM) (JEOL, JSM-6510LV; JEOL Ltd, Tokyo, Japan) was used to characterize the topographic features of the fracture surfaces of broken files.

Bending Resistance

The files were tested for bending resistance by using cantilever-bending test, as described previously (4, 18). Load was applied by using a stainless steel wire (length of 40 cm and diameter of 0.34 mm), with one of the termini fixed to the universal testing machine (Model TT-B; Instron Corp, Canton, MA) and the other end fixed 3 mm away from the tip. The bending test was performed until the tip of each file underwent an elastic displacement of 45°. The load cell used was 20 N, and the crosshead speed was 15 mm/min.

Vickers Microhardness

The apical portion of 4 mm in length of each file was cut by using a low-speed diamond saw (Isomet 1000; Buehler Ltd, Lake Bluff, IL) for measuring the Vickers microhardness (VHN). Each specimen was mounted and polished according to American Society for Testing and Materials standard E3-11 for preparation of metallographic specimens (19). VHN was measured by using a digital microhardness tester (FM-7; Future Tech Corp, Tokyo, Japan). A diamond indenter with 300-g load and a dwell time of 15 seconds were used (1). Five microindentations were made for each file. The VHN for each specimen was calculated by using the following formula:

$$VHN = \frac{1.8544 \times L}{d^2}$$

where L is the applied load (kg), and d is the mean indentations diagonal length (mm).

Statistical Analysis

Statistical analyses (SPSS 15.0; SPSS Inc, Chicago, IL) of the torsional resistance data were analyzed by using the nonparametric Kruskal-Wallis and Mann-Whitney *U* tests. Bending resistance and microhardness data were analyzed by using 1-way analysis of variance and Tukey post hoc tests. Statistical significance level was set at $P < .05$.

TABLE 1. Mean ± Standard Deviation of Torsional Resistance, Bending Resistance, Microhardness (VHN) of Brand Systems, and Tukey Analysis

Brand systems	Torsional resistance*	Bending resistance (gf)†	Microhardness (VHN)
PTN	1258.6 ± 208.23^A	267.2 ± 25.92^B	351.95 ± 6.68^A
TF	1.0 ± 0.0^C	238.7 ± 21.97^C	296.35 ± 6.54^C
RC	358.15 ± 135.36^B	353.55 ± 22.96^A	334.45 ± 7.6^B

Mean values for each property represented with different superscript uppercase letter (column) are significantly different ($P < .05$).

*Number of loads to fracture the files.

†Maximum force to bend the files.

Results

The means and standard deviations of the tested properties for each brand are presented in Table 1. PTN showed the highest torsional resistance ($P < .05$). The ranking in the torsional resistance values was as follows: PTN > RC > TF. The fracture cross sections of all brands showed the typical pattern of torsional fracture, including skewed dimples near the center of the fracture surface and circular abrasion streaks (Fig. 1).

The average bending resistance as measured by the maximum force (gf) to bend instruments revealed that TF had significantly lower resistance to bend than other brands ($P < .05$). The ranking in the bending resistance values was as follows: RC > PTN > TF. On the other hand, for microhardness, PTN had significantly higher VHN values than other brands ($P < .05$). The ranking in the VHN values was as follows: PTN > RC > TF (Table 1).

Discussion

There are several variations in the design and raw materials used in fabrication of endodontic files that have great influence on file properties. Hence, it is essential for clinicians to know the properties and the differences of these materials to gain advantage of the newest technology (1). This study compared the mechanical properties of recently introduced PTN file that is manufactured by using M-Wire NiTi with a rectangular cross-section design and asymmetric rotary motion (2, 17) with TF and RC. TF and RC were selected to evaluate different manufacturing process and design on mechanical properties.

There are various factors that have a significant influence on the torsional behavior and stress distribution of NiTi rotary files including cross-sectional design, chemical composition of the alloy, and thermomechanical process applied during manufacturing (8, 20, 21). In the present study, torsional resistance was evaluated by using a custom-made metal block with a cubical hole similar to that described by Park et al (8). By this method, a consistent torsional stress was applied repeatedly to simulate repetitive locking of NiTi rotary instruments during canal preparation (8). On the other hand, the American Dental Association specification no. 28 evaluates the ultimate torsional strength of the instrument by performing a torsional load running in a clockwise direction at 2 rpm (22). This method would not assess the possibility of fracture because of repeated taper locking (8).

A torque of 1 N.cm was selected because it has been reported that torsional stresses higher than 1 N.cm were found to cause fracture of TF and RC; on the other hand, stresses lower than 1 N.cm would take a long time for file breakage (8). PTN had a significantly greater torsional resistance than TF and RC files. PTN files were associated with a higher number of load application cycles to failure, which implies a higher resistance to torsional failure of the instrument (8). This could be attributed to the manufacturing process including M-Wire technology and the rectangular cross-section design (2). M-Wire (Dentsply Tulsa

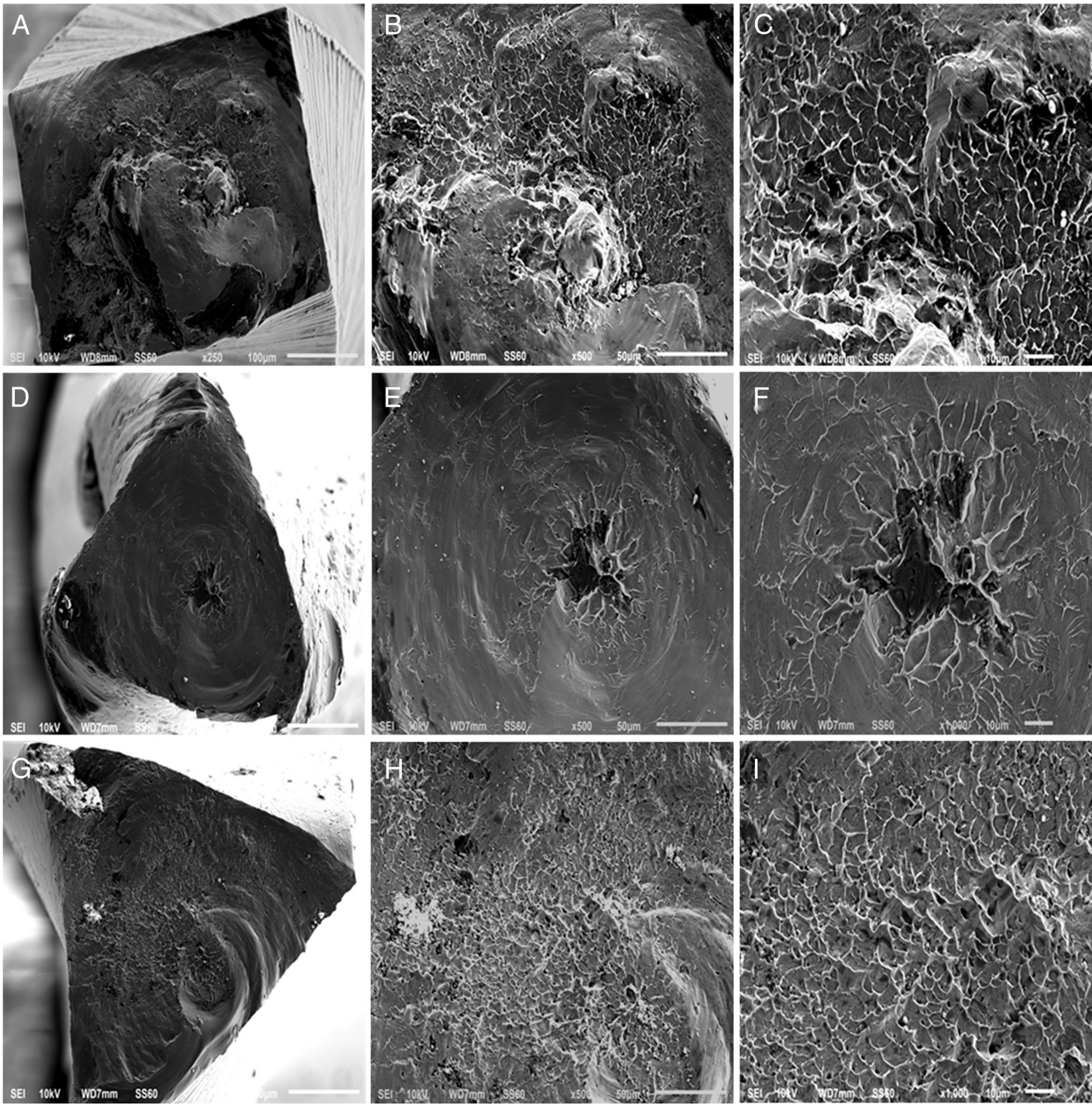

Figure 1. Scanning electron micrographs of fracture surface of separated segments after torsional test. All showed the typical pattern of torsional fracture, including skewed dimples near the center of the fracture surface and circular abrasion streaks. (*A–C*) PTN, (*D–F*) TF, and (*G–I*) RC.

Dental Specialties, Johnson City, TN) is formed by using a series of heat treatments to NiTi wire blanks. M-Wire instruments include Dentsply's ProFile GT Series X, ProFile Vortex, and recently PTN (2, 23). It has been reported that M-Wire technology provides more resistance to fracture than traditional NiTi rotary instruments (9, 24, 25).

The off-centered rectangular cross-section design of PTN might improve the strength (2, 17) and enhance the torsional resistance (26) besides the M-Wire technology. It has been reported that increasing the central core diameter of the file cross section will improve the resistance of a rotary file to the torsional stress (8, 9, 21, 27). The rectangular cross-section design of PTN files as compared with the equilateral triangular cross section of TF and RC could explain the higher resistance before fracture. High stress concentration is created in the equilateral triangular cross section because of the short distance between the middle of each side and the centroid (8, 21), whereas the rectangular cross-section design of PTN provides a greater inner core diameter. In a supplementary examination, the cross section of each instrument was captured at D5 under SEM and measured the area with ImageJ software (http://rsbweb.nih.gov/ij). PTN revealed the highest area (approximately 128,651 μm^2), followed by RC (approximately 83,515 μm^2), whereas TF presented with the smallest area (approximately 58,921 μm^2). In addition, it could be speculated that the PTN files with nonuniform and reduced contact points between the instrument and the root canal wall could have improved the fracture resistance (2). Only one study has evaluated the torque and force formed by PTN instruments during simulated canal preparation (26). The authors recommended that PTN instruments should be used at higher rotational speed (350 rpm) and with a gentler movement to have the lowest levels of torque (26).

Although TF and RC have similar cross-section design, TF had a significantly lower torsional resistance. This finding is in agreement with previous studies (8, 9, 28). It could be attributed to the purported R-phase NiTi alloy from which TF is produced, because this material exhibits better superelasticity with an elastic modulus lower than that of the austenitic phase (8, 20, 29). Consequently, the manufacturing process of this alloy allows a higher amount of deformation at a similar torque than austenitic NiTi alloy (8). In addition, the lower torsional resistance could be attributed, to some extent, to the short distance between the shaft and clamped position for TF (shaft length, 23 mm) compared with other instruments (shaft length, 25 mm), because the shorter the distance, the higher the stress formation (8).

SEM observations of the fracture cross sections of all brands showed comparable surface features of torsional fracture including skewed dimples near the center of the fracture surface and circular abrasion streaks (8, 28). It appeared that the TF instrument (Fig. 1*D–F*) had a smaller diameter than the other brands. This could be due to the localized necking of the material that could have decreased the cross section (28).

Flexibility of NiTi rotary instruments is a significant property because it predicts the mechanical behavior and performance of endodontic instruments while preparing curved canals (4). In the present study, the instruments were fixed 3 mm away from the tip because this is the point of apprehension for instruments submitted to bending according to ISO 363101-1 specification, and also the maximum curvature is found in the majority of root canals at this point (3, 30). TF was associated with significantly higher flexibility than the other brands tested. This finding is in agreement with previous studies (3, 31, 32). TF is manufactured by a proprietary method of heating and cooling that results in the purported formation of R-phase molecular structure (33). NiTi can be twisted in this phase, which produced instruments with enhanced properties (8, 33). The alloy exhibits superelasticity and shape memory that allow the development of more flexible instruments compared with the ground NiTi instruments (8, 33, 34).

It has been reported that the average root dentin microhardness is 67 VHN (35). Accordingly, the hardness of all 3 NiTi brands chosen in this study should be appropriate (approximately 5 times harder than dentin) for shaping and cleaning canal walls. This finding is in agreement with a previous study (1). TF instruments were significantly softer than RC and PTN instruments. Comparable results have been reported by Braga et al (3), who found TF had lower VHN values than RC instruments. PTN exhibited the highest VHN values compared with other brands. High surface microhardness indicates improvement in the cutting efficiency and wear resistance of NiTi rotary instruments (1, 25). It has been reported that endodontic instruments manufactured with M-Wire are anticipated to have superior strength and wear resistance than comparable instruments made of conventional superelastic NiTi wires as a result of its distinctive nanocrystalline martensitic microstructure (25).

Within the limitations of the methodology, it could be concluded that PTN improved its resistance to torsional stresses and wear compared with TF and RC. It is essential for clinicians to know the characteristics of different NiTi rotary systems and associated implications for use according to the clinical conditions of root canals (9). For instance, in the present study, TF showed improved flexibility compared with PTN and RC. Consequently, TF could be used for preparing curved canals. On the other hand, PTN revealed more resistance to torsional stresses and could be used to prepare highly constricted root canals. The clinical performance of the tested brands should be evaluated *in vivo* to give reliable recommendations for endodontists.

Acknowledgments

The authors deny any conflicts of interest related to this study.

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