Dynamic Torsional Resistance of Nickel-Titanium Rotary Instruments

Su-Young Park, DDS,[*‡] *Gary S.P. Cheung, BDS, MDS, PhD, FRACDS, FDSRCSEd,*[†‡] *Jiwan Yum, DDS, MS,*[*] *Bock Hur, DDS, MS, PhD,*[*] *Jeong-Kil Park, DDS, MS, PhD,*[*] *and Hyeon-Cheol Kim, DDS, MS, PhD*[*]

Abstract

Introduction: The cyclic fatigue of nickel-titanium (NiTi) rotary instruments has been studied extensively, but there is little information available on torsional fracture. Moreover, a clinical repeated locking effect was not considered in previous studies that evaluated torsional resistance of NiTi instruments. Thus, this study was aimed to compare the repetitive torsional resistance of various NiTi instruments with clinical relevance. **Materials and Methods:** Five brands of NiTi rotary instruments were selected: Twisted File (TF; SybronEndo, Orange, CA) and RaCe systems (FKG Dentaire, La Chaux-de-Fonds, Switzerland), both with an equilateral triangular cross-section, and the ProTaper (Dentsply Maillefer, Ballaignes, Switzerland), Helix (DiaDent, Chongju, Korea), and FlexMaster (VDW, Munchen, Germany), which had a convex triangular cross-section. Five millimeters of the tip of each file was embedded in composite resin block, and uniform torsional stresses (300 rpm, 1.0 N.cm) were applied repetitively by an endodontic motor with auto-stop mode until the file succumbed to torsional failure. The number of load applications leading to fracture was recorded. All fracture surfaces were examined under the SEM. Results were analyzed nonparametrically with $\alpha = 0.05$. **Results:** Under the mode of load applications in this study, TF had the lowest and FlexMaster the highest torsional resistance among the groups ($p < 0.05$). Scanning electron microscopy examination revealed a typical pattern of torsional fracture for TF, RaCe, and ProTaper that was characterized by circular abrasion marks and skewed dimples near the center of rotation. In addition to these marks, Helix and FlexMaster presented a rough, torn-off appearance. **Conclusion:** It was concluded that files of same cross-sectional design may exhibit different resistance to fracture probably as a result of the manufacturing process. *(J Endod 2010;36:1200–1204)*

Key Words

Machining groove, nickel-titanium rotary file, repetitive load, shear fracture, torsional resistance, Twisted File

Nickel-titanium (NiTi) rotary instruments are commonly used for endodontic treatment nowadays. Root canal preparation with NiTi rotary files is easier and faster than with hand instruments (1). Despite the increased flexibility and strength, compared with stainless steel instruments (2), NiTi rotary instruments appear to have a higher risk of separation (3).

Increasing the resistance to fracture has been a focus in the design of NiTi rotary systems because fracture of the instrument in use can potentially lower the healing probabilities (4). Several strategies have been suggested by manufacturers to reduce the chance of separation of NiTi instruments. These methods include (i) modifying the surface of the instrument through such process as electropolishing (eg, RaCe; FKG Dentaire, La Chaux-de-Fonds, Switzerland), (ii) reducing the contact area between the instrument and the root canal wall by modifying the instrument's cross-sectional geometry (eg, FlexMaster; VDW, Munchen, Germany) and/or by varying the taper over the length of the cutting blades (eg, ProTaper; Dentsply Maillefer, Ballaignes, Switzerland), and (iii) improvement in the manufacturing process or the use of new alloys that provide superior mechanical properties (eg, Twisted File [TF]; SybronEndo, Orange, CA) (5, 6).

The fracture of rotary instruments has been attributed to torsional failure and cyclic fatigue, with the former contributing to a significant proportion of the failures (7). Although cyclic fatigue is caused by repetitive compressive and tensile stresses acting on outermost fibers of a file rotating in a curved canal, torsional failure occurs when the tip of the instrument binds but the shank of the file (driven by the handpiece) continues to rotate. Shear fracture of the material then occurs when the ultimate strength of the material is exceeded (8). The measurement of torsional strength of root canal instruments is typically performed in a torsiometer, as is stipulated by the American Dental Association specifications numbered 28 (9). In this method, the tip of the instrument is clamped rigidly, and a torsional moment is applied. The maximum torque and angular deflection at break are recorded (9, 10). However, torsional loading under such a monotonic condition rarely occurs clinically. Rotary instruments are subjected to varying loads in real clinical situations (11), with fractures likely to be the result of a combination of repetitive flexural and torsional stresses.

Fatigue may be defined as the failure of a material after repeated stressing at levels below its yield point (12). Clinically, it is possible that repeated locking (and release) of the rotary instruments would occur (13), especially when a torque-controlled motor is

From the *Department of Conservative Dentistry, School of Dentistry, Pusan National University, Yangsan, Korea; and †Area of Endodontics, Faculty of Dentistry, the University of Hong Kong, Hong Kong SAR, China.

‡Su-Young Park and Gary S.P. Cheung contributed equally to this work and have the first authorship shared.

Address requests for reprints to Dr Hyeon-Cheol Kim, Department of Conservative Dentistry, School of Dentistry, Pusan National University, 3-3, Beomeo-Ri, Mulgeum, Yangsan, Gyeongnam, 626-810 Korea. E-mail address: golddent@pusan.ac.kr.

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used. In narrow canals, rotary instruments would be subjected to higher torsional stresses than in the wider canals (14), and, hence, the chance of experiencing such repetitive torsional loads would be increased.

Cyclic flexural fatigue of NiTi rotary instruments has been studied extensively, but only one report is available on torsional fatigue (13). The effect of repeated locking of the instrument has not been considered in those other studies that examined (monotonic) torsional resistance of NiTi instruments. Thus, the purpose of this study was to compare the fracture resistance of various NiTi rotary instruments to repetitive torsional loads.

Materials and Methods

Five commercially available NiTi rotary instruments with two different cross-sectional geometries were selected for this study: (1) equilateral triangular cross-section that included the TF and RaCe and (2) "convex-triangular" cross-section that included ProTaper, FlexMaster, and Helix (DiaDent, Chongju, Korea). The size of TF, RaCe, Helix, and FlexMaster files was #25, 0.06 taper, and the ProTaper F1 files were studied. The last instrument (F1: tip size #20 with 7% taper for the apical few millimeters) was selected for having the same diameter (0.55 mm) as with other files at D5 (ie, 5 mm from file tip), thus a similar cross-sectional area at that length. All files, except TF, were of a 25-mm length. TF instruments are available in 23 mm and 27 mm, and the former was used in this study. Each group consisted of 10 new files from each brand.

To evaluate the pure torsional resistance and exclude the influence of flexural fatigue, repetitive torsional stress was applied to the file in a straight state (ie, without bending). A metal block with a cubical hole (5 mm^3) was constructed in which 5 mm of the tip of each file was rigidly held in place by filling the mold with a resin composite (Premise Flowable; Kerr, Orange, CA) and light cured (Bluphase; Ivoclar Vivadent, Amherst, NY) for 80 seconds at 1,000 mW/cm^2 (Fig. 1).

Using an endodontic "torque-controlled" motor (X-Smart; Dentsply Maillefer, Ballaigues, Switzerland) with the "auto-stop" mechanism engaged, the applied torque was limited to a maximum of 1.0 Nc.m. Each file was driven clockwise at 300 rpm until the preset torque was reached and the engine stopped automatically. This was counted as one start-stop loading cycle. The engine was allowed to start again and the process repeated. The number of such load applications before fracture was recorded for each instrument. The results were analyzed statistically using the nonparametric Kruskal-Wallis and Mann-Whitney *U* test to examine for any differences between groups at a significance level of $p = 0.05$.

All broken fragments were ultrasonically cleaned in absolute alcohol for approximately 120 seconds. The fractured surface was evaluated under the scanning electron microscope (SEM) (S-4800 II; Hitachi High Technologies, Pleasanton, CA) for topographic features.

Results

Torsional Resistance

The minimum, maximum, and mean numbers of stress applications to fracture are presented in Table 1. TF showed the least resistance to repeated torsional stresses; FlexMaster had the best resistance among the groups tested followed by Helix ($p < 0.05$).

SEM Observations

The topographic appearances of the fractured surface of all but FlexMaster instruments showed the typical pattern of torsional fracture characterized by circular abrasion marks and skewed dimples near the center of rotation (Fig. 2*A–C*). The SEM images of Helix and FlexMaster showed an additional and somewhat different feature in cross-section; they looked like they were torn or sheared off at the plane of fracture (Fig. 2*D* and *E*).

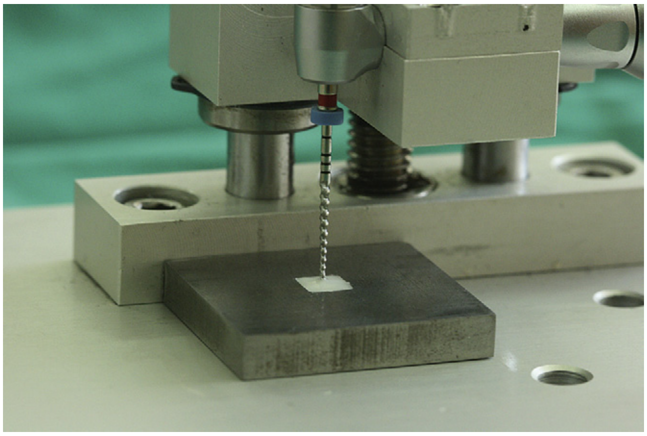

Figure 1. The setup for the torsional resistance test. (This figure is available in color online at www.aae.org/joe/.)

Discussion

Several factors including operator's handling, method of use, anatomy of the root canal system, and the dimension of the NiTi rotary file could influence the propensity of the instrument to fracture. The property of NiTi files in torsion is related to its design (15–17), chemical composition of the alloy, and thermomechanical processes applied during manufacturing (18). In particular, the cross-sectional configuration seems to have a decisive influence on the torsional behavior and stress distribution of NiTi rotary instruments (16, 17, 19, 20).

The relative size of the instrument and of the root canal would govern the amount of torsional loads on the instrument during root canal preparation (14). Smaller instruments may become wedged in constricted canal areas, producing a so-called "taper lock" effect. The torque required to rotate the shaft of a "taper-locked" instrument may exceed the alloy's shear strength, leading to separation at a position with a relatively small diameter near the instrument tip (14). It is plausible that torsional failure of NiTi rotary instruments can occur from such repeated locking in the clinical situation and hence the design of this study for comparing various NiTi rotary instruments to withstand repeated torque applications. Although the American Dental Association Specification No. 28 examines the ultimate torsional strength of the instrument (by applying a torsional load running in a clockwise direction at 2 rpm), this approach would not evaluate the chance of fracture because of repeated "taper locking." In our experiment here, uniform torsional stress was applied repetitively to simulate repeated locking of

TABLE 1. The Range and Mean Value of the Results of Torsional Resistance Test ($n = 10$ in each group)

Group	Minimum	Maximum	Mean ± SD*	Average rank†
TF	1	1	1.0 ± 0.0 [a]	6.00
RC	1	351	92.1 ± 111.4 [b]	19.00
PT	3	653	192.4 ± 236.6 [b]	21.60
HL	480	2159	1398.7 ± 588.4 [c]	39.00
FM	1406	1960	1705.6 ± 169.8 [c]	41.90

TF = Twisted File; RC = RaCe; PT = ProTaper; HL = Helix; FM = FlexMaster.

*Groups with different superscript letters indicated a statistically significant difference between them (Mann-Whitney *U* test).

†Average ranks were from the nonparametric Kruskal-Wallis test.