A Comparison of Torsional Stress Properties of Three Different Nickel-Titanium Files with Similar Cross-Sectional Design

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A COMPARISON OF TORSIONAL STRESS PROPERTIES OF THREE DIFFERENT NICKEL-TITANIUM FILES WITH SIMILAR CROSS-SECTIONAL DESIGN

by

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ABSTRACT

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The purpose of this study was to compare the *in vitro* torsional stress characteristics of Twisted Files (SybronEndo, Orange, CA) with two milled files of similar cross section, EndoSequence (Brasseler USA, Savannah, GA) and ProFile Vortex (DENTSPLY Tulsa Dental, Tulsa, OK).

Files of size 25/.06 and 30/.06 from the three file types were compared (n=20/group). Torsional stress resistance was evaluated by measuring the torque in gram-centimeters (g-cm) and angle of rotation (degrees) required for instrument separation with use of a torsiometer instrument. The fractured files were examined using SEM to look at deformation and fracture surface characteristics. The data was analyzed with ANOVA to determine statistical differences.

The three file types showed a statistically significant difference in both maximum torsional stress and angle of rotation prior to failure. Twisted Files displayed the least amount of torsional stress resistance and the highest angle of rotation. The 30/.06 size files of all three types withstood more torsional stress than the size 25/06 files of the same type. Within each file design, there was not a statistically significant difference in angular rotation between the 25/.06 and 30/.06 groups. The SEM analysis of all three file types revealed dimpling near the center of rotation on the fractured surface indicative of torsional stress.

The novel techniques used in manufacturing Twisted Files do not make them more resistant to torsional stress as compared with milled nickel-titanium endodontic files of similar cross-sectional design.

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INTRODUCTION

Nickel-Titanium (NiTi) was first described for use in endodontic files in 1988 (1). It has been shown to have advantageous bending and torsional properties when compared with stainless steel due to its low modulus of elasticity. This flexibility allows instrumentation of curved canals with less risk of transportation (2). File fracture, however, has been shown to be a problem in clinical use of NiTi files. Because of this, file manufacturers have tried to find new designs and manufacturing processes to minimize fracture occurrence.

One study found that NiTi files fractured seven times more often than stainless steel files (3). Other studies have found a file fracture rate of approximately 5% in clinical use. Alapati et al looked at discarded NiTi files from two graduate endodontic programs and examined them under SEM to compare fatigue characteristics (4). Parashos et al examined discarded files from 14 endodontists in four countries to look for defects produced during clinical use (5). Defect rates varied significantly among endodontists and operator differences appeared to have the largest effect on defect formation. Instrument design differences were also shown to affect the observed defect rate, however to a lesser extent.

NiTi files have been shown to fracture due to two different mechanisms—cyclic fatigue and torsional stress (6). Cyclic fatigue results in failure of the file when repeated cycles of tension and compression occurring during bending are sufficient to cause structural breakdown and eventual fracture. This is most often the case clinically in curved canals that contribute to the tension/compression cycling as a file is rotating.

Torsional stress is generated by the twisting of a file about its longitudinal axis at one end while the other end is fixed. This can happen in straight or curved canals if the tip binds. When the elastic limit of the metal is exceeded, the rotary instrument undergoes plastic deformation. The file will ultimately fracture if the load is sufficiently high (7).

Parashos et al (5) found cyclic fatigue to be the more common mechanism of file fracture in clinical practice. Sattapan et al (6) conversely found that torsional stress was slightly more prevalent as the cause of fracture. Sattapan's model examined discarded files from normal use in a specialist endodontic practice. They found that almost 50% of the files showed some visible defect; 21% were fractured and 28% showed other defects without fracture. Torsional fracture occurred in 55.7% of all fractured files, whereas cyclic fatigue caused fracture in 44.3% of the total fractured files. In clinical practice, files can fracture as a result of either mechanism, often with little to no warning. This is why file manufacturers must endeavor to minimize the effects of both causes of file fracture.

Many physical or design characteristics of rotary NiTi files can influence their resistance to fatigue and fracture. Previous studies have demonstrated that there is a strong relationship between the torsional stress resistance and the diameter of the instruments. Peters et al tested Profile .04 tapered instruments against torsional stress and found that larger-diameter instruments had higher resistance against torsional fatigue (7). Bahia et al tested ProFile .04 and .06 tapered files of different tip sizes that had already been stressed through cyclic fatigue (8). These pre-stressed files were then tested for torsional stress resistance. They found that files with larger diameters were more resistant to torsional loads.

Cross-sectional design configuration also has a demonstrable effect on torsional stress resistance. Berutti et al looked at a mathematical model of two different cross sectional designs and simulated torsional and bending forces (9). They found that a simulated ProTaper file showed lower and better distributed stresses than a simulated ProFile model. Xu et al tested several different types of cross-sectional designs against torsional stress (10). They classified the designs as convex (ProTaper), triple helix (Hero642), S-type (Mtwo), triple U (ProFile), Z-type (Quantec), and triangle (NiTiflex). They subjected the files to stress testing and found widely ranging stress resistance values. Factors influencing the stress distribution included the cross-sectional inertia, depth of the flute, area of the inner core, radial land, and peripheral surface ground. They also found that as the area of the inner core of the cross-section increased, the file design was more resistant to torsional stress.

Alterations or treatments of the metal, and other manufacturing processes may also influence the fatigue resistance of endodontic files. Kim et al looked at surface characteristics prior to use and correlated them with fracture resistance (11). They found that files with abundant machining grooves seemed to have a higher risk of cyclic fatigue fracture. Nickel-Titanium files are typically manufactured by spiral milling cutting flutes into blanks of NiTi. Twisted Files (SybronEndo, Orange, CA) are manufactured by twisting metal blanks to create the cutting flutes. The metal is also treated with a proprietary R-phase heat treatment to reportedly enhance superelasticity. The manufacturer claims that this new type of file is more resistant to both cyclic fatigue and torsional stress (12). Larsen et al used simulated curved canals to test Twisted Files, EndoSequence, and ProFile GTX instruments' resistance to cyclic fatigue (13). They found that Twisted Files were significantly more resistant to cyclic fatigue than EndoSequence but not different from ProFile GTX when comparing the same taper and tip size. Gambarini et al also tested files in a simulated curved canal and found that Twisted Files were significantly more resistant to cyclic fatigue than ProFile GTX and K3 files (14).

Several studies have shown that this file is more resistant to cyclic fatigue, but there have been fewer studies testing the torsional stress characteristics. Of these, maximum torsional strength was either not determined or cross-sectional design was not consistent across all files tested. The purpose of this study was to compare *in vitro* the torsional stress characteristics of Twisted Files (Sybron Endo, Orange, CA) with two milled files of similar cross section, EndoSequence (Brasseler USA, Savannah, GA) and ProFile Vortex (DENTSPLY Tulsa Dental, Tulsa, OK).

MATERIALS AND METHODS

Three NiTi rotary file designs (Twisted File, EndoSequence, and ProFile Vortex) of two sizes (25/.06 and 30/.06) were included in this study. Twenty individual files were used in each group for a total of 120 files tested. EndoSequence and ProFile Vortex groups were comprised of 25 mm files whereas 23 mm files were used in the Twisted File group since 25 mm files are not commercially available. Torsional stress was applied to failure and measured with a torsiometer instrument (Sabri Dental Enterprises, Inc., Downers Grove, IL, Figure 1). Each tested file was secured into the torsiometer by chucks on both ends of the file. A jig was used to ensure 3 mm of the tip of the file was secured on one end, and the entire length of the latch-type shank was secured at the other end. When the test was initiated, the motor caused the tip end of the file to be twisted at a constant two rotations per minute while the other end remained stationary. When sufficient torsional stress was applied to cause the file to fracture, the torsiometer sensed the sudden change in torque and stopped rotation. The values of maximum torque applied (g-cm) and angle of rotation (degrees) were displayed on the display of the machine and were recorded for each of the files tested. Statistical analysis was undertaken with ANOVA at a 95% confidence level to identify statistical differences between the groups. Additional imaging and examination of the files was then completed.

To demonstrate the cross-sectional design of each file type, one file of each brand was mounted vertically in epoxy resin (Sampl-Kwick, Buehler, Lake Bluff, IL), ground with silicon carbide paper (Carbimet Discs; Buehler) following standard metallographic procedures, and polished with a 1.0 µm alumina suspension (Alpha Micropolish Alumina, Buehler).

Figure 1. Torsiometer Instrument. Sabri Dental Enterprises, Inc., Downers Grove, IL

The cross-section was viewed with a metallurgical microscope (Olympus PME3, LECO Corporation, St. Joseph, MI) and digital micrographs were obtained. Additionally, fractured files were also viewed with a scanning electron microscope (SEM; JSM-35, JEOL Ltd., Tokyo, Japan) to examine the fracture surface and deformation along the long axis.

RESULTS

Torsional Stress Testing

All of the tested files fractured after application of torsional stress. They all fractured at the same position along the length of the file—three millimeters from the tip of the cutting end (d3). The mean and standard deviation for torque and angle of rotation are displayed in Table 1. These values are displayed graphically in Figures 2 and 3. Significant differences ($p<.05$) were found with regard to both size and brand of file. Size 30/.06 files withstood significantly more torque than the size 25/.06 files but no significant differences were observed for angle of rotation between the two sizes. For brand, Tukey post-hoc analysis showed ProFile Vortex withstood a significantly greater amount of torque compared to EndoSequence, which was significantly greater than Twisted File. In terms of angle of rotation, Twisted File were found to rotate significantly more prior to fracture compared to the ProFile Vortex and EndoSequence files, which were statistically similar.

Brand	Maximum Torque (g-cm)		Angle of Rotation (degrees)	
	25/.06*	30/.06	25/.06	30/.06
EndoSequence**	77 (10)	113 (14)	336 (32)	346 (24)
Twisted File	47 (10)	61 (13)	541 (40)	538 (35)
ProFile Vortex	109 (15)	146 (27)	327 (43)	333 (35)

Table 1. Torsional Resistance and Angle of Rotation of Files

*Maximum torque of 30/.06 was significantly greater than 25/.06 ($P < .05$). No significant differences were found for angle of rotation between 25/.06 and 30/.06 ($P > .05$).
** ProFile Vortex withstood a significantly greater amount of torque compared to EndoSequence, which was significantly greater than Twisted File ($P < .05$). Twisted File rotated significantly more than the other two brands ($P < .05$).

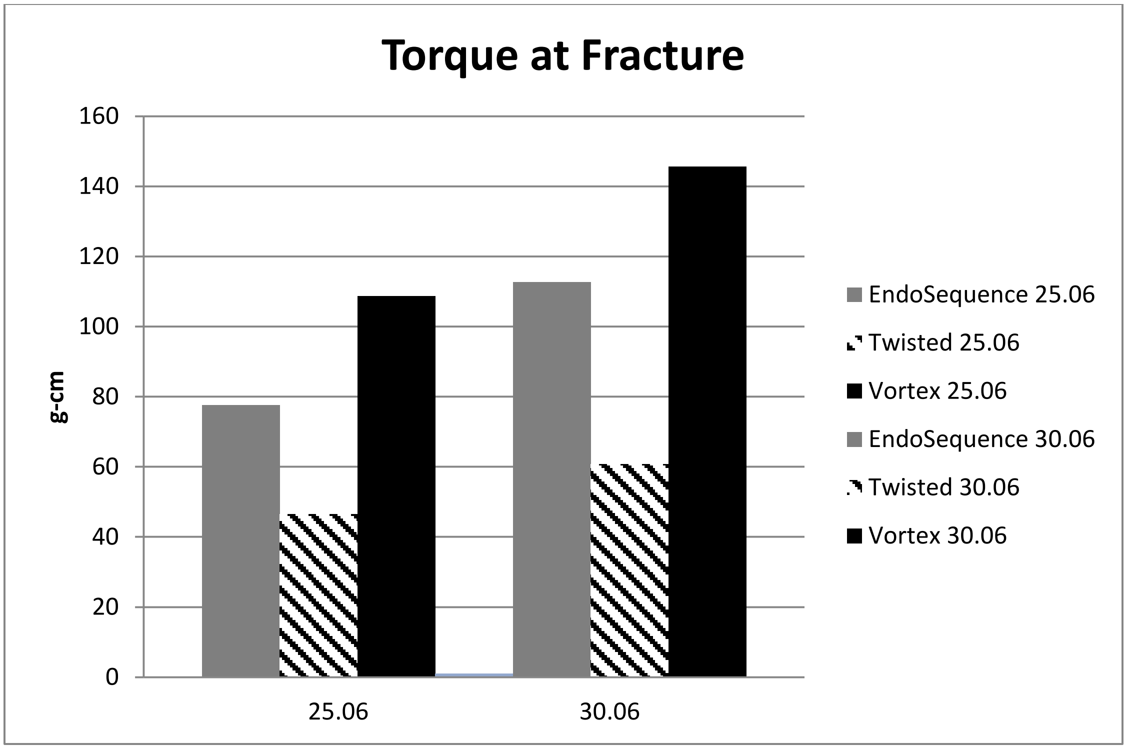

Figure 2. Graphical representation of maximum torque values

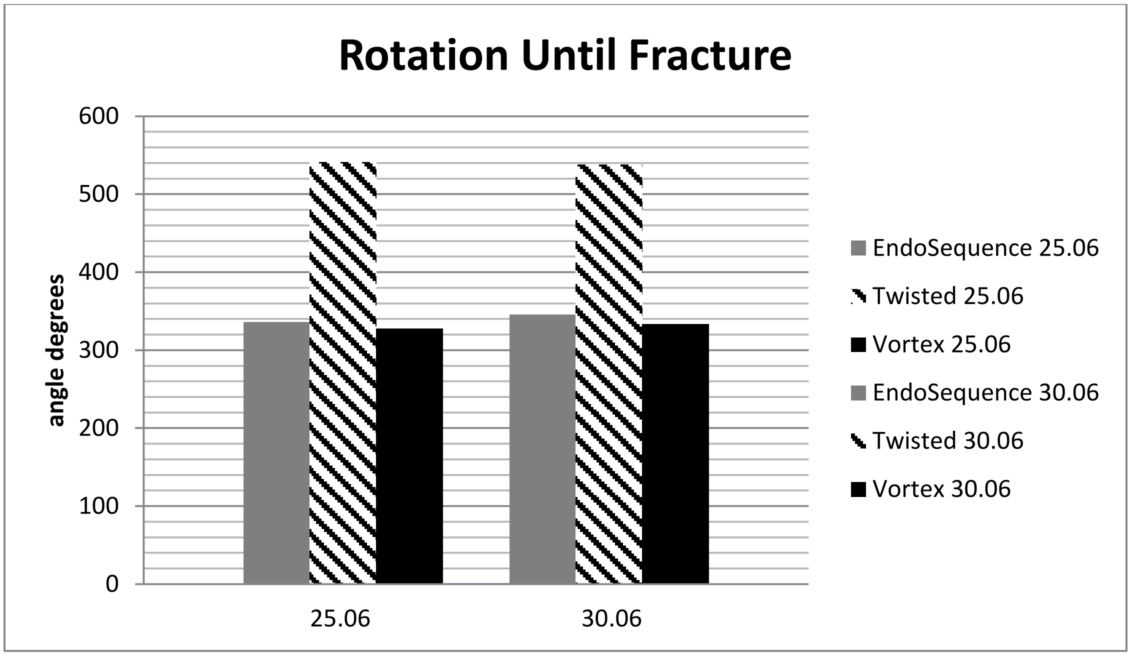

Figure 3. Graphical representation of angle of rotation values.

Microscopy Observations

The images obtained from the metallurgical microscope demonstrated the similar cross sections of each file (Figure 4). The SEM images showed that all 3 brands of files demonstrated topographic features on the fractured surface typical of torsional failure including dimpling near the center of rotation (Figure 5). The longitudinal views showed the most marked deformation or unwinding in the Twisted File. The EndoSequence file showed less unwinding and the ProFile Vortex file showed almost no permanent deformation along the longitudinal axis.

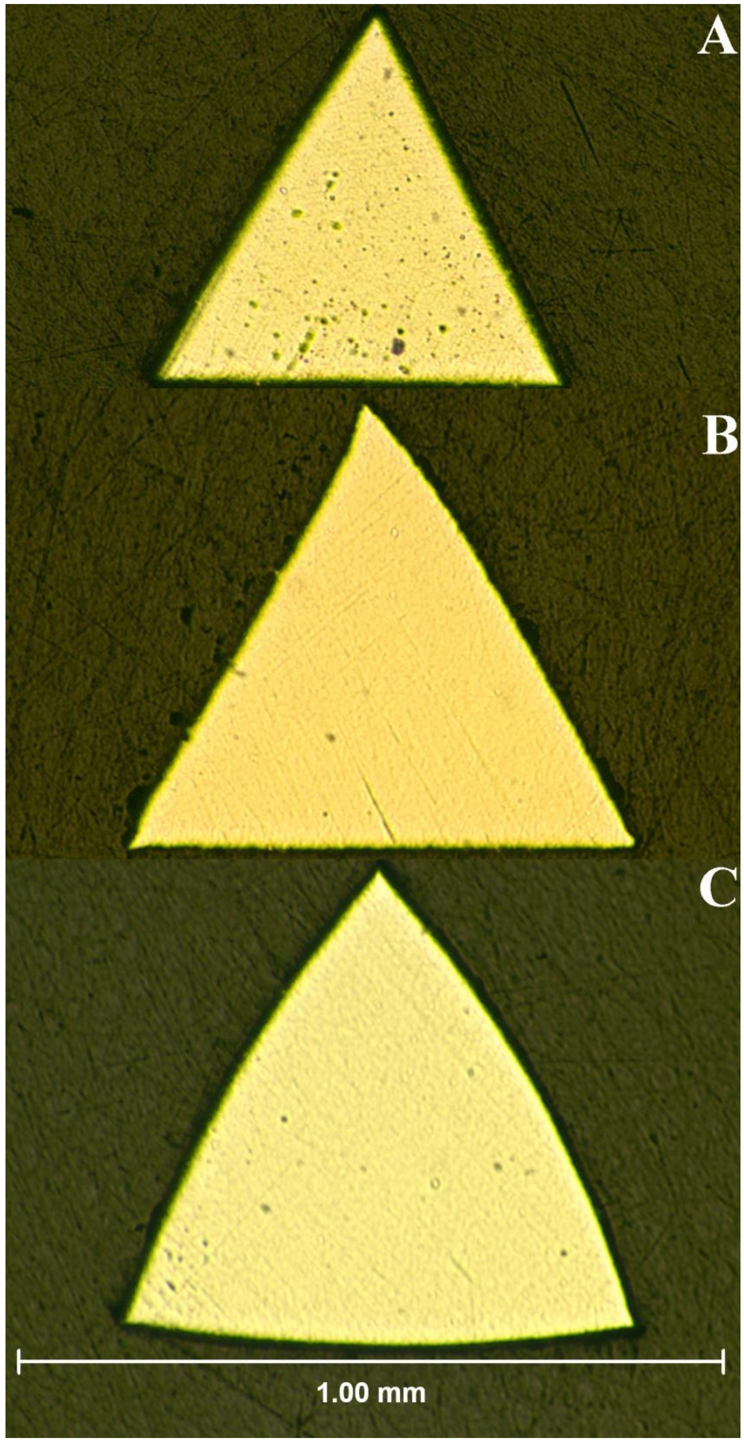

Figure 4. Optical micrographs of file cross-sections: A) EndoSequence, B) Twisted File, and C) ProFile Vortex.

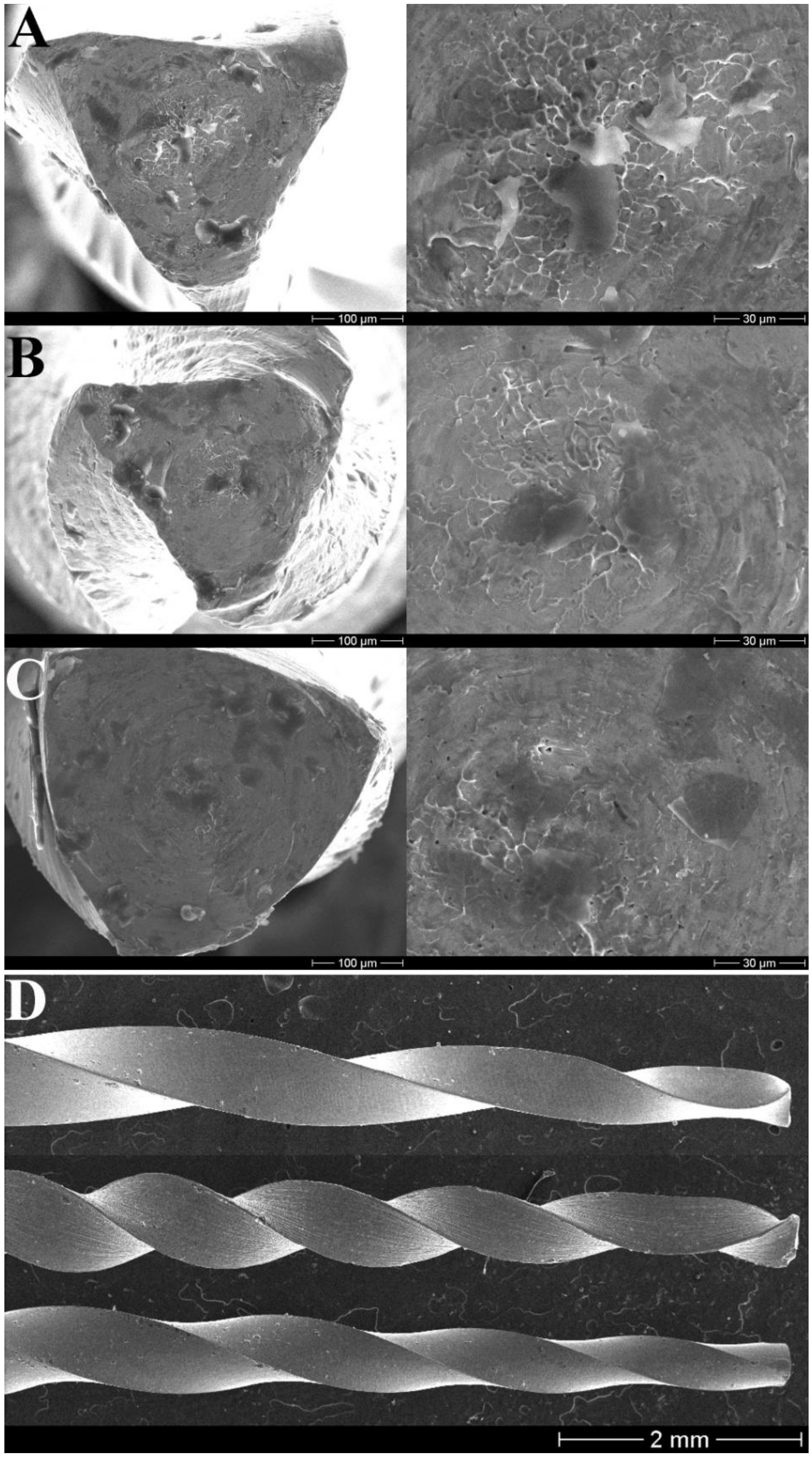

Figure 5. SEM micrographs of fractured files. Fracture surfaces at 300x and 1000x for A) EndoSequence, B) Twisted File, and C) ProFile Vortex. D) Longitudinal view of EndoSequence, Twisted File, and ProFile Vortex (from top to bottom).

DISCUSSION

In this study, the resistance to torsional stress of Twisted File was compared with that of two similarly shaped file systems that are manufactured by grinding, EndoSequence and ProFile Vortex. There was a significant difference between Twisted File, EndoSequence, and ProFile Vortex files in both maximum torsional stress and angle of rotation. Twisted File withstood the least amount of torque and also displayed the most angular rotation before failure.

The ProFile Vortex files showed the greatest resistance to torsional fatigue. It has been shown that if the central core of the file design is larger, the file will be more resistant to torsional stress (10). The convex triangular shape of ProFile Vortex as opposed to the equilateral triangular cross section of the other two designs could contribute to higher stress resistance prior to fracture. ProFile Vortex files are made with proprietary "M-wire" which has also been said to be more resistant to fracture than traditional nickel-titanium. Gao et al examined fractured files under scanning electron microscopy and found that files made of M-wire showed a single crack initiation site in contrast to the multiple crack initiation sites on files made of regular NiTi wire (15). They also found that files made with M-wire had superior cyclic fatigue resistance when compared with regular NiTi files (~150% longer in fatigue life). However, another study found that there was not a statistically significant difference in torsional stress resistance between M-wire and files made with traditional nickel-titanium. Kramkowski et al found no statistical difference in torsional stress resistance between ProFile GT and ProFile GTX (made with M-wire) (16). They also found some of their test groups to show better cyclic fatigue resistance in the ProFile GT groups (made with regular NiTi) as compared with the ProFile GTX groups (made with M-wire).

In this study, Twisted Files showed the highest angle of rotation prior to fracture and also withstood the least amount of torsional stress, allowing the file to “unwind” much more easily. This might be expected since the files are manufactured by twisting rather than grinding. The torque during instrumentation is applied in the opposite direction as the initial twisting during manufacturing and therefore the torsional stress is in effect returning the file to its original configuration by “unwinding” it. The question then becomes: how much unwinding is too much? Clinicians might have a hard time deciding when to discard a file if flute unwinding is to be used as an indicator that the file might be at risk of fracture.

The results of this study are consistent with those of Park et al (17). They used a dynamic torsional stress testing model using a uniform amount of torsional stress applied repeatedly until file separation. Using a torque-control endodontic motor set to 300 rpm and 1.0 Ncm, they applied repeated torsional stress to files embedded in composite resin. They found Twisted Files to be the least resistant to torsional stress compared to several other milled nickel-titanium files. Their study, however, did not identify maximum torsional stress values or angular rotation for the different designs, nor did it give absolute values for comparing one file to another. Twisted Files fractured with only one application of 1 Ncm, so the relative performance of the file was not determined. It could only be said that the torsional stress limit for the file design is somewhere below 1 Ncm.

The type of testing used in this study is a standardized testing method for endodontic files as described in American Dental Association specification number 28 (18). Other studies that have tested Twisted File in this way have also found them to withstand lower torque levels at fracture when compared to other files possessing variable cross sections, tapers, and sizes. Yum et al tested several different file designs for torsional stress resistance (19). They selected Twisted Files and RaCe with equilateral triangle cross section, ProTaper with convex triangle, ProFile with U-shape, and Mtwo with S-shape. All tested files had the same taper and tip size of 25/.06 except the ProTaper, which had a variable taper. The Twisted Files' cutting flutes and produced by twisting NiTi blanks, whereas the other tested files are milled. The Twisted Files had by far the lowest torsional stress resistance of the tested file types. Casper et al tested three different file types to torsional stress testing after 0, 1, 2, 3, and 7 steam autoclave cycles (20). The files tested were ProFile Vortex, Twisted Files, and 10 Series files made from CM wire. They found the autoclave cycles had no significant effect on torsional stress performance. Of the file types tested, they found the Twisted Files to demonstrate the lowest levels of torsional stress resistance.

This study aimed to focus on the file material and manufacturing method as the main variable. This is why testing was done on three files with very similar cross-sectional and flute designs. The tested files also shared identical tip size and taper. Twisted Files have a triangular cross-section and are manufactured through twisting, ProFile Vortex have a convex triangular cross-section and are manufactured through milling, and EndoSequence have a triangular cross section and are manufactured through milling. File size was also examined as a secondary variable to see if the difference in file size affected the performance of the different files equally in the testing results. The testing apparatus only displayed maximum torsional stress and angular rotation at failure, therefore comparisons cannot be made about the stages of deformation of the tested files.

There are many variables that affect the performance of endodontic files in clinical practice and their resistance to fatigue and separation. Some of these variables include size, taper, cross-sectional design, manufacturing techniques, and operator skill (15,16,21,22). It is important for clinicians to know the characteristics of different file designs and associated implications for use in different clinical situations. Each file performs better in some areas and worse in others and this information is important to help choose the best instruments for each clinical case.

The results of this present study suggest that the novel techniques used in manufacturing Twisted Files do not make them more resistant to torsional stress as compared with traditionally manufactured nickel-titanium endodontic files of similar design. Additional studies are needed to evaluate the clinical performance and fatigue characteristics of these files *in vivo*.

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