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Cyclic and torsional fatigue resistance of heat treated and conventional super elastic nickel-titanium files

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Key Words: Cyclic fatigue, EdgeFile, Torsional fatigue, K3, Profile, Profile Vortex, EndoSequence

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Cyclic and torsional fatigue resistance of heat treated and conventional super elastic nickel-titanium files

Steven J Todd, DMD, Stephanie J Sidow, DDS, Joseph M Dutner, DMD, Peter M Parker, BA,BS, Douglas Dickinson, PhD

Abstract

Introduction: Fracture of nickel-titanium (NiTi) rotary instruments can occur via either cyclic or torsional fatigue. The purpose of this study was to compare the torsional and cyclic fatigue resistance of various NiTi rotary files.

Methods: Forty files each of Profile Vortex, Profile, EndoSequence, K3, and EdgeFile were selected for this study. File sizes of 25/.04 and 40/.04 were subjected to cyclic fatigue testing (n=10) and torsional fatigue testing (n=10) using an Instron Universal testing machine (model #E10000, UK). Cyclic fatigue resistance was measured with file rotation around a 5mm radius 90 degree curve. Torsional resistance was measured using a metal mounting block with 5 mm of the file tip affixed with composite resin in a central cuboidal hole. ANOVA statistical analysis was performed for each file size.

Results: Cyclic fatigue testing of file size 25/.04 demonstrated that EdgeFile was at least two-fold more resistant to cyclic fatigue than the other four file types. Torsional fatigue testing of size 25/.04 showed EdgeFile to have significantly greater torque at failure than all other file types except K3. Cyclic fatigue testing of file size 40/.04 showed that Profile was the most resistant to failure. Torsional fatigue testing for file size 40/.04 showed that Profile had the greatest maximum torque at failure compared to the other four file types.

Conclusion: Among the 25/.04 files tested, EdgeFile was most resistant to cyclic and torsional fatigue. Among the 40/.04 files tested, Profile was most resistant to cyclic and torsional fatigue.

Key Words: Cyclic fatigue, EdgeFile, Torsional fatigue, K3, Profile, Profile Vortex, EndoSequence

Introduction

Nickel-titanium (NiTi) rotary files are commonly used during endodontic treatment to clean and shape the root canal system. Historically, instrumentation was completed with stainless steel files; however stainless steel files were prone to fracture, with decreased ability to negotiate curved canals and increased risk of transportation and perforations (1). It wasn't until 1988 that Dr. Walia introduced NiTi for use in Endodontics. A significant advantage of NiTi over stainless steel files is its flexibility (1), which allows the instrument to navigate curved canals with less risk of transportation or instrument fracture (2). NiTi alloy contains three different microstructural phases, the martensite, austenite, and R-phase (3). NiTi alloys in the martensite phase will be soft, ductile, and easily deformed while NiTi in the austenite phase will be strong and hard (4). The transformation through various phases grants the metal its super elasticity and shape memory (5). While possessing desirable properties, NiTi is susceptible to both cyclic and torsional fatigue.

Cyclic fatigue occurs as the file negotiates around a curve while it continues to rotate (6). On the inside of the curve, a compressive stress is applied to the file, while on the outside of the curve, a tensile stress is applied. As the file rotates, the bent segment experiences alternating tensile and compressive stresses, resulting in microfractures in the NiTi matrix, eventually leading to file fracture (6). Torsional fatigue occurs as the file rotates while the tip of the file is locked in place. The shank of the file will continue to rotate, and the locked segment will separate (7). The type of fatigue a file is susceptible to is impacted by the diameter of the file. A larger file size with greater taper is more likely to succumb to cyclic fatigue while a smaller file size with less taper is more likely to succumb to torsional fatigue (6, 8, 9).

M-wire (Dentsply Tulsa Dental Specialties, Tulsa, OK) was developed in an effort to improve the NiTi file's ability to withstand both cyclic and torsional fatigue resistance. The improved flexibility of M-wire is achieved through proprietary thermomechanical treatment of the NiTi files (10). In a study comparing M-wire, and conventional NiTi, M-wire had an increased cyclic fatigue resistance of up to 390% compared to conventional NiTi (11). According to Gao et al, torsional fatigue resistance testing of the raw materials stainless steel, conventional superelastic NiTi, M-wire NiTi, and Vortex Blue NiTi found stainless steel to have 30% greater peak torque compared to M-wire NiTi (12).

Introduced in 2010, controlled memory wire (CM) undergoes a special thermomechanical process that controls the memory of the material, making the files extremely flexible. CM exists in a mixture of martensite and austenite at room temperature (13). The thermomechanical process lends the file to increased flexibility without the shape memory seen in most NiTi files. CM instruments have shown an increase in cyclic fatigue resistance from 300-800% compared to conventional NiTi files (10). When comparing torsional fatigue, there are mixed results as reported by Ninan et al., who demonstrated an improved torsional fatigue resistance whereas Park et al., reported the CM file had the least torsional fatigue resistance when compared to conventional NiTi files (14, 15). Companies will continue to seek out improvements in the metallurgy, flute design, and other properties in an attempt to create the most flexible, clinically efficient Endodontic file that is also most resistant to fracture.

Recently, FireWire (Edge Endo, Albuquerque, NM) has been introduced which is a NiTi material also treated by a proprietary thermomechanical process. With the ability to pre-curve the file and maintain the bend, FireWire appears to demonstrate CM-like characteristics. According to the manufacturer, the EdgeFile X7, which is composed of FireWire, is compatible with the following file systems: Profile Vortex, Profile, K3 SybronEndo,Glendora, CA), and EndoSequence (Brasseler, Savannah, GA). To date, cyclic and torsional fatigue resistance tests have not been published for the EdgeFile X7. The purpose of this study was to compare the torsional and cyclic fatigue resistance of heat-treated and conventional NiTi files.

Methods and Materials

Ten 25 mm 25/.04 files and ten 25 mm 40/.04 files were tested from each file system: EdgeFile, Profile Vortex, Profile, K3, and EndoSequence. All files were tested according to the ISO 3630-1 testing standards.

Cyclic Fatigue

The design for this study was based on previous work by Whipple et al (16). Briefly, the apparatus consisted of a grooved steel cylinder in which the files were rotated according to manufacturer-recommended settings with simultaneous axial movement of the Instron Universal testing machine (model# E10000, Instron, Norwood, MA) arm of 4 mm at 1 Hz around a 5mm radius of curvature 90 degree arc (Fig. 1). Using 4.8x- magnification and illumination, the tip of each file was observed until fracture occurred. The time to fracture was recorded with a digital stopwatch (Seiko S143; Seiko USA, Mahwah, NJ) accurate to 0.01 seconds. The cycles to failure (CTF) were calculated.

Torsional Fatigue

Torsional fatigue resistance was determined as described by Yum (17). A metal block was prepared with a cubical hole (5 mm^3), in which 5 mm of the tip of each file was rigidly held in place with light-cured resin composite (Premise™ Flowable; Kerr, Orange, CA) Torsional load was evaluated in an Instron Universal testing machine by applying a uniform clockwise rotation at a rate of 2 rpm with the file in an unbent position. The fracture strengths (Nm) and the respective distortion angles (degrees of rotation) at which the file fractured were recorded.

Results

Cyclic fatigue (Fig. 2)

A significant difference among CTF means for the 25/.04 files was observed (one way ANOVA; $p<0.0001$). Among the 25/.04 files, the rank order from greatest to least CTF was EdgeFile, Profile, K3, Profile Vortex, and EndoSequence. The EdgeFile CTF was significantly greater than the other four files tested ($p<0.0001$). The Profile CTF was significantly greater than that of EndoSequence, K3, or Profile Vortex ($p<0.0001$).

There were no significant differences in CTF between the EndoSequence, K3, and Profile Vortex files.

Among the 40/.04 files, the rank order from greatest to least CTF was Profile, EdgeFile, Profile Vortex, K3, and EndoSequence. The Profile CTF was significantly greater than the other four products ($p<0.0001$), and the EdgeFile was significantly greater than those of EndoSequence, K3, or Profile Vortex ($p<0.0001$). There were no significant differences in CTF between the Profile Vortex, K3, and EndoSequence files.

Torsional Fatigue (Fig. 3)

The 25/.04 files showed a highly significant difference among maximum torsional fatigue resistance means ($p<0.0001$). Tukey's multiple comparisons test detected significant differences among mean torque resistance for all pairwise comparisons ($p\leq0.022$). The rank order for torsional fatigue resistance from greatest to least was EdgeFile, K3, EndoSequence, Profile Vortex, and Profile. The mean EdgeFile 25/.04 torque at failure (0.324 ± 0.062Nm) was significantly greater than EndoSequence ($p=0.003$), Profile ($p<0.0001$), and Profile Vortex ($p<0.0001$) files, but there was no significant difference between the EdgeFile and K3 files. Both the EndoSequence and K3 25/.04 files demonstrated a mean torsional fatigue resistance significantly greater than both Profile and Profile Vortex files ($p\leq0.022$).

Among the 40/.04 files, the rank order from greatest to least torsional fatigue resistant was Profile, K3, Profile Vortex, EndoSequence, and EdgeFile. Profile had a significantly higher torsional fatigue resistance than EdgeFile ($p=0.0002$) and EndoSequence ($p=0.0005$) files, but with no significant difference between the Profile, K3, and Profile Vortex files. The K3 torsional fatigue resistance was significantly greater ($p<0.001$) than EdgeFile files with no significant difference between the K3, Profile Vortex, or EndoSequence files.

Discussion

The purpose of this study was to compare the torsional and cyclic fatigue resistance of various NiTi rotary files to include FireWire, M-wire, and conventional superelastic NiTi. While all files tested possessed the same tip size and continuous taper, they differed in cross-sectional design and composition. According to the manufacturer, the Profile system has radial-landed U-shaped flutes and exists as a cold-worked alloy with increased hardness but decreased ductility (18). Profile Vortex files are made from M-wire and receive their proprietary manufacturer-specific thermomechanical procedure to improve the overall flexibility (19). K3 files are described as having a positive rake angle, variable helical flute angle, and a variable core diameter (20). According to the manufacturer, EndoSequence files are electropolished without any radial lands (21). This report was unable to determine which of these factors influenced the mechanical properties of the files tested.

The results of this study are similar to those of Shen et al. who demonstrated the superior cyclic fatigue resistance of controlled memory files compared to conventional NiTi files (10). Although the 25/.04 EdgeFile demonstrated superior cyclic fatigue resistance in our study, interestingly, the same was not true for the 40/.04 files. The Profile 40/.04 outperformed the EdgeFile 40/.04 in cyclic fatigue resistance. Possible reasons could be related to the flute depth, inner core diameter, or cross-sectional shape of the Profile.

The results of the torsional fatigue testing demonstrated that the EdgeFile 25/.04 and Profile 40/.04 were the most resistant to fracture. These results are similar to the study by Ninan et al. (14) in which Hyflex CM (Coltene, Whaledent, Cuyahoga Falls, OH) demonstrated higher torque values than conventional or M-wire files whereas, Profile and Profile Vortex 40/.04 demonstrated greater values than the Hyflex 40/.04 CM. These results are in contrast to those by Park et al. who concluded that the size 25/.06 CM file had the least torsional fatigue resistance when comparing CM files with 4 other commercially available NiTi files (15). One property possibly contributing to the Profiles greater torsional fatigue resistance is its large central core (22).

Additional investigations should determine the file’s ability to maintain canal anatomy while cleaning and shaping the root canal system. Possible future research should compare files with similar metallurgy and/or design to control for multiple variables. Further development can proceed towards files with improved flexibility and fatigue resistance within canal systems, allowing for greater respect for the original anatomy and more desirable clinical outcomes.

Acknowledgment

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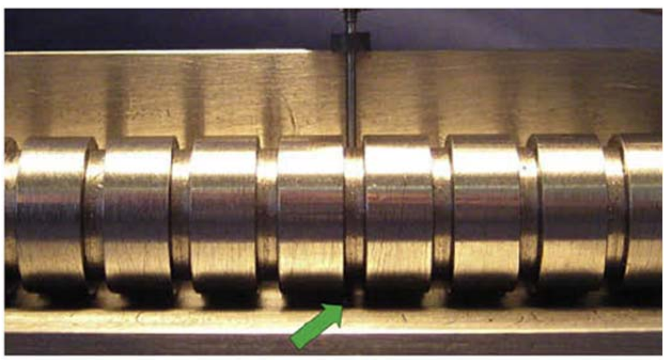


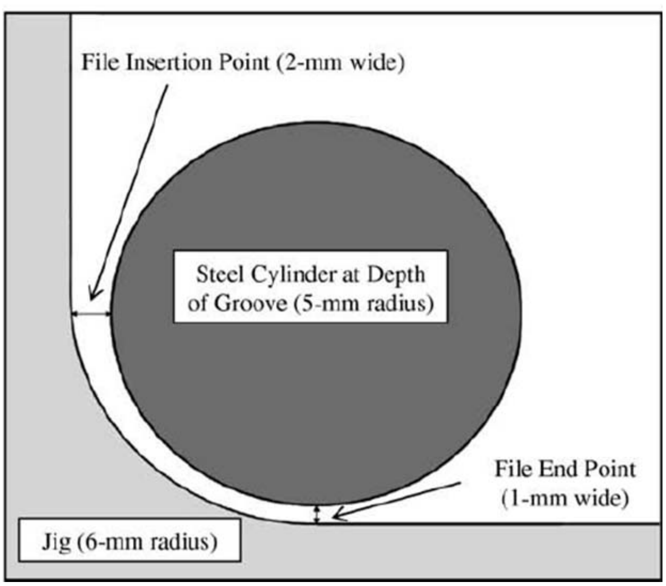


Figure 1

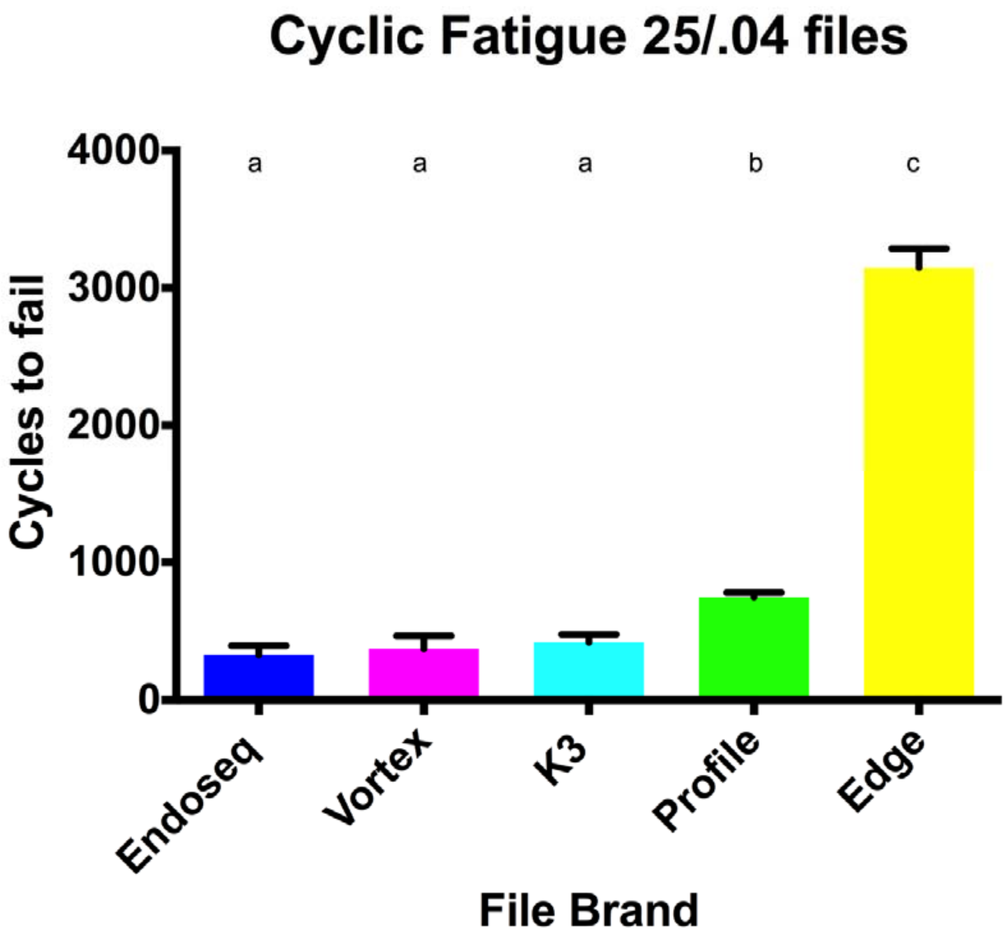


Figure 2A

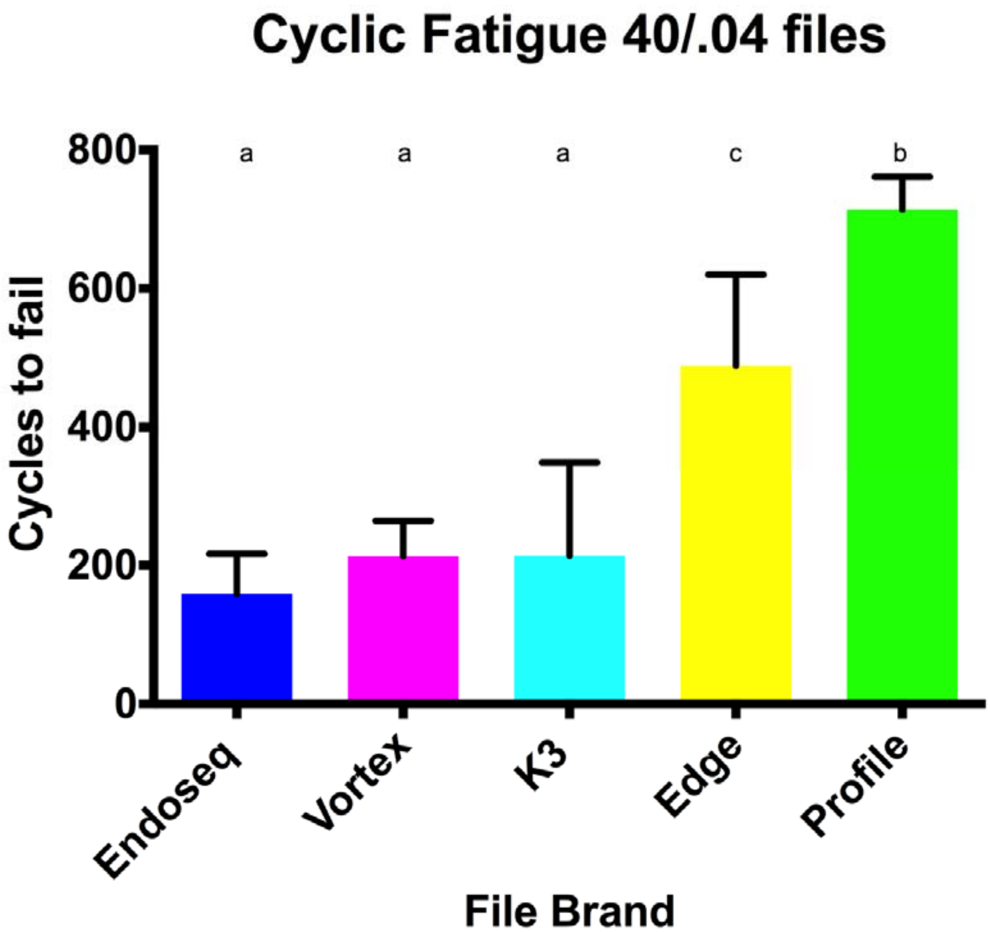
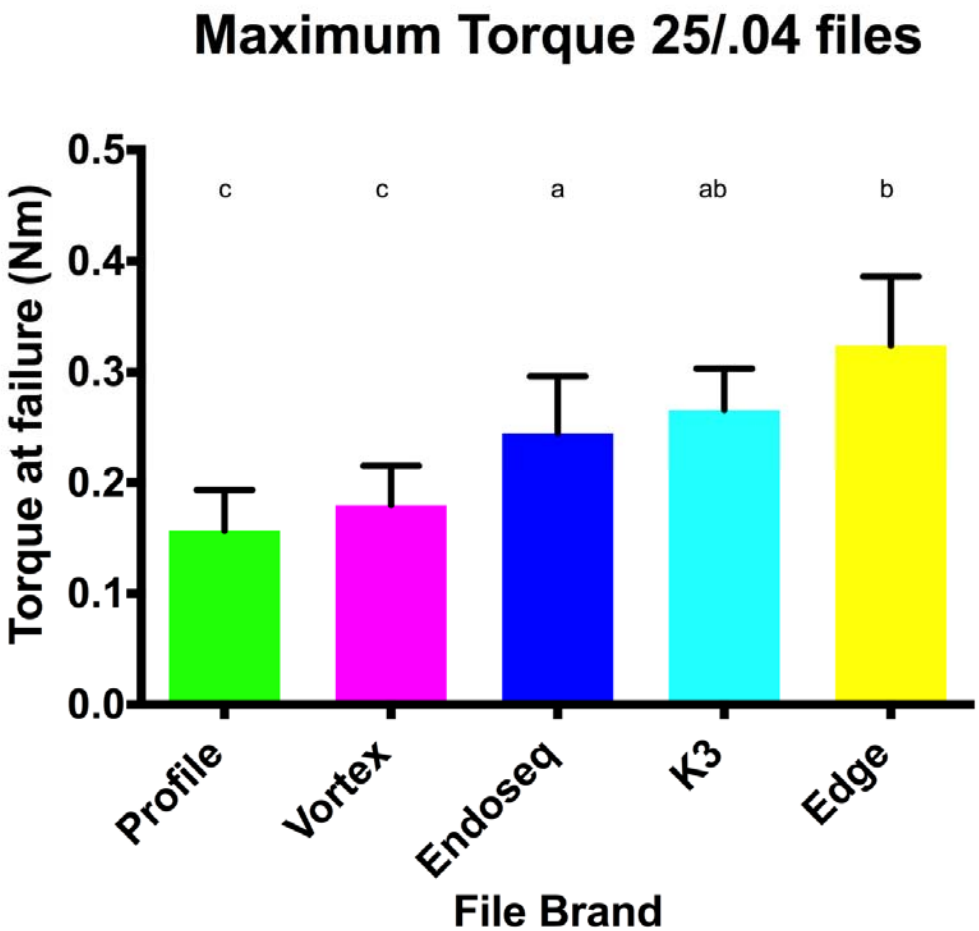

Cyclic Fatigue 40/.04 files
Cycles to fail
800
600
400
200
0
a
a
a
c
b
Endoseq
Vortex
K3
Edge
Profile
File Brand

Figure 2B



Maximum Torque 25/.04 files
Torque at failure (Nm)
0.5
0.4
0.3
0.2
0.1
0.0
c
c
a
ab
b
Profile
Vortex
Endoseq
K3
Edge
File Brand

Figure 3A

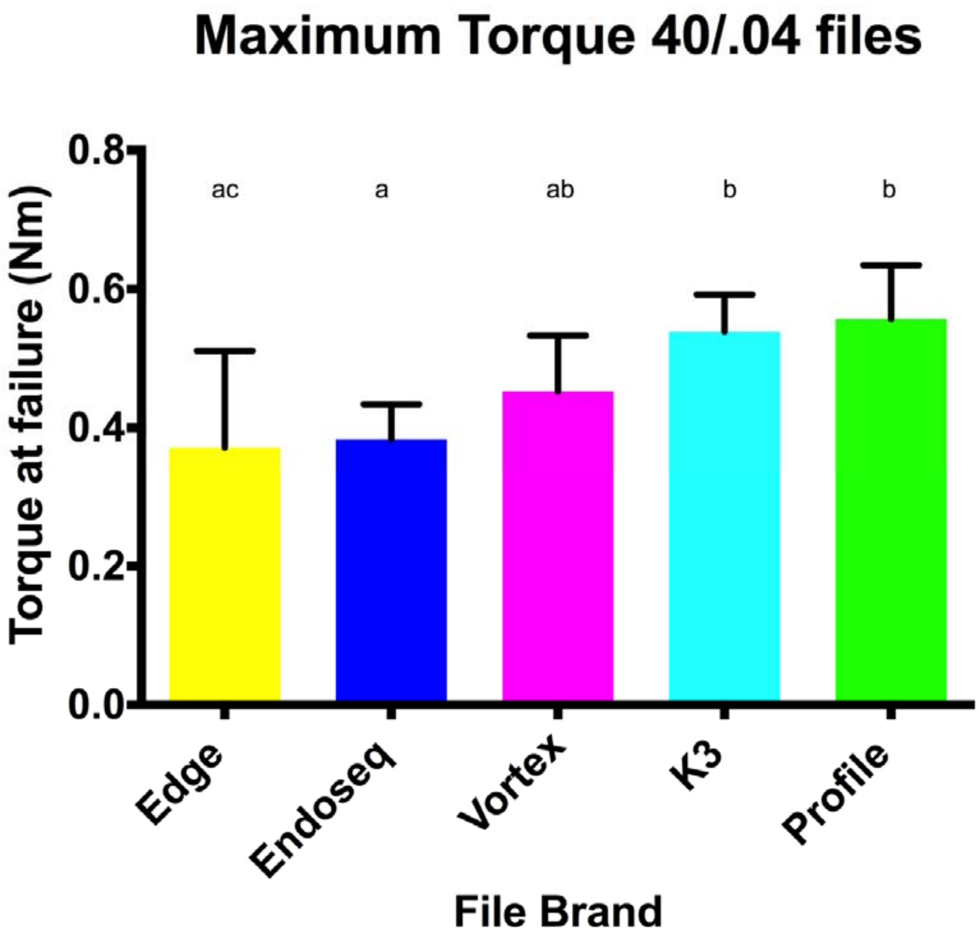


Figure 3B

Legend of Figures

Figure 1. File being inserted into apparatus (top) for cyclic fatigue testing, with file tip in position (green arrow). A schematic of the apparatus in cross-section (bottom). Images provided with written permission from Dr. Whipple and Dr. Kirkpatrick.

Figure 2: Distribution data for cyclic fatigue time to failure. Figure 2A: A bar graph of mean values for cycles-to-failure for each 25/.04 file sample in each manufacturing group is shown, with the standard deviation (smaller bars). Figure 2B: A bar graph of mean values for cycles-to-failure for each 40/.04 file sample in each manufacturing

group is shown, with the standard deviation (smaller bars). Groups showing statistically significant differences are identified by different lettering.

Figure 3: Distribution data for torsional fatigue maximum torque at failure. Figure 3A: A bar graph of mean values for maximum torque (in Nm) for each 25/.04 file sample in each manufacturing group is shown, with the standard deviation (smaller bars). Figure 3B: A graph of mean values for maximum torque (in Nm) for each 40/.04 file sample in each manufacturing group is shown, with the standard deviation (smaller bars). Groups showing statistically significant differences are identified by different lettering.