Mechanical Properties of Various Glide Path Preparation Nickel-titanium Rotary Instruments

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Abstract

Introduction: The aim of this study was to compare the cyclic fatigue, torsional resistance, and bending stiffness of single-file glide path preparation nickel-titanium instruments. **Methods:** ProGlider (#16/progressive taper; Dentsply Sirona, Ballaigues, Switzerland), One G (#14/.03; Micro-Mega, Besancon, France), and EdgeGlidePath (#16/progressive taper; Edge Endo, Albuquerque, NM) were tested. For the bending stiffness test, the instrument was bent to a 45° angle along the main axis while 3 mm of the tip was secured. Cyclic fatigue resistance was measured during pecking movement, whereas the file was rotated within a reproducible simulated canal with a 3-mm radius and a 90° angle of curvature. The ultimate torsional strength and toughness were evaluated using a custom device. While tightly holding the end of the file at 3 mm, a rotational load of 2 rpm speed was applied until fracture. The results were analyzed using 1-way analysis of variance and Tukey post hoc comparison. A microscopic inspection was performed on the surface of a separate instrument using a scanning electron microscope. **Results:** EdgeGlidePath showed superior cyclic fatigue resistance compared with the other systems. One G showed higher maximum torsional strength than the others. One G showed the largest distortion angle and the highest toughness followed by EdgeGlidePath and ProGlider ($P < .05$). One G also showed larger bending stiffness than the others, whereas EdgeGlidePath showed a larger residual angle than the others ($P < .05$). **Conclusions:** Conventional wire showed higher toughness and torsional resistance than M-Wire and heat-treated nickel-titanium instruments. However, heat-treated wire showed higher cyclic resistance than conventional wire and M-Wire. *(J Endod 2019;45:199–204)*

Key Words

Cyclic fatigue resistance, FireWire, glide path file, M-Wire, nickel-titanium rotary file, torsional fracture resistance

Significance

The geometric feature and alloy type have influences on the physical characteristics of glide path preparation instruments, and, thus, clinicians may need to choose the appropriate file for each clinical situation.

The introduction of the nickel-titanium (NiTi) rotary instrument has facilitated more effective root canal treatment processes (1, 2). Additionally, even beginners can easily learn how to use NiTi rotary instruments (3). Nevertheless, there is still a possibility of instrument fracture during clinical use (4–8). Instrument separation can occur through 2 mechanisms: cyclic and torsional fatigue. Instruments can fail because of fatigue from repetitive tension/compression cycles when the instrument rotates in a curved canal. Torsional stress can be induced when the instrument rotates while binding within the canal (5, 6).

To reduce the fracture risk of NiTi instruments, a glide path during initial root canal preparation is necessary (9–11). By securing an open pathway to the canal terminus, the instrument can subsequently work under less torsional stress, and the risk of canal transportation is reduced. Rather than establishing a glide path with a hand instrument, glide path preparation using rotary instruments has more associated benefits, such as less debris extrusion and less time consumption (1, 12, 13). Moreover, NiTi rotary instruments can maintain the original canal anatomy better and make less canal curvature modifications, which result in fewer canal aberrations (13–15).

Various NiTi glide path rotary instruments have been developed with various sizes or metallurgies, such as the PathFile (Dentsply Sirona, Ballaigues, Switzerland), HyFlex GPF (Coltene-Whaledent, Alstetten, Switzerland), ScoutRace (FKG Dentaire SA, La Chaux-de-Fonds, Switzerland), and R-Pilot (VDW, Munich, Germany). More recently, because of the trend of reducing the number of shaping steps (instruments) for an easy and efficient procedure, new single-file systems have been introduced for glide path establishment. The ProGlider (PG, Dentsply Sirona), which is made of M-Wire NiTi alloy, has an ISO #16 diameter at the tip and a progressive taper. The One G (OG; Micro-Mega, Besancon, France), which is made of conventional NiTi, has an ISO #14 diameter at the tip and a 3% constant taper, and the EdgeGlidePath (EG; Edge Endo, Albuquerque, NM) has an ISO #16 diameter at the tip and a progressive taper. According to the manufacturer, the EdgeGlidePath is made of a heat-treated alloy named FireWire (Edge Endo). There have been numerous publications regarding the canal shaping instruments but not enough articles published so far about glide path instruments with different geometries and alloys. The purpose of this study was to compare the cyclic fatigue, torsional resistance, and bending stiffness of 3 brands of single-file glide path preparation NiTi instruments: OG, PG, and EG.

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Materials and Methods

In this study, the cyclic fatigue resistance, torsional resistance, and bending stiffness were compared across the 3 groups of glide path instruments. PG (#16/progressive taper), OG (#14/.03), and EG (#16/progressive taper) were selected because of their different alloys (described previously) and geometric features of a square cross section, an irregular asymmetric cross section, and a triangular cross section, respectively. Before the experiment, every instrument was visually inspected to check for any flaws or deformities under a dental operating microscope (Zeiss Pico; Carl Zeiss MediTec, Dublin, CA) at 10× magnification.

Cyclic Fatigue Resistance

A customized device (AEndoS; DMJ System, Busan, Korea) and an artificial simulated curved canal made of stainless steel were used to evaluate the cyclic fatigue resistance of the instruments (Fig. 1*A–D*). Cyclic fatigue resistance was measured by limiting the instrument's movement of files within the artificial simulated canal. The artificial canal block had a 3-mm radius and a 90° angle of curvature as measured by the Schneider method (16, 17). In each group, 15 instruments were rotated in the artificial canal at a speed of 300 rpm in a dynamic mode (4-mm up-and-down pecking movement–speed 4 mm/s). A chronometer was used to record the time up to the point where breakage occurred as determined by visual and auditory inspection. The number of cycles to failure for each instrument was calculated by multiplying the rotation speed by the time (seconds) until the instrument broke. The length of the broken piece of file was measured with a digital microcaliper (Mitutoyo, Kawasaki, Japan) under a dental operating microscope at 10× magnification.

Torsional Resistance

Fifteen files for each group were used for the torsional resistance test. The apical 3 mm of the file tip was fixed with 2 polycarbonate resin blocks and rotated clockwise at a speed of 2 rpm until broken. We measured ultimate torsional strength (Ncm) and distortion angle (°) until fracture using AEndoS (n = 15). The toughness was calculated using Origin v6.0 Professional software (Microcal Software Inc, Northampton, MA). The toughness of the instrument refers to the area under the plot of the distortion angle (x-axis) and torsional load (y-axis).

Bending Stiffness

The bending stiffness was measured according to the American National Standard/American Dental Association specification no. 28 and ISO specification 3630-1:2008. Using AEndoS and a specialized jig, 15 files for each group were fixed at the apical 3 mm of the file tip and were bent 45° along the main axis (n = 15). The bending movement was recorded by the same custom device. The term "residual angle" was defined as the angle between the bent file and the first position where the bent file did not return to the starting position.

Scanning Electron Microscopic Analysis

After cyclic fatigue and torsional resistance testing, the broken instruments were examined under a scanning electron microscope

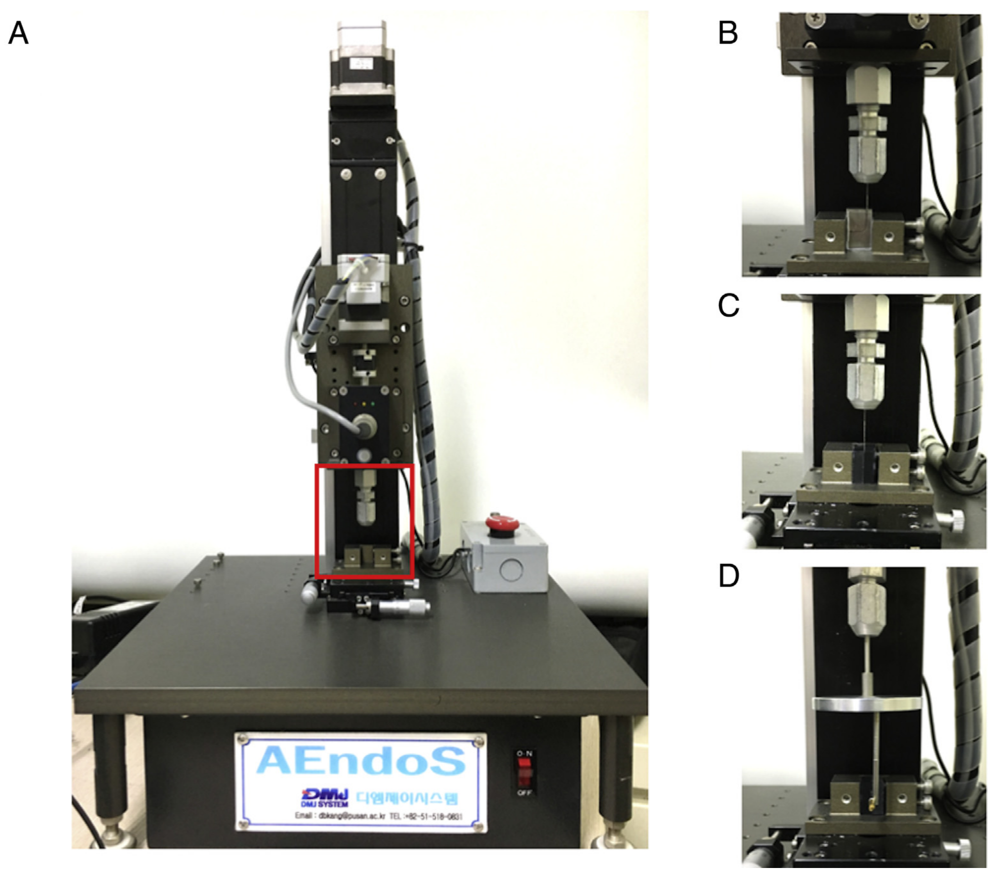

Figure 1. The devices used in this study. (*A*) The custom device used for the test (AEndoS), (*B*) a jig and simulated canal used for the cyclic fatigue test, (*C*) a jig and polycarbonate resin blocks used for the torsional resistance test, and (*D*) a jig and loading part used for the bending stiffness test.

TABLE 1. Cyclic Fatigue Resistance, Torsional Resistance, and Bending Stiffness of Tested Single-file Glide Path Preparation Nickel-titanium Instruments (Mean $\pm$ Standard Deviation)

System	Cyclic fatigue resistance		Torsional resistance			Bending stiffness	
	NCF	Fragment length (mm)	Maximum torsional strength (Ncm)	Distortion angle (°)	Toughness (Ncm°)	Residual angle (°)	Bending stiffness (Ncm)
ProGlider	$3568 \pm 282^{\dagger}$	2.82 ± 0.17	$0.16 \pm 0.01^{\dagger}$	$317 \pm 26^{\ddagger}$	$47 \pm 6^{\ddagger}$	$4.70 \pm 1.00^{\dagger}$	$0.10 \pm 0.02^{\dagger}$
One G	$1529 \pm 192^{\ddagger}$	2.21 ± 0.42	$0.21 \pm 0.02^{*}$	$760 \pm 75^{*}$	$130 \pm 26^{*}$	$5.41 \pm 0.96^{\dagger}$	$0.17 \pm 0.04^{*}$
EdgeGlide	$5079 \pm 714^{*}$	2.33 ± 0.99	$0.17 \pm 0.03^{\dagger}$	$581 \pm 127^{\dagger}$	$85 \pm 19^{\dagger}$	$8.96 \pm 1.31^{*}$	$0.09 \pm 0.02^{\dagger}$

*,†,‡ Different superscripts indicate significant differences between groups ($P < .05$).

(S-4800 II; Hitachi High Technologies, Pleasanton, CA) to assess the features of the broken surfaces.

Statistical Analysis

The data were statistically analyzed using 1-way analysis of variance and the Tukey post hoc comparison test for differences among groups at a significance level of 95% using SPSS software (Version 19.0; IBM Corp, Armonk, NY).

Results

The mean and standard deviations of the cyclic fatigue resistance, torsional strength, and bending stiffness of each instrument group are presented in Table 1. The cyclic fatigue resistances were significantly different among all groups ($P < .05$). EG showed the highest cyclic fatigue resistance followed by PG, and OG showed the least resistance ($P < .05$). OG showed a higher maximum torsional strength than PG and EG; OG showed the largest distortion angle followed by EG, and PG showed the smallest angle ($P < .05$). Among these instruments, OG showed the highest toughness, followed by EG, and PG showed the lowest toughness ($P < .05$). OG had a greater bending stiffness than the other instruments, whereas EG showed a larger residual angle than the others ($P < .05$).

The SEM topographic examinations showed typical appearances of two failure modes from cyclic fatigue fractures (Fig. 2) and torsional fractures (Fig. 3). Specimens from the cyclic fatigue tests showed overload fast fracture zone with numerous ductile dimples for all brands (Fig. 2). Specimens from the torsional resistance tests had typical appearances including circular abrasion marks and skewed dimples near the center of rotation on cross-sectional views (Fig. 3).

Discussion

Since the concept of a glide path was introduced into endodontics in the early 2000s, its importance has been emphasized to reduce the fracture of NiTi shaping instruments (13–15). In particular, the use of the glide path file has been reported to aid in the safe use of noncutting and/or passive tip NiTi files (13–15). A smooth pathway from the canal orifice to the apical foramen is essential for achieving better endodontic treatment outcomes (9, 14, 15). The creation of a glide path using NiTi rotary files has been reported to extrude lower amounts of debris and show better clinical efficiency than the use of manual stainless steel files (12, 13). Although multisequence instrument systems use 2 or 3 files, the instruments used in this study establish the glide path using only 1, making them highly effective and convenient (18–20).

The typical minimum glide path size is #15 (between #10 and #20) for a proper glide path to ensure safe introduction of the shaping instrument (9, 13–15). Therefore, in the present study, 3 single-file glide path NiTi rotary instruments with apical tip sizes ranging from #14 (OG) to #16 (PG and EG) were investigated for the following mechanical properties: cyclic fatigue resistance, torsional resistance, and bending stiffness. Previous studies have shown that the cross-sectional shape of the file, pitch length, taper, and type of alloy can affect the physical properties of the file (5, 11, 16, 21–25). Generally, more flexible wires are easier to bend and have lower bending stiffness (21–24).

In the present study, it was found that EG had significantly higher cyclic fatigue resistance than PG, whereas there were no significant bending stiffness differences between the 2 file systems. The difference in cyclic fatigue resistance between the 2 files with similar flexibility was because of the different cross-sectional shapes of the 2 files and the different alloy properties (7, 17, 21). Although the square cross section of PG may have the largest cross-sectional area and thus lower cyclic fatigue resistance than others with triangular and asymmetric triangular cross sections (25), the reason why PG and EG had higher fatigue resistance than OG would be that these were made of M-Wire and FireWire instead of conventional NiTi alloy (16, 24, 26–28).

Under the conditions of this study, OG showed the lowest cyclic fatigue resistance. This may be related to the nature of the OG alloy made of conventional NiTi, which is less flexible than that of M-Wire or heat-treated wire. Pereira et al (29) evaluated the mechanical properties of M-Wire compared with conventional NiTi by a rotating-bending fatigue test. They confirmed that M-Wire is more flexible and fatigue resistant than conventional NiTi wire. It can be assumed that the highest cyclic fatigue resistance of EG results from its better flexibility because of heat treatment. EG is made of FireWire, which is a novel heat-treated NiTi wire. Heat treatment affects the phase transformation behavior of the NiTi instrument and its mechanical properties through improving the instrument's flexibility. A flexible file is effective for the preparation of curved canals and maintaining the original curvature of the root canal.

From the bending stiffness test results, EG had the largest residual angle followed by OG and PG, which did not significantly differ from each other. Heat-treated files present reduced superelasticity, which results in lower resilience. Hence, heat-treated files can retain their modified form and tend to present large residual angles (24, 26–28, 30). These files are known to be beneficial in maintaining the center of the root canal (14). In accordance with the results of the present study, OG and PG have a similar degree of superelasticity.

Generally, more flexible wires tend to have stronger cyclic resistance but weaker torsional resistance (5). Kwak et al (11) reported that glide path files have sufficient flexibility and fatigue fracture resistance because of their small size; therefore, it is important to have high torsional resistance. In this context, OG showed the highest torsional strength followed by PG and EG. The differences of structural and geometric features could affect instrument torsional resistance. The cross-sectional dimension, structural features, and nature of the alloy have definitive influences on the mechanical properties of NiTi instruments. Baek et al (25) reported that the torsional resistance of NiTi rotary files might be reduced by increasing the number of thread and cross-sectional areas rather than by increasing the central core area.

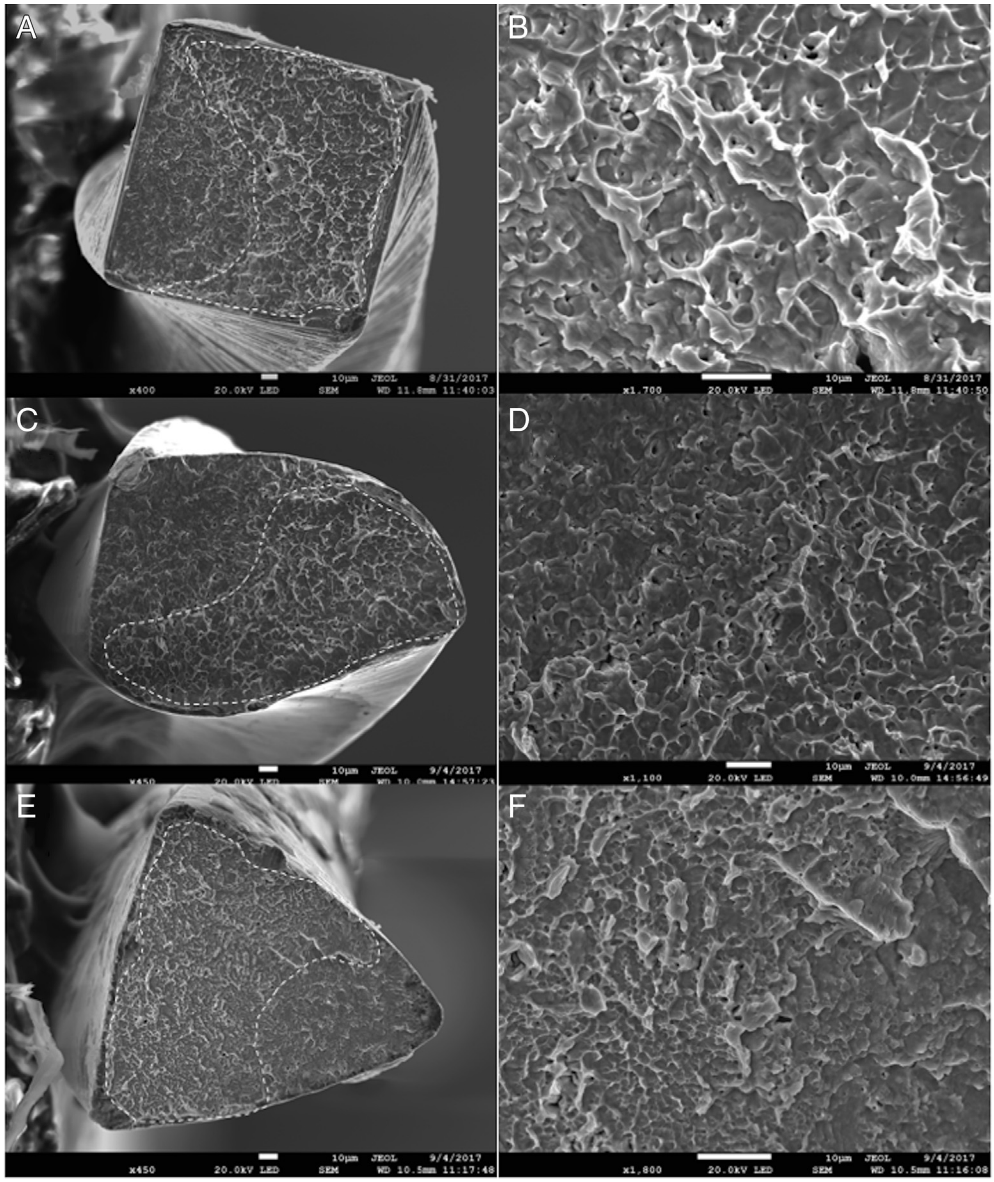

Figure 2. Representative scanning electron microscopic images (cross-sectional aspects) of the fractured surfaces of the separated instruments after the cyclic fatigue tests. The *dimpled area outlined with the dotted line* indicates an overload fast fracture zone ([*A*] PG, [*C*] OG, and [*E*] EG). The magnified view shows an overload fast fracture zone with numerous ductile dimples (*B*, *D*, and *F* are the magnified views from *A*, *C*, and *E*, respectively).

Toughness is defined as the ability of a material to absorb energy while plastically deforming, before fracture (5). This term represents the strength and ductility of a material and the amount of area under the stress-strain curve. Toughness, maximum torsional strength, and distortion angle at the break can affect the durability and fracture resistance of an instrument. The maximum torsional strength and distortion angle do not invariably connect to the durability of the NiTi file. In the present study, the ranking of instruments according to maximum torsional strength showed similar trends to the rankings by toughness and distortion angle. However, although PG and EG were similar in torsional strength, EG had a significantly higher toughness than PG. This suggests that as torsional stress is applied, EG experiences plastic deformation and requires more energy to fracture. Yum et al (5) reported that the ultimate strength may be associated with geometric characteristics but is not always proportional to toughness. Therefore, it is important to compare the toughness of NiTi files to improve our understanding of the torsional resistance of NiTi rotary instruments.

Even though NiTi rotary instruments have brought considerable progress to endodontic treatment, they still have a risk of fracture because of various causes (4, 6, 8). The mechanical behavior of NiTi instruments is affected by canal anatomy and intrinsic factors of the instruments, such as cross-sectional dimension, size, taper, and alloy composition (6, 11, 21–26). Two modes of failure are primarily investigated by researchers: torsional failure and cyclic fatigue, which can occur simultaneously in clinical situations (6, 17, 21). Although breakage caused by cyclic fatigue can occur unexpectedly, clinicians may reduce the risk of instrument separation by limiting the number of uses (4, 7). Considering the situations in which glide path instruments are used, it is important to understand the features that may affect the mechanical properties of the instruments. Because of

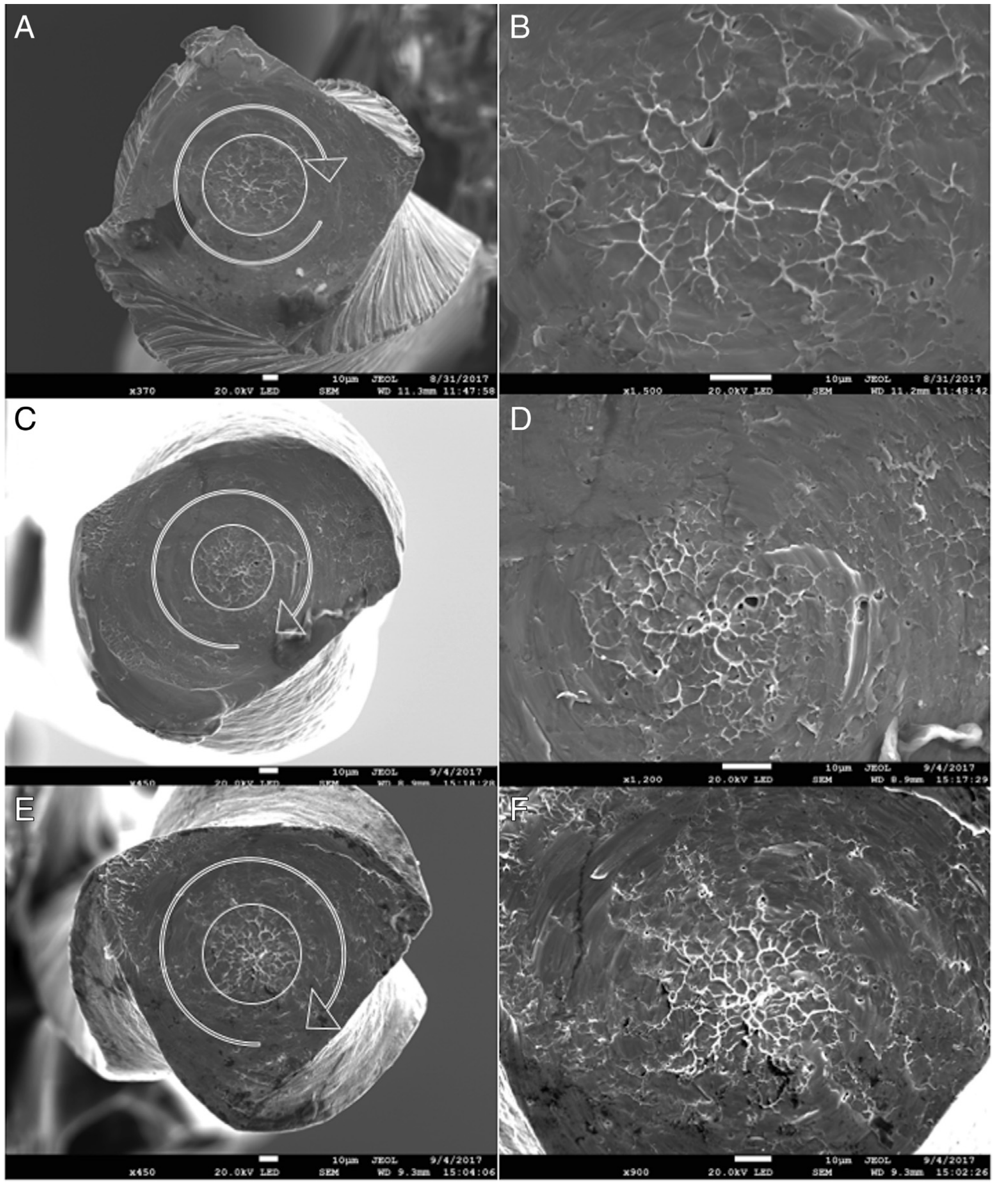

Figure 3. Representative scanning electron microscopic images (cross-sectional aspects) of the fractured surfaces of the separated instruments after the torsional resistance tests. The *circle arrows* indicate the circular abrasion marks, and the *full circles* indicate skewed dimples near the center of rotation ([*A*] PG, [*C*] OG, and [*E*] EG). The magnified views in the right column show numerous ductile dimples (*B*, *D*, and *F* are the magnified views from *A*, *C*, and *E*, respectively).

their use in the initial stages of root canal preparations, most glide path files have a small taper and small cross-sectional dimension; therefore, they are vulnerable to torsional stress. Moreover, when applied to the glide path preparation on untouched dentin surfaces, NiTi rotary instruments are likely to be exposed to greater frictional forces and torsional stresses, even in a straight coronal root canal area. Therefore, it would be better to choose instruments with stronger torsional resistance than ones with stronger cyclic resistance. Continuous torsional stress induces plastic deformation of the instrument, which results in unwinding before breakage. Thus, clinicians should precisely check the instruments before use to avoid instrument separation.

With respect to the limitations of this study, heat-treated NiTi glide path instruments showed higher cyclic fatigue resistance and lower torsional strength than conventional NiTi instruments. To prevent fracture of the engine-driven NiTi shaping instruments and to effectively shape a root canal, it is necessary to understand the physical property changes of files in association with different alloys and geometric features and then select the proper file according to the clinical situation.

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

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