# Evaluation of the Cyclic Fatigue and Torsional Resistance of Novel Nickel-Titanium Rotary Files with Various Alloy Properties

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## Abstract

**Introduction:** The purpose of this study was to evaluate the cyclic fatigue and torsional resistance of Hyflex EDM, ProTaper Gold (PTG), and ProTaper Universal (PTU) instruments. **Methods:** For the cyclic fatigue test, 10 instruments from each group were tested by using a stainless steel block with 1.5-mm diameter and 3-mm radius of 60° angle of curvature. The instruments were allowed to rotate by using a low-torque motor, and number of cycles from the beginning to the fracture was recorded. Torsional resistance of the instruments (n = 10) was evaluated according to ISO 3630-1. The rotational speed of the instruments was set in the clockwise direction at 2 rpm. The maximum torque and angular deflection until fracture of the instrument were recorded. The data were analyzed by using one-way analysis of variance followed by post hoc Tukey test ($P$ = .05). **Results:** HyFlex EDM instruments exhibited the highest cyclic fatigue resistance and were followed by PTG and PTU groups, respectively. The mean fragment length for PTU instruments was significantly shorter than that for Hyflex EDM and PTG instruments. PTG instruments demonstrated significantly higher torsional resistance than HyFlex EDM files ($P$ = .025), and the distortion angle of the instruments ranged as follows: PTU < PTG < Hyflex EDM files. **Conclusions:** Hyflex EDM files demonstrated significantly higher cyclic fatigue resistance. Although PTG and PTU have similar cross-sectional design, PTG instruments presented higher cyclic fatigue and torsional resistance than PTU instruments. The enhanced alloy properties of PTG might be considered as the main reason for those differences. *(J Endod 2016;42:1840–1843)*



## Key Words

Cyclic fatigue, electrical discharge machining, Hyflex EDM, torsional resistance


### Significance

Hyflex EDM files could be used more safely in severely curved canals because of their higher flexural fatigue, and PG instruments, which exhibited highest torsional resistance, could be more reliable in the treatment of the calcified and narrow root canals.

Instrument fracture is an unpredictable and troublesome complication for clinicians. Removal of a separated instrument from the root canal is a challenging and time-consuming procedure, and in some cases, attempts for removing the fractured part may be unsuccessful (1). To prevent this procedural complication, investigations are focused on innovative manufacturing processes for increasing the flexibility and the resistance of endodontic instruments. Improvement of the cross-sectional design, thermal treatment protocols, electropolishing, and electro-discharge machining (EDM) are some of the preferred methods (2).

HyFlex EDM files (Coltene/Whaledent, Altstätten, Switzerland) are novel nickel-titanium (NiTi) rotary instruments manufactured from the controlled memory (CM) wire by using EDM technology, which allows well-controlled and non-contact shaping of the files and could improve their mechanical properties (3). HyFlex EDM One files with a tip size of 25 demonstrated 0.08 constant taper in the apical 4 mm of the instruments, and the taper of the instruments decreases progressively up to 0.04 in the coronal region. In addition, the cross-sectional design of these files is rectangular in the apical part and transforms to 2 different trapezoidal forms in the middle and coronal portions (4, 5).

ProTaper Gold instruments (PTG) (Dentsply Tulsa Dental Specialties, Tulsa, OK) are newly introduced endodontic instruments that are designed similarly to ProTaper Universal instruments (PTU) (Dentsply Tulsa Dental Specialties). The manufacturer claimed that these instruments presented enhanced mechanical properties because of their innovative metallurgy, which had 2-stage specific transformation behavior and high $A_f$ temperatures (6). PTU and PTG instruments demonstrate convex triangular cross section and have a continuously changing helical angle. The instruments divided into 2 categories, shaping (Sx, S1, S2) and finishing files (F1, F2, F3, F4, F5). Although shaping instruments demonstrate progressively tapered design, finishing instruments have fixed tapers between D1 and D3, and their tapers decrease progressively from D4 to D14 (7).

In clinical practice, instrument fractures occur in a dynamic mechanism and may result from flexural and torsional stresses. Even though these factors should be taken into consideration to prevent unexpected instrument fractures, there are limited number of studies about the cyclic fatigue and torsional resistance of Hyflex EDM (3, 4) and

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PTG instruments (6, 8, 9), and there is no comparative evaluation of the cyclic fatigue and torsional resistance of Hyflex EDM and PTG instruments. Therefore, the aim of the present study was to comparatively evaluate the cyclic fatigue and torsional resistance of Hyflex EDM, PTG, and PTU rotary instruments.

## Materials and Methods

In the first part of the study, instruments with similar sizes (25/.08) from 3 different NiTi rotary systems (Hyflex EDM [25/.08], PTG [F2], and PTU [F2]) were selected for the cyclic fatigue resistance test (n = 10). A simulated canal was prepared in a stainless steel block with 1.5-mm diameter, 60° angle of curvature, and curvature radius of 3 mm, similarly to that described by Larsen et al (10). The working length was set at 19 mm, and synthetic oil (WD-40 Company, Milton Keynes, England) was used for lubrication as recommended by Nguyen et al (11) to minimize the friction between the tested instrument and the simulated canal wall. The stainless steel block was covered by using a glass plate, which allows observing the instruments safely and accurately during the testing period. The instruments were allowed to rotate in air at a temperature of 23°C by using an endodontic motor (VDW Silver; VDW, Munich, Germany) according to the manufacturers' instructions (PTG and PTU at 300 rpm and Hyflex EDM instruments at 500 rpm). The time until occurrence of fracture was recorded in seconds, and the number of cycles to fracture (NCF) was calculated.

In the second part of the study, torsional resistance of the endodontic instruments from Hyflex EDM, PTG, and PTU groups (n = 10) was evaluated according to ISO 3630-1 (12). After attaching the instrument by using a chuck from the shaft to the torsion test device (Sabri Dental Enterprises, Inc, Downers Grove, IL), apical 3 mm of the instrument was fastened by using an opposing chuck. The rotational speed of the instruments was set in the clockwise direction at 2 rpm, and then the maximum torque and angular deflection until fracture of the instrument were recorded.

The data were analyzed by using one-way analysis of variance followed by post hoc Tukey test (SPSS for Windows 11.0; SPSS Inc, Chicago, IL) at 95% confidence level.

## Results

The results for cyclic fatigue and the torsional resistance for each group are presented in Table 1. HyFlex EDM instruments demonstrated the highest cyclic fatigue resistance, followed by PTG and PTU groups, respectively ($P < .001$). The mean of the fragment length for PTU instruments was significantly shorter than that for Hyflex EDM and PTG instruments ($P < .05$). Hyflex EDM files demonstrated longest fragment length.

Maximum torque values for the instruments in the torsional resistance test indicated that PTG instruments demonstrated significantly higher torsional resistance than HyFlex EDM files ($P = .025$). For other comparisons regarding the torsional resistance, there was no statistically significant difference among the tested groups ($P > .05$). In addition, distortion angles of the instruments ranged in increasing order as follows: PTU < PTG < Hyflex EDM files ($P < .001$).

## Discussion

During root canal preparation, preferring the instruments with higher fracture resistance would help to decrease the incidence of instrument failures; therefore, recent studies have been focused on testing the fracture resistance of the endodontic files and understanding the reasons for failures. In the literature, cyclic fatigue resistance of the endodontic instruments was evaluated by using various study designs (13, 14). Using a curved metal tube or a grooved block, rotating the instruments against an inclined plane, and 3-point bending are frequently used previous methods (13). Using an artificial simulated canal in a stainless steel block was preferred for cyclic fatigue analysis of the present study. The inner diameter of the simulated canal was set to 1.5 mm to provide free rotation of the instruments with minimal torque values. This testing method is reliable and could provide standardized conditions for each tested instrument (10, 15, 16). In addition, stainless steel blocks could contain artificial canals in various designs, allowing testing the instruments under different conditions (16).

During the cyclic fatigue testing procedure, friction between the instrument and the walls of the simulated canals and the internal friction of the materials could cause heat generation (17), and elevation of the local temperature may affect the cyclic fatigue resistance of the NiTi rotary instruments (18, 19); therefore, using a lubricant or coolant during the testing period was recommended to control the local temperature (18). Nguyen et al (11) reported that temperature elevation did not exceed 3°C when the instruments were tested in a simulated canal at 300 and 500 rpm under oil lubrication. Considering the findings of Nguyen et al, in the present study we used synthetic oil for preventing the elevation of the temperature.

In the previous studies the effect of the alloy properties on cyclic fatigue resistance was evaluated for different endodontic files (6, 8, 20), and the importance of the alloy properties was underlined. In agreement with the previous studies, PTG instruments presented significantly higher cyclic fatigue resistance than PTU instruments. It might be speculated that alloy properties of the PTG and PTU instruments were the main factor for the different mechanical performance of the instruments because both instruments have similar cross-sectional design.

Previously, Pirani et al (3) evaluated the cyclic fatigue resistance and the microstructural features of Hyflex EDM instruments. According to their observations, HyFlex EDM files presented low degradation after multiple canal preparation, and 40.04 HyFlex EDM files demonstrated approximately 8 times higher cyclic fatigue resistance than 40.04 HyFlex CM files (3). In the present study, similarly HyFlex EDM files showed higher NCF values compared with the other tested instruments.

It was previously reported that the size of the instruments affects the cyclic fatigue resistance of the rotary instruments, and it was recommended to test the instruments with similar diameters to compare the

**TABLE 1.** Results of Cyclic Fatigue and Torsional Resistance Test (Mean ± Standard Deviation)

| | | Cyclic fatigue resistance | | Torsional resistance | |
|---|---|---|---|---|---|
| Groups | N | Fragment length (mm) | NCF | Torque (gf/cm) | Distortion angle (°) |
| HyFlex EDM | 10 | $7.1^a \pm 1.8$ | $3689^a \pm 1577$ | $133^a \pm 10$ | $334^a \pm 31$ |
| ProTaper Universal | 10 | $4.9^b \pm 0.1$ | $350^b \pm 30$ | $137^{ab} \pm 24$ | $177^b \pm 18$ |
| ProTaper Gold | 10 | $5.9^a \pm 0.9$ | $915^c \pm 136$ | $153^b \pm 11$ | $217^c \pm 11$ |
| Analysis of variance $P$ value | | <.05 | <.001 | .024 | <.001 |

Same superscript letters within 1 column indicate statistically similar values ($P > .05$).

effects of the design and manufacturing properties of the novel instruments more accurately (15, 21). In the present study, instruments in all groups have a tip diameter equivalent to size 0.25 mm and 0.08 constant taper between D1 and D4, and they presented decreasing tapers more coronally than D4; however, Hyflex EDM instruments demonstrated different decreasing percentages compared with PTG and PTU instruments (4, 5, 7).

Standardized cyclic fatigue testing setup could generate similar stress points on the instruments, and the lengths of the fractured segment might be similar (22); however, different bending moments depending on the alloy properties and cross-sectional design of the instruments could change the location of the maximum stress points, and different fragment lengths might be observed for different types of instruments (15, 23, 24). In the present study the mean fragment length of the PTU instruments was observed to be shorter than that of other tested instruments. It might be due to different bending moments of the tested instruments.

In the present study, torsional tests were performed according to the ISO Standard 3630-1 similar to previous studies (4, 25). After fastening the apical 3 mm and the shaft of the instruments, rotational speed was set at 2 rpm. The torque was applied in a clockwise direction because all instruments tested in the present study were designed to be used in clockwise direction. Using a standardized and frequently used method gives the opportunity for comparison of the mechanical properties of the instruments that were used in the present and previous studies.

In a previous study, Campbell et al (26) compared cyclic fatigue and torsional resistance of 2 types of Typhoon instruments (TYP; Clinician's Choice Dental Products, New Milford, CT), which were manufactured by using CM NiTi wire or conventional NiTi, and they reported approximately 7 times higher cyclic fatigue resistance for TYP CM files compared with TYP files; however, they did not find any significant difference between the torsional resistance of both instruments. Similarly, Pereira et al (27) reported higher flexibility for TYP CM files compared with PTU, ProFile Vortex (Dentsply Tulsa Dental Specialties), and Vortex Blue (Dentsply Tulsa Dental Specialties) instruments; however, ProFile Vortex group demonstrated highest torsional resistance, followed by Vortex Blue, TYP, and PTU. The findings of our study were in agreement with those of previous reports (26, 27). Hyflex EDM files demonstrated significantly lower torsional resistance than PTG instruments, despite their superior flexibility compared with other tested instruments. This could be due to the microstructure and mechanical behavior of NiTi materials because NiTi instruments were deformed until the complete transformation to martensite phase, after that failure occurred at the ultimate tensile strength of this phase (27, 28).

Although commonly used study designs for cyclic fatigue and torsional resistance evaluation could not reflect identical clinical conditions, the findings of the *in vitro* studies could give clinicians important information during the endodontic treatment protocols. Previous studies (4, 27) stated that instruments with higher torsional resistance are suggested for constricted and calcified root canals, and instruments with greater flexibility are considered more suitable for root canals with severe curvature. In addition, higher angular deflection of the instruments before the fracture could be another advantage for the clinicians because plastic deformation of the instrument could previse clinicians for discarding the instruments before an imminent failure (29). On the basis of above-mentioned information and within the limitations of this study, it could be considered that Hyflex EDM files could be used more safely in severely curved canals because of their higher flexural fatigue, and PG instruments, which exhibited highest torsional resistance, could be more reliable in the treatment of calcified and narrow root canals.

## Conclusion

Hyflex EDM files demonstrated significantly higher cyclic fatigue resistance among the tested groups. Although PTG and PTU have similar cross-sectional design, PTG instruments presented higher cyclic fatigue and torsional resistance than PTU instruments. The enhanced alloy properties of PTG might be considered as the main reason for these differences.

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