

## Research Article



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No potential conflict of interest relevant to this  
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# In vitro comparison of the cyclic fatigue resistance of HyFlex EDM, One G, and ProGlider nickel titanium glide path instruments in single and double curvature canals

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## ABSTRACT

**Objectives:** It was aimed to compare the cyclic fatigue resistances of ProGlider (PG), One G (OG), and HyFlex EDM (HEDM) nickel titanium glide path files in single- and double-curved artificial canals.

**Materials and Methods:** 40 PG (16/0.02), 40 OG (14/0.03), and 40 HEDM (10/0.05) single-file glide path files were used in the present study. Sixty files were subjected to cyclic fatigue test by using double-curved canals and 60 files by using single-curved canal ( $n = 20$ ). The number of cycles to fracture (NCF) was calculated and the length of the fractured fragment (FL) was determined by a digital micro-caliper. Twelve pieces of fractured files were examined with scanning electron microscope to determine fracture types of the files ( $n = 2$ ). The NCF and the FL data were analyzed using one-way analysis of variance and *post hoc* Tukey test using SPSS 21 software ( $p < 0.05$ ).

**Results:** In all of the groups, NCF values were significantly lower in double-curved canals when compared to single-curved canals ( $p < 0.05$ ). For both of single- and double-curved canals, NCF values of HEDM group in apical and coronal curvatures were found to be significantly higher than NCF values of PG and OG groups ( $p < 0.05$ ). In both of single- and double-curved canals, NCF value of PG group was found significantly higher than OG group ( $p < 0.05$ ).

**Conclusions:** Within the limitations of this study, HEDM glide path files were found to have the highest cyclic fatigue resistance in both of single- and double-curved canals.

**Keywords:** Cyclic fatigue; Double curvature; HyFlex EDM; One G; ProGlider

## INTRODUCTION


A new era has begun in endodontics with the development of nickel titanium (NiTi) files in 1980s [1]. The mechanical features of NiTi files grant the flexibility to the files, and provide convenience in preparation of curved canals [2]. Despite this advantage and all the conveniences that NiTi files offer, the most important disadvantage is that they can unexpectedly fracture. These fractures occur as a result of torsional or cyclic fatigue [3]. The

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cyclic fatigue fractures occur as a result of the repetitive compression and tension stresses that the file is exposed to within the curved canals. On the other hand, the torsional fractures occur as a result of the continuance of rotation of coronal part of the file, while the tip or a part of file is stuck in the canal [3,4].

The concept of glide path, which is defined as the space from the orifice to the apex, is of significant importance for safely shaping the root canals [5,6]. Together with the advances in manufacturing methods and metallurgy, many NiTi rotary glide path files were introduced to the market to facilitate the formation of glide path. ProGlider (PG; Dentsply Maillefer, Ballaigues, Switzerland) and One G (OG; Micro-Mega, Besancon, France) are the single file systems developed for the glide path. PG is made of M-Wire alloy that has been developed via the special thermal methods in order to improve cyclic fatigue resistance and flexibility of NiTi alloys [7]. Moreover, different from other glide path files, PG has 0.16 mm of tip diameter, taper varying between 2%–8% through the shaft, and 4 cutting edges with square cross-section [8]. OG has 0.14 mm of tip diameter and 3% taper that is constant throughout the shaft. The file has 3 cutting edges with asymmetric cross-section. The manufacturer claims that the cutting edges having different radii provide better debris elimination [9].

Recently introduced HyFlex EDM (HEDM; Coltene/Whaledent AG, Altstätten, Switzerland) NiTi files are manufactured using the technique of electrical discharge machining (EDM) with controlled-memory feature. When compared to HyFlex CM (Coltene/Whaledent AG) file, the manufacturer claims that this method offer up to 700% higher cyclic fatigue resistance [10]. HEDM glide path file has 0.10 mm diameter and 5% taper throughout the shaft. The file has 3 different cross-sections along the shaft; quadratic in apical, trapezoidal in middle and triangular in coronal.

In comprehensive literature review, no study examining the cyclic fatigue resistances of PG, OG, and HEDM glide path files in double-curved (S-shaped) artificial canals was found. For this reason, the objective of present study was to compare the cyclic fatigue resistances of PG, OG, and HEDM NiTi glide path files in single- and double-curved artificial canals in static cyclic fatigue testing model. The null hypothesis was that there would be no statistical difference between the files' cyclic fatigue resistance under static model in single- and double-curved canals.

## MATERIALS AND METHODS

Forty PG (16/0.02), 40 OG (14/0.03), and 40 HEDM (10/0.05) single-file glide path files were included in the present study. Sixty files ( $n = 20$ /each group) were subjected to cyclic fatigue testing by using double-curved artificial canal. The double-curved artificial canals' first coronal curve has 60° angle of curvature with 5 mm radius and the center of the curvature was located 8 mm distant from the tip of the canal, while the second apical curve has 70° angle of curvature with a radius of 2 mm and the center of the curvature located 2 mm distant from the tip of the canal as in previous studies [11-13]. The working length of the artificial canal was 18 mm and its inner diameter was 1.5 mm (**Figure 1**).

Sixty files ( $n = 20$ /each group) were subjected to cyclic fatigue testing by using single-curved artificial canal. The single-curved artificial canal has 60° angle of curvature with 5 mm radius,



**Figure 1.** Artificial canal with double curvature that used in the present study.

1.5 mm inner diameter and the center of the curvature was located 5 mm distant from the tip of the canal. The working length of artificial canal was 17 mm (**Figure 2**).

All the instruments were operated using a torque-controlled endodontic motor (VDW Gold, VDW, Munich, Germany) and were used according to the manufacturers' recommendations as follows: PG at 300 revolutions per minute (rpm) and 200 gcm<sup>-1</sup> torque, HEDM at 300 rpm and 1.8 gcm<sup>-1</sup> torque, and OG at 300 rpm and 1.2 gcm<sup>-1</sup> torque. In order to minimize the friction between the files and the artificial canals, the synthetic lubricant (WD Company, Milton Keynes, UK) was used. The number of cycles to fracture (NCF) for each file was calculated with formula:

$$\text{NCF} = \text{rpm} \times \text{Time to fracture (seconds)} / 60$$

The fracture length (FL) of the apical part was calculated by measuring the fractured tip directly. However, the FL of the coronal fragment was calculated by subtraction the remaining length of the file from the total length. In the measurement, a digital micro-caliper was used using ImageJ software (National Institutes of Health, Bethesda, MD, USA).



**Figure 2.** Artificial canal with single curvature that used in the present study.

A total of 12 pieces of fractured files, 2 pieces from each group, was examined with a scanning electron microscope (SEM; JSM-7001F, JEOL, Tokyo, Japan) to determine fracture types of the files, and photomicrographs were taken from the fractured surfaces under different magnifications. From the SEM images, the cross-sectional areas of the fractured surfaces were calculated.

### Statistical analyses

The NCF and the FL data were analyzed by using one-way analysis of variance (ANOVA) and *post hoc* Tukey tests. The apical and coronal comparison was performed using Student's *t*-test. All of the analyses were performed using SPSS 21 software (IBM-SPSS Inc., Chicago, IL, USA), and the statistical significance level was set at 5%.

## RESULTS

The mean NCF and FL values and standard deviations of the files are presented in **Table 1**. In double-curved canals, all of the files fractured firstly in apical curvature and then in coronal curvature. In double-curved canals, the apical curvature NCF values of all of the groups were significantly lower than coronal curvature NCF values ( $p < 0.05$ ). For both of single- and double-curved canals, NCF value of HEDM group was significantly higher than NCF values of PG and OG groups ( $p < 0.05$ ). Moreover, in both of single- and double-curved canals, NCF value of PG group was significantly higher than in OG group ( $p < 0.05$ ).

The mean FL was also recorded to evaluate the correct positioning of the tested instrument inside the canal curvature and whether similar stresses were being induced. No statistically significant difference in the mean FL was evident for the instruments (**Table 1**).

SEM analysis of the fractured cross-sectional surfaces revealed typical features of cyclic failure including crack origins, fatigue zone, and an overload fast fracture zone (**Figure 3**). The areas of the fracture surface of the files were 0.11653 mm<sup>2</sup> in HEDM group, 0.40172 mm<sup>2</sup> in OG group, and 0.48452 mm<sup>2</sup> in PG group.

## DISCUSSION

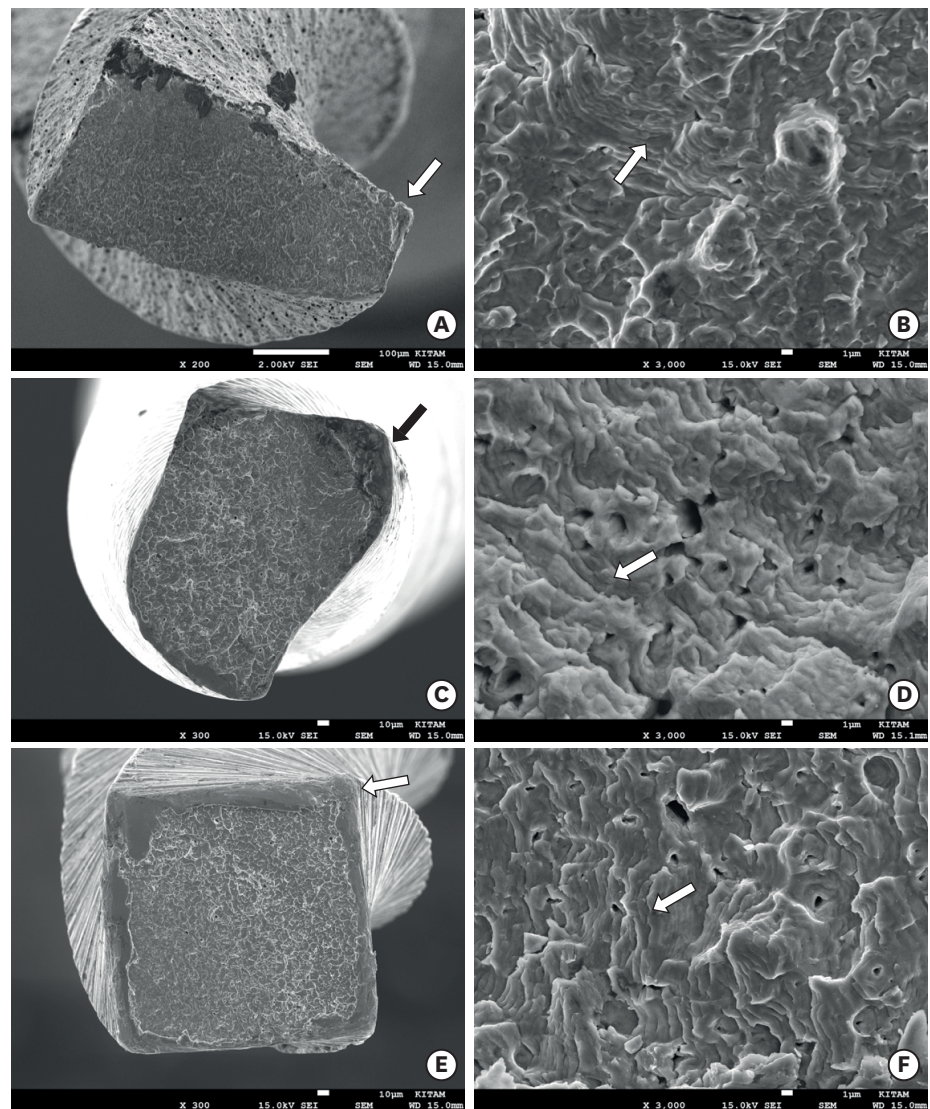
Glide path was shown to be capable of eliminating the complications that are observed during the root canal preparation process [14]. Together with the clinicians' increasing demand on single-file systems in order to make preparation easier, the single-file glide path

**Table 1.** The number of cycles to failure and length (mm) of fractured fragments of instruments during cyclic fatigue testing in double and single curvature

Group	No.	Double curvature				Single curvature	
		Coronal curvature		Apical curvature		NCF	FL
		NCF	FL	NCF	FL		
One G	20	470.21 ± 152.76 <sup>aa</sup>	6.72 ± 1.67 <sup>a</sup>	395.63 ± 139.05 <sup>aa</sup>	2.08 ± 0.34 <sup>a</sup>	846.94 ± 274.96 <sup>a</sup>	5.43 ± 1.39 <sup>a</sup>
ProGlider	20	1,020.28 ± 375.34 <sup>ba</sup>	6.03 ± 1.05 <sup>a</sup>	961.87 ± 293.45 <sup>ba</sup>	2.11 ± 0.56 <sup>a</sup>	1,614.65 ± 601.42 <sup>b</sup>	4.93 ± 1.02 <sup>a</sup>
HyFlex EDM	20	2,458.32 ± 538.65 <sup>ca</sup>	6.68 ± 1.39 <sup>a</sup>	1,966.46 ± 412.43 <sup>cb</sup>	2.24 ± 0.64 <sup>a</sup>	3,441.24 ± 961.84 <sup>c</sup>	5.25 ± 1.22 <sup>a</sup>
<i>p</i> value	-	< 0.05	> 0.05	< 0.05	> 0.05	< 0.05	> 0.05

Manufacturer information is follow as; One G, Micro-Mega, Besancon, France; ProGlider, Dentsply Maillefer, Ballaigues, Switzerland; HyFlex EDM, Coltene/Whaledent AG, Altstätten, Switzerland. Different superscripts indicate statistically significant difference at 0.05 (<sup>a,b,c</sup>for columns; <sup>a,b</sup>for rows). NCF, number of cycles to fracture; FL, length of fracture.





**Figure 3.** Scanning electron microscopic appearances of the One G (OG), ProGlider (PG), and HyFlex EDM (HEDM) files after cyclic fatigue testing. View of the fractured surface (A) HEDM, (C) OG, and (E) PG and high-magnification view of (B) HEDM, (D) OG, and (F) PG instruments showing fatigue striations typical of cyclic fatigue (arrows). One G, Micro-Mega, Besancon, France; ProGlider, Dentsply Maillefer, Ballaigues, Switzerland; HyFlex EDM, Coltene/Whaledent AG, Altstätten, Switzerland.

systems were introduced to the market. PG, OG, and HEDM are the glide path files systems consisting of single file.

Many studies examining the NiTi files cyclic fatigue resistance were carried out on the artificial canals [15,16]. The aim of using artificial canals is to minimize the anatomic variation, which might arise from the natural teeth, and to ensure certain level of standardization. The angle and number of curvatures within the canal are among the most important factors testing the cyclic fatigue resistance of files [15]. Under the clinical conditions, 2 curvatures might exist in the same canal at the same time, and the canals having this geometry are defined as S-shaped canals. Moreover, the S-shaped canals, which are frequently missed out in conventional radiographies, lay the foundation of failures. When compared to single-curved canals, double-curved canals were reported to cause the

decreases in cyclic fatigue resistance of files and the fracture to occur in shorter times [11]. In the literature, few studies on the cyclic fatigue of NiTi files were carried out on the double-curved canals [11,17]. In comprehensive literature review, no study examining the cyclic fatigue resistances of NiTi glide path files, which were tested in present study on double-curved artificial canals, was found. For this reason, it was aimed to compare the cyclic fatigue resistances of glide path files in single- and double-curved artificial canals. According to the results of present study, it was determined that, when used at torque and speed settings recommended by the manufacturers, NCF values of HEDM files in both of single- and double-curved canals' apical and coronal sections were statistically significantly higher than PG and OG files. For this reason, the null hypothesis was rejected.

Some of the factors influencing the cyclic fatigue resistances of NiTi files are the type of alloy [18] that the files are manufactured and the application of heat treatment on the NiTi files [19,20]. According to the results of present study, cyclic fatigue resistance of HEDM glide path files made of controlled memory (CM) alloy with EDM treatment had significantly higher cyclic fatigue resistance than PG made of M-Wire alloy and OG glide path files made of conventional NiTi alloy. Difference among the groups might be related to the manufacturing procedures that the files made. Conventional NiTi alloys are in the austenite phase at mouth and room temperatures. At room temperature, the CM alloys exist in both austenite and martensite phases because the martensite is softer than austenite, and the higher martensite content of files made of CM alloy has a positive effect on their cyclic fatigue resistance [21]. Capar *et al.* [22] compared the cyclic fatigue resistances of PathFile (Dentsply Maillefer), G-File (Micro-Mega), Scout Race (FKG Dentaire, La Chaux-de-Fonds, Switzerland), HyFlex GPF (Coltene/Whaledent AG), and PG glide path files. The authors reported that the highest cyclic fatigue resistance was found in HyFlex GPF group, and the authors attributed the difference to the difference between manufacturing methods and to the structural superiority of CM alloy. The previous studies on CM alloys corroborate this conclusion [23-26]. Moreover, similarly to the results of present study, Uslu *et al.* [27] reported the cyclic fatigue resistance of PG files to be higher than OG files. In a similar study, it was reported that the cyclic fatigue of NiTi files made of M-Wire alloy was 400% higher than the files made of conventional NiTi alloy [28].

The results of present study indicated that the duration and NCF decreased together with the increase in the amount and complexity of curvatures within the canal. The present results show similarities with the previous studies examining the effects of canal complexity on the file fractures [15,16]. Moreover, Al-Sudani *et al.* [11], Shen *et al.* [29], and Topçuoğlu *et al.* [17] corroborated this conclusion in their studies on double-curved canals.

Considering all the files employed in present study, the data obtained indicate that, in double-curved canals, the cyclic fatigue resistance of files in apical curvature is lower than the resistance in coronal curvature. We believe that this originates from the higher angle of apical curvature (70°) in proportion to the angle of coronal curvature (60°) and much lower radii of apical curvature (2 mm) in proportion to the radii of coronal curvature (5 mm). Regardless of the differences between the files used in present study, it can be stated that the anatomies of double-curved canals may cause lower NCF of files by leading to higher level of stress accumulation than in single-curved canals.

It is difficult to make comparison among different brands because of the differences between their designs, cross-sectional areas, and types of alloy used. Moreover, in clinic

use, different irrigation solutions and usage forces may affect the cyclic fatigue resistance of the tested files. Thus the results of the present study should be applied to clinic carefully.

## CONCLUSIONS

Within the limitations of present study, HEDM glide path files were found to have the highest cyclic fatigue resistance in both of single- and double-curved canals. Moreover, the cyclic fatigue resistances of all the glide path files tested in present study were found to be lower in double-curved canals than in single-curved canals.

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