ABSTRACT

Objectives: The purpose of this study was to evaluate the cyclic fatigue, bending resistance, and surface roughness of EdgeEvolve (EdgeEndo) and ProTaper Gold (Dentsply Tulsa Dental Specialties) nickel-titanium (NiTi) rotary files.

Materials and Methods: The instruments (n = 15/each) were tested for cyclic fatigue in single- (60° curvature, 5-mm radius) and double-curved (coronal curvature 60°, 5-mm radius, and apical curvature of 30° and 2-mm radius) artificial canals. The number of cycles to fracture was calculated. The bending resistance of both files were tested using a universal testing machine where the files were bent until reach 45°. Scanning electron microscopy and x-ray energy-dispersive spectrometric analysis were used for imaging the fractured segments, while the atomic force microscope was used to quantify the surface roughness average (Ra).

Results: EdgeEvolve files exhibited higher cyclic fatigue resistance than ProTaper Gold files in single- and double-curved canals (p < 0.05) and both files were more resistant to cyclic fatigue in single-curved canals than double-curved canals (p < 0.05). EdgeEvolve files exhibited significantly more flexibility than did ProTaper Gold files (p < 0.05). Both files had approximately similar Ni and Ti contents (p > 0.05). EdgeEvolve files showed significantly lower Ra values than ProTaper Gold files (p < 0.05).

Conclusions: Within the limitation of this study, EdgeEvolve files exhibited significantly higher cyclic fatigue resistance than ProTaper Gold files in both single- and double-curved canals.

Keywords: Cyclic fatigue test; EdgeEvolve; Nickel titanium rotary instrument; ProTaper Gold; Scanning electron microscopy; Universal testing machine

INTRODUCTION

Nickel-titanium (NiTi) rotary instruments have been proven to perform well in root canal preparation, with short procedure times and high success rates [1]. However, despite their improved performance in root canal preparation, they are prone to sudden failure through cyclic fatigue because of recurrent tension and compression inside curved canals [2]. Many factors affect cyclic fatigue, including file design, surface treatment, heat-treatment of NiTi alloy, and canal curvature [3]. The root canal curvature affects the file fracture and its lifetime. Double curvature canals exert a high amount of stress and have an adverse effect on fatigue resistance [4-6].
The thermal treatment of NiTi alloy optimizes the microstructure and transformation behavior and maximizes flexibility and resistance to cyclic fatigue \([7,8]\). Today, instruments made of controlled memory wires exhibit greater resistance to cyclic fatigue than do conventional NiTi alloys \([4,9,10]\).

ProTaper Gold (Dentsply Tulsa Dental Specialties, Tulsa, OK, USA) is a new heat-treated rotary system that has the same design as the ProTaper Universal, which includes a convex triangular cross section and variable taper of 0.08\(^{v}\). The ProTaper Gold has advanced metallurgy for superior flexibility and exhibits 2-stage transformation behavior and a high \(A_f\) temperature that is similar to controlled memory wires. Further, the file is more resistant to cyclic fatigue than are the ProTaper Universal, ProTaper Next, and files \([8,11]\). The EdgeEvolve file (EdgeEndo, Albuquerque, NM, USA) is another heat-treated NiTi rotary system made of an annealed heat-treated, cryogenically tempered NiTi alloy called Fire-Wire. The EdgeEvolve does not have the shape memory properties and has a triangular cross section and a constant taper of 0.08.

No previous study has evaluated the bending resistance and cyclic fatigue of EdgeEvolve rotary files. Thus, the goal of this study was to evaluate the bending resistances, surface roughness and cyclic fatigue of the EdgeEvolve and ProTaper Gold files in artificial canals with single and double curvature. The null hypothesis was that there is no significant difference in the bending resistance and cyclic fatigue of the EdgeEvolve and ProTaper Gold instruments.

**MATERIALS AND METHODS**

**Instruments selection**

A total of fifty instruments were utilized in the current study from each rotary system. The instruments with similar ISO tip size of 25, 0.08 taper, and 25 mm length were selected: the instruments tested were the F2 ProTaper Gold (Dentsply Tulsa Dental Specialties) and the size 25 EdgeEvolve file (EdgeEndo). The Metallurgical Microscope (Model: MX7520, MEIJI TECHNO, Saitama, Japan) was used at \(\times 100\) magnification to inspect the new instruments for defects. Four new files of each rotary system were selected randomly and examined for machining grooves, manufacturing defects, and surface integrity using scanning electron microscopy (SEM; Quanta 250 FEG, FEI, Eindhoven, The Netherlands). The same operator performed all steps in the laboratory experiment.

**Cyclic fatigue test: power analysis**

The power of the test was calculated using an independent \(t\)-test. The authors achieved a power of 0.99 for the given values from the \(t\)-test with an alpha level of 0.05, and sample size of 60 (15 per group for each outcome: number of cycles at single- and double-curved canals).

Thirty instruments were tested from each system (\(n = 30/each\)). Fifteen instruments were tested in single curvature canal and the other fifteen were tested in the double curvature canal. The static mode of cyclic fatigue was selected for this study. The instruments were tested in an artificial canal within a stainless steel block. This canal was milled using a laser with the aid of a computer program that reproduces the instrument size and taper with 19 mm length \([12]\). In each group, the instruments were tested for cyclic fatigue in two artificial canals (\(n = 15/each\)). The first canal had a single curvature (60\(^{\circ}\) curvature, 5-mm radius), and the second had a double curvature (coronal curvature 60\(^{\circ}\), 5-mm radius, and apical...
curvature of 30° and 2-mm radius) as described by Duke et al. [6]. The instruments were used according to the manufacturer’s recommendations at 300 rpm, and activated by an I-Endo Dual (Acteon, Mérignac, France; Figure 1). Artificial oil (Midwest Plus Lubricant, DENTSPLY Professional, Des Plaines, IL, USA) was applied to the canal to decrease the friction between the instrument and the metal canal. The time to fracture was recorded at 1/10 second using a chronometer. The total number of cycles to fracture (NCF) was calculated by multiplying the time (seconds) to fracture by the number of rotations or cycles per seconds. The length of the fractured segments was measured using digital micro-calipers (Filetta, Schut Geometrical Metrology, Ebnatstrasse, Switzerland).

**Bending resistance test**

The bending resistance test was implemented for 10 files selected randomly from each system using the universal testing machine (MultiTest 2.5i, Mecmesin, Slinfold, UK), as described in previous studies [13,14]. A 20-N load cell was used at 15 mm/min by means of a flexible stainless steel wire. One end of the wire was fastened to the machine head, while the other end was attached 3 mm from the tip of the instrument tested. The machine was activated until the tip of the instrument underwent elastic displacement to reach 45°. The machine loading was supported by a computer program that guarantees a reliable 45° position for all instruments tested. The load required at the moment of bending was recorded for each file (Emperor, Mecmesin).

**Atomic force microscope**

The surface roughness average (Ra) of files new files of both rotary instruments ($n = 6$/ each) was quantified using the Atomic force microscope (AFM; Innova, Bruker, Berlin,
Germany). The files were fixed to the glass plate using double-sided adhesive. Fifteen points were scanned randomly along a 3-mm section starting at the file tip. The AFM images were recorded using contact mode under ambient conditions with scan rate of 1 Hz, scan range of 5 μ, and scan area of 5 × 5 μm². The AFM probes (curvature radius < 10 nm) were mounted on cantilevers (250 μm) with a spring constant of 0.1 Nm⁻¹. The three-dimensional image (256 x 256) lines were processed by using NanoScope analysis software (Bruker NanoScope V1.5 data analysis software, Innova, Bruker, Berlin, Germany). The Ra parameter was selected as a property that quantifies the vertical surface topography of the rotary files [15].

**Scanning electron microscopy evaluation**

Four new files from each group were selected randomly and inspected with the SEM to determine surface integrity and identify machining defects. These new files were analyzed with X-ray energy-dispersive spectrometer to determine the average amounts of nickel (Ni), titanium (Ti), and other elements in the rotary instruments. After cyclic fatigue testing, four samples of each instrument selected randomly from each group, cleaned ultrasonically in absolute alcohol (Power Sonic 405, HWAHIN technology, Seoul, Korea) and imaged with the SEM from the lateral views and the fracture face at various magnifications (×150–×1,500). The cross section of the fracture face was measured for each file using SEM software (Scandium Universal SEM imaging solution, Olympus GMBH, Munster, Germany).

**Statistical analysis**

SPSS v22 was used to analyze the data (SPSS, Chicago, IL, USA), and the Kolmogorov-Smirnov test was used to determine the normality of the data. To compare the mean levels of the two instruments at each angle, an independent t-test was used with a p value of 0.05.

**RESULTS**

Both EdgeEvolve and ProTaper Gold files had significantly higher resistance to cyclic fatigue in the single- than the double-curved canal (p < 0.05). The EdgeEvolve file exhibited significantly greater resistance to fracture than did the ProTaper Gold in both the single- and double-curvatures (p < 0.05). No significant differences in the segments’ length were found between the EdgeEvolve and ProTaper Gold in single- and double-curvatures (p > 0.05). There were significantly shorter fractured segments in canals with a double-curve than in those with a single-curve (p < 0.05, Table 1). EdgeEvolve file was significantly less resistant to bending test than ProTaper Gold (p < 0.05).

**Energy-dispersive spectrometer analysis**

In the ProTaper Gold and the EdgeEvolve files, the proportion of Ni 50%–52% was higher than that of Ti 37%–39% (Figure 2), and there was no significant differences of Ni and Ti contents between the two files.

| Group          | NCF          | Bending resistance (N) | Ra (nm)        | Segment length (mm)          |
|----------------|--------------|------------------------|---------------|-----------------------------|
|                | Single curvature | Double curvature      |               | Single curvature | Double curvature |
| EdgeEvolve     | 3,871.80 ± 33.91** | 569.10 ± 11.55**      | 0.13 ± 0.01*  | 27.93 ± 4.30**  | 5.43 ± 0.21**  |
| ProTaper Gold  | 1,036.40 ± 59.62** | 482.40 ± 13.05**      | 0.28 ± 0.08*  | 90.36 ± 3.57**  | 4.80 ± 0.86**  |

Different uppercase superscripts indicate statistically significant differences between the files.
Different lowercase superscripts indicate statistically significant differences between single- and double curvature canals.

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Both instruments had surface irregularities. The EdgeEvolve file had significantly less Ra compared to the ProTaper Gold files ($p < 0.05$, Figure 3).

**Figure 3.** Surface roughness of the tested files. (A, B) Three-dimensional atomic force microscope images and (C, D) scanning electron micrograph images. (A, C) ProTaper Gold; (B, D) EdgeEvolve. Ra, surface roughness average.
Scanning electron microscopy results

The surface features of the new instruments revealed that the ProTaper Gold files exhibited deep machining grooves. In contrast, the EdgeEvolve file had a smooth electropolished surface. Despite having a smooth surface, the surface of EdgeEvolve files showed a shadow of a remnant of machining grooves (Figure 3). The topographic analysis of the fractured surface in the two systems exhibited the same fractographic signs of a typical pattern of ductile fracture without plastic deformation, as characterized by the presence of the crack initiation area, fatigue striations, and overloaded areas. The ProTaper Gold files exhibited either single or double layer fractures with one or more crack initiation areas, micro-voids, and surface pitting near the fracture lines, while the EdgeEvolve files exhibited slow crack propagation with irregular lateral cracks close to the fracture area (Figure 4). ProTaper Gold fractured face cross-sectional area measured 4.58 ± 1.51 mm² while EdgeEvolve represents 3.80 ± 1.23 mm² as a cross-sectional area.

DISCUSSION

Recently, many brands of NiTi rotary files have been introduced to the market. With respect to clinicians’ concerns, sudden fracture during treatment is considered a major problem that can affect instrument selection and treatment outcome [16]. Among all factors that
contribute to instrument fracture, thermomechanical treatment and canal curvature are considered the most important factors that modify instrument cyclic failure critically. Thermomechanical treatment improves the mechanical properties and flexibility of NiTi files \cite{8,9}. Further, the canal curvature affects the file’s resistance to cyclic failure. Double curvatures in root canals represent a much more stressful and challenging anatomy than do single curvature canals, in which fatigue resistance may be affected by an increased canal curvature \cite{5,6,17}. The ProTaper Gold and EdgeEvolve files were selected for this study because they are manufactured from heat-treated NiTi alloy. Both files tested have the same taper of 0.08 with a triangular cross section for EdgeEvolve and a convex triangular cross section for ProTaper Gold. Both files do not have shape memory similar to the files manufactured of controlled memory alloy. Therefore, canals with double curvature were selected to expose them to the maximum cyclic stress load as in previous studies \cite{5,6,10}. In addition, the single curvature canal was selected as a reference for comparison.

Based on the results of the study, we rejected the null hypothesis, as the EdgeEvolve file exhibited significantly greater resistance to cyclic fatigue than did the ProTaper Gold. The EdgeEvolve’s high resistance to cyclic failure may be attributable to the temperature and amount of heat treatment each brand receives. Based on Zhang et al. \cite{18} results, phase transformation hysteresis ($A_f - M_f$) increases with a decreased cooling rate. The manufacturer of EdgeEvolve claims that the alloy was tempered cryogenically. This heat treatment affects the phase transformation behavior and the microstructure, and consequently affects the degree of flexibility and fracture resistance \cite{19-21}. In addition, the smooth electropolished surface of the EdgeEvolve file seems to prevent the initiation of cracks and hamper their propagation, which consequently delays fracture. This is consistent with Lopes et al. \cite{22}, who concluded that the depth of surface roughness affects the NCF. Moreover, other studies have found that files with a smooth surface have greater NCF than do those with a rough surface \cite{23}.

Based on the results of Grande et al. \cite{24}, the cross-sectional metal mass influences cyclic fatigue resistance. Accordingly, the small triangular cross section of the EdgeEvolve file is expected to be more resistant to cyclic fatigue than are the large convex triangles of ProTaper Gold. Conversely, in the study of Hieawy et al. \cite{8} and Uygun et al. \cite{11}, the ProTaper Gold and ProTaper Universal have a similar cross-sectional design, but ProTaper Gold instruments exhibited higher resistance to cyclic fatigue than did ProTaper Universal instruments. In this comparison, the thermomechanical treatment-enhanced alloy properties of ProTaper Gold are considered the main reason for those differences, as ProTaper Gold has a two-phase transformation and greater resistance to cyclic failure \cite{25,26}.

Yahata et al. \cite{19} concluded that the heat treatment will cause a change in the transformation behaviour and subsequently increase the flexibility. Zhang et al. \cite{27} reported that rate of cooling has a great influence on the phase transformation temperature and martensitic start and finish temperature, which will decrease when, shorten the rate of cooling. This means the file will contain much matensite at room temperature and will be able to deform easily. Moreover, the correlation between stiffness and cross-sectional area was highly significant \cite{28}. Accordingly, it was expected that the bending resistance of EdgeEvolve file will be less than ProTaper Gold.

A limitation of the study is the static mode used in the cyclic fatigue test, which does not represent the actual pecking motion during mechanical preparation. On the other hand, the computer-assisted programs used in dynamic fatigue testing also do not represent the actual
clinical movement. Therefore, the authors decreased the variables in this study by selecting two files with a similar geometry. Moreover, irrigation and debris inside the root canal were not modifying factors in the cyclic fatigue of the rotary files in this study, as we used an artificial stainless steel canal.

CONCLUSIONS

The EdgeEvolve files showed higher flexibility and lower surface roughness compared to ProTaper Gold files. Also, cyclic fatigue test results indicated higher cyclic fatigue resistance of EdgeEvolve file than ProTaper Gold files in single- and double-curvature canals.

REFERENCES

1. Cheung GS, Liu CS. A retrospective study of endodontic treatment outcome between nickel-titanium rotary and stainless steel hand filing techniques. J Endod 2009;35:938-943.
2. Sattapan B, Nervo GI, Palamara JE, Messer HH. Defects in rotary nickel-titanium files after clinical use. J Endod 2000;26:161-165.
3. Parashos P, Gordon I, Messer HH. Factors influencing defects of rotary nickel-titanium endodontic instruments after clinical use. J Endod 2004;30:722-725.
4. Shen Y, Qian W, Abtin H, Gao Y, Haapasalo M. Fatigue testing of controlled memory wire nickel-titanium rotary instruments. J Endod 2011;37:997-1001.
5. Al-Sudani D, Grande NM, Plotino G, Pompa G, Di Carlo S, Testarelli L, Gambarini G. Cyclic fatigue of nickel-titanium rotary instruments in a double (S-shaped) simulated curvature. J Endod 2012;38:987-989.
6. Duke F, Shen Y, Zhou H, Ruse ND, Wang ZJ, Hieawy A, Haapasalo M. Cyclic fatigue of ProFile Vortex and Vortex Blue nickel-titanium files in single and double curvatures. J Endod 2015;41:1686-1690.
7. de Arruda Santos L, de Azevedo Bahia MG, de Las Casas EB, Buono VT. Comparison of the mechanical behavior between controlled memory and superelastic nickel-titanium files via finite element analysis. J Endod 2013;39:1444-1447.
8. Hieawy A, Haapasalo M, Zhou H, Wang ZJ, Shen Y. Phase transformation behavior and resistance to bending and cyclic fatigue of ProTaper Gold and ProTaper Universal instruments. J Endod 2015;41:1134-1138.
9. Capar ID, Kaval ME, Ertas H, Sen BH. Comparison of the cyclic fatigue resistance of 5 different rotary pathfinding instruments made of conventional nickel-titanium wire, M-wire, and controlled memory wire. J Endod 2015;41:535-538.
10. Topçuğlu HS, Topçuğlu G, Aktı A, Düzgün S. In vitro comparison of cyclic fatigue resistance of ProTaper Next, HyFlex CM, OneShape, and ProTaper Universal instruments in a canal with a double curvature. J Endod 2016;42:969-971.
11. Uygun AD, Kol E, Topcu MK, Seckin F, Ersoy I, Tanriver M. Variations in cyclic fatigue resistance among ProTaper Gold, ProTaper Next and ProTaper Universal instruments at different levels. Int Endod J 2016;49:494-499.
12. Plotino G, Grande NM, Cordaro M, Testarelli L, Gambarini G. Measurement of the trajectory of different NiTi rotary instruments in an artificial canal specifically designed for cyclic fatigue tests. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2009;108:e152-e156.
13. Silva EJ, Rodrigues C, Vieira VT, Belladonna FG, De-Deus G, Lopes HP. Bending resistance and cyclic fatigue of a new heat-treated reciprocating instrument. Scanning 2016;38:837-841.

14. De-Deus G, Silva EJ, Vieira VT, Belladonna FG, Elias CN, Plotino G, Grande NM. Blue thermomechanical treatment optimizes fatigue resistance and flexibility of the Reciproc files. J Endod 2017;43:462-466.

15. Cai JJ, Tang XN, Ge JY. Effect of irrigation on surface roughness and fatigue resistance of controlled memory wire nickel-titanium instruments. Int Endod J 2017;50:718-724.

16. Lin LM, Rosenberg PA, Lin J. Do procedural errors cause endodontic treatment failure? J Am Dent Assoc 2005;136:187-193.

17. Shen Y, Hicawy A, Huang X, Wang ZL, Maezono H, Haapasalo M. Fatigue resistance of a 3-dimensional conforming nickel-titanium rotary instrument in double curvatures. J Endod 2016;42:961-964.

18. Zhang Y, Jiang S, Zhao Y, Tang M. Influence of cooling rate on phase transformation and microstructure of Ti-50.9%Ni shape memory alloy. T Nonferr Metal Soc J 2012;22:2685-2690.

19. Yahata Y, Yoneyama T, Hayashi Y, Ebihara A, Doi H, Hanawa T, Suda H. Effect of heat treatment on transformation temperatures and bending properties of nickel-titanium endodontic instruments. Int Endod J 2009;42:621-626.

20. Braga LC, Faria Silva AC, Buono VT, de Azevedo Bahia MG. Impact of heat treatments on the fatigue resistance of different rotary nickel-titanium instruments. J Endod 2014;40:1494-1497.

21. Gu Y, Kim KY, Perinpanayagam H, Kim C, Kim DJ, Lim SM, Chang SW, Baek SH, Zhu Q, Yoo Y. Various heat-treated nickel-titanium rotary instruments evaluated in S-shaped simulated resin canals. J Dent Sci 2017;12:14-20.

22. Lopes HP, Elias CN, Vieira MV, Vieira VT, de Souza LC, Dos Santos AL. Influence of surface roughness on the fatigue life of nickel-titanium rotary endodontic instruments. J Endod 2016;42:965-968.

23. Kim BH, Ha JH, Lee WC, Kwak SW, Kim HC. Effect from surface treatment of nickel-titanium rotary files on the fracture resistance. Scanning 2015;37:82-87.

24. Grande NM, Plotino G, Pecci R, Bedini R, Malagnino VA, Somma F. Cyclic fatigue resistance and three-dimensional analysis of instruments from two nickel-titanium rotary systems. Int Endod J 2006;39:755-763.

25. Elnahy AM, Elsaka SE. Mechanical properties of ProTaper Gold nickel-titanium rotary instruments. Int Endod J 2016;49:1073-1078.

26. Kaval ME, Capar ID, Ertas H. Evaluation of the cyclic fatigue and torsional resistance of novel nickel-titanium rotary files with various alloy properties. J Endod 2016;42:1840-1843.

27. Zhang YQ, Jiang SY, Zhao YN, Tang M. Influence of cooling rate on phase transformation and microstructure of Ti-50.9%Ni shape memory alloy. Trans Nonferrous Met Soc China 2012;22:2685-2690.

28. Schäfer E, Dzepe A, Danesh G. Bending properties of rotary nickel-titanium instruments. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2003;96:757-763.