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ORIGINAL RESEARCH ARTICLE

Cyclic Fatigue Resistance and SEM Evaluation of Fractured Instrument Surfaces; Comparison of ProTaper Universal and ProTaper Gold Files

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Abstract

Purpose: To compare the cyclic fatigue resistance of ProTaper Universal (PTU) and ProTaper Gold (PTG) nickel titanium files at different angles and to examine the fractured surface areas by using scanning electron microscope (SEM).
Materials & Methods: A special static test device made of stainless steel with artificial canals at 3 different angles. The files were rotated until they were broken in artificial canals with 45°, 60° and 90° angles and also the time to fracture was recorded using a digital stopwatch. The number of cycles to failure was calculated for each instrument. Statistical analyzes were made by using one-way analysis of variance (Anova) for comparison between main groups.
Results: PTG files showed higher fatigue resistance ($p<0.001$) than PTU files in all groups. SEM results displayed similar characteristic structures in pits and fissures caused by fracture due to cyclic fatigue regardless of angle and file type.
Conclusion: Although surface properties of broken instruments do not play a decisive role in clinical practice it was observed that heat-treated Ni-Ti files exhibited higher fatigue resistance at all angles compared to conventional files according to the number of cycles during experimental period.

Key words: cyclic fatigue; fractured instrument; protaper gold; protaper universal; scanning electron microscopy (SEM)

Introduction

Nickel-titanium (Ni-Ti) rotary instruments are frequently used in preparing root canals.[1,2] In 1988, the use of Ni-Ti files significantly changed the clinical procedures of endodontic treatment for root canal preparation after the first study on Ni-Ti files by Walia et al.[3] Ni-Ti files have become popular in root canal preparing processes in recent years due to their superior cutting capability and flexibility.[4] However, one of the biggest problems of Ni-Ti files is that they may fracture during preparation procedure especially in the curved root canals.[5,6] Generally, two mechanisms plays role in file breakage.These mechanisms are cyclic fatigue and torsional failure.[7] The first of these mechanisms is more frequent in curved canals due to repetitive pressure, and the stress on the file which occurs while rotating. The second mechanism occurs when the tip of the file is locked in the canal but the file body still rotating. During root canal preparation, the stress created on the file depends on the physician's usage technique, method of use and the anatomical structure of the root canal. In addition, the geometry of the file, its alloy composition and production method significantly affects the stress behavior of Ni-Ti files. Although the size and cross-sectional design of files effect fracture resistance, production techniques are more imperative today.[8,9]During or after the manufacturing process of the files, the chemical and mechanical properties of Ni-Ti alloys can be improved.[10]

ProTaper Universal (PTU; Dentsply Maillefer, Ballaigues, Switzerland) is a file system made of conventional Ni-Ti alloy. The PTU has a variable taper angle and a convex triangular cross section. In 2012, Dentsply Sirona introduced a new heat treatment procedure for controlled memory alloys. The instruments were repeatedly heat-treated and cooled. As a result, color change was observed on the surface due to the thickening of the titanium oxide layer. ProTaper Gold (PTG; Dentsply, Tulsa Dental Specialties, Tulsa, OK, USA) is one of the instruments produced by using this technology. PTG instruments have a geometric design which is similar to PTU ones but PTG ones are more flexible and developed with advanced metallurgical techniques. Previous studies showed that PTG instruments have more cyclic fatigue resistance than PTU ones.[11] However, a few number of studies about the comparison of cyclic fatigue resistance behavior at different angles between PTG and PTU instruments are available in literature.

In recent years, different thermomechanical processes have been used to improve the superelastic and fatigue resistance of Ni-Ti instruments. The superelastic property results from a reversible conversion from austenic phase to a stress-reduced martensitic phase. Therefore, conversion temperatures between phases have a significant effect on the mechanical properties of the files.[12] Through heat treatment technology developed with advanced metallurgy techniques, ProTaper instrument files contain different phase transformations; PTG files contain 2 special phase transformations, while PTU ones have 1 phase transformation. Heat treatment applied to Ni-Ti alloys is a process that increases the cyclic fatigue resistance compared to traditional Ni-Ti alloys.[11,13]

The aim of this study was to compare the cyclic fatigue resistance of conventional and heat treated Ni-Ti files in artificial canals at 45°, 60° and 90° angles and to examine the fractured surface areas by using SEM. It is also hypothesized in this study that there are significant differences between the cyclic fatigue resistances and fractured surface patterns of the tested PTG and PTU files at different angles.

Materials and Methods

For this study, a total of 108 new Ni-Ti files were selected, including 54 ProTaper Universal F2 (PTU, Dentsply Maillefer, Ballaigues, Switzerland) and 54 ProTaper Gold F2 (PTG, Dentsply Maillefer, Ballaigues, Switzerland) instruments. All instruments were examined with an optical stereomicroscope for morphological structures and visible deformations (Leica, MZ12, Germany, USA) before testing. All defective instruments were excluded from the study. In order to perform the cyclic fatigue tests of the instruments, a special test device Figure 1 is evaluated using custom made device as described by the literature.[14–16] It is made of stainless steel by CNC (Computer Numerical Control) machine. Artificial canals at 3 different angles were used. The test model had a clear acrylic cover that enabled the files to be observed while rotating and removed from the canal after failure. Simulated root canals were designed 90°, 60°, and 45° angle of curvature, and 5 mm radius, 1.5 mm inner diameter and 19 mm length stainless steel Figure 1. Glycerin was used to reduce the friction force of the instruments between the artificial canal walls. PTU F2 and PTG F2 Ni-Ti files were used with an endo-motor (VDW Gold Reciproc. GmbH, Munich, Germany) and a 6:1 reduction handpiece suitable for the torque characteristics of the instruments. All files were used at 300 rpm and 3N torque according to manufacturer's instructions. The groups were separated according to the curvature degree of the artificial canals (45°, 60°, and 90°) with 18 files each and 6 experimental groups were formed as; Group 1A ProTaper Universal (PTU) - 45° Group 2A ProTaper Gold (PTG) - 45° Group 1B ProTaper Universal (PTU) - 60° Group 2B ProTaper Gold (PTG) - 60° Group 1C ProTaper Universal (PTU) - 90° Group 2C ProTaper Gold (PTG) - 90°

All instruments were rotated until a fracture occurred. The time to fracture was recorded with a 1/100-second digital chronometer (Delta). The number of cycles to failure (NCF) was calculated for each instrument; NCF = time to failure (sec) x rotation speed (rpm) / 60.

The length of the fractured part was also recorded with digital caliper for each instrument (MarlCal, Germany). Data analysis was performed using SPSS 11.5 (IBM-SPSS Inc., Chicago, IL, USA) program, One way analysis of variance (ANOVA) for comparison between the main groups, and Tukey's post hoc tests for subgroup comparisons within the two groups.

All images were generatedwith the Promax 3D Max (Planmeca, Helsinki, Finland) CBCT device. The images were evaluated in a dimly lit room on a 15-inch Toshiba Qosmio monitor (Toshiba, Tokyo, Japan) set at a resolution of 1920 × 1080 and a color depth 32-bit.

Figure 1. The static cyclic fatigue test model

Descriptive statistics were calculated. Statistical analysis was performed with SPSS software (ver.20, IBM SPSS Inc., New York, NY, USA). The chi-squared test was used for comparisons of categorical variables. A level of $p < 0.05$ was accepted as statistically significant.

Results

PTG files showed higher fatigue resistance ($p<0.001$) than PTU files for all experimental groups Table 1. There were no statistically significant differences between 45° to 60° and 45° to 90° angles groups ($p>0.05$) for PTU files, whereas the significance was observed between the angles at 60° and 90° ($p<0.001$). PTG files did not show any difference between the angles at 45° and 60° ($p>0.05$); however, fracture resistance for the angle 90°was much lower than angles with 45° and 60° ($p<0.001$). There was no statistically significant difference between PTU and PTG files according to the fracture lengths for 45° ($p> 0.05$), while that difference was found for the angle of 60° ($p <0.001$). On the other hand, the p-value was 0.05 for 90° angle of curvature indicated a numerically considerable result for fracture lengths of PTG and PTU files Table 2 After the cyclic fatigue test, the fractured surface areas of the samples were randomly examined using SEM (Quanta 200F, FEI, USA). Magnification ratios were between 250x and 400x for general images and between 2000x and 8000x for detailed images. General images obtained at low magnification showed fracture surfaces due to cyclic fatigue. At high magnification images, pits and/or gaps were observed on these fractured surfaces Figure 2. SEM results showed similar characteristic structures in pits and fissures which are caused by fracture due to cyclic fatigue regardless of angle and file type. In addition, it was observed that the fracture areas on the surfaces started from corners or edges.

Discussion

Since anatomical variations in teeth cannot be standardized, it is not appropriate to perform cyclic fatigue tests on extracted teeth.[17] However, there is no specific and standardized model type used in cyclic fatigue tests. Both static and dynamic models are used in in vitro cyclic fatigue resistance tests.[18] Although the dynamic model provides an environment close to the clinical brushing or pecking motion, it cannot restrict the instruments in a precise trajectory.

However, the preferred reason for the static model is that the instruments assessed can be tested in a device limited to a precise line. In these static test models, the files are examined by rotating them until they are broken in a fixed bent position. In the studies, 25 pieces of Ni-Ti instruments with a diameter of 0.06 were chosen. The reason is that the final master apical file (as F2 in many root canal preparations) is made with Ni-Ti files with that diameter.[14,19] The radius and angle of artificial canals are among the factors affecting cyclic fatigue resistance. As the curvature angle increases, the useful life of the instruments decreases[19–21] For this purpose,

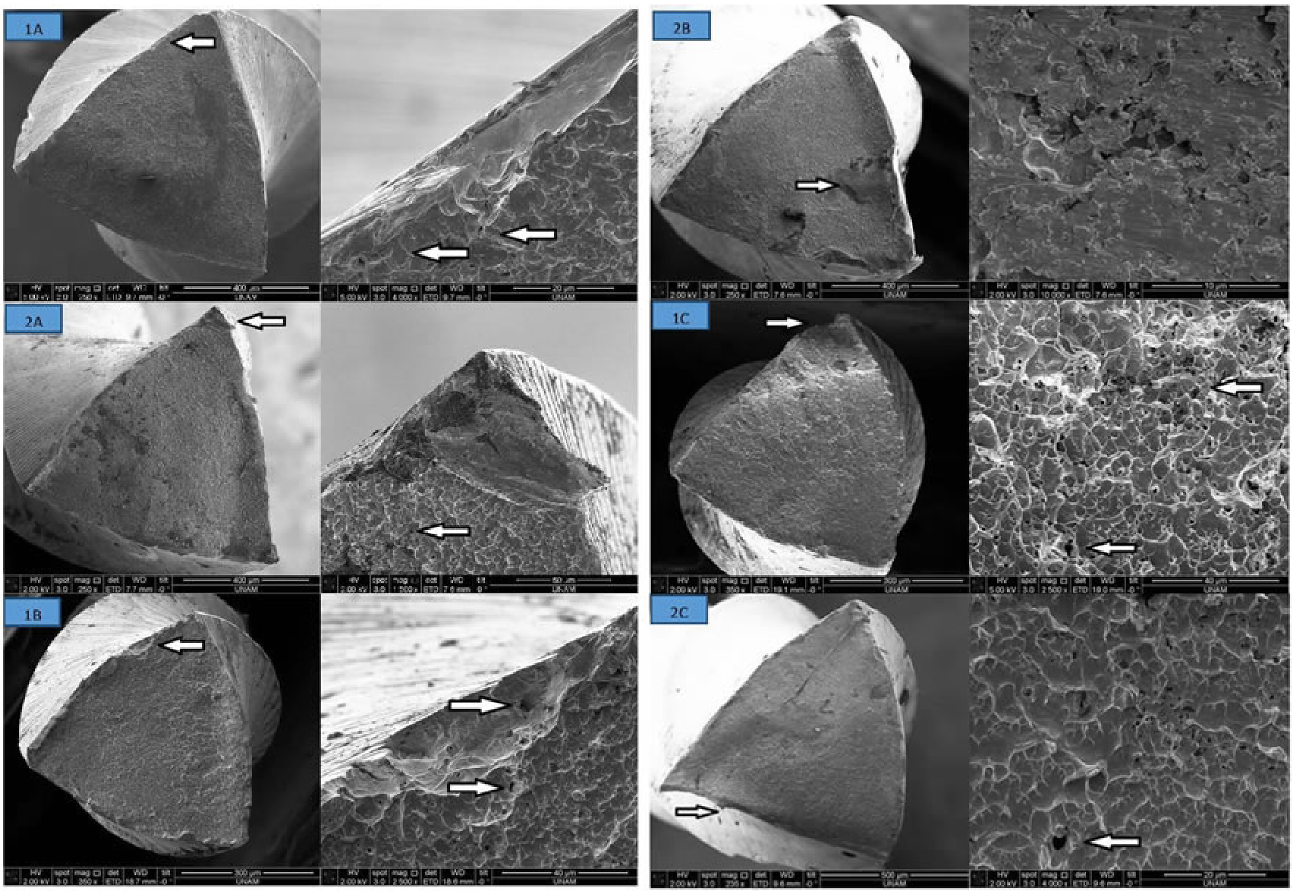

Figure 2. Images under the scanning electron microscope of fracture surfaces caused by cyclic fatigue. (1A) Fatigue lines at the cutting edges of the PTU F2 file at low magnification (250x), pits and gaps due to cyclic fatigue of the PTU F2 file at high magnification (6000x), (45° angle). (2A) Fatigue lines at the cutting edges of the PTG F2 file at low magnification (250x), pits and gaps due to cyclic fatigue of the PTG F2 file at high magnification (6000x) (45° angle). (1B) Fatigue lines on the surface of the PTU F2 file at low magnification (400x), micro-pits due to cyclic fatigue of the PTU F2 file at high magnification (3000x), (60° angle). (2B) Fatigue lines at the cutting edges of the PTG F2 file at low magnification (250x), pits due to cyclic fatigue of the PTG F2 file at high magnification (4000x), (60° angle). (1C) Fatigue lines at the cutting edges of the PTU F2 file at low magnification (325x), pits due to cyclic fatigue of the PTU F2 file at high magnification (2000x) (90° angle). (2C) Fatigue lines at the cutting edges of the PTG F2 file at low magnification (400x), pits due to cyclic fatigue of the PTG F2 file at high magnification (6000x), (90° angle).

Table 1. The number of cycles to failure (NCF) (n=18) during cyclic fatigue testing in curved canals

	Canal with 45° angle of curvature		Canal with 60° angle of curvature		Canal with 90° angle of curvature	
File Type	**Mean**	**Standard Deviation**	**Mean**	**Standard Deviation**	**Mean**	**Standard Deviation**
PTU	425.56	132.07	535.00	192.10	315.28	55.08
PTG	1312.22	282.15	1396.67	321.03	841.39	157.31

Table 2. The mean and standard deviation values of fracture lengths (n=18) of the files for 45°, 60° and 90° angles of curvature canals

	Canal with 45° angle of curvature		Canal with 60° angle of curvature		Canal with 90° angle of curvature	
File Type	**Mean**	**Standard Deviation**	**Mean**	**Standard Deviation**	**Mean**	**Standard Deviation**
PTU	16.05	0.34	5.81	1.15	6.88	1.37
PTG	16.08	0.06	16.05	0.12	9.21	4.55

the 45° canal curvature was selected. The 90° curvature angle was chosen to simulate the sudden apical curvature, which is difficult for rotating instruments in clinical practice.

In our study, the fracture resistance of PTG file in 45° angle canal was found to be statistically higher than PTU file. Ruiz-Sánchez et al.[22] compared the cyclic fatigue strength of conventional alloy PTU. The new generation heat-treated ProFile Vortex files were performed in two different artificial canals 45° and 60°. In their study, they concluded that ProFile Vortex file, which is a heat-treated Ni-Ti instrument, has a much higher fracture resistance in both angled canals. Our results are in consistent with results of Algedairi et al.[23] They study in artificial canals at 45°, comparing the cyclic fatigue of PTG files, PTU and PTN files, and demonstrating that PTG files show high resistance compared to other files.

According to the results of our study, the PTG file was found to have a much higher fracture resistance in the 60° angle canal compared to the ProTaper Universal file. Elnaghy et al.[24] compared PTG and PTU files in terms of cyclic fatigue resistance in 60° artificial canals. They found that the PTG file was more resistant and more flexible in terms of cyclic fatigue than the PTU file. In another study, Uygun et al.[25] compared PTU and PTG files with cyclic fatigue resistance in artificial canals with 60° at different levels of the canal. At the end of the study, they concluded that PTG file was much more resistant than PTU file at all canal levels.[25] In another study, Plotino et al.[26] compared the cyclic fatigue resistance of PTG and PTU files in 60° angle artificial canals and concluded that the PTG file had statistically higher resistance.Kaval et al.[25] found that HyflexEDM (Coltene / Whaledent, Altstatten, Switzerland), which produced with control memory EDM technology, exhibits higher fatigue resistance than PTG and PTU files in 60° artificial canals. However, they concluded that it showed higher cyclic fatigue resistance than PTU even though the PTG has a geometric cross-section similar to PTU. In our study, we observed that PTG file had a much higher fracture resistance in the 90° canal compared to PTU file. Nguyen et al.[27] compared the cyclic fatigue resistance of ProTaper Next (X1-X5), Vortex Blue (20/0.04-50/0.04) and PTU (S1-F5) instruments with 5 mm radius and 90° artificial canals. Similar to our results, they reported that the fatigue resistance of PTU is lower than ProTaper Next and Vortex Blue files.

In the study of Kaval et al.[25] it was mentioned that standard cyclic fatigue test devices can create similar stress points on instruments and therefore, fracture lengths may be similar. Additionally, depending on the cross-sectional designs and alloy properties of the instruments, they stated that differences in bending times can displace the maximum stress points and different fracture lengths are observed in different instrument types. In this study, the lengths of the fracture pieces at different angles were also compared. For PTG instruments fracture lengths were not found to be statistically significant in 45° canals, whereas for 60° and 90° angle canals it was significant when compared to PTU instruments. Different bending movements of the tested instruments may lead to these results.

As a result, it can be mentioned that SEM results obtained in our study are consistent with the SEM results from other studies.[11,17] Their results showed similar characteristic structures in pits and fissures on fractured surfaces, regardless of angle and file type. In addition, it was observed that the fracture areas on the surfaces start from edges.

Conclusion

PTG exhibited higher fatigue resistance at all canals compared to the PTU file. In addition, when the images of the fractured parts were evaluated, it was found that they are not different each other according to the angle and file type. When we compare the file types with respect to the length of the broken pieces, the broken piece lengths of PTG files were found to be longer than PTU files in 60° and 90° canals. As a result, special heat-treated files are more resistant than conventional Ni-Ti alloy files and should be recommended for curved canals.

Author Contributions

Conceptualization M.D.O.; Data curation N.B.; Investigation N.B., E.O.T; Methodology N.B ; Project administration M.DO.; Supervision E.O.T; Validation E.O.T.; Visualization N.B; Roles/Writing – original draft E.O.T., N.B.; Writing – review & editing M.D.O.

Conflict of Interest

The authors declare that they have no conflict of interest.

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References

1. Peters OA. Current challenges and concepts in the preparation of root canal systems: a review. J Endod. 2004;30(8):559–567. doi:10.1097/01.don.0000129039.59003.9d.
2. Schäfer E, Schulz-Bongert U, Tulus G. Comparison of hand stainless steel and nickel titanium rotary instrumentation: a clinical study. J Endod. 2004;30(6):432–435. doi:10.1097/00004770-200406000-00014.
3. Walia H, Brantley WA, Gerstein H. An initial investigation of the bending and torsional properties of Nitinol root canal files. J Endod. 1988;14(7):346–351.
4. Bird DC, Chambers D, Peters OA. Usage parameters of nickel-titanium rotary instruments: a survey of endodontists in the United States. J Endod. 2009;35(9):1193–1197. doi:10.1016/j.joen.2009.05.027.
5. Sattapan B, Nervo GJ, Palamara JE, Messer HH. Defects in rotary nickel-titanium files after clinical use. J Endod. 2000;26(3):161–165. doi:10.1097/00004770-200003000-00008.
6. Young JM, Van Vliet KJ. Predicting in vivo failure of pseudoelastic NiTi devices under low cycle, high amplitude fatigue. J Biomed Mater Res B Appl Biomater. 2005;72(1):17–26. doi:10.1002/jbm.b.30113.
7. Jamleh A, Alghaihab A, Alfadley A, Alfawaz H, Alqedairi A, Alfouzan K. Cyclic Fatigue and Torsional Failure of EdgeTaper Platinum Endodontic Files at Simulated Body Temperature. J Endod. 2019;45(5):611–614. doi:10.1016/j.joen.2019.02.008.
8. Turpin YL, Chagneau F, Vulcain JM. Impact of two theoretical cross-sections on torsional and bending stresses of nickel-titanium root canal instrument models. J Endod. 2000;26(7):414–417. doi:10.1097/00004770-200007000-00009.
9. Tripi TR, Bonaccorso A, Condorelli GG. Cyclic fatigue of different nickel-titanium endodontic rotary instruments. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2006;102(4):e106–114. doi:10.1016/j.tripleo.2005.12.012.
10. Alapati SB, Brantley WA, Iijima M, Clark WA, Kovarik L, Buie C, et al. Metallurgical characterization of a new nickel-titanium wire for rotary endodontic instruments. J Endod. 2009;35(11):1589–1593. doi:10.1016/j.joen.2009.08.004.
11. 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(7):1134–1138. doi:10.1016/j.joen.2015.02.030.
12. Shen Y, Zhou HM, Zheng YF, Peng B, Haapasalo M. Current challenges and concepts of the thermomechanical treatment of nickel-titanium instruments. J Endod. 2013;39(2):163–172. doi:10.1016/j.joen.2012.11.005.
13. 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(5):494–499. doi:10.1111/iej.12471.
14. Plotino G, Grande NM, Sorci E, Malagnino VA, Somma F. Influence of a brushing working motion on the fatigue life of NiTi rotary instruments. Int Endod J. 2007;40(1):45–51. doi:10.1111/j.1365-2591.2006.01179.x.
15. Fishelberg G, Pawluk JW. Nickel-titanium rotary-file canal preparation and intracanal file separation. Compend Contin Educ Dent. 2004;25(1):17–8, 20–2, 24; quiz 25, 47.
16. Mounce R. Rotary nickel titanium instrumentation. A literature

review. Dent Today. 2004;23(2):119–20, 124–6, 128; quiz 129.
17. Yao JH, Schwartz SA, Beeson TJ. Cyclic fatigue of three types of rotary nickel-titanium files in a dynamic model. J Endod. 2006;32(1):55–57. doi:10.1016/j.joen.2005.10.013.
18. Plotino G, Grande NM, Cordaro M, Testarelli L, Gambarini G. A review of cyclic fatigue testing of nickel-titanium rotary instruments. J Endod. 2009;35(11):1469–76. doi:10.1016/j.joen.2009.06.015.
19. 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(10):755–763. doi:10.1111/j.1365-2591.2006.01143.x.
20. Pruett JP, Clement DJ, Carnes J D L. Cyclic fatigue testing of nickel-titanium endodontic instruments. J Endod. 1997;23(2):77–85. doi:10.1016/s0099-2399(97)80250-6.
21. Haïkel Y, Serfaty R, Bateman G, Senger B, Allemann C. Dynamic and cyclic fatigue of engine-driven rotary nickel-titanium endodontic instruments. J Endod. 1999;25(6):434–440. doi:10.1016/s0099-2399(99)80274-x.
22. Ruiz-Sánchez C, Faus-Matoses V, Alegre-Domingo T, Faus-Matoses I, Faus-Llácer VJ. An in vitro cyclic fatigue resistance comparison of conventional and new generation nickel-titanium rotary files. J Clin Exp Dent. 2018;10(8):e805–e809. doi:10.4317/jced.55091.
23. Alqedairi A, Alfawaz H, Bin Rabba A, Almutairi A, Alnafaiy S, Khan Mohammed M. Failure analysis and reliability of Ni–Ti-based dental rotary files subjected to cyclic fatigue. Metals. 2018;8(1):36. doi:10.3390/met8010036.
24. Elnaghy AM, Elsaka SE. Mechanical properties of ProTaper Gold nickel-titanium rotary instruments. Int Endod J. 2016;49(11):1073–78. doi:10.1111/iej.12557.
25. 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(12):1840–1843. doi:10.1016/j.joen.2016.07.015.
26. Plotino G, Grande NM, Bellido MM, Testarelli L, Gambarini G. Influence of temperature on cyclic fatigue resistance of ProTaper Gold and ProTaper Universal rotary files. J Endod. 2017;43(2):200–202. doi:10.1016/j.joen.2016.10.014.
27. Nguyen HH, Fong H, Paranjpe A, Flake NM, Johnson JD, Peters OA. Evaluation of the resistance to cyclic fatigue among ProTaper Next, ProTaper Universal, and Vortex Blue rotary instruments. J Endod. 2014;40(8):1190–3. doi:10.1016/j.joen.2013.12.033.