

Effect of adaptive motion on cyclic fatigue resistance of a nickel titanium instrument designed for retreatment

Taha Özyürek*, Koray Yılmaz, Gülşah Uslu

Department of Endodontics,
Faculty of Dentistry, Ondokuz Mayıs
University, Samsun, Turkey

Objectives: The aim of this study was to evaluate the cyclic fatigue resistance of the ProTaper Universal D1 file (Dentsply Maillefer) under continuous and adaptive motion. **Materials and Methods:** Forty ProTaper Universal D1 files were included in this study. The cyclic fatigue tests were performed using a dynamic cyclic fatigue testing device, which had an artificial stainless steel canal with a 60° angle of curvature and a 5 mm radius of curvature. The files were randomly divided into two groups (Group 1, Rotary motion; Group 2, Adaptive motion). The time to failure of the files were recorded in seconds. The number of cycles to failure (NCF) was calculated for each group. The data were statistically analyzed using Student's *t*-test. The statistical significant level was set at $p < 0.05$. **Results:** The cyclic fatigue resistance of the adaptive motion group was significantly higher than the rotary motion group ($p < 0.05$). **Conclusion:** Within the limitations of the present study, the 'Adaptive motion' significantly increased the resistance of the ProTaper Universal D1 file to cyclic failure. (*Restor Dent Endod* 2017; 42(1):34-38)

Key words: Cyclic fatigue; Dynamic model; Endodontics; Nickel titanium; ProTaper Universal Retreatment

Introduction

One of the main disadvantages of nickel titanium (NiTi) root canal instruments is their propensity to fracture. Such fractures usually occur without warning, while using the instruments in the root canal.^{1,2} There are two causes of fracture during clinical applications: torsional fatigue and cyclic fatigue.³ In an attempt to eliminate this problem, manufacturers have made a number of innovations, both in canal instruments and endodontic motors. Traditional endodontic motors work with a continuous clockwise (CW) rotation. A new endodontic motor (Elements Motor, SybronEndo, Orange, CA, USA) offers combined rotational and reciprocation motion. The aim of this motor is to prevent fracture of instruments by minimizing the stress that accumulates on NiTi instruments during canal preparation.⁴ During the operation of the instrument, the motor stops momentarily upon reaching 600° full CW rotation and then restarts, continuing its CW rotation. If the instrument becomes stuck in dentine or root canal filling material, the motor switches the rotational motion to reciprocation motion due to the increased stress. The angles of reciprocation are not fixed, and the motor modifies the CW and counterclockwise (CCW) angles from 600/0° up to 370/50°, depending on the stress inside the canal.

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Özyürek T, Yılmaz K, Uslu G

*Correspondence to

Taha Özyürek, DDS, PhD.
Research Assistant, Department of
Endodontics, Faculty of Dentistry,
Ondokuz Mayıs University, Samsun,
Turkey
TEL, +905052602749; FAX,
+903624576032; E-mail,
tahaoyurek@hotmail.com

ProTaper Universal (Dentsply Maillefer, Ballaigues, Switzerland) retreatment NiTi file system specifically designed for retreatment consists of three files: D1, D2, and D3. The convex triangular cross-section of the files is designed for effective removal of root canal filling material from the root canal during continuous CW rotation.⁵ The adaptive motion has been proposed in order to maximize the advantages of reciprocation while minimizing its disadvantages. When the file is not (or very lightly) stressed in the canal, the movement can be described as a continuous rotation, allowing better cutting efficiency and removal of debris. This interrupted motion is not only as effective as continuous rotation in lateral cutting, thus allowing optimal brushing or circumferential filing for better debris removal in oval canals, but also it minimizes iatrogenic errors by reducing the tendency of 'screwing in' that is commonly seen with NiTi instruments of great taper. Also adaptive motion is therefore meant to reduce the risk of intracanal failure without affecting performance.⁶

Only one study has investigated the effects of adaptive motion on the cyclic fatigue resistance of endodontic files.⁶ Thus, the aim of the present study was to evaluate the cyclic fatigue resistance of the ProTaper Universal D1 file in a dynamic model under continuous and adaptive motion. The null hypothesis was that there would be no difference in the cyclic fatigue resistance of the ProTaper Universal D1 under continuous and adaptive motions.

Materials and Methods

Forty ProTaper Universal D1 files (size 30/0.09, Dentsply Maillefer, lot No., 1106241) were included in this study. Prior to the cyclic fatigue testing under the dynamic model, all the files were checked under a stereomicroscope, with $\times 20$ magnification (Olympus BX43, Olympus Co., Tokyo, Japan) to determine any deformation on their surfaces.

The cyclic fatigue tests were performed using a specially designed dynamic cyclic fatigue testing device (Figure 1). The device has an artificial stainless steel canal, with a 60° angle of curvature and a 5 mm radius of curvature. The center of curvature of the canal is located at 5 mm in the coronal from the end of the canal, and the internal diameter of the canal is 1.5 mm. The files were randomly divided into two groups ($n = 20$) and underwent the following procedures:

Group 1: Rotary motion (RM)

The files were used with a VDW Silver Motor (VDW, Munich, Germany), connected to the cyclic fatigue testing device and operated according to the manufacturer's instructions at 500 rotations per minute (rpm) and 300 g cm^{-1} torque until they broke.

Group 2: Adaptive motion (AM)

The files were used with an Elements Motor (SybronEndo), connected to the cyclic fatigue testing device, using the 'TF Adaptive' program until they broke.

While the cyclic fatigue test was performed in the AM group, the movements of the files until they broke were recorded in Quick Time Movie (MOV) format, using a device with a slow-motion camera (iPhone 6 Plus, Apple Inc., Cupertino, CA, USA) that was adapted for use with the cyclic fatigue testing device. Later, the records were transferred to a computer. Three different observers counted number of rpm of slow-motion videos. In the RM group, the number of cycles to failure (NCF) was calculated at 500 rpm.

The files were placed on the device and operated with an axial motion (back and forth) inside the canal at a speed of 3 mm/sec to simulate clinical use. Synthetic oil (WD-40 Company, Milton Keynes, UK) was used to reduce the friction between the files and the walls of the artificial canal and enable free rotation. When the file on the cyclic fatigue device broke, the device automatically stopped, and the time on the device screen was recorded in seconds. The NCF was calculated for each file, using the following formula: $\text{NCF} = \text{rpm} \times \text{time (seconds)} / 60$.

Four pieces of broken files, two from each group, were examined using a scanning electron microscope (SEM, JEOL, JSM-7001F, Tokyo, Japan), and photomicrographs of the fracture surfaces were taken under different magnifications to determine the fracture type.

Statistical analysis

The normality of the data distribution was first verified with the Anderson-Darling test, and the Levene test was

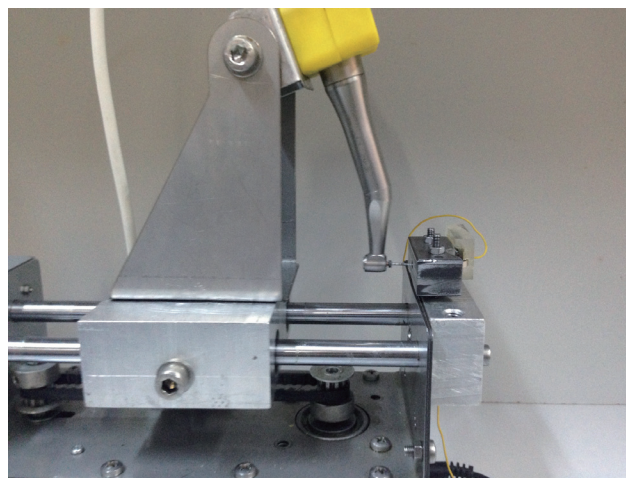


Figure 1. Dynamic cyclic fatigue testing device.

Table 1. The mean and the standard deviation values of number of cycles to failure of two groups during dynamic cyclic fatigue test

Group	<i>n</i>	NCF
Rotary motion	20	810.0 ± 62.0 ^a
Adaptive motion	20	1625.8 ± 59.7 ^b

*Different superscript letters mean statistically significant difference ($p < 0.05$).

NCF, number of cycles to failure.

used for the homogeneity of variances. SPSS 21.0 (IBM-SPSS Inc., Chicago, IL, USA) was used for the statistical analysis, and the results of the cyclic fatigue resistance analysis were analyzed using a Student's *t*-test. The statistical significant level was set at $p < 0.05$.

Results

The counted rpm values of the RM group and the AM group were 500 and 345, respectively. The mean and standard deviations of NCF values of each group until the fracture occurred are presented in Table 1. The cyclic fatigue resistance of the AM group was significantly higher than that of the RM group ($p < 0.001$). The SEM analysis of the fractured cross-sectional surfaces revealed typical features of cyclic failure, including crack origins, fatigue zones, and an overload fast fracture zone (Figure 2).

Discussion

Although many factors can cause files to fracture, cyclic fatigue resistance is a particularly common cause.⁶ Different information exists in the literature on the reciprocation angle and rpm of the various file systems introduced in the market. Gambarini and Glassman⁶ investigated the cyclic

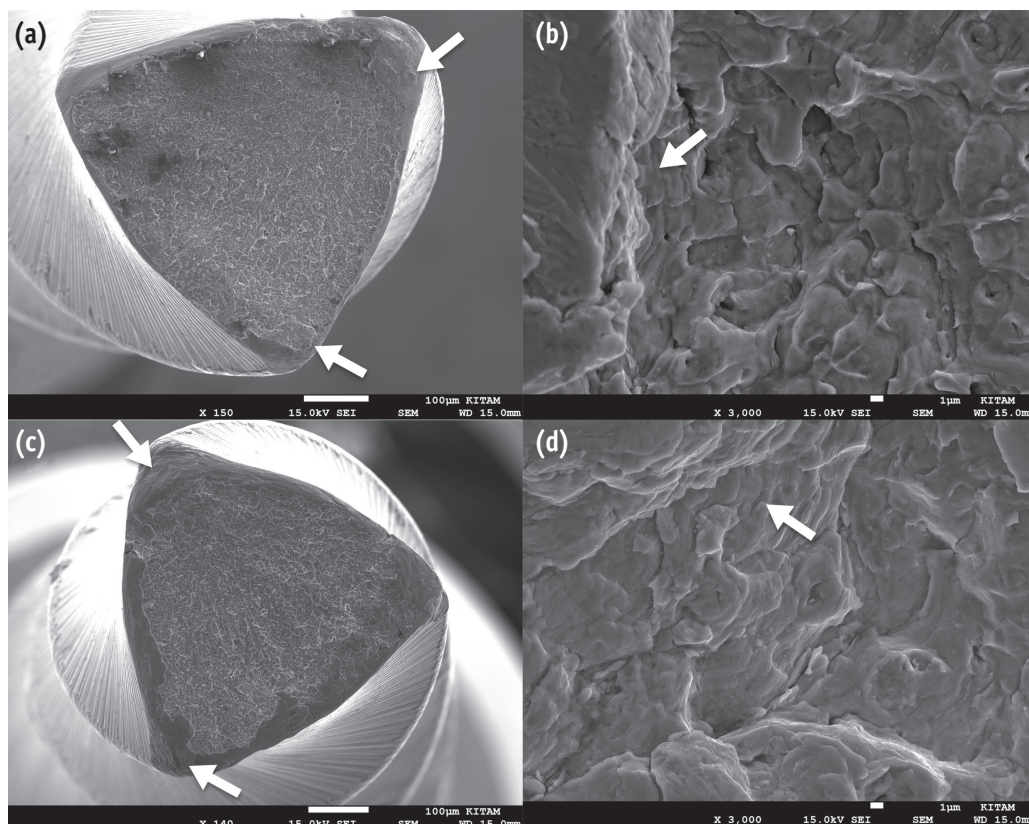


Figure 2. SEM appearances of the ProTaper Universal retreatment D1 files after cyclic fatigue testing. (a) and (c) General view of D1 instrument with fatigue zones, and an overload fast fracture zone (white arrows); (b) and (d) High-magnification view of D1 instrument showing fatigue striations typical of cyclic fatigue (white arrows). (a) and (b) Rotary motion group; (c) and (d) Adaptive motion group.

fatigue resistance of the Twisted File (TF, SybronEndo) under rotary and adaptive motion and compared the time to fracture rather than the NCF values of the files. Higuera *et al.*⁷ compared the resistance of Reciproc, WaveOne, and TF Adaptive systems to cyclic fatigue and determined that the rpm of adaptive motion was 400 rpm. They then calculated the NCF of the TF Adaptive files using this value.

During root canal preparation, NiTi files face different stresses inside the root canal because of various canal anatomies (different curves, etc.). In the presence of different rates of stress, the Elements Motor adjusts the number of rotations of the files, according to the rate of stress. As a result, the rpm values of the files change. For these reasons, in the present study, a camera capable of recording 240 frames per minute was used to record the rpm in the AM group, and the videos were recorded in 'MOV' format. The rpm values of the files were then determined by counting. According to the results of the present study, the NCF value of the files under adaptive motion was 345, which was lower than the value of 400 rpm reported by Higuera *et al.*⁷ We believe that the difference in the results was due to the variation in the tip diameter and taper of the file used in these two studies.

In the static cyclic fatigue test model, compressive and tensile stresses accumulate in one area because the file does not move axially (back and forth). These cumulative stresses induce microstructural changes in the file. Therefore, the cyclic fatigue tests in the present study were carried out using a dynamic test model in a stainless steel canal with a 60° curvature angle, 5 mm curvature radius, and 1.5 mm internal diameter, as done in many other studies.⁸⁻¹¹ The curvature center was located at 5 mm in the coronal of end of the artificial canal.

Although several studies have investigated the cyclic fatigue resistance of NiTi files used for root canal preparation,^{12,13} only a few studies have examined the cyclic fatigue resistance of NiTi files specifically produced for retreatment.¹⁴⁻¹⁶ Thus, in the present study, the D1 file of the ProTaper Universal Retreatment NiTi rotary file was used.

According to the results of the present study, the cyclic fatigue resistance of the AM group was significantly greater than that of the RM group ($p < 0.05$). Therefore, the null hypothesis was rejected. As there are no reports in the literature on the use of a high-speed camera, followed by the NCF counting method, to determine cyclic fatigue resistance, the results of the present study cannot be directly compared with those of other studies. In the literature, there is only one study of the effects of adaptive motion on the cyclic fatigue resistance of files.⁶ That study compared the time to fracture rather than the NCF values of the files and reported that adaptive motion significantly increased the resistance of the files to cyclic fatigue resistance, supporting the findings of the present

study. Previous studies showed that reciprocation motion increased the cyclic fatigue resistance of files compared to continuous rotational motion, regardless of the type of file.¹⁷⁻²¹ The results of those studies support our findings. We attribute the increased cyclic fatigue resistance of the files in the AM group to the Elements Motor, which changes the motion type from continuous rotation to reciprocation motion, depending on the level of stress.

Conclusion

Within the limitations of the present study, we conclude that the 'Adaptive motion' program significantly increases the resistance of the ProTaper Universal D1 file to cyclic fatigue fracture.

Orcid number

Taha Özyürek, 0000-0003-3299-3361

Conflict of Interest: No potential conflict of interest relevant to this article was reported.

References

1. Pruett JP, Clement DJ, Carnes DL Jr. Cyclic fatigue testing of nickel-titanium endodontic instruments. *J Endod* 1997;23:77-85.
2. Arens FC, Hoen MM, Steiman HR, Dietz GC Jr. Evaluation of single-use rotary nickel-titanium instruments. *J Endod* 2003;29:664-666.
3. Berutti E, Chianussi G, Paolino DS, Scotti N, Cantatore G, Castellucci A, Pasqualini D. Canal shaping with WaveOne Primary reciprocating files and ProTaper system: a comparative study. *J Endod* 2012;38:505-509.
4. Gambarini G, Testarelli L, De Luca M, Milana V, Plotino G, Grande NM, Rubini AG, Al Sudani D, Sannino G. The influence of three different instrumentation techniques on the incidence of postoperative pain after endodontic treatment. *Ann Stomatol (Roma)* 2013;4:152-155.
5. Giuliani V, Cocchetti R, Pagavino G. Efficacy of ProTaper universal retreatment files in removing filling materials during root canal retreatment. *J Endod* 2008;34:1381-1384.
6. Gambarini G, Glassman G. *In vitro* analysis of efficiency and safety of a new motion for endodontic instrumentation: TF Adaptive. *Roots* 2013;3:12-15.
7. Higuera O, Plotino G, Tocci L, Carrillo G, Gambarini G, Jaramillo DE. Cyclic fatigue resistance of 3 different nickel-titanium reciprocating instruments in artificial canals. *J Endod* 2015;41:913-915.
8. Li UM, Lee BS, Shih CT, Lan WH, Lin CP. Cyclic fatigue of endodontic nickel titanium rotary instruments: static and dynamic tests. *J Endod* 2002;28:448-451.
9. Lopes HP, Britto IM, Elias CN, Machado de Oliveira JC,

- Neves MA, Moreira EJ, Siqueira JF Jr. Cyclic fatigue resistance of ProTaper Universal instruments when subjected to static and dynamic tests. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2010;110:401-404.
10. Lopes HP, Elias CN, Vieira MV, Siqueira JF Jr., Mangelli M, Lopes WS, Vieira VT, Alves FR, Oliveira JC, Soares TG. Fatigue life of Reciproc and Mtwo instruments subjected to static and dynamic tests. *J Endod* 2013;39:693-696.
 11. Rodrigues RC, Lopes HP, Elias CN, Amaral G, Vieira VT, De Martin AS. Influence of different manufacturing methods on the cyclic fatigue of rotary nickel-titanium endodontic instruments. *J Endod* 2011;37:1553-1557.
 12. Elnaghy AM, Elsaka SE. Torsion and bending properties of OneShape and WaveOne instruments. *J Endod* 2015;41:544-547.
 13. Pedullà E, Lo Savio F, Boninelli S, Plotino G, Grande NM, La Rosa G, Rapisarda E. Torsional and cyclic fatigue resistance of a new nickel-titanium instrument manufactured by electrical discharge machining. *J Endod* 2016;42:156-159.
 14. Topçuoğlu HS, Topçuoğlu G, Aktı A. Comparative evaluation of cyclic fatigue resistance of D-RaCe and ProTaper retreatment instruments in curved artificial canals. *Int Endod J* 2016;49:604-609.
 15. Inan U, Aydin C. Comparison of cyclic fatigue resistance of three different rotary nickel-titanium instruments designed for retreatment. *J Endod* 2012;38:108-111.
 16. Hussne RP, Braga LC, Berbert FL, Bueno VT, Bahia MG. Flexibility and torsional resistance of three nickel-titanium retreatment instrument systems. *Int Endod J* 2011;44:731-738.
 17. Gambarini G, Gergi R, Naaman A, Osta N, Al Sudani D. Cyclic fatigue analysis of twisted file rotary NiTi instruments used in reciprocating motion. *Int Endod J* 2012;45:802-806.
 18. Gavini G, Caldeira CL, Akisue E, Candeiro GT, Kawakami DA. Resistance to flexural fatigue of Reciproc R25 files under continuous rotation and reciprocating movement. *J Endod* 2012;38:684-687.
 19. Shin CS, Huang YH, Chi CW, Lin CP. Fatigue life enhancement of NiTi rotary endodontic instruments by progressive reciprocating operation. *Int Endod J* 2014;47:882-888.
 20. Gambarini G, Rubini AG, Al Sudani D, Gergi R, Culla A, De Angelis F, Di Carlo S, Pompa G, Osta N, Testarelli L. Influence of different angles of reciprocation on the cyclic fatigue of nickel-titanium endodontic instruments. *J Endod* 2012;38:1408-1411.
 21. De-Deus G, Moreira EJ, Lopes HP, Elias CN. Extended cyclic fatigue life of F2 ProTaper instruments used in reciprocating movement. *Int Endod J* 2010;43:1063-1068.