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Comparison of Four Different Endodontic Rotary Systems in Terms of Cyclic Fatigue#

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Research Article

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History

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ABSTRACT

Objectives: The aim of this study was to compare four endodontic rotary systems in terms of cyclic fatigue.
Material and Methods: 25/08 Twisted File (TF), TF Adaptive, Reciproc and WaveOne rotary files were used to test the cyclic fatigue strength in this study. Four different artificial canals, compatible with the file size and taper, were created, with the curvature angle and radius of 45°-2 mm, 60°-2 mm, 45°-5 mm and 60°-5 mm, respectively. The front surface of the artificial canals was covered with a removable glass plate. The files were operated in the canals according to their own working principles until they fractured. The fracture time was determined by using a chronometer with 1/100 second accuracy and the cyclic fatigue strength was evaluated according to the time until fracture occurs. A total of 40 files, 10 in each canal, were used in each group. SPSS program was used for statistical analysis. Mann-Whitney U test was applied for pairwise comparisons. Bonferroni correction was applied and P< .008 was considered as statistically significant.
Results: In all canals, fracture time was the highest for Reciproc files, followed by WaveOne, TF Adaptive and TF files, respectively. For the canal curvature of 45°-2 mm, the Reciproc files were significantly more resistant to fracture than the others. While there was no significant difference between TF Adaptive and TF, WaveOne was significantly more resistant than both groups. In canals with the curvature of 60°-2 mm and 45°-5 mm Reciproc and WaveOne were significantly more resistant to fracture than TF Adaptive and TF. In addition, TF Adaptive was significantly more resistant than TF. For the curvature of 60°-5 mm, the difference between all groups was significant.
Conclusions: Regardless of the canal curvature, the Reciproc exhibited the highest cyclic fatigue strength, while the TF showed the lowest fatigue strength.

Keywords: Rotary File, Cyclic Fatigue, Continuous Rotation, Reciprocation, Adaptive Motion.

Dört Farklı Endodontik Döner Eğe Sisteminin Döngüsel Yorgunluk Açısından Karşılaştırılması#

Bilgi
#Bu çalışma 23-25 Kasım 2021 tarihleri arasında düzenlenen 'Sivas Cumhuriyet Üniversitesi 1. Uluslararası Diş Hekimliği Kongresi'nde sözlü bildiri olarak sunulmuştur.
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ÖZ

Amaç: Bu çalışmanın amacı dört endodontik döner eğe sisteminin döngüsel yorulma dayanımının karşılaştırılmasıdır.
Gereç ve Yöntemler: Çalışmamızda döngüsel yorulma dayanımını test etmek üzere 25/.08 Twisted File (TF), TF Adaptive, Reciproc ve WaveOne eğeler kullanıldı. Eğe boyutunu ve taperını taklit edecek şekilde, eğrilik açısı ve yarıçapı sırasıyla 45°-2 mm, 60°-2 mm, 45°-5 mm ve 60°-5 mm olan 4 farklı yapay kanal oluşturuldu. Yapay kanalların ön yüzeyi takılıp çıkarılabilir cam bir levha ile örtüldü. Eğeler kanallar içerisinde kendi çalışma prensiplerine göre kırılana kadar çalıştırıldı. 1/100 saniye hassasiyetinde bir kronometre yardımıyla kırılma süresi tespit edildi ve döngüsel yorulma dayanımı kırılma oluşana kadar geçen süreye göre değerlendirildi. Her grupta, her kanalda 10 adet olmak üzere toplam 40 eğe kullanıldı. İstatistiksel analiz için SPSS programı kullanıldı. İkili karşılaştırmalar için Mann-Whitney U testi yapıldı. İstatistiksel anlamlılık için Bonferroni düzeltmesi uygulandı ve P<0.008 istatistiksel olarak anlamlı kabul edildi.
Bulgular: Bütün kanallarda kırılma süresi Reciproc eğelerde en yüksek olup bunu sırasıyla WaveOne, TF Adaptive ve TF eğeler izledi. 45°-2 mm eğimli kanalda Reciproc eğeler kırılmaya karşı diğerlerine göre anlamlı derecede daha dayanıklıydı. TF Adaptive ile TF arasında anlamlı fark bulunmazken (P= .041), WaveOne her iki gruba göre anlamlı derecede daha dayanıklıydı. 60°-2 mm ve 45°-5 mm eğimli kanallarda Reciproc ve WaveOne, kırılmaya karşı TF Adaptive ve TF'ye göre anlamlı derecede daha dayanıklıydı (P< .001). Ayrıca TF Adaptive da TF'ye göre anlamlı derecede daha dayanıklıydı. 60°-5 mm eğimli kanalda ise bütün gruplar arasındaki fark anlamlıydı.
Sonuçlar: Kanal eğimine bağlı olmaksızın en yüksek döngüsel yorulma dayanımını Reciproc eğeler sergilerken, TF eğeler en düşük yorulma dayanımını gösterdi.

Anahtar kelimeler: Döner Eğe, Döngüsel Yorulma, Devamlı Rotasyon, Resiprokasyon, Adaptif Hareket

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Introduction

Nickel titanium (NiTi) rotary instruments has benefited endodontic practice by increasing speed and quality with reduced procedural errors in chemomechanical root canal preparation.[1,2] However, despite its obvious advantages, NiTi rotary instruments carry a high risk of fracture during use, especially in curved root canals, which adversely affects the prognosis of the treated tooth.[3]

The main causes of file fracture are cyclic fatigue and torsional fatigue. Cyclic fatigue occurs as a result of the repetitive compressive and tensile stress that the file is subjected, at the point of curvature while continuing to rotate freely in the canal. Torsional fatigue occurs when the tip of the file is locked in the root canal while the body of it continues to rotate.[4] Torsional fatigue can be predicted by signs of plastic deformation, whereas cyclic fatigue fractures occur with little or no plastic deformation.[5,6]

With the technological developments, new production techniques, different kinematics and advanced alloys that increase the cyclic fatigue resistance of NiTi files have come to the fore. [7] NiTi files produced with M-wire and R-phase technology have been shown to have higher cyclic fatigue resistance compared to conventional NiTi files.[8,9] It has also been suggested that reciprocating motion extends the life of files by increasing cyclic fatigue resistance compared to continuous rotation.[10,11]

Reciproc (VDW, Munich, Germany) is a single file system made of M-wire alloy, and works with reciprocation, 150° counterclockwise (CCW) and 30° clockwise (CW). It has three different sizes, R25, R40 and R50, the tip diameters and apical tapers of which are 25/.08, 40/.06 and 50/.05, respectively. These files have an S-shaped cross-section, a non-cutting tip, and sharp cutting edges.[12]

WaveOne (Dentsply Maillefer, Ballaigues, Switzerland) is another file system made of M-Wire alloy, that works with reciprocation (170° CCW-50° CW). It has three different sizes, Small, Primary and Large, with the tip diameters and tapers of 21/.06, 25/.08 and 40/.08, respectively.[13] The files have a modified convex triangular cross-section with radial areas in the apical, and a convex triangular cross-section without radial areas in the middle and coronal sections.[14]

Twisted File (TF; SybronEndo, Orange, CA, USA) system is produced by R-phase technology and shaped by bending. In addition, electrochemical surface polishing is applied to the surfaces of the files. TF system works with continuous rotation movement, and offers multiple file possibilities with different tip diameters and tapers. In addition, the cross-section of these files is triangular and they have a safe tip design.[15]

TF Adaptive file system (SybronEndo, Orange, CA, USA) works with adaptive motion. It performs interrupted continuous rotation (600°-0) when the file is subjected to little or no stress in the root canal. Depending on the stress that occurs during shaping, the system changes into reciprocation mode, reducing the risk of intra-canal failure. The reciprocation angles are not constant, and they vary from 600°-0 to 370°-50° depending on the anatomical difficulty and the intracanal stress on the file.[16] There are two file groups in this file system, SMALL (SM) and MEDIUM/LARGE (ML). The SM group includes files 20/.04, 25/.06 and 35/.04. The ML group consists of files numbered 25/.08, 35/.06 and 50/.04.

The aim of this study was to compare TF, TF Adaptive, WaveOne and Reciproc systems in terms of cyclic fatigue in curved root canals and to contribute to clinical practice in determining a reliable system for root canal shaping. The null hypothesis was that there was no difference in cyclic fatigue strength between file groups.

Materials and Methods

In the present study, TF 25/.08, Twisted File Adaptive ML-1, Reciproc R25 and WaveOne Primary files, each with 0.25 mm tip diameter and 8% taper, were used to test the cyclic fatigue strength. A custom-made static test device and artificial canals were prepared for this study by Karadeniz Technical University, Department of Mechanical Engineering.

Four different artificial canals imitating the size and taper of the files were prepared in a stainless steel block with the curvature angle and radius of 45°-2 mm, 60°-2 mm, 45°-5 mm and 60°-5 mm. The working length was 19 mm and the point of maximum curvature was 7 mm from the apex. The front surface of the artificial canals was covered with a removable glass plate so that the fracture of the file can be seen and the fractured piece can be removed easily (Figure 1).

Figure 1. The artificial root canals with the curvature angle and radius of 45°-2 mm, 60°-2 mm, 45°-5 mm and 60°-5 mm, respectively.

A total of 40 files, 10 for each canal, were used from each file group. WaveOne and Reciproc files were used with VDW Reciproc Silver (VDW GmbH, Munich, Germany) in WAVEONE ALL and RECIPROC ALL programs, respectively. TF and TF Adaptive files were used with Elements Motor (California, USA) in continuous rotation and adaptive programs, respectively. Each file was adjusted to the working length and placed in the test device. The artificial canal was filled with glycerine prior to insertion of each file to reduce friction and associated heat during testing. The file was operated in the artificial canal according to the manufacturer's instructions until the fracture occurred (Figure 2). A chronometer with an accuracy of 1/100 seconds was operated simultaneously with the endodontic motor and it was stopped as soon as the file fractured, and the fracture time was recorded.

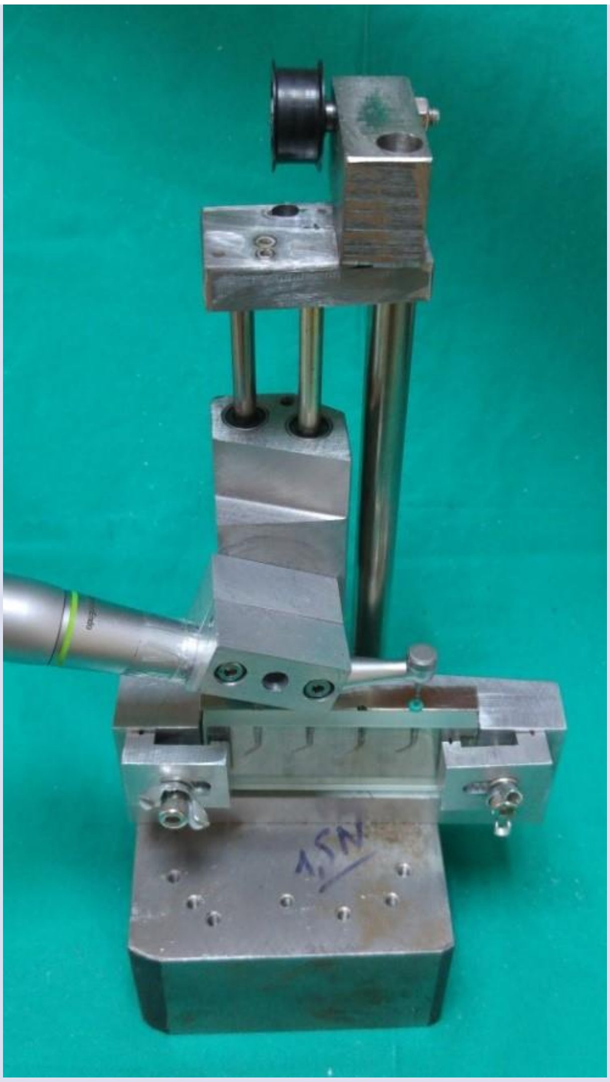

Figure 2. The cyclic fatigue test device

Statistical Analysis

SPSS (SPSS version 21.0; SPSS, IBM; Chicago, IL, USA) program was used in the statistical analysis. The distribution of the data was analyzed by applying the Shapiro-Wilk test. As the data weren't normally distributed, the Kruskal-Wallis test was applied. Mann-Whitney U test was used for pairwise comparisons. P<0.05 value was considered statistically significant. Bonferroni correction was applied for pairwise comparisons (P<0.008).

Results

The fracture time of the file groups for each artificial canal were given as mean, standard deviation, minimum and maximum values in Table 1-4.

In the artificial canals with the curvature angle and radius of 45°-5 mm and 60°-2 mm there was no significant difference between Reciproc and WaveOne (P=0.034 and P=0.070, respectively), and they exhibited significantly higher fatigue strength compared to TF Adaptive and TF groups (P<0.001). In addition, the TF Adaptive group was significantly more resistant to cyclic fatigue compared to the TF group (P<0.008) (Table 1, 2).

In the artificial canal with the curvature angle and radius of 45°-2 mm, the Reciproc group exhibited significantly the highest fracture time, thus the highest cyclic fatigue strength (P<0.008). This was followed by WaveOne, TF Adaptive and TF groups, respectively. The WaveOne group exhibited significantly higher fatigue strength than the TF Adaptive and TF groups (P<0.001). There was no significant difference between TF Adaptive and TF groups (P=0.041) (Table 3).

In the artificial canal with the curvature angle and radius of 60°-5 mm, the Reciproc group exhibited the highest fracture time (P<0.001). This was followed by WaveOne, TF Adaptive and TF groups, respectively. The difference was statistically significant between all groups (P<0.008) (Table 4).

Discussion

While it is ideal to perform cyclic fatigue test on curved canals of extracted human teeth, each file should be tested on a different tooth as the root canal shape will change during preparation. For this reason, standardization of the experimental conditions is difficult because the canal structure of each tooth is different from each other.[17] Therefore, artificial canals imitating the size and taper of the file have been used instead of human teeth.[18] These allow the files to follow a constant and repeatable path in accordance with the determined curvature values, and to be compared with each other under standard conditions.[19] So, in the present study the cyclic fatigue test was performed on artificial canals reflecting file size and taper.

There is a positive correlation between file fractures caused by cyclic fatigue and the curvature angle of the root canal.[20] The root canals with a curvature angle of more than 30° are considered difficult.[21] To date, different values of curvature radius, such as 2 mm, 5 mm or 10 mm used for cyclic fatigue test, and it has been reported that the radius of curvature also affects the cyclic fatigue of NiTi files. The cyclic fatigue strength of the files decreases as the radius decreases.[20,22-24] In addition, in most of the studies in the literature, the center of the curvature was determined at a distance of 5-7 mm from the file tip.[4] Considering these literature data, the curvature angles of the artificial canals were determined as 45° and 60°, and the curvature radii were determined as 2 mm and 5 mm in the present study. Thus, we used four different artificial canals, from the most difficult to the easiest, with the curvature angle and radius of 60°-2 mm, 60°-5 mm, 45°-2 mm and 45°-5 mm, respectively. And it was found that as the severity of the canal increased, the time to fracture of the files was decreased in all experimental groups.

Table 1. Fracture time values in the canal with the curvature of 45°-5 mm (sec)

Groups	Mean	Standard Deviation (±)	Minimum	Maximum
Reciproc	402.03[a]	74.51	265.05	518.32
WaveOne	319.78[a]	59.64	254.38	453.61
TF daptive	113.30[b]	15.08	93.89	144.28
Twisted File	81.66[c]	9.38	66.98	99.09

Superscripts with different letters indicate statistical significance (P<0.008)

Table 2. Fracture time values in the canal with the curvature of 60°-2 mm (sec)

Groups	Mean	Standard Deviation (±)	Minimum	Maximum
Reciproc	154.28[a]	33.03	98.55	200.15
WaveOne	131.41[a]	30.90	89.11	199.45
TF Adaptive	66.28[b]	11.52	43.97	82.71
Twisted File	51.88[c]	7.63	43.27	71.31

Superscripts with different letters indicate statistical significance (P<0.008)

Table 3. Fracture time values in the canal with the curvature of 45°-2 mm (sec)

Groups	Mean	Standard Deviation (±)	Minimum	Maximum
Reciproc	285.49[a]	56.43	232.83	395.04
WaveOne	217.15[b]	33.60	174.92	267.67
TF Adaptive	86.29[c]	13.45	67.32	108.73
Twisted File	71.31[c]	14.50	53.24	93.23

Superscripts with different letters indicate statistical significance (P<0.008)

Table 4. Fracture time values in the canal with the curvature of 60°-5 mm (sec)

Groups	Mean	Standard Deviation (±)	Minimum	Maximum
Reciproc	208.62[a]	19.99	171.14	252.34
WaveOne	156.80[b]	25.44	110.25	188.68
TF Adaptive	77.67[c]	15.09	56.23	107.06
Twisted File	58.44[d]	13.60	37.11	73.77

Superscripts with different letters indicate statistical significance (P<0.008)

To date, in cyclic fatigue studies, the time to fracture or the number of cycles until fracture (NCF) is used for the evaluation of fatigue resistance.[25,26] The NCF is calculated by multiplying the time to fracture (seconds) by 1/60 of the rotation per minute (NCF= time x rpm/60) However, in adaptive motion it is difficult to calculate the NCF accurately, as the operating mode and rpm value is modified according to the canal anatomy and the stress on the file.[27] Therefore, in the present study, the cyclic fatigue was compared according to the time to fracture.

The studies evaluated cyclic fatigue strength of NiTi rotary files have revealed that kinematics significantly affects the cyclic fatigue. Completing 360° rotations in 1 cycle in continuous rotation movement leads to increased stress on the file and further expansion of the surface cracks. The tensile stresses concentrate at a certain point of the file and cause the file to fracture.[28] In the reciprocating motion, since the full rotation is completed with more than one cycle, the stress is distributed to different points on the working part of the file and reduces the opening of surface cracks.[29] In addition, since the progression angle of each reciprocating system is determined not to exceed the elastic limit of the file, this movement increases the resistance against torsional and cyclic fractures.[30]

Castello-Escriva *et al.* compared the cyclic fatigue strength of 25/.08 size ProTaper F2, WaveOne and TF files and concluded that reciprocating WaveOne files exhibited higher fatigue strength than TF and ProTaper files with continuous rotation.[31] In addition, Kim *et al.* evaluated the cyclic fatigue of ProTaper F2, Reciproc and WaveOne files, and reported that Reciproc files exhibited the highest fatigue strength and both reciprocation systems were significantly more resistant to cyclic fatigue compared to ProTaper F2.[13] Consistent with these studies, it was revealed in the present study that Reciproc and WaveOne groups exhibited significantly higher cyclic fatigue strength compared to TF group in all artificial canals, supporting that cyclic fatigue strength is higher in reciprocating motion than in rotational motion. Thus, the null hypothesis was rejected.

Pedulla *et al.* evaluated the cyclic fatigue of Reciproc R25, WaveOne Primary, Mtwo (25/.06) and TF (25/.06) files used with Reciproc ALL, WaveOne ALL and continuous rotation mode, in an artificial canal with the curvature angle and radius of 60°-5 mm.[32] It was determined that both reciprocation modes significantly increased the fatigue strength compared to the rotation mode, in line with other studies. However, when each system was used with its own movement, it was found that TF group with rotation movement exhibited the greatest fatigue strength, followed by Reciproc, Mtwo and WaveOne files, respectively. While there was no significant difference between TF, Reciproc and Mtwo, cyclic fatigue strength was found to be significantly lower in the WaveOne group compared to the others. These findings contradict our study. The difference between the two studies can be attributed to the taper of the files used. In the study of Pedulla *et al.*, 06 tapered TF files were compared with 08 tapered WaveOne and Reciproc files, while all files compared in the present study were 08 tapered. The files with smaller cross-sections are expected to show greater resistance to cyclic fatigue because they are more flexible.[17] So, the longer fatigue life of TF files despite their rotational motion might have been due to their smaller cross-sectional area.

The progression angle of reciprocation also affects the cyclic fatigue of NiTi files. An increase in the progression angle decreases the cyclic fatigue strength.[33,34] In the present study, Reciproc and WaveOne groups exhibited reciprocation movements of 150° CCW-30° CW and 170° CCW-50° CW, respectively, and both had a progression angle of 120°. As the adaptive movement adapts automatically to the stress that occurs in the root canal during preparation, no clear information can be obtained about the progression angle in TF Adaptive group. However, as the angle of adaptive motion varies from 600°-0 to 370°-50°, in the present study the progression angle of TF Adaptive group was expected to be higher than that of the Reciproc and WaveOne groups. Therefore, the lower fatigue strength of the TF Adaptive group compared to the Reciproc and WaveOne groups may be attributed to the higher progression angle.

Higuera *et al.* compared the cyclic fatigue strength of TF Adaptive M-L1, Reciproc R25 and WaveOne Primary files in a stainless steel artificial canal with the curvature angle and radius of 60°- 5 mm, using each group with its specific kinematic. [35] According to the findings of this study, the TF Adaptive M-L1 group exhibited the highest fatigue strength and followed by the Reciproc R25 group, with no significant difference between them. The WaveOne Primary group, on the other hand, exhibited significantly lower fatigue strength than the other groups. Our findings are not compatible with the findings of this study. The difference in the results of these two studies can be attributed to the evaluation parameter used. While fracture time values were used for analysis in the present study, NCF was used in Higuera *et al.*'s study. In addition, there is no information about the location of the curvature center, showing the maximum stress point, in Higuera *et al.*'s study. In the artificial canals used in the present study, the center of curvature was adjusted to be 7 mm away from the apex. The location of the center of curvature is an important parameter for cyclic fatigue, as the fatigue strength decreases as the file diameter at the maximum stress point increases.[24]

Özyürek *et al.* also compared the cyclic fatigue strength of TF Adaptive ML-1, Reciproc R25 and WaveOne Primary files according to NCF in an artificial canal with a curvature angle and radius of 60°- 5 mm.[36] During the test, they detected the real rpm values of the files by recording a slow-motion video with a high speed camera, and these values were used for calculating NCF. In conclusion, unlike Higuera *et al.* they obtained similar results with our study.

In a study on Reciproc and WaveOne files, Plotino *et al.* found that Reciproc files exhibited significantly greater cyclic fatigue strength and stated that this result could be associated with the smaller metal mass of Reciproc files at the maximum stress point. [37] Kim *et al.* compared Reciproc R25, WaveOne Primary and ProTaper F2 files, and they reported that both reciprocating systems were more durable than ProTaper, and Reciproc R25 files showed higher fatigue strength compared to WaveOne files. As a further evaluation, the authors measured the cross-sectional area of each file at the D5 level and found that WaveOne files had the highest cross-sectional area (323,000 μm^2), and Reciproc files the lowest (275,000 μm^2). In line with these findings, they attributed the high fatigue strength of Reciproc files to their S-shaped design and small cross-sectional area at the point of maximum curvature.[13] Additionally, Sekar *et al.* examined the effect of cross-sectional design on fatigue strength in files used with reciprocating motion, and found that S-shaped Mtwo files exhibited higher fatigue strength compared to Revo-S SU with triple helical cross-section, and OneShape with the cross section of triple helical in apical and S-shaped in coronal.[38] Consistent with these studies, the higher fatigue strength of Reciproc group compared to WaveOne, can be attributed to their S-shaped cross-section and smaller cross-sectional area at the point of maximum curvature.

Conclusions

Within the limitations of our study; reciprocation (Reciproc, WaveOne) was found to be related with higher fatigue strength compared to rotational motion (TF), and files with higher progression angle (TF Adaptive) exhibited lower fatigue strength. It was also determined that the cross-sectional design of the files, as well as the kinematics, could be effective on their cyclic fatigue strength.

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