

## Research Article



# Comparison of cyclic fatigue life of nickel-titanium files: an examination using high-speed camera

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### Conflict of Interest

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

### Author Contributions

Conceptualization: Özyürek T; Data curation: Keskin NB, Furuncuoğlu F; Formal analysis: Özyürek T; Funding acquisition: Özyürek T, Keskin NB, Furuncuoğlu F; Investigation: Özyürek T; Methodology: Özyürek T, Keskin NB, Furuncuoğlu F; Project administration: Özyürek T; Resources: Özyürek T, Keskin NB, Furuncuoğlu F; Software: Özyürek T; Supervision: Özyürek T, İnan U; Validation: Özyürek T, Keskin NB, Furuncuoğlu F; Visualization: Özyürek T; Writing - original

## ABSTRACT

**Objectives:** To determine the actual revolutions per minute (rpm) values and compare the cyclic fatigue life of Reciproc (RPC, VDW GmbH), WaveOne (WO, Dentsply Maillefer), and TF Adaptive (TFA, Axis/SybronEndo) nickel-titanium (NiTi) file systems using high-speed camera.

**Materials and Methods:** Twenty RPC R25 (25/0.08), 20 WO Primary (25/0.08), and 20 TFA ML 1 (25/0.08) files were employed in the present study. The cyclic fatigue tests were performed using a dynamic cyclic fatigue testing device, which has an artificial stainless steel canal with a 60° angle of curvature and a 5-mm radius of curvature. The files were divided into 3 groups (group 1, RPC R25 [RPC]; group 2, WO Primary [WO]; group 3, TF Adaptive ML 1 [TFA]). All the instruments were rotated until fracture during the cyclic fatigue test and slow-motion videos were captured using high-speed camera. The number of cycles to failure (NCF) was calculated. The data were analyzed statistically using one-way analysis of variance (ANOVA,  $p < 0.05$ ).

**Results:** The slow-motion videos were indicated that rpm values of the RPC, WO, and TFA groups were 180, 210, and 425, respectively. RPC ( $3,464.45 \pm 487.58$ ) and WO ( $3,257.63 \pm 556.39$ ) groups had significantly longer cyclic fatigue life compared with TFA ( $1,634.46 \pm 300.03$ ) group ( $p < 0.05$ ). There was no significant difference in the mean length of the fractured fragments.

**Conclusions:** Within the limitation of the present study, RPC and WO NiTi files showed significantly longer cyclic fatigue life than TFA NiTi file.

**Keywords:** Cyclic fatigue life; Reciproc; WaveOne; TF Adaptive; Slow motion

## INTRODUCTION

Nickel-titanium (NiTi) rotary file systems are widely utilized in root canal preparation because of their high-level cutting capabilities and flexibility [1]. Despite the advantages of NiTi files, the most important problem seen in NiTi rotary file systems is the unexpected file fractures during clinical use due to cyclic or torsional stress [2,3]. Depending on the use of files, the pressures and stresses on files cause fatigue, and the fatigue causes file fracture without any prior sign [4]. The fractured files stuck in the root canals might negatively affect the prognosis of root canal treatment [5].

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Some of the factors causing fracture in NiTi files are the file design, the speed and torque of use, the type of alloy used [6], angle and radii of the canal curvature [7], and number of use [8]. The kinematic of NiTi files has been shown to be important factor for cyclic fatigue life of NiTi files, and specifically the reciprocation motion has been reported to increase the cyclic fatigue life of NiTi files [9]. For this purpose, the reciprocating file systems have been developed in order to improve the performance and reliability of NiTi files [10]. Reciproc (RPC; VDW GmbH, Munich, Germany) and WaveOne (WO; Dentsply Maillefer, Ballaigues, Switzerland) are the most popular ones among the single file reciprocating systems. Both RPC and WO files made of M-Wire alloy (M-Wire Electrical Ltd., Preston, UK) were shown to be more resistant to cyclic fatigue than the file systems having continuous rotation motion [11-13].

Twisted File Adaptive (TFA; Axis/SybronEndo, Orange, CA, USA) is another NiTi file systems that uses both reciprocation and continuous rotation motions on its own endodontic motor (Elements Motor, Axis/SybronEndo). The movement depends on the stress rate in the canal that the file faces. When there is no stress on the file, the file rotates 600° clockwise and stops and then restarts again in the clockwise direction. When the stress rate on the file increases, the microprocessors in the Elements Motor calculates the rate of the stress and modifies the movement rotation to reciprocation up to 370° clockwise and 50° counterclockwise according to the stress rate on the file [14].

In literature review, there were only 2 studies comparing the cyclic fatigue life of NiTi files using high-speed camera [15,16]. But none of these studies were on the cyclic fatigue life of RPC and WO NiTi files. For this reason, the objective of the present study was to determine the actual revolutions per minute (rpm) values and compare the cyclic fatigue life of RPC, WO, and TFA NiTi file systems. The null hypothesis of present study was that there would be no difference between the cyclic fatigue lives of tested NiTi file systems.

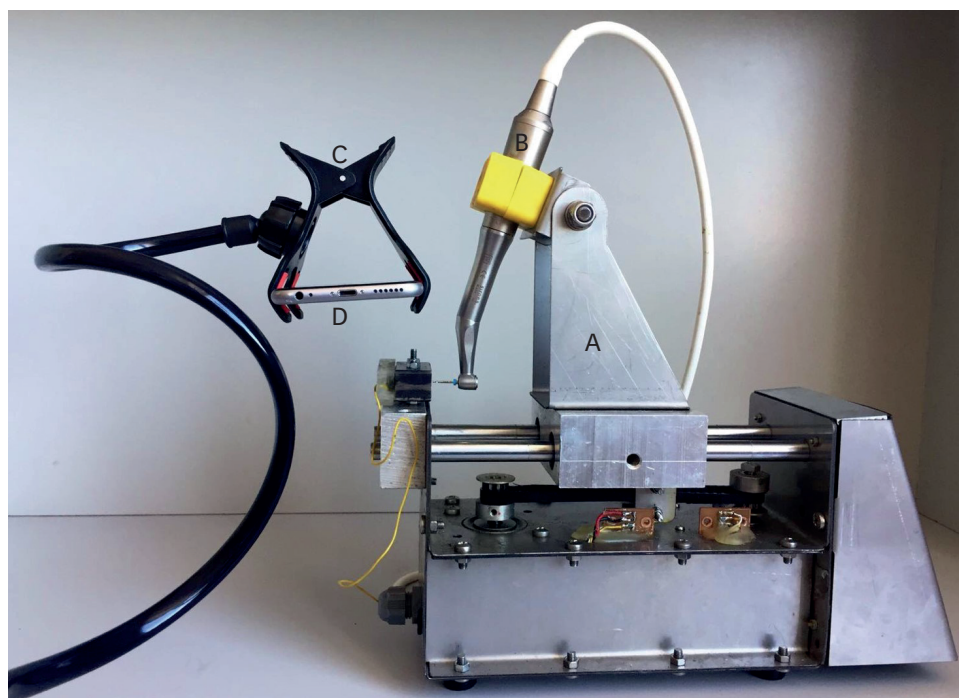
## MATERIALS AND METHODS

Twenty TFA ML 1 (25/0.08), 20 RPC R25 (25/0.08), 20 WO Primary (25/0.08) files were included to the present study. Before starting the cyclic fatigue test under dynamic model, the files were checked under stereomicroscope (Olympus BX43, Olympus Co., Tokyo, Japan) with ×20 magnification in order to determine whether any deformation exists on file surfaces or not.

Cyclic fatigue tests were performed using custom-made dynamic cyclic fatigue testing device (**Figure 1**). The device has an artificial canal with 60° angle of curvature and 5 mm radii of curvature. The canal inner diameter is 1.5 mm and its curvature center is located at the coronal 5 mm from the end of the artificial canal. The files were divided into 3 groups ( $n = 20$ /each) and the following procedures were performed:

Group 1. RPC R25 (RPC group): The files in this group were used with VDW Reciproc Gold (VDW GmbH) endodontic motor that connected to dynamic cyclic fatigue testing device. Files were operated in 'RECIPROC ALL' program according to the manufacturer's recommendations until the fracture occurred.

Group 2. WO Primary (WO group): The files in this group were used with VDW Reciproc Gold (VDW GmbH) endodontic motor that connected to dynamic cyclic fatigue testing device. Files were operated in 'WAVEONE ALL' program according to the manufacturer's recommendations until the fracture occurred.



**Figure 1.** Image of custom-made dynamic cyclic fatigue testing device. (A) Main device; (B) Micro-motor; (C) Camera holder; (D) Camera.

Group 3. TF Adaptive ML 1 (TFA group): The files in this group were used with Elements Motor (Axis/SybronEndo) that connected to dynamic cyclic fatigue testing device. Files were operated in 'TF Adaptive' program according to the manufacturer's recommendations until the fracture occurred.

Back and forth movement of the file in axial direction inside the artificial canal was set to 3 mm/sec to simulate clinical usage. In order to reduce the effect of friction of the canal files on the artificial canal walls and facilitate their rotation, synthetic oil (WD-40 Company, Milton Keynes, England) was used as lubricant. When the files fractured, the device automatically stopped and the time on the device's screen in seconds was recorded. Moreover, while performing the cyclic fatigue test in all of the groups, a device (iPhone 6 Plus, Apple Inc., Cupertino, CA, USA) that could record slow-motion video was mounted on the cyclic fatigue test device. The camera was mounted on the top of artificial canals in order to easily detect the files motion. Then the slow-motion videos were recorded in QuickTime movie format (MOV) until the fracture occurred [15,16]. The obtained video records were transferred to computer environment. The video records were converted into 1 minute videos. Because the recording device (iPhone 6 Plus) could capture 240 frame per second (fps), the video lengths correspond to 8 minutes of slow-motion videos. Then 8-minute slow-motion videos for each group were counted by 3 different observers to determine the rpm values of the tested NiTi files. In calculating the number of cycles to failure (NCF), the counted rpm values were used. The NCF for each file was calculated using formula:  $NCF = rpm \times time (sec)/60$ . The length of the fractured file tip was measured by using a digital micro-caliper (Mitutoyo, Kawasaki, Japan).

A total of 6 pieces of fractured files, 2 pieces from each group, were examined with a scanning electron microscope (SEM) device (JSM-7001F, JEOL, Tokyo, Japan) to determine fracture types of the files and photomicrographs were taken from the fractured surfaces under different magnifications.

### Statistical analysis

The data were first verified with Shapiro-Wilk test for normality of the data distribution. Then statistical analyses of the cyclic fatigue resistance data were analyzed using one-way analysis of variance (ANOVA) SPSS version 21.0 (IBM-SPSS Inc., Chicago, IL, USA). The statistical significant level was set at  $p < 0.05$ .

## RESULTS

The slow-motion videos were indicated that the rpm values of the RPC, WO, and TFA groups were 180, 210, and 425, respectively (**Table 1**). The mean and standard deviations of the cyclic fatigue resistance for each group are presented in **Table 1**. RPC ( $3,464.45 \pm 487.58$ ) and WO ( $3,257.63 \pm 556.39$ ) groups had significantly longer cyclic fatigue life compared with TFA ( $1,634.46 \pm 300.03$ ) group ( $p < 0.05$ ).

The mean length of the fractured segment was also recorded in order to evaluate the correct positioning of the tested instrument inside the canal curvature and whether similar stresses were being induced. There was no significant difference in the mean length of the fractured fragments ( $p > 0.05$ , **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 2**).

## DISCUSSION

According to the results of the present study, NCF values of RPC and WO groups were significantly higher than TFA group. For this reason, the null hypothesis of present study was rejected.

Standard artificial canals in cyclic fatigue studies are useful from the aspect of minimizing the other factors that may affect the results. For this reason, the standard artificial canals made of stainless steel were employed in the present study [15]. The SEM images were captured from the fractured surfaces of the tested files to determine fracture types of the files. All the images confirmed that the tested files fractured due to the cyclic fatigue. Moreover, the mean lengths of the fractured segments in all the groups did not show any significant difference. This showed that the tested instruments were correctly positioned within the canal curvature and also demonstrated that similar stresses were being induced.

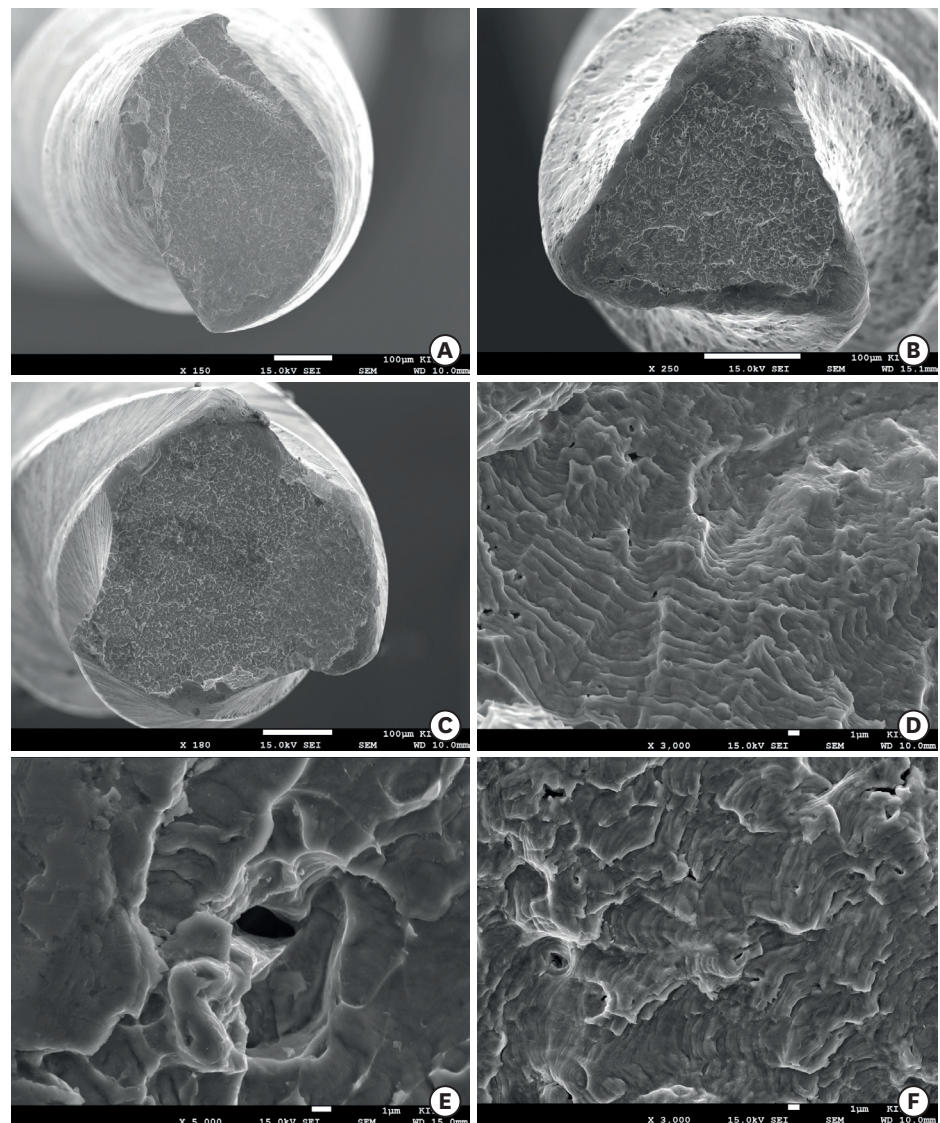
In corroboration with the results of present study, previous studies reported that the cyclic fatigue life increased as the difference between clockwise and counterclockwise

**Table 1.** Number of cycles to failure (NCF), fracture length (FL), and revolutions per minute (rpm) values of 3 groups during dynamic cyclic fatigue test

Group	NCF	FL	rpm value
RPC R25	$3,464.45 \pm 487.58^b$	$5.12 \pm 1.43^a$	180
WO Primary	$3,257.63 \pm 556.39^b$	$4.92 \pm 1.12^a$	210
TF Adaptive ML 1	$1,634.46 \pm 300.03^a$	$5.03 \pm 1.04^a$	425
<i>p</i> value	$< 0.05$	$> 0.05$	-

Different superscript letters were statistically significant ( $p < 0.05$ ). The values are means  $\pm$  standard deviations.





**Figure 2.** Scanning electron microscopic appearances of the Reciproc (RPC; VDW GmbH, Munich, Germany), WaveOne (WO; Dentsply Maillefer, Ballaigues, Switzerland), and TF Adaptive (TFA; Axis/SybronEndo, Orange, CA, USA) files after cyclic fatigue testing. General view of (A) RPC; (C) TF Adaptive; (E) WO and high-magnification view of (B) RPC; (D) TF Adaptive; (F) WO instruments showing fatigue striations typical of cyclic fatigue (arrows).

rotation angles (reciprocation angle) decreased in reciprocation motion [17,18]. Similarly, Arslan *et al.* [19] compared the cyclic fatigue resistances of RPC R25 files with different reciprocation angles and authors reported that the cyclic fatigue life of file groups having lower reciprocation angle was longer than the other groups. We believe that the significantly shorter cyclic fatigue life of TFA file might be due to the higher reciprocation angles of the TFA file, because reciprocation angle of RPC and WO files used in present study were lower than the TFA file.

On the contrary with the results of present study, Plotino *et al.* [20] and da Frota *et al.* [21] compared the cyclic fatigue resistances of RPC and WO file systems and then reported the RPC files to be more resistant to cyclic fatigue than WO. Scelza *et al.* [22] compared the cyclic fatigue resistances of RPC R25 and WO Primary file systems, and reported that RPC files had

higher cyclic fatigue resistance than WO files in both of dynamic and static models. Similarly, De-Deus *et al.* [23] compared the cyclic fatigue resistances of RPC R40 and WO Large NiTi file systems under dynamic and static models, and then reported that RPC R40 files had higher cyclic fatigue resistance values than WO Large files had. The reason for the difference from present study can be attributed to the difference between the methods used in calculating the NCF values. Researchers reported the rpm values to be 300 for RPC files and 350 for WO files [20,21]. But, in the present study, the slow-motion video records revealed that rpm value of RPC files was 180 and that of WO files was 210.

In the literature, there is no exact information on the rpm values of 'RECIPROC ALL' and 'WAVEONE ALL' programs of VDW Reciproc Gold (VDW GmbH) endodontic motor and 'TF Adaptive' program of Elements Motor (Axis/SybronEndo). Shin *et al.* [18] compared the cyclic fatigue resistances of Twisted File (TFA, Axis/SybronEndo) files under rotary and adaptive motion; authors used the duration to fracture instead of NCF values while comparing the groups, and reported that the adaptive motion significantly increased the TF cyclic fatigue resistance. Higuera *et al.* [24] compared the cyclic fatigue resistances of RPC, WO, and TFA systems; authors reported the rpm value of adaptive motion to be 400, and calculated the NCF value of TFA system by using this value. Since different stress rates will occur on the files in different canal anatomies under adaptive motion, Elements Motor will modify the rpm values of files according to this stress rate. For these reasons, while testing the TFA files under adaptive motion in dynamic cyclic test device, the slow-motion videos were captured using a device that is capable of capturing 240 fps video in MOV format; the actual rpm values of the files (425 rpm) were determined. According to the results of present study, the actual rpm value of files under adaptive motion was found to be 425. The findings of previous study corroborate this result [16]. Keskin *et al.* [16] used the same NiTi file (TFA 25/0.08) with the same dynamic cyclic fatigue device; they stated that the rpm value of the file was 425. This result is higher than the result of previous findings (400 rpm). We believe that the reason for this is the change in the number of rotation of Elements Motor in each of artificial canals. On the contrary with the results of the present study, Higuera *et al.* [24] compared the cyclic fatigue resistances of RPC, WO, and TFA systems and reported that RPC and TFA file systems had higher resistance to cyclic fatigue than WO files. The difference between rpm values can be considered as the reason for this difference.

## CONCLUSIONS

Within the limitation of the present study, the actual rpm values of the RPC, WO, and TFA groups were found to be 180, 210, and 425, respectively. Moreover, cyclic fatigue life of RPC and WO NiTi files was significantly longer than TFA NiTi file.

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