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Research Article

The Effects of Adaptive Motion on Cyclic Fatigue Resistance of Twisted Files

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Abstract

Aim: To evaluate the cyclic fatigue resistance of TF Adaptive 25.08 files in a dynamic model under continuous rotation movement and adaptive motion.

Materials and Methods: Forty pieces of TF Adaptive (25.08) files were included in the study. The cyclic fatigue tests were performed using a specially manufactured dynamic cyclic fatigue-testing device, which have an artificial stainless steel canal with 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 movements of the files until the files broke were recorded in "MOV" format, using a device with a slow-motion camera. The number of cycles to failure (NCF) was calculated for each group. The data were analyzed statistically ($P < .05$).

Results: There were no significant difference between the cyclic fatigue resistances of the adaptive motion group (1612.14 ± 218.90) and the rotary motion (1539.50 ± 257.16) group ($P > .05$).

Conclusion: Within the limitation of the present study, adaptive motion did not significantly increase the cyclic fatigue resistance of TF 25.08 files compared to that of continuous rotational motion.

Keywords: Cyclic fatigue; Dynamic model; TF Adaptive; Kinematic; Endodontics

Introduction

Root canal instruments made of nickel-titanium (NiTi) were first used in 1988 [1]. Thanks to their greater flexibility compared with conventional files manufactured from stainless steel. NiTi canal instruments are commonly used in endodontic treatments. Although NiTi instruments are stronger and more flexible than stainless steel instruments, they are vulnerable to fracture within the root canal during root canal treatment. The latter is a major disadvantage of NiTi instruments.

Two factors can cause fracture of endodontic rotary instruments: torsional fracture and cyclic fatigue [2,3]. Torsional fracture occurs when the tip or any part of the instrument is locked in a canal, while the shaft continues to rotate, as the elastic limit of the metal is exceeded, causing plastic deformation. Cyclic fatigue occurs in response to continuous rotation of an instrument in a curved canal space. At the time of cyclic fatigue, the opposing sides of the instruments are subjected to alternating tensile and compressive stresses. Work hardening and metal fatigue cause this type of fracture. NiTi instruments may show no visible signs of permanent deformation, and the instrument mat break unexpectedly [4].

The use of materials with superior mechanical properties or using instruments with different motions may help prevent cyclic fatigue [5]. If the highest areas of stress coincide with machining marks or miniature grooves formed during the manufacturing process, the strength of the file is particularly poor [6]. Machining also produces microcracks and tool marks that are thought to be crystalline dislocation centers. These may induce fracture propagation and result in the degradation of the mechanical properties of NiTi [7].

The manufacturing technique used to produce twisted files (TF; SybronEndo, Orange, CA, USA) differs from that used to produce other types of files. In the fabrication of twisted files, basic austenite NiTi wire is transformed into R-phase NiTi wire (premartensitic) by a process of heating and cooling. As R-phase NiTi wire is not amenable to grinding, mechanical twisting is necessary to produce the desired form. After the twisted shape is formed, a series of heating and cooling steps transform the twisted R-phase wire back to an austenite crystalline structure, which becomes super elastic when stressed [5].

The TF Adaptive (SybronEndo) system uses a combination of continuous and reciprocation motion. When the amount of stress on the file is minimal, the file uses continuous rotation. When it encounters dentin and a load is applied, it uses reciprocal motion. The manufacturer claims that this adaptive motion and twisted file design increase the flexibility of the instrument and allows the file to adjust to intracanal torsional forces, according to the amount of pressure load on the file [8].

The aim of the present study was to evaluate the cyclic fatigue resistance of TF Adaptive 25.08 files in a dynamic model under continuous rotation movement and adaptive motion. The null hypothesis tested was that the cyclic fatigue resistance of the TF Adaptive 25.08 files would be the same, irrespective of the type of motion that was used.

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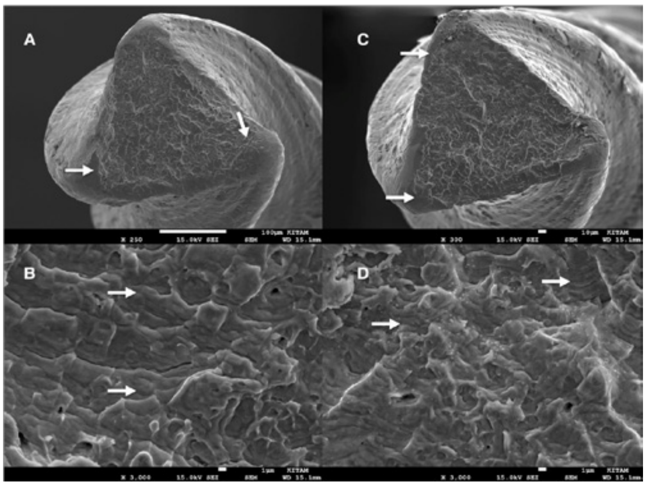

Figure 1: SEM appearances of the TF Adaptive 25.08 files after cyclic fatigue testing. General view of TF Adaptive 25.08 instrument with crack origins (A-C; white arrows) High-magnification view TF Adaptive 25.08 instrument showing fatigue striations typical of cyclic fatigue (B-D; white arrows) (A-B: Rotary motion group; C-D: Adaptive motion group).

Materials and Methods

Forty pieces of TF Adaptive (25.08) files were included in the study. Prior to the cyclic fatigue test under the dynamic model, all the files were checked under a stereomicroscope (Olympus BX43, Olympus Co., Tokyo, Japan), with 20× magnification to determine whether deformation existed on their surfaces.

The cyclic fatigue tests were performed using a specifically designed dynamic cyclic testing device. The device has an artificially prepared canal, with a 60° curvature angle and 5 mm curvature radius. The inner diameter of the canal is 1.5 mm, and its curvature center is located at the coronal 5 mm from the apical. The files were randomly divided into two groups (n = 20), and the following procedures were performed:

Group 1: Rotary motion (RM)

The files were used with an Elements Motor (Axis/SybronEndo, Orange, CA, USA), connected to the dynamic cyclic fatigue-testing device, and operated according to the manufacturer's recommendations at 500 rpm and 400 gcm-1 torque values until they fractured.

Group 2: Adaptive motion (AM)

The files were used with the "TF Adaptive" program, using the Elements Motor connected to the dynamic cyclic fatigue-testing device until they fractured.

A device (iPhone 6 Plus; Apple Inc., Cupertino, CA, USA) with a camera capable of shooting videos in slow-motion was mounted on the cyclic fatigue test device, and the motions of the files in the AM group during the cyclic fatigue test were recorded in MOV format. The images obtained were then transferred to a computer. To calculate the number of cycles to failure (NCF), three different observers counted the rpm in 60 seconds of slow-motion video.

The back and forth movement of the file in the axial direction inside the canal was set to 3 mm/sec to stimulate clinical usage. To reduce the effect of friction of the files on the artificial canal walls and facilitate their rotation, synthetic oil (WD-40 Company; Milton Keynes, England) was used as a lubricant. When the files broke under cyclic fatigue, the device automatically stopped, and the time on the device screen in seconds was recorded. The NCF for each file was calculated using the following formula: (NFC = rotation speed (rpm) × time (sec)/60).

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

Statistical analysis

The normality of the data distribution was first verified with a Shapiro–Wilk test. The cyclic fatigue resistance data were analyzed using a Student's t-test (SPSS 21.0; IBM-SPSS Inc., Chicago, IL, USA). The statistical significant level was set at $P < .05$.

Results

According to the video recordings, the rpm of the AM group was 425 rpm. The mean and standard deviations of the cyclic fatigue resistance for each group are presented in Table 1. The cyclic fatigue resistance of the AM (1612.14 ± 218.90) group was higher than that of the RM (1539.50 ± 257.16) group, but the difference was not statistically significant ($P > .05$).

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 1).

Discussion

The aim of the present study was to compare the cyclic fatigue resistance of TF Adaptive 25.08 files under adaptive and rotary motion. Various studies have examined the number of cycles of files per minute under adaptive motion. In a study of the cyclic fatigue resistance of the Twisted File (TF; Axis/SybronEndo, Orange, CA, USA) under rotary motion and adaptive motion, Gambarini and Glassman [9] compared the time to failure rather than the NCF and reported that the adaptive motion significantly increased the resistance to cyclic fatigue. Higuera et al., [10] compared the cyclic fatigue resistance of Reciproc, WaveOne, and TF Adaptive systems and reported that the NCF was 400 rpm under adaptive motion. The authors then calculated the NCF of TF Adaptive files using this value. Different stresses occur in different canal anatomies of the files during adaptive motion. The Elements Motor varies the rotation levels of the files according to the level of stress. Thus, the rpm of the files varies during adaptive motion. For these reasons, in the present study, in the dynamic cyclic test device under adaptive motion, the rpm of the TF Adaptive files were recorded with a camera capable of taking 240 frames/min. The videos were recorded in "MOV" format. According to the findings of the present study, the rpm of the files was 425 rpm. This value is higher than the previously reported value (400 rpm) [10]. We believe that the discord in the rpm values is likely due to the unique adaptive motion of the Elements Motor.

In the static test model, as the file doe not move in an axial (forwards-backwards) direction, the pressure and tension stresses

Table 1: Number of cycles to failure (NCF; means and standard deviations) of 2 groups during dynamic cyclic fatigue test.

Group	NCF	*P* - value
TF Adaptive	1612.14± 218.90[a]	>.05
TF Rotary	1539.50± 257.16[a]	

*Different superscripts letter were statistically significant (*P*< .05).

accumulate in a single point. These cumulative stresses induce micro structural changes. For this reason, in the present study, the fatigue tests were performed in an artificial canal, with a 60° curvature angle and 5 mm radius of curvature, as was done in many other studies [11-16]. The center of curvature of the artificial canal was located 5 mm coronal from the end of the canal, and the procedure was carried out using a dynamic test model in a stainless steel canal with an internal diameter of 1.5 mm

According to the results of the present study, although the cyclic fatigue resistance of the AM group was greater than that of the RM group, the difference was not statistically significant (P> .05). For this reason, the null hypothesis of the present study was accepted. As there are no reports in the literature on the use of a high-speed camera to calculate cyclic fatigue, the results of this study cannot be directly compared with those of other studies. There is only one study in the literature on the effects of adaptive motion on the cyclic fatigue resistance of files. That study, in contrast to the results of our study, reported that adaptive motion significantly increased the cyclic fatigue resistance of the TF [11]. We attribute this discord to the fact that the previous study compared the time until the fracture of the files, whereas the current study compared the rpm of the files until fracture. In contrast to our results, a number of studies reported that, regardless of the file type, reciprocation motion increased the cyclic fatigue resistance of files more than continuous rotation [17-21] stated earlier, the Elements Motor changes the rotation motion to reciprocation when the file is exposed to stress in the canal. The TF has been shown to be elastic and very resistant to cyclic fatigue [22-24]. In the present study, we believe that the TF Adaptive system was not exposed to significant stress in the artificial canal and consequently the Element Motor did not switch to reciprocation-type motion. In conclusion, in the present study, there was no significant difference in the cyclic fatigue resistance of the TF Adaptive system using adaptive motion and rotation motion.

Conclusion

Within the limitation of the present study, we conclude that adaptive motion did not significantly increase the cyclic fatigue resistance of TF 25.08 files compared to that of continuous rotational motion.

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