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Original Article

Assessment of the role of cross section on fatigue resistance of rotary files when used in reciprocation

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ABSTRACT

Objective: The purpose of this study was to assess the role of cross section on cyclic fatigue resistance of One Shape, Revo-S SU, and Mtwo rotary files in continuous rotation and reciprocating motion in dynamic testing model. **Materials and Methods:** A total of 90 new rotary One Shape, Revo-S SU, and Mtwo files (ISO size 25, taper 0.06, length 25 mm) were subjected to continuous rotation or reciprocating motion. A cyclic fatigue testing device was fabricated with 60° angle of curvature and 5 mm radius. The dynamic testing of these files was performed using an electric motor which permitted the reproduction of pecking motion. All instruments were rotated or reciprocated until fracture occurred. The time taken for each instrument to fracture was recorded. All the fractured files were analyzed under a scanning electron microscope (SEM) to detect the mode of fracture. Statistical analysis was performed using one-way ANOVA, followed by Tukey's honestly significant difference *post hoc* test. **Results:** The time taken for instruments in reciprocating motion to fail under cyclic loading was significantly longer when compared with groups in continuous rotary motion. There was a statistically significant difference between Mtwo rotary and the other two groups in both continuous and reciprocating motion. One Shape rotary files recorded significantly longer duration to fracture resistance when compared with Revo-S SU files in both continuous and reciprocating motion. SEM observations showed that the instruments of all groups had undergone a ductile mode of fracture. **Conclusion:** Reciprocating motion improved the cyclic fatigue resistance of all tested groups.

Key words: Cyclic fatigue, Mtwo system, nickel–titanium, One Shape rotary file, reciprocating files

INTRODUCTION

The introduction of nickel–titanium (NiTi) files has created a new epoch in cleaning and shaping in endodontic field.[1-3] Despite having advantages such as increased flexibility and elasticity, unexpected fracture of these NiTi rotary instruments is a major concern. One of the main reasons for fracture of NiTi instruments is torsional or cyclic fatigue.[4,5] Torsional fatigue occurs when the tip of the instrument binds in the canal while the shank continues to rotate. Cyclic fatigue of an instrument occurs due to repetitive alternating compressive and tensile stresses inside the curvature of the canal which ultimately results in fracture of NiTi instruments.[6,7]

The phase transformational behavior and microstructure of NiTi is one of the factors that contributes to the fracture resistance of an instrument.[8] Other features such as cross-sectional shape, circumferential shape,

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diameter, mass, flute depth, number of spirals, and taper influence the fatigue life of the files.[9-12] Surface imperfections such as scratches, transitional angles, microcavities, and debris which are introduced during the manufacturing process may also contribute to the fracture of files.[13] Electropolishing, ion implantation, and thermal treatment of files have shown to improve fatigue resistance of files.[6,14]

In a study by Yared, it was proved that using a rotary file in reciprocating motion increases the fatigue life of an instrument.[15] This concept has led to two new, different approaches in current cleaning and shaping techniques. One is the use of rotary files in reciprocating motion. The other is the invention of reciprocating files for cleaning and shaping.[16,17] Numerous studies have proved that reciprocation motion increases the cyclic fatigue resistance of files.[18-20]

The cross section of an instrument also plays an important role in fatigue resistance of the file.[7] It has been shown that a file with transitional zone may fail earlier than a file with uniform cross section throughout its length.[20] Recently, One Shape, a single file rotary instrument, has been introduced which has varying cross-sectional designs in the working portion. The apical cross section of One Shape is triple helical which is similar to Revo-S SU rotary files, and the coronal part is italic S-shaped similar to Mtwo rotary files. The file has a gradual transitional zone in between these two regions.[21] Till date, there is no study comparing the effect of varying cross sections in a single file on its fatigue life in both rotary and reciprocation method.

Thus, the aim of the study is to evaluate the role of cross section on cyclic fatigue resistance of One Shape, Revo-S SU, and Mtwo rotary files in continuous rotation and reciprocating motion using a dynamic model and to assess the mode of fracture under scanning electron microscope (SEM). The null hypothesis is that there is no difference in the cyclic fatigue resistance among the experimental groups in continuous rotation and reciprocating motion.

MATERIALS AND METHODS

Thirty new Mtwo (VDW, Munich, Germany), One Shape (Micro-Mega, Besançon, France), Revo-S SU (Micro-Mega, Besançon, France) instruments (ISO tip size 25, taper 0.06, length 25 mm) were selected. These were divided into two groups according to the rotary motions used ($n = 15$). All the instruments were inspected under an optical stereomicroscope (Zoom Stereo Binocular Microscope [ZSM-111], Hicksville, NY, USA), with ×20 magnification for any visible signs of defects.

Cyclic fatigue testing device

Cyclic fatigue testing was performed using a custom-made dynamic model [Figure 1]. The device consisted of a main platform to which an artificial canal system and support for the handpiece were attached. The simulated canal consisted of two adjustable frames made of brass that can accommodate any instrument to its exact size and taper. It was constructed with 60° angle of curvature. The curvature started at 5 mm from the tip of canal. The WaveOne handpiece was mounted over the support. The whole set of platform along with the handpiece was powered by the electric motor system, reproducing the pecking motion, with 2.5 mm/min each (forward or backward) direction. This movement took place at a speed of 1 cycle per second.

Cyclic fatigue test

Thirty samples of each file system were randomly divided into two groups ($n = 15$) according to the type of rotatory motions used.

Group OSc (One Shape rotary files in continuous rotation)
Fifteen One Shape instruments were allowed to rotate in continuous rotation (CW) motion using a WaveOne motor set in continuous rotation mode with recommended torque control settings and constant speed of 400 rpm.

Group OSr (One Shape rotary files in reciprocating motion)
Fifteen One Shape instruments were allowed to rotate in reciprocating motion (counter clockwise = 170° and

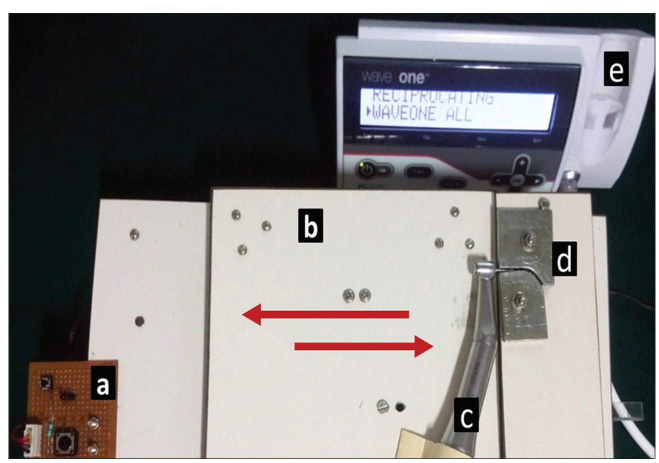

Figure 1: Dynamic testing model with red arrows indicating to-and-fro motion. (a) Microprocessor, (b) platform, (c) handpiece, (d) artificial metal canal, (e) WaveOne motor

CW = 50°) using a WaveOne motor set in WaveOne All mode with recommended torque control settings and constant speed of 350 rpm.

Group RSc (Revo-S SU rotary files in continuous rotation)
Fifteen Revo-S SU files were operated in continuous rotation similar to OSc group.

Group RSr: (Revo-S SU rotary files in reciprocating motion)
Fifteen Revo-S SU files were operated in reciprocating motion similar to OSr group.

Group Mtc: (Mtwo rotary files in continuous rotation)
Fifteen Mtwo instruments were operated in continuous rotation similar to OSc and RSc group at a constant speed of 350 rpm.

Group Mtr: (Mtwo rotary files in reciprocating motion)
Fifteen Mtwo instruments were operated in reciprocating motion similar to OSr and RSr group.

Glycerin (Glycerin Pure; AB Enterprises Mumbai, India) was used as a lubricant during instrumentation. Instruments were allowed to rotate or reciprocate until fracture occurred. All files were tested by the first operator under a dental operating microscope (Seiler Microscope, St. Louis, MO, USA). Simultaneously, the second operator measured the time to fracture (TTF) of these files with the aid of a stopwatch. The length of the broken fragments was measured using a Vernier caliper by observing under a dental operating microscope (×20 magnification).

Scanning electron microscopic analysis

Five representative samples from each group were selected randomly. The fractured surfaces of the files were examined under SEM (FEI Quanta FEG 200; Hillsboro, OR, USA) to determine the modal characteristics of fracture. Longitudinal analysis of the instruments: A longitudinal photograph of one new file from each group was taken with a digital camera (Nikon D-7000). The number of threads in each file system was evaluated.

Cross-sectional area analysis

A new file from each group was cut exactly at 4 mm from the tip of the instrument and was observed under SEM. The cross-sectional area of the files was calculated using ImageJ software (Bethesda, maryland, USA).

Statistical analysis

The mean and standard deviation of the TTF were calculated for all the experimental groups. The Kolmogorov–Smirnov test was used to assess the normality of sample distribution. To compare the mean values between six groups, one-way ANOVA was applied followed by Tukey's honestly significant difference *post hoc* test for multiple pair-wise comparison of means. Both intragroup and intergroup comparisons of cyclic fatigue resistance of the samples were performed using the software (SPSS version 17; SPSS, Chicago, IL, USA). A *P* value of less than 0.05 is considered significant.

RESULTS

Descriptive statistics for the three experimental groups and its subgroups are listed in Table 1. It was observed that the cyclic fatigue resistance of all tested NiTi rotary files showed a significant difference when operated in reciprocating motion compared with the continuous rotation motion. It was also observed that Mtwo rotary files showed significantly more resistance to fracture under cyclic loading than One Shape and Revo-S SU files in both continuous and reciprocating motion. Similarly, there was a statistically significant difference between One Shape and Revo-S SU groups with One Shape better than Revo-S SU in both motions. The mean length of all the fractured segments was observed as 3.5–4.5 mm, which was not statistically significant among the groups.

Results of scanning electron microscope analysis

SEM analysis of fractured surfaces of all the groups revealed crater-like formation along with numerous dimples, circular abrasions, and microbubbles [Figure 2] indicative of ductile mode of fracture.

Results of longitudinal analysis of the instrument

Revo-S SU and Mtwo rotary files have a total of 11 and 7 threads, respectively. One Shape rotary files have 14 threads along the working portion of the file.

Table 1: Intra - and inter-group comparison of mean and standard deviation of time taken to fracture of instruments

Groups (n=15)	Time±SD		P
	Continuous	Reciprocating	
One Shape	187.73±33.457^{A,a}	275.27±58.41^{B,a}	<0.001
Revo-S SU	116.67±37.663^{A,a}	197.60±41.092^{B,a}	<0.001
Mtwo	301.13±54.463^{A,b}	836.53±67.960^{B,b}	<0.001

A significant difference in *P* values on intergroup analysis is marked as A and B (P<0.05). A significant difference in *P* values on intragroup and intergroup analysis is marked with different upper and lower case alphabets (P>0.05). SD: Standard deviation

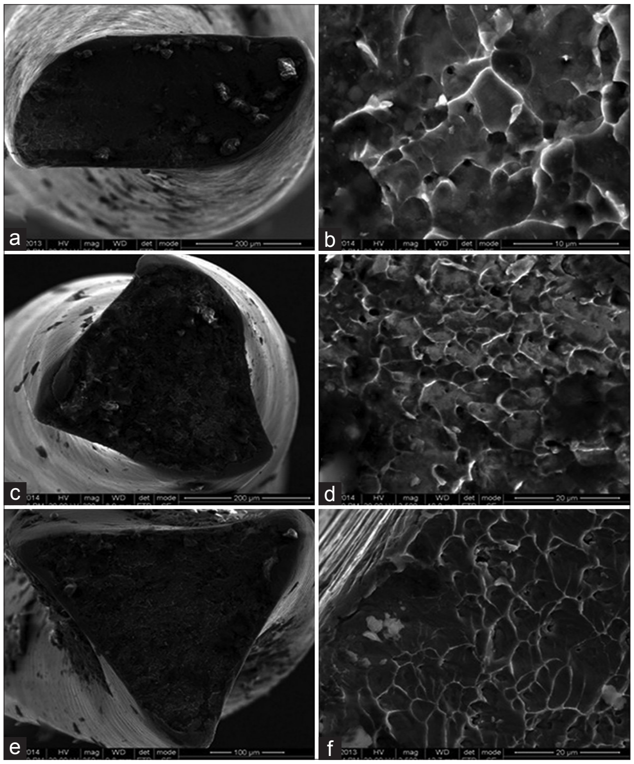

Figure 2: Scanning electron microscope images of rotary files indicating dimples, craters, microbubbles, and valleys. (a and b) Mtwo, (c and d) One Shape, (e and f) Revo-S SU

Results of area analysis

The areas of One Shape, Revo-S SU, and Mtwo rotary files at 4 mm from the tip of the instrument were 4.256, 5.034, and 3.758 mm^2, respectively. Revo-S SU had an increased cross-sectional area followed by One Shape and Mtwo.

DISCUSSION

In our study, a dynamic testing model is used to simulate a clinical situation. The to-and-fro pecking motion decreases the chance of stress accumulation over a particular area of the instrument which happens in a static model.[22,23] Cyclic fatigue resistance of files was evaluated by TTF rather than a number of cycles to fracture (NCF). In continuous rotation motion, the NCF can be calculated by multiplying the rotational speed by the time elapsed until fracture occurred. However, in reciprocation motion, the NCF can be determined only by knowing the amplitude of the oscillating motion with a constant time unit, which is not provided by the manufacturers.

One Shape files have three different cross-sectional zones: The first zone (apical) presents a variable 3-cutting-edge design; the second is the transitional zone which has a cross section that progressively changes from 3 to 2 cutting edges, and the third (coronal) is provided with 2 cutting edges. The innovative asymmetrical cross section of Revo-S SU files is known to provide less stress on the instrument because of its snake-like movement. The cross section of Revo-S SU files is similar to that of One Shape in the apical region. The cross section of Mtwo files is an italic “S” with two blade-cutting surfaces which is similar to the cross section of One Shape rotary files in the coronal portion. Hence, these three files were compared in this study.

The cyclic fatigue resistance of all the tested files was better in reciprocating motion when compared to rotary motion. In this study, the time taken to fracture for One Shape, Revo-S SU, and Mtwo rotary files were 1.7, 1.5, and 2.7 times greater in reciprocating motion when compared to rotary motion. For any file to fail due to cyclic fatigue, the critical value of the force of molecular cohesion has to be overcome which occurs when there is a surface crack in the file.[11] The cyclic fatigue resistance of a file is inversely proportional to the width of opening and closing of the surface crack. In reciprocating motion, a file reciprocates thrice to complete one rotation. Thus, the width of the crack in reciprocating motion is less.[20,24]

In continuous rotation, Mtwo rotary files exhibit 1.6 and 2.5 times better cyclic fatigue resistance than One Shape and Revo-S SU rotary files, respectively. One Shape rotary files were 1.6 times better than Revo-S SU rotary files. However, in reciprocation, Mtwo rotary files showed 3 and 4.2 times better cyclic fatigue resistance than One Shape and Revo-S SU rotary files, respectively. One Shape rotary files were 1.3 times better than Revo-S SU rotary files. Two interpretations that can be observed are that the cyclic fatigue resistance of Mtwo is superior to other tested files in both rotary and reciprocation motion. The other interesting observation is that the proportional increase in cyclic fatigue resistance of Mtwo in reciprocation is approximately 1.5 times more than the proportional increase of cyclic fatigue resistance of Revo-S SU and One Shape when compared to rotary motion. The design characteristics of Mtwo favors improved cyclic fatigue resistance; probably, the reciprocating motion aids this property.

Resistance to cyclic fatigue depends on various factors such as diameter, metal mass, flexibility, cross-sectional shape, regressive surface area, and presence of transitional zones in files. The crack initiation mainly occurs at the leading edge of the file. Mtwo has only two leading edges in comparison to the triple helical-shaped One Shape and Revo-S SU. The other probable reason for superior fatigue resistance of Mtwo is that it has the least number of threads along the working portion. This decreases the number of stress concentration points and hence less crack initiation.[11] It was also observed that the cross-sectional area of Mtwo is the least among the tested files. The file's resistance to fatigue has a close inverse relationship with the square of the file radius.[11] The rpm of the files tested could also play a role in cyclic fatigue resistance.[25] Revo-S SU and One Shape rotary files were operated at 400 rpm and Mtwo at 350 rpm, respectively. Revo-S SU and One Shape rotary files could have experienced more stress cycles of tension and compression per minute when compared to Mtwo for the same time period.

A previous study observed that the transitional zone of RaCe rotary files could act as points of stress concentration thereby leading to instrument fracture.[20] Despite the presence of transitional zone in One Shape rotary files, it performed better than Revo-S SU in both rotary and reciprocating motion. The gradual transition of One Shape and its decreased cross-sectional area when compared to Revo-S SU could have attributed to its better performance.

The limitations of this study are that the testing was done in a nontooth dynamic model wherein the amplitude, speed of pecking motion, and axial movement were standardized. These parameters are purely subjective in clinical practice. The ability to constrain the files in a precise trajectory is also difficult in dynamic testing.

CONCLUSION

Within the limitations of the study, reciprocating motion of rotary files increased the cyclic fatigue resistance. Mtwo rotary files were more resistant to cyclic fatigue than One Shape and Revo-S SU rotary files in both continuous rotation and reciprocating motion. One Shape rotary files performed better than Revo-S SU rotary files in both continuous rotation and reciprocating motion.

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Conflicts of interest
There are no conflicts of interest.

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