IDR International Dental Research

Original Article

Comparison of cyclic fatigue of a reciprocating file system at different angles of rotation

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Received: 15 January 2021
Accepted: 18 May 2021

Access Online

DOI: 10.5577/intdentres.2021.vol11.suppl1.11

Abstract

Aim: The purpose of this in vitro study is to compare the cyclic fatigue resistance of Reciproc Nickel-Titanium (Ni-Ti) rotary files (VDW GmbH, Munich, Germany) while operating root canals using in three different reciprocal angles.

Methodology: Forty-five Reciproc R25 root canal files were tested using artificial canals with a 60° angle of curvature, 5 mm curvature radius, and 1.5 mm diameter carved into a stainless steel block. The Ni-Ti files were checked with a stereomicroscope and then randomly separated into three groups. Group 1 consisted of reciprocal angles CCW 150°— CW 30°, Group 2 consisted of CCW 180°—CW 60°, and Group 3 consisted of CCW 210°—CW 90°. The duration of the cyclic fatigue being measured, elapsed time until a file fractured was determined with a chronometer. The lengths of the fractured pieces were measured with a digital caliper. After the cyclic fatigue test, two samples from each group were examined with a Scanning Electron Microscope (SEM) to determine the signs of cyclic fatigue.

Results: One-way analysis of variance (ANOVA) was applied to the normally distributed groups ($p<0,05$). Since there was a significant statistical difference of file's cyclic fatigue resistance ($p=0,001$) between the groups, Tukey's honestly significant difference (HSD) post hoc pairwise comparison tests were used for determining to between groups. While there were statistically significant differences between Group 1 and Group 2 ($p=0,001$), and between Group 1 and Group 3 ($p=0,001$), there was no significant difference between Group 2 and Group 3 ($p=0,376$). Group 1 displayed the highest resistance to cyclic fatigue. There were no statistically significant differences between the lengths of the fractured files within the three groups according to the one-way analysis of variance ($p=0,847$).

Conclusion: In our study, it was observed that the reciprocal angles of CCW 150°— CW 30°, which were also suggested by the file manufacturer firms, had the highest fracture resistance against cyclic fatigue.

Keywords: cyclic fatigue, reciprocal movement, kinematics, Reciproc file

How to cite this article: Akay A, Adıgüzel Ö, Erkan Akay S, Kaya S. Comparison of cyclic fatigue of a reciprocating file system at different angles of rotation. Int Dent Res 2021;11(Suppl.1):67-73. https://doi.org/10.5577/intdentres.2021.vol11.suppl1.11

Introduction

Chemomechanical shaping is a significant stage in root canal treatment (1, 2). Root canal files, which are the most important files of the shaping process, tend to break in the canal. If the broken files cannot be removed, they cause difficulties in the stages of irrigation, preparation, and filling. To eliminate the issue of broken files, several alterations have been made in file's, design, and metallurgical properties (3).

Many studies have been conducted on the fractures caused by root canal files. Some variables in these studies are the rotation speed of the files, the torque value of the rotary files, the curvature angle of the teeth in the models, the movement of the files, and more. Researchers who explore cyclic fatigue aim to collect data on the rotation limit of the files and the elapsed time until a fracture occurs (4).

During an examination of the movement of the files, researchers remained within specified reciprocal angles suggested by the file manufacturers. However, it has been proven that while files making a rotating motion exhibit an increase in cyclic fatigue resistance, various reciprocal angles need to be tested (5, 6).

The purpose of this in vitro study is to compare the cyclic fatigue resistance of the files during cyclic fatigue resistance tests using three different reciprocal angles of the Reciproc file system. In this study, unlike other studies, the angle of progression (was standardized. By the end of the study, the goal was to determine which reciprocal angles the files exhibited the best cyclic fatigue resistance.

Materials and Methods

In this research, a Reciproc file system making a reciprocal motion was submitted to a cyclic fatigue test using different reciprocal angles in an artificial canal carved into a metal block. During this cyclic fatigue experiment, the duration of the process until the files fractured was determined with a digital caliper. Statistical tests were employed to see whether or not these durations (in seconds) across groups were statistically significant.

In this mechanism, which aims to keep the file stable by opening an artificial root canal on a stainless-steel block, the curvature angle and radius were obtained according to Pruett's method (7). In the model we used in our study, an artificial canal with a curvature angle of 60°, a radius of curvature of 5 mm, and a width of 1.5 mm was created. Our model drawing consisting of these dimensions was obtained using the AutoCAD program (Autodesk, San Rafael, CA, USA) (Fig. 1 and 2).

The specifications of the artificial canal and the mechanism

Method: Static
Material of canal: Stainless steel
Diameter of canal: 1.5 mm
Length of canal: 16 mm
Angle of canal: 60°
Radius of curvature: 5 mm
Temperature of environment: Room temperature
Lubricant: Synthetic oil

In utilizing the Reciproc file operation system, despite cutting at a reciprocal angle at counterclockwise (CCW) 150°, a rotation of clockwise (CW) 30° allowed the file to easing in canal, letting the file work for longer periods without fracturing in the canal. This file system, with its S-shaped cross-section, had a positive cutting angle. Since the files are manufactured with M-Wire technology, they produce high cyclic resistance. A total of 45 Reciproc R25 root canal files, previously checked with a stereomicroscope for manufacturing faults, were randomly separated into three groups. The files in each group (numbered within themselves) were put into different ziplock bags.

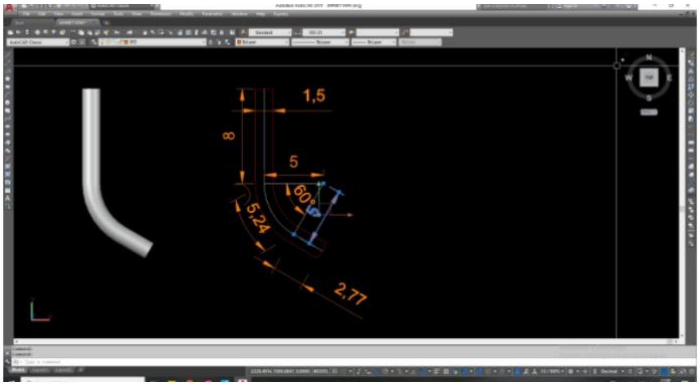

Figure 1. Drawing of the model used in the study using AutoCAD software

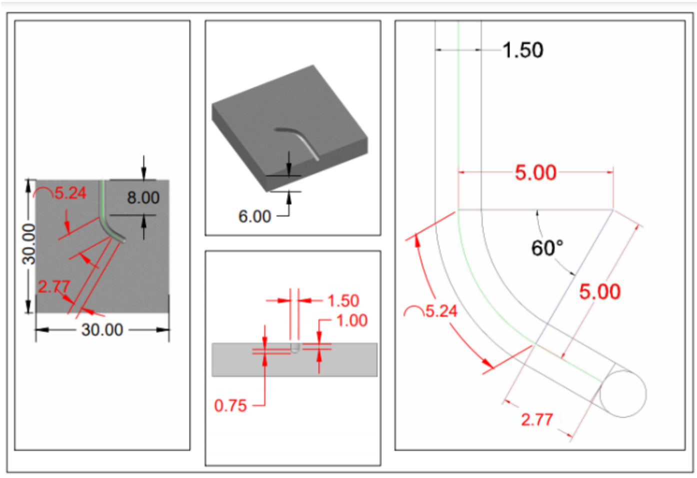

Figure 2. Technical drawing of the model used in the study

The files were separated into three groups, each containing 15 Reciproc files:

Group 1: CCW 150°— CW 30°
Group 2: CCW 180°— CW 60°
Group 3: CCW 210°— CW 90°

After immobilized the endomotor and the stainless-steel block in cyclic fatigue testing model, the upper part of the stainless-steel block was covered with a glass panel, attaching it to the model at two points (Fig. 3). An endomotor with an adjustable reciprocal angle, E Connect S (Eighteeth, Changzhou, China), was used. During the changing of the files, Akfix A40 (Akkim, Istanbul, Turkey) spray lubricant was sprayed in canal order to eliminate torsional forces and to prevent overheating. While determining elapsed time until a fracture occurred using a chronometer, a second observer assured the accuracy of the values (in second), and the process was recorded with a digital camera (Fig. 4).

Figure 3. Experimental mechanism used in the study

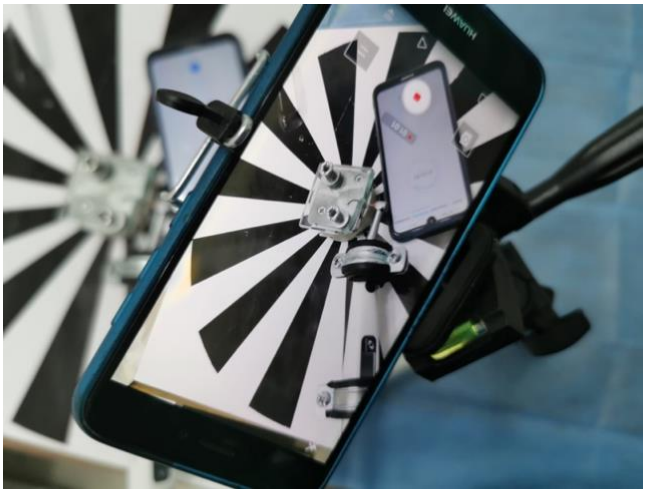

Figure 4. Recording the experiment with a digital camera

The lengths of the fractured file pieces were measured with a digital caliper (Alex Makine, Istanbul, Turkey). The differences between the groups and the lengths of the fractured file pieces were statistically examined using one-way analysis of variance (ANOVA) ($p<0,05$). Tukey's honestly significant difference (HSD) post hoc pairwise comparison tests were used to determine the groups with significant statistical differences ($p<0,05$).

Two fractured files from each group were examined using a Scanning Electron Microscope (SEM) to determine the types of fractures. The debris on the surface of the fractures was removed with an air spray before the SEM scanning. Photomicrographs of broken file surfaces were taken using different magnification settings (250X/5000X). The images were taken at the Dicle University Science and Technology Research Center (DUBTAM) with the SEM imaging instrument Quanta FEG 250 (FEI, Hillsboro, OR, USA).

Statistical analysis

Analysis of the data was carried out with SPSS software version 22 (IBM SPSS Inc., Armonk, NY, USA). One-way analysis of variance (ANOVA) was performed on groups that were found to have normal distribution by Levene's homogeneity test of variance ($p<0.05$). Tukey HSD post hoc pairwise comparison tests were applied because there was a significant difference between the groups ($p=0.001$).

Results

ANOVA was used to perform a statistical comparison of the values from the elapsed time (in seconds) until the fracturing of the files within different groups.

The results from utilizing one-way analysis of variance showed a statistically significant difference between the three groups ($p=0,001$) (Table 1). Tukey's HSD post hoc pairwise comparison tests were applied to determine which pair of reciprocal angle out of the three groups resulted in the largest statistical difference.

When Tukey's HSD post hoc pairwise comparison tests were finalized, it was determined that Group 1 statistically showed the highest cyclic fatigue resistance than Group 2 and Group 3 ($p=0,001$). Although Group 2 showed more cyclic fatigue resistance than Group 3 (Table 1), they both did not produce a significant statistical difference ($p=0,375$) (Table 2).

ANOVA comparing the lengths of broken files did not produce a statistically significant difference between the groups ($p=0,847$) (Table 3). Microindentations, protrusions, scattered micropores, and fracture lines seen on the photomicrographs acquired by SEM analysis indicated that the file fractures were caused by cyclic fatigue (Fig. 5).

Table 1. Results from the one-way analysis of variance on the time elapsed until fracture (in seconds).

Group	N	Mean	Standard Deviation	Median	Minimum	Maximum	P
			Time elapsed until fracture				
Group 1 (150°-30°)	15	308,53	36,3787	310	252	379	0,001*
Group 2 (180°-60°)	15	224,13	25,40772	231	181	260	
Group 3 (210°-90°)	15	208,93	29,66351	212	165	258	

*One-way analysis of variance

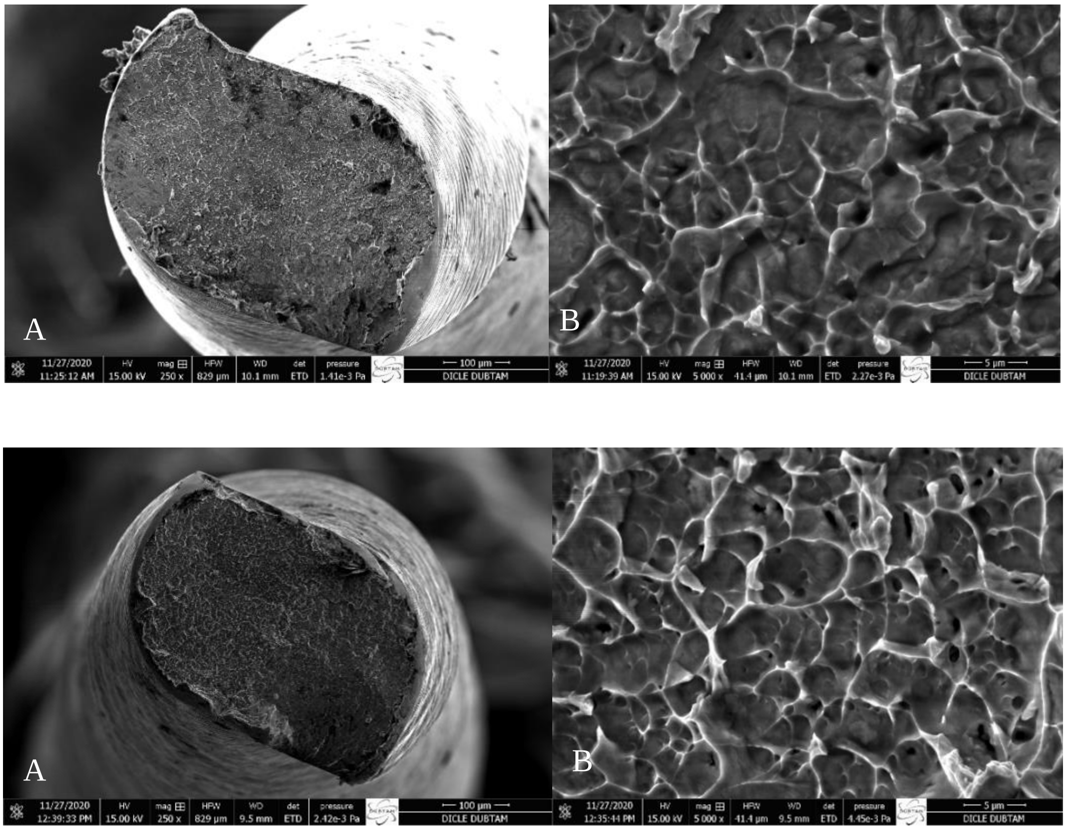

Figure 5. SEM images taken from the Reciproc files, respectively (A) 250X, (B) 5000X.

Table 2. Results from the Tukey HSD post hoc pairwise comparison test.

	Group 1	Group 2	Group 3
Group 1		0,001*	0,001*
Group 2	0,001*		0,375*
Group 3	0,001*	0,375*	

*Tukey's HSD

Table 3. Results from the one-way analysis of variance on the fractured file pieces

Lengths of fractured file							
Group	N	Mean	Standard Deviation	Median	Minimum	Maximum	P
Group 1 (150°-30°)	15	4,903	0,215	4,96	4,54	5,27	0,847*
Group 2 (180°-60°)	15	4,932	0,211	4,93	4,58	5,21	
Group 3 (210°-90°)	15	4,952	0,221	4,94	4,47	5,34	

*One-way analysis of variance

Discussion

The cyclic fatigue test results, based on the reciprocal motion of the files with regular kinematics consisting of continuous rotation, proved to be more successful than the original kinematics of the files (5, 6). Based on these results, researchers emphasized the necessity of testing the reciprocal files at various reciprocal angles (8). Reciproc file systems are accepted as an ideal file system to examine these new angles since they are commonly studied and widely used (5).

The differences between reciprocal angles are significant because researchers Saber et al. showed in 2013 that in using the angles CCW 150°— CW 30°/ CCW 120°— CW 30°/ CCW 90°— CW 45°, the fracture resistance of the file increased with the angle of progression, while decreasing the transportation risk of canal and increasing the canal preparation time (9).

In a similar study in 2013, Gambarini et al. examined the impact of the angle of progression on the cyclic fatigue resistance of the files. They used the K3XF file with CW 90° — CCW 30°/CW 150°— CCW 30°/ CW 210°— CCW 30°/ CW 390°— CCW 30° and CW 360° continuous rotation modes and concluded that increasing the angle of progression decreased the resistance against cyclic fatigue (10). Knowing that, the angle of progression for each reciprocation cycle was stabilized (120°) in this study to eliminate potential differential results associated with the angle of progression. The angles were utilized in a way such that all groups could finish a full 360° rotation with three reciprocal cycles.

Given these facts, the Reciproc rotary file was used at the reciprocal angles of CCW 150°— CW 30°/ CCW 180°— CW 60°/ CCW 210°— CW 90°. As a result, it was proven that the best cyclic fatigue resistance was produced with CCW 150°— CW 30°, which was also suggested by the file manufacturer, and there was a significant statistical difference between the other groups in regards to cyclic fatigue resistance. While the study groups of CCW 180°— CW 60° and CCW 210°— CW 90° resulted in lower cyclic fatigue resistance, they did not show significant statistical differences. The results obtained were consistent with the other researchers who worked before on cyclic fatigue (6, 8).

While examining the cyclic fatigue of the files regarding their curvature, it was realized that the outer surface of the file was exposed to tensile stress and the inner surface to compressive stress. The expansion and decompression of manufactural microfractures, caused by the continuous tensile and compressive stress on the surface during rotation, was the main cause for file fractures (11, 12).

When examining the cyclic fatigue of a reciprocal file, it is best to measure the time of exposure to tensile and compressive stress rather than the number of cycles. Like the other studies, statistical data of cyclic fatigue resistance in relation to the time elapsed until fracture was produced, making it possible to compare this study with similar studies and to prevent any unknown component caused by unshared information from the file manufacturers (13).

Similarly, Kim et al. suggested that while computing the number of tours in cyclic fatigue calculations, it is required to multiply the endo motor's speed with the time (sec) elapsed until a fracture occurs (14). In this study, the rotation speed per second remained the same, but the number of tours was not calculated.

In the study models used for cyclic fatigue tests (to be able to simulate the structure of a mouth), some artificial canals, which would allow the files to follow a predetermined path, reflect the appropriate curvature sizes, and file lengths were carved into stainless steel blocks (15-18). Likewise, this study used a model based on the drawings from Duke et al. (19).

Static and dynamic models can be used in cyclic fatigue testing systems. It is well known that a dynamic study model extends the lifetime of all Ni-Ti files (20). However, Wan et al. stated that Dynamics models do not reflect clinical applications and that the speed and amount of a random reverse or forward motion might yield inaccurate results (21). Similarly, Silva et al. suggested that using a static model in studies would prevent any file fractions, except for cyclic fatigue fractions (22). Therefore, a static model was preferred in which a rotational fracture could be observed.

In their study with HyFlex and Reciproc files in 2013, Rubini et al. discovered that increased reciprocal-motion-related cyclic fatigue resistance to the tensile and compressive stress on the file surface caused varying amounts of force distribution when interrupted by each reciprocal motion. Normally, tensile and compressive stress display a sinusoidal graph. The interruption of this force decreased the overall amount of force put onto the file and prevented it from becoming deformed (23). In this study, it was also observed that when the reciprocal angle increased (while it approached full rotation), the operation time decreased along with the number of complete tours. This is because the sinusoidal tensile and compressive graph is infrequently interrupted, and the initial microfractures expand at an earlier phase.

The weakness of such studies is due to the lack of a universally accepted test mechanism simulating the structure of teeth that can be used by clinicians and the manufacturers to test the cyclic fatigue resistance of files. Based on the results of this study, it is suggested that it is important to follow the recommendations of the file manufacturers. However, for these studies to increase contribution to academic literature, it is necessary to conduct further studies in which comparative results from various file systems with varying physical specifications can be observed.

Conclusions

Since there are no current studies in which the angles of progression are stable, this study concludes that the increase in one or two of the reciprocal angles, rather than the angles of progression, decreases cyclic fatigue resistance. This can be explained in that the reciprocal angle's values close to the continuous rotational motion lead to low performance.

Based on the given results, the best performing Reciproc file is obtained with the angles of CCW 150°—CW 30°. This shows the necessity to observe manufacturer instructions unless otherwise proven with studies.

Acknowledgments: This study was presented as a full-text oral presentation at the 1st International Dental Research and Health Sciences Congress held between 20-22 May 2021.

Peer-review: Externally peer-reviewed.

Author Contributions: Conception – A.A.; Design – Ö.A.; Supervision – S.E.A.; Materials – A.A.; Data Collection and/or Processing – Ö.A.; Analysis and/or Interpretation – S.E.A.; Literature Review – Ö.A.; Writer – A.A.; Critical Review – Ö.A.

Conflict of Interest: No conflict of interest was declared by the authors.

Financial Disclosure: This research has been supported by Dicle University, Scientific Research Project Coordination Unit. Project Number: DİŞ.20.018

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