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Assessment of Kinematic Motions on the Cyclic Fatigue Resistance of Two Nickel Titanium Systems in Non-Surgical Retreatment

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ABSTRACT

Background: Removal of obturating materials from curved root canals affects the cyclic fatigue resistance (CFR) of Nickel Titanium instruments (NiTi). Kinematic motion, such as Reciprocation motion, is thought to have a higher CFR than the single continuous rotation motion. Also, clinical usage of NiTi instruments influences the CFR of the files. ***Aim:*** To evaluate the effect of using two kinematic motions on the CFR of two NiTi files after removing obturating materials in the retreatment of curved canals. ***Materials and Methods*:** A total of Eighteen sets of X1 EdgeFile used in reciprocation motion and X7 EdgeFile used in single continuous rotation motion (n=9 each), size 25, taper 6%, were evaluated for CFR testing inside a custom-made artificial canal (60º angle, 2 mm radius of curvature). Each group was subdivided into three subgroups (n=3 each) according to the number of usages: subgroup (A): New X7, Subgroup (B): X7 used after 3 root canal retreatments (Re-RCT), Subgroup (C): X7 Used after 9 Re-RCT, Subgroup (D): New X1, Subgroup (E): X1 Used after 3 Re-RCT, Subgroup (F): X1 Used after 9 Re-RCT. The number of Cycles to failure (NCF) was then achieved. ***Results:*** Reciprocation had a considerably greater NCF value than rotation ($p<0.001$). The highest NCF value was found in new files, followed by 3, then 9 Re-RCT. ***Conclusion*:** EdgeFile X1 had a higher CFR than EdgeFile X7. New EdgeFile X1 and X7 showed the highest CFR when compared to EdgeFile X1 and X7 used after 3 and 9 Re-RCT**.**

Keywords: Continuous rotation motion, Reciprocation motion, EdgeFile, Clinical usage

INTRODUCTION

Root canal retreatment aims to gain access to the apical foramen by removing all of the previous filling material. This ensures thorough preparation of the root canal system, aiming for clinical success as the final outcome.[1] Many Techniques have been supported to effectively remove the obturating material from the root canal system, such as hand files as well as lasers, ultrasonic instruments, and rotary Nickel Titanium (NiTi) files sideways with the use of chemicals/solvents.[2] The main problem

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with these NiTi instruments is the probability of fracture during clinical usage due to cyclic fatigue failure, even if the super elasticity of NiTi allows the instruments to be efficiently used in curved canals.[2,3] In a curved root canal, cyclic fatigue failure occurs when an instrument rotates and experiences an excessive number of cycles of compression and tension at the point where the curvature is greatest.[3]

For NiTi instruments, alternative kinematics (rotation or reciprocation) movement has also been proposed as a way to decrease torsional stress and increase fracture resistance (cyclic fatigue). Besides, reciprocating root canals with a single file was also recommended to cut down on instrumentation time, expense, and cross-contamination risk.[4] To decrease the fracture incidence of rotary NiTi files, reciprocating motion and tools constructed from new alloys, such as M-wire and R-phase NiTi have been introduced by the manufacturers. These files are said to have higher CFR than the usual NiTi files.[5] The relative benefits of reciprocating versus continuous motions and their impacts on cycle fatigue, however, are still a debate.[4,5] A study conducted by Ismail et al.[5] found that the reciprocation motion of Waveone Gold had a higher CFR than the rotation motion of ProTaper Next (PTN). In addition, Elsewify et al.[6] compared the CFR of the Hyflex EDM file used in Continuous rotation motion with the R Motion file and discovered that the CFR of the HyFlex EDM file was greater than that of the R-Motion. Most studies indicate that reciprocating motion, as opposed to continuous rotation, increases the fatigue resistance of endodontic instruments, regardless of other factors like rotational speed, the angle or radius of curvature of the modeled canals, geometry, and taper of the NiTi instruments.

Thermal heat-treated NiTi alloys have recently invaded the market to enhance the mechanical characteristics of NiTi files.[7,8] Recent heat-treated NiTi instruments, including reciprocating, rotary, and retreatment endodontic files, have been introduced by the EdgeEndo company (Albuquerque, USA). The EdgeFiles instruments are characterized by having unique Annealed Heat Treatment (AHT) to create Fire-Wire™ NiTi, which improves cycle fatigue resistance and flexibility. EdgeFiles instruments include rotary (X3, X5, X7), reciprocating (X1), and retreatment (XR) rotary files.[9] The EdgeFile X7 instrument is the most commonly used rotation file system among EdgeFiles, while the EdgeFile X1 is a reciprocating file system. Both instruments are characterized

by having a parabolic cross-section and constant taper. However, evidence is still conflicting when comparing CFR of NiTi instruments used with single continuous rotation motion and reciprocation motion after removal of obturating material.[10]

So, this study was conducted to assess the effect of using two kinematic motions of two NiTi files on the CFR after the removal of obturating materials in the retreatment of curved canals. The null hypothesis suggested that there is no variation in CFR between two NiTi files used with a single continuous rotation motion and reciprocation motion after the removal of obturating materials used in the retreatment of curved canals.

MATERIALS AND METHODS

Sample Size Calculation:

A power analysis was planned to have adequate power to apply a two-sided statistical test of the null hypothesis that no difference would be found in CFR between two NiTi files with different kinematics. Through adopting an alpha level of (0.05), a beta of (0.2), i.e. power=80%, and an effect size (d) of (1.56), calculated based on the results of a previous study.[11] The predicted sample size (n) was found to be a total of (18) samples. Sample size calculation was performed using G*Power version 3.1.9.72.

Teeth Selection:

Seventy-two (72) Mandibular molars with average mesial root curvature (25-35º),[12,13] according to Schneider, were used in this study. Molars that meet the criteria were collected. Molars with root caries, cracks, canal calcification, and fillings were excluded. All mandibular molars were occlusally flattened by a diamond disc to standardize the length to 16 mm. Access cavity preparation was performed on all teeth. In order to get an accurate working length, the Mesiobuccal (MB) root canals were explored by using a 10 K-type file (Dentsply Maillefer) up until the instrument tip was visible at the apical foramen, and then one mm was subtracted. The MB canals of all molars were prepared by 20/0.06 EdgeFile X7 (EdgeEndo Company, USA) in a continuous rotation motion. Speed and torque were adjusted as stated by the manufacturer's instructions (Speed: 400 RPM/ torque: 300 g-cm). All canals were then irrigated utilizing 20 ml of 2.5% sodium hypochlorite throughout the whole root canal preparation and then obturated using the cold lateral condensation using epoxy resin-based sealer (Adseal; META BIOMED, Chungcheongbuk-do, Korea). Then the gutta percha was removed from the canals immediately after obturation using continuous motion and reciprocation motion

with the aid of solvent.

Inclusion criteria: Sound-extracted molars with curved root canals (mesial root curvature 25-35º) and completely formed roots.

Exclusion criteria: Presence of caries, cracks, and previous restorations.

Sample classification:

The study included 18 sets of EdgeFiles with the same size (tip diameter 0.25mm/taper 0.06). They were divided into two main groups according to the kinematic motion, either single continuous rotation or reciprocation motion. (n=9 for each); **Group I**: X7 EdgeFile used in a single continuous rotation motion, and **Group II**: X1 EdgeFile used in a reciprocation motion.

Each group was subdivided into three subgroups according to the number of files usage as follows: **Subgroup A:** Testing CFR of New Edge File X7, **Subgroup B:** Testing CFR of Edge File X7 used after 3 Re-RCT, **Subgroup C:** Testing CFR of Edge File X7 used after 9 Re-RCT, **Subgroup D:** Testing CFR of New Edge File X1, **Subgroup E:** Testing CFR of Edge File X1 used after 3 Re-RCT, and **Subgroup F:** Testing CFR of Edge File X1 used after 9Re-RCT.

The new instruments in subgroups A and D were subjected to cyclic fatigue testing. The used instruments in subgroups B, C, E, and F were used in the removal of obturating material from the canals of previously mentioned molars with the aid of a solvent, such as Carvene (Prevest Direct, India). The instruments were ultrasonically cleaned and sterilized after the complete removal of obturating material in an autoclave.

Dynamic cyclic fatigue resistance testing:

A new custom-made device, as shown in **Figure (1),** for dynamic CF testing was used.[14,15]

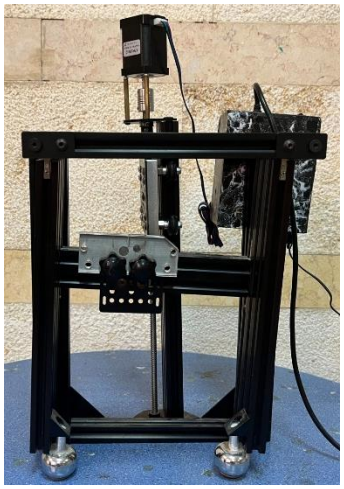

Figure (1): photograph showing the cyclic fatigue testing machine.

The artificial canal was used to simulate a natural root canal in order to evaluate the CF of the file. The dimensions of the artificial canal were: a radius of 5 mm and 60º angle of curvature.[16] while the instrument tip was 6 mm away from the center of the curvature. An endodontic motor was fixed to the device to confirm the correct placement of all instruments inside the simulated artificial

canal each time. New and used files were rotated until fracture (Torque and setting were adjusted according to the manufacturers' instructions). To reduce excessive heating that occurs during file friction against the artificial canal walls, a synthetic oil (WD-40 company, San Diego, CA, USA) was used to lubricate the canals. In order to obtain the number of cycles to failure (NCF), an equation was used to calculate it in which the time to fracture (seconds) was recorded and multiplied by operating rpm.[17]

Statistical analysis:

Numerical data were described as mean and standard deviation (SD) values. They were tested for normality using Shapiro-Wilk's test. The data were normally distributed and were analyzed using two-way ANOVA. Comparisons of simple effects were obtained by applying the error model from the ANOVA model with p-value adjustment using Bonferroni correction. The significance level was set at $p<0.05$ within all tests.

RESULTS

The Shapiro-Wilk test discovered that the data were normally distributed. The NCF mean and standard deviation for each file were calculated. The ANOVA test indicated that both the kinematic motion and the number of file usage had a significant effect on NCF ($p<0.001$). Reciprocation had a considerably greater NCF value than rotation ($p<0.001$). The highest NCF value was found in new files, followed by files used for 3 canals, while the lowest value was found in files used for 9 canals**.** Post hoc pairwise comparisons revealed new files to have considerably greater values than files used for 9 canals ($p<0.001$). **(Table 1)**

Table (1): Intergroup comparisons, mean and standard deviation (SD) values of (NCF) for different kinematic motions within other variables.

File usage	(NCF) (Mean ±SD)		p-value
	Rotation	Reciprocation	
New file	511.11±101.84	802.22±45.38	0.011*
3 canals	424.44±84.42	608.89±53.89	0.033*
9 canals	257.78±10.18	584.44±50.04	<0.001*

**Statistically Significant at P<0.05.*
NCF, Number of cycles to failure

DISCUSSION

The performance of endodontic instruments is considered a serious issue in root canal procedures.[14] NiTi rotary instruments showed superior flexibility,

super elasticity, and improved cutting efficiency. Nevertheless, Instrument fractures during root canal procedures remain a concern in endodontic treatment.[15,16] Rotary NiTi instruments showed two types of failure: torsional failure and cyclic fatigue failure.[18-23] However, Instrument fractures during root canal procedures remain a concern in endodontic treatment.[24-26] Cyclic fatigue failure occurs when the file is exposed to repeated cycles of compression and tension at the area of highest root canal curvature.[27] Several aspects can influence the fatigue fracture behavior of NiTi instruments, including the root canal's radius and angle of curvature[17], the number of files' usage[16], motor torque, and speed[28], the NiTi system employed[5], surface heat treatment[29], and the sterilization procedure.[8] Movement kinematics has also been thought to affect the NiTi instruments' cycle fatigue resistance.[7] NiTi instruments are traditionally used in rotational motion, which causes stress on the walls of the root canal while reciprocating motion relieves stress on the instrument through special anticlockwise (cutting action) and clockwise movements (relief of the instrument).[5,22]

Recent heat-treated NiTi instruments, including reciprocating, rotary, and retreatment endodontic files, have been introduced by the EdgeEndo company (Albuquerque, USA).[7] EdgeFile instruments are characterized by having unique Annealed Heat Treatment (AHT) to create Fire-Wire™ NiTi, which improves CFR and flexibility.[8] The files chosen to be tested in this study were EdgeFile X7 used in continuous rotation motion and EdgeFile used in reciprocation motion and must be following the WaveOne® motor setting (150º (CCW) cutting action and 30º (CW) release) as instructed by the manufacturer.[10] All examined files used had the same length (25mm), tip size (25), taper (6%), and same alloy. EdgeFile X7 instrument is the most commonly used rotation file system among EdgeFiles, while EgdeFile X1 is a reciprocating file system. Both instruments are characterized by having a parabolic cross-section and constant taper.[7-10]

Cyclic fatigue has been tested using several methods, such as natural teeth or artificial canals. Using natural human teeth to assess flexural CFR of NiTi instruments is ideal due to their ability to simulate clinical conditions accurately.[30] MB canals of extracted mandibular molars were chosen for this study. They were characterized by having completely formed and curved roots, especially mesial curvature (25º-35º). The degree of curvature chosen to be tested in this

study was selected according to the Schneider's method.[12,13,31]

Accordingly, a customized artificial canal was used for CF testing to ensure accurate standardization.[32] The simulated artificial canal design used in the study followed the approach described by Pruett et al.,[31] who used the angle and radius of curvature to determine root canal curvature. They also claimed that the cyclic fatigue life of NiTi instruments is reduced by increasing the angle and radius of curvature, rotating speed, and instrument diameter. The simulated canal had a radius of 5 mm[14-15] and an angle of curvature of 60°[14-17]. The canal was made from stainless steel with a working length of 18 mm and an interior diameter of 1.5 mm which is wider than the diameter (1.25mm) of the files used (size 25 taper6%) to allow free rotation of the file in the canal to avoid any additional stresses that may occur due to locking during rotation.[30,32]

Abu Naeem et al.[7] indicated that the artificial canal block is milled out of stainless steel to prevent wear of the canals after repeated use and provide a consistent path for all files. A glass top cover instead of an acrylic one was used on the stainless-steel testing block to visualize the file and the moment of fracture.[33,34] Also, glass has a higher hardness than NiTi, reducing the risk of wear in comparison to acrylic cover.[35] Since the rotation of the file inside the artificial canal produces heat which may affect the test results, A highly flowable synthetic oil was used to control the rise in temperature that occurs during the procedure.[36] To standardize the instrument positioning inside the canals each time, the length of the file was set to 16mm with a file stopper.[7]

There have been few studies on how kinematic motion affects the CFR of NiTi files after retreatment. However, there are no available studies analyzing the effect of kinematic motion on CFR of EdgeFiles X1 and X7 after retreatment. Regarding the effect of Kinematic motion, the results of our study have shown that in comparison to continuous rotation motion, reciprocation motion increased the CFR of NiTi files. This was in agreement with a study directed by Ismail et al.[5] They found that reciprocation motion had a higher CFR than rotation motion. The reason was that the reciprocation motion eliminates taper lock problems by repeating clockwise and anticlockwise rotations in an asymmetrical pattern, which releases the applied tension on the file and reduces the chance of cycle fatigue failure.

This was also in full agreement with Serefoglu et al.,[12] who stated that the

reciprocating motion in instruments releases stress distributions and improves fracture resistance. These results were confirmed by Abu Naeem et al.,[7] Keskin et al.,[34] and Ismail et al.,[26] They stated that continuous rotation files were associated with a greater fracture risk than reciprocating motion and reciprocating files are designed to minimize breakage since they have a shorter circumferential distance than rotary instruments, resulting in less stress. Contrary to our findings, Gündoğar and Őzyürek.[36] compared the CFR of HyFlex EDM with OneShape, Reciproc Blue, and WaveOne Gold files. They concluded that the manufacturing process (electropolishing) as well as the type of alloy have a significant influence on CFR. Pedulla et al.[17] concluded that HyFlex EDM showed higher CFR than Reciproc and WaveOne instruments. They explained that the reason for their conclusion might be related to the difference in alloy and manufacturing processes of the tested instruments.

Regarding the effect of clinical usage, results showed that the new NiTi files showed higher CFR than the files used in 3 and 9 canals while the files used in 3 canals showed higher CFR than the files used in 9 canals. This also agrees with several studies that evaluated the effect of clinical usage. Serefoglu et al.[12] discovered that the NCF values of the brand-new and initially used Reciproc Blue files were significantly higher than those of the second and third times used.

CONCLUSION

Within the limitations of this study, features such as kinematic motion and a number of file usage had significant influences on the CFR of the NiTi instruments. Results revealed that EdgeFile X1 (25.06) had a higher CFR than EdgeFile X7 (25.06). In addition, New EdgeFile X1 and X7 showed the highest CFR when compared to EdgeFile X1 and X7 used after 3 canal retreatments and 9 canal retreatments.

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INTEREST CONFLICTS

The authors declare no conflict of interest.

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