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EFFECT OF DIFFERENT KINEMATICS ON THE CYCLIC FATIGUE RESISTANCE OF RECIPROC BLUE FILE IN DIFFERENT CANAL CURVATURES *(AN IN VITRO STUDY)*

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KEYWORDS

Canal curvature, Continuous rotation, Cyclic fatigue resistance, NiTi instruments, Reciprocation, Reciproc-Blue.

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ABSTRACT

Introduction: Ni-Ti instruments used in reciprocation reduce instrument separation. Reciproc-Blue is a thermally-treated NiTi single reciprocating system coated by an oxide layer caused by the thermomechanical process improving fatigue resistance. **Aim:** To evaluate the effect of different kinematics on the cyclic fatigue resistance of the Reciproc-Blue file and examine the influence of different canal curvatures on its cyclic fatigue resistance. **Method:** Eighty new Reciproc-Blue files divided into four groups (n=20) according to the reciprocation angles 150°CCW–30°CW, 210°CCW–30°CW, 90°CCW–40°CW and 360°CCW(continuous-rotation), each group was subdivided into two subgroups (n=10) according to the canal curvature 45°and 60°angles. All instruments were operated until the fracture occurred, Cyclic fatigue resistance was determined by recording the time to fracture in seconds. Data were statistically analyzed by applying ANOVA test followed by Post Hoc Tukey test at 95% significance level. **Results:** all reciprocating motions yielded a significant increase in time to failure when compared to continuous rotation in both canal curvatures. There was a significant difference in time to failure among all reciprocating groups in both canal curvatures. All experimental groups revealed greater cyclic fatigue resistance at 45°compared to 60°angles of curvature. There was no significant difference in the length of the fractured fragment for all tested groups in both canal curvatures. **Conclusion:** Movement kinematics has a significant influence on the cyclic fatigue life of Reciproc-Blue instruments. Also, Increasing the angle of progression for each reciprocation cycle decreases the cyclic fatigue resistance of NiTi instruments.

INTRODUCTION

Since the invention of NiTi alloys, NiTi files fracture without notice at the time of clinical usage has been an issue [(1)]. Cyclic fatigue and torsional stresses are two separate mechanisms that cause files to suddenly and unexpectedly fracture [(2,3)]. The torsional fracture occurs when the instrument's tip binds into the canal whereas the shank is rotating, exceeding the metal's elastic limit [(4)]. Among the main reasons for abrupt instrument separation is cyclic fatigue failure, which is brought on by repeated compression and tension stress cycles on the region of maximal root canal curvature [(2,3)]. Several factors, including the instrument's kinematics, the alloy, the operating settings, and the metallurgical properties, influence cyclic fatigue resistance [(4–6)].

For improving the fracture resistance of NiTi-rotary instruments, manufacturers added many alterations to files such as changing their designs, using various alloys, and applying different heat treatments, in addition to altering the kinematics of NiTi rotary files. Yared introduced a new method in 2008, which led to an alternative viewpoint of NiTi instrument kinematics, this approach was to finish the root canal shaping using just one file and to minimize armamentarium by using reciprocation movement. This motion was claimed to boost the lifetime of the file by introducing it to less stress than continuous rotation (7).

One definition of a reciprocating motion is that the object keeps rotating in one direction, then changes direction to complete a full rotational cycle (clockwise CW and counterclockwise CCW movement)(8). Contrary to continuous rotation, it was shown that reciprocating motion enhances cycle fatigue resistance (8,9).

Ni-Ti instruments used in reciprocating motion were suggested to lower the fracture risk during use. Reciprocating motion always operates under the instruments elastic limit, extending the cyclic fatigue life, as compared to their use in continuous rotation motion(10). Reciproc R25 is a single reciprocating file system fabricated from M-Wire. Reciproc was improved to Reciproc Blue (VDW, Munich, Germany) By a unique thermal treatment that alters the molecular structure of the alloy coating it with an oxide layer, a blue color is imparted to the instrument. Reciproc Blue has an S-shaped cross-section, with two cutting edges and a non-cutting tip (11).

Compared to its predecessor, this thermal treatment was found to enhance the instrument flexibility and cycle fatigue resistance, as well as reduce the instrument surface microhardness (11). Up to our knowledge, none of the earlier investigations have investigated the cyclic fatigue resistance of Reciproc Blue in different reciprocation angles. Additionally, no published research studied the relationship between reciprocation angles and angles of canal curvature regarding the cyclic fatigue behavior of the Reciproc Blue file.

The null hypothesis assumes no significant difference among continuous rotation and different reciprocation angles on the cyclic fatigue resistance of the Reciproc Blue file. Moreover, there is no significant distinctness between different canal curvatures on the cyclic fatigue resistance of the Reciproc Blue file. So, the current research aims to assess the influence of various kinematics (reciprocation and continuous rotation motions) on the cyclic fatigue resistance of Reciproc blue file, as well as the impact of various canal curvatures on the cyclic fatigue resistance of Reciproc-blue file.

MATERIALS AND METHODS

Study design:

The research was waived from the approval of the Research Ethics Committee (REC), Faculty of Dentistry, Suez Canal University, code number 166/2019, as no living subjects were subjected to any risk during this study.

It was carried out in the Department of Endodontics, Faculty of Dentistry, Suez Canal University, Ismailia, Egypt. Faculty of Science, (Al-Azhar University), Cairo, Egypt, and Egyptian Mineral Resource Authority (EMRA), Cairo, Egypt.

Sample size calculation

A total of 80 samples is the minimal sample size that was sufficient to notice the impact size of 0.4, a power (1-β=0.85) of 85% at a significance probability level of p<0.05. Based on the sample size calculation, a total of 80 files were applied. Each rotation/ reciprocation angle group (A1, A2, A3, A4) was represented by 20 Reciproc blue files, subdivided into each canal curvature subgroup (B1, B2) represented by 10 Reciproc blue files [12]. The sample size was evaluated using G*power version 3.1.9.3 [13].

Cyclic fatigue testing

A total of eighty brand new Reciproc Blue files R25/08 were gathered for this investigation. The cyclic fatigue resistance of Reciproc Blue files was determined utilizing a custom-made testing block, with 80*40*5 mm dimensions, made of tempered steel with simulated canals resembling that proposed by Plotino et al [14]. The simulated canals were fabricated by replicating the instruments size and taper which was (25/.08), giving them an accurate trajectory. The fabricated canals diameter was 0.1 mm larger than that of the file along their whole length, allowing for free rotation.

There are two models of artificial canals based on the canal curvature angle. The inner diameter is (1.5) and (5) mm radius, the curvature center was 5mm from the file tip and the length of the curved part of the canal was 5 mm. Angles of curvature were (45°) and (60°) as measured according to the method of Pruett[15]. To observe the operating file in the canal and remove the fractured instruments between testing, an acrylic top face cover was created.

For standardization, the steel block was mounted over an aluminum plate to secure both the steel block and the endomotor in place. The aluminum frame dimensions were 150*220*10 mm. All files were inspected by stereomicroscope with x30 magnification for standardization and reliability of the experiment and for detection of any visible deformation [16], there was no defective instrument to be discarded.

The instruments were operated at room temperature by an electric endo-motor E-Connect S that was placed on a cyclic fatigue testing device. The motor enables the user to alter and adjust the reciprocating angles in both clockwise (CW) and counterclockwise (CCW) directions based on the manufacturer's recommendation. The speed was set to 300 RPM and the torque to 2 Ncm as recommended for Reciproc blue file[17]. The artificial canals were flooded with synthetic oil [16], before each file insertion to decrease the friction of the file and artificial canal walls.

Classification of samples:

Eighty brand-new Reciproc Blue NiTi files were randomly distributed into four groups (n=20) according to the reciprocation angle, each was subdivided into two subgroups (n=10) based on the artificial canal curvature, as follows:

1. Group A1:

Reciproc blue NiTi files R25 were operated in a simulated canal in a custom-made block made of tempered steel in continuous rotation. Fig. (1)

2. Group A2:

Reciproc blue NiTi files R25 were operated with a reciprocation angle set at 150° CCW- 30° CW. (angle of progression of each cycle is 120°, number of strokes for a complete rotation cycle is three) Fig. (1)

3. Group A3:

Reciproc blue NiTi files R25 were operated with a reciprocation angle set at 210° CCW- 30° CW. (angle of progression of each cycle is 180°, number of strokes for a complete rotation cycle is two). Fig. (1)

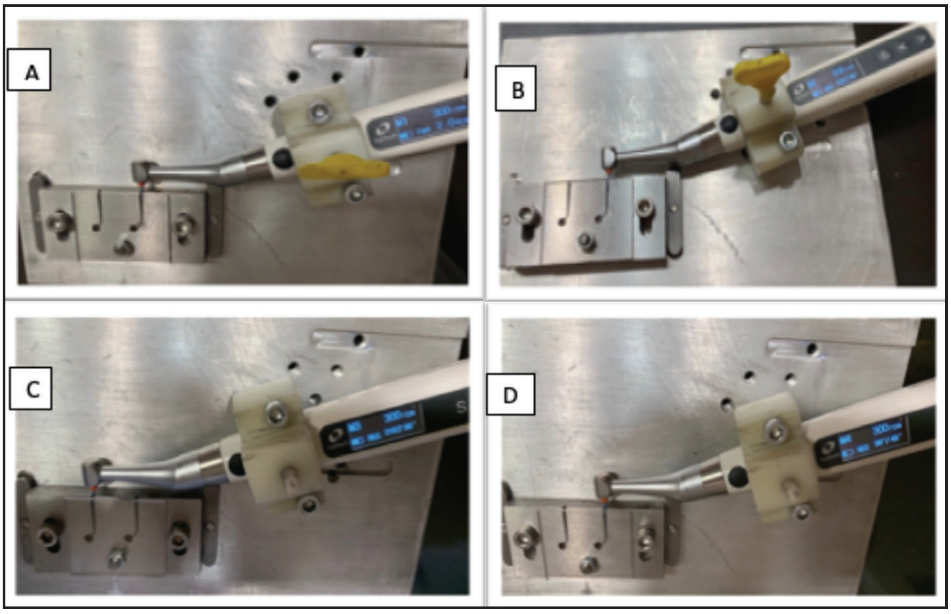

Fig. (1) Photographs showing Reciproc blue file operated in different motions: A: Continuous rotation motion, B: 150° CCW- 30° CW reciprocation motion, C: 210° CCW- 30° CW reciprocation motion and D: 90° CCW- 40° CW reciprocation motion.

4. Group A4:

Reciproc blue NiTi files R25 were operated with a reciprocation angle set at 90° CCW- 40° CW. (angle of progression of each cycle is 50°, number of strokes for a complete rotation cycle is 7.2) Fig. (1)

According to the artificial canal curvature, each group was further divided into two subgroups.:

1. **Subgroup B1:** Files were operated in a 60° artificial canal curvature.
2. **Subgroup B2:** Files were operated in a 45° artificial canal curvature.

All files were operated within their corresponding artificial canal until fracture occurred.

Assessment of samples:

Once a fracture is noticed visually and/or audibly, the time to fracture was measured in seconds using a stopwatch [18]. The number of cycles to fracture (NCF) of each file was measured by multiplying time to fracture in seconds (TTF) by the number of rotations or cycles [NCF = RPM x TTF] [17]. The length of the fractured tip was determined using a digital caliper, and the site of fracture was observed.

Scanning Electron Microscope (SEM)

A sample from each group was postoperatively scanned by SEM in three different magnifications: x250, x350, and x500 to detect the microcracks and surface changes at the site of fracture [19].

Statistical methods:

The collected data were analyzed for descriptive statistics both in graphical and numerical description. Inferential statistics for evaluation of the differences between different groups were performed at significance levels of 0.05 using SPSS for Windows (version 23 (2015), IBM Co. USA) [20]. Data were tested by the Shapiro-Wilk test and showed normal distribution (parametric distribution). Statistical analyses of the results were performed by applying the ANOVA test (one way) followed by the Post Hoc Tukey test. Pearson Correlation coefficient test was applied to study the correlation between TTF, NCF, and fractured length using the SPSS statistical package (version 23 (2015), IBM Co. USA).

RESULTS

Regarding the TTF

A. The effect of angle of canal curvature:

As presented in Table (1), B2 (45º) displayed a statistically significant variation in comparison to B1 (60º) in all tested groups. The p-value was statistically significant.

Table (1) *Intergroup comparison of Mean ±SD of TTF between the two angles of curvature 60º (B1) and 45º (B2) for all groups.*

TTF (sec)	B1(60º)	B2(45º)	P-value*
A1(c. rotation)	320.47±31.89^{c}	698.29±6.13^{a}	P £ 0.001
A2(150/30)	833.11±9.26^{b}	1959.17±165.02^{b}	P £ 0.001
A3(210/30)	737.08±95.54^{b}	933.80±133.42^{c}	P £ 0.001
A4(90/40)	1612.56±44.88^{a}	2120.33±75.48^{a}	P £ 0.001
P-value*	P £ 0.001	P £ 0.001	
Overall mean	875.80±45.39	1427.90±95.01	P £ 0.001

**Overall p-value of Intragroup comparison (B1 vs. B2), significant at (p<0.05). Overall p-value of Intergroup comparison, small letters for intergroup comparison (A1 vs. A2 vs. A3 vs. A4) with different superscripts within the same column are statistically significant different at (P ≤ 0.05).*

B. The effect of different kinematics of Reciproc Blue file:

At 60º curvature, the outcomes of the Post Hoc test signified that there was a significant difference in the mean of TTF between A1 and all groups as well as A4 and all groups. Also, there were no statistically significant differences between A2 and A3. While at 45º curvature, the results showed significant differences in the mean of TTF among all groups. The A4 group at 45º curvature is the best (have the highest mean of TTF). There was a significant difference between 60º and 45º curvatures among all groups.

Regarding NCF

A. The effect of angle of canal curvature:

As displayed in Table (2), B2 (45º) showed a statistically significant difference in comparison to B1 (60º) in all tested groups. The p-value was statistically significant.

B. The effect of different kinematics of Reciproc Blue file:

At 60º curvature. The results of Post hoc test indicated that there were no statistically significant differences in the mean of NCF between A1 and A2, as well as A1 and A3. While there were statistically significant differences in the mean of NCF between A4 and all groups. While at 45º curvature, the results indicated there were significant differences in the mean NCF between A4 and all groups as well as A3 and all groups. Also, there were no statistically significant differences between A1 and A2 groups. The A1 group at 45º curvature is the best (have the highest mean of NCF). There was no statistically significant difference between 60º and 45º curvatures in all groups.

Table (2) *Intergroup comparison of Means ±SD of NCF between the two angles of curvature 60º (B1) and 45º (B2) for all groups.*

NCF	B1(60º)	B2(45º)	P-value*
A1(c. rotation)	96139.5±7588.9[ab]	209408.9±2998.1[a]	P £ 0.001
A2(150/30)	83309.7±1019.3[b]	195916.8±16501.9[a]	P £ 0.001
A3(210/30)	110561.3±12653.0[a]	140069.3±19577.0[b]	P £ 0.001
A4(90/40)	67190.0±1226.9[c]	88346.9±3185.9[c]	P £ 0.001
P-value*	P £ 0.001	P £ 0.001	
Overall mean	89300.1±5622.0	158435.0±10565.7	P £ 0.001

** Overall p-value of Intragroup comparison (B1 vs. B2), significant at (p<0.05). Overall p-value of Intergroup comparison, small letters for intergroup comparison (A1 vs. A2 vs. A3 vs. A4) with different superscripts within the same column are statistically significant different at (P ≤ 0.05).*

Table (3) *Intergroup comparison of Mean ±SD of fractured segment length between the two angles of curvature 60º (B1) and 45º (B2) for all groups.*

Fracture length	B1(60º)	B2(45º)	P-value*
A1(c. rotation)	3.23±0.46[b]	3.13±0.37[b]	0.993[ns]
A2(150/30)	3.76±0.41[a]	3.70±0.05[a]	0.999[ns]
A3(210/30)	4.01±0.14[a]	3.82±0.07[a]	0.811[ns]
A4(90/40)	3.23±0.02[b]	3.46±0.33[a]	0.621[ns]
P-value*	P £ 0.001	0.03	
Overall mean	3.56±0.26	3.53±0.21	0.991[ns]

**Overall p-value of Intragroup comparison (B1 vs. B2), ns: non-significant (p>0.05). Overall p-value of Intergroup comparison, small letters for intergroup comparison (A1 vs. A2 vs. A3 vs. A4) with different superscripts within the same column are statistically significant different at (P ≤ 0.05).*

Regarding the fractured segment length (mm):

A. The effect of angle of canal curvature:

As demonstrated in Table (3), In all studied groups, there was no statistically significant difference between B2 (45º) and B1 (60º). The p-value was not statistically significant.

B. The effect of different kinematics of Reciproc Blue file:

At 60º curvature, the results of Post hoc test indicated there were no statistically significant differences in the mean of fractured segment length between A1 and A4, Also no significant difference between A2 and A3. While at 45º curvature, the results indicated that there were no statistically significant differences in the mean of fractured segment length between A2 and A3 as well as A2 and A4. The A3 group at 60º curvature has the highest mean of fractured length. There was no statistically significant difference between 60º and 45º curvatures in all groups.

SEM was applied postoperatively to investigate the fracture segment surfaces of one sample from each subgroup. Different magnifications were used (X250, X350, and X500) Fig. (2).

Pearson correlation between different variables is shown in Table (4):

The result of the Pearson correlation test between different variables (TTF, NCF, and Fractured segment length) is tabulated in table (4); from the results, we can conclude the following:

Regarding group A1: continuous rotation:

At 60º curvature (B1), there was a nonsignificant positive correlation between TTF & NCF, TTF & fractured segment length, and between NCF & fractured segment length. While at 45º curvature (B2), there was a nonsignificant positive correlation between TTF & NCF and a nonsignificant negative correlation between both TTF & fractured segment length, and between NCF & fractured segment length.

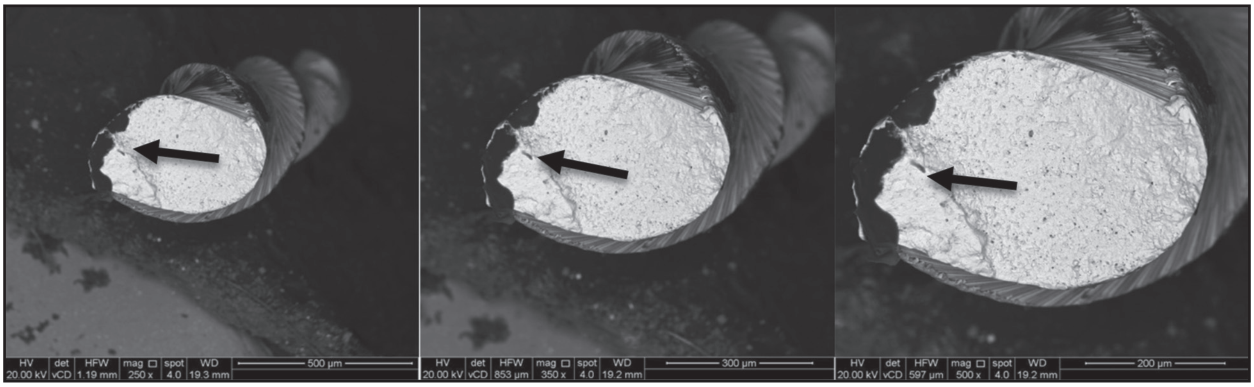

Fig. (2) A photograph showing SEM analysis of the fractured surfaces of a representative sample from the A2B1 group after testing for cyclic fatigue. The images show magnifications of x250, x350, and x500. Arrows point at the crack origin.

Table (4) *Correlation between all variables (TTF, NCF, and Fractured segment length) for all groups and subgroups*.

		NCF*TTF	NCF*FL	TTF*FL
A1	B1	NS Moderate +ve	NS Moderate +ve	NS Moderate +ve
	B2	NS Weak +ve	NS Moderate –ve	NS Moderate –ve
A2	B1	HS Complete	NS Moderate –ve	NS Moderate –ve
	B2	HS Complete	NS Moderate –ve	NS Moderate –ve
A3	B1	NS Weak –ve	NS Moderate +ve	NS Weak +ve
	B2	NS Moderate +ve	NS Weak +ve	NS Moderate +ve
A4	B1	NS Moderate +ve	NS Moderate –ve	NS Weak +ve
	B2	NS Moderate +ve	NS Moderate +ve	NS Moderate +ve

NS= non-significant (p-value >0.05), HS= highly significant (Correlation is significant at the 0.01 level)

***Regarding* group A2: 150 ccw 30 cw**

In both canal curvatures (B1) and (B2), there were highly significant complete correlations between TTF and NCF, a nonsignificant negative correlations between both TTF & fractured segment length, and between NCF and fractured segment length.

***Regarding* group A3: 210 ccw 30 cw**

At (B1), there was a nonsignificant negative correlation between TTF & NCF, and a nonsignificant positive correlation between both TTF & fractured segment length, and between NCF & fractured segment length. While at (B2), there was a nonsignificant positive correlation between TTF & NCF, TTF & fractured segment length, and between NCF & fractured segment length.

***Regarding* group A4: 90 ccw 40 cw**

At (B1), there was a nonsignificant positive correlation between both TTF & NCF and between TTF & fractured segment length, and a nonsignificant negative correlation between NCF & fractured segment length. While at (B2), there was a nonsignificant positive correlation between TTF & NCF, TTF & fractured segment length, and between NCF & fractured segment length.

DISCUSSION

Using nickel-titanium (NiTi) files has revolutionized root canal therapy due to their superior flexibility, Super elasticity decreased ledge development, and the potential to decrease operation time for even inexperienced operators [13,14]. Although NiTi instruments offer evident benefits over stainless steel ones, NiTi root canal files may fracture even in the absence of macroscopic deformations [21].

The two main factors that lead to endodontic instrument fracture are torsional and cyclic fatigue[22]. When an endodontic instrument rotates inside a curved canal while remaining within its elastic limits, it creats alternate tensile and compressive stresses that cause mechanical load creation. Through low-cycle fatigue, the cyclic recurrence of these loads causes instrument fracture [23]. More than one-third of clinically broken instruments are caused by cyclic failure, which is most likely to occur in the maximal canal curvature [23].

The reciprocation motion reduces stresses on the file by applying CCW and CW motions which significantly extend the NiTi file lifespan in comparison to continuous rotary motion [7,20].

NiTi alloys may be categorized into those that include mostly austenite (austenitic: conventional NiTi, M-Wire, R-Phase) and those that contain predominantly martensite (martensitic: CM Wire, Gold, and Blue-heat-treated NiTi) [24].

Special heating-cooling treatments coat the file surface with a visible titanium-oxide layer[19]. Reciproc Blue files were introduced by VDW (Munich, Germany) and are a progression of Reciproc M-wire. The design and the operating motion of both instruments are identical, but Reciproc Blue has undergone a particular thermal treatment that has left a thin film of blue titanium oxide on its surface [25]. Reciproc Blue can be pre-curved during clinical usage because of its martensitic phase [23].

Reciproc Blue is one of the main examples of single-file reciprocating systems that are commercially available. A particular electric motor (VDW Silver Reciproc) is required to operate Reciproc Blue in reciprocating motion with a preset reciprocating mode (BRECIPROC ALL which presents a 150° CCW/30° CW motion with 300 rpm speed)[26]. E-connect S wireless electric motor was chosen in the current study as it allows the operator to alter and adjust the reciprocating angles in both CW and CCW directions.

Reciproc Blue exhibited higher resistance to cycle fatigue as compared to Reciproc instruments[27]. This enhancement is most likely attributable to the inventive thermal treatment applied during manufacturing, which helps to restore the grain structure deformed during machining [28].

In the present study, Reciproc Blue R25 was chosen as a single reciprocating file system made of blue heat-treated CM wire for its outstanding resistance to cyclic fatigue when compared to several rotating and reciprocating file systems [29]. As a single file system, the Reciproc Blue file is exposed to mechanical stresses during usage that would usually be divided among several successive instruments. That's why manufacturers recommend a single use for reciprocating single-file systems to inhibit the high risk of file separation in case of multiple uses [30].

No randomization was adopted in the present study because all files were preoperatively inspected using a stereomicroscope [16] with x30 magnification for standardization and reliability of the experiment and for detection of any visible deformation, there were no defective instruments to be discarded, which reflects high manufacturing quality.

It was important to evaluate the cyclic fatigue resistance of the Reciproc blue file in various canal curvatures using different kinematics. There are different methods introduced to determine the root canal curvature. In the present investigation, the canal curvature was assessed using the Pruett approach(15) since a novel method was required to describe canal curvature in parameters able to determine files stress and, hence, file fatigue life. The variables that describe the shape of the canal are the angle and radius of curvature. As published by Schneider(31), the standard canal curvature measurement method estimates canal shape by a single parameter which is only the curvature angle. This method neglects the radius of curvature as an important factor in measuring the geometry of the canal. The usage of just one parameter to describe the shape of the canal doesn't characterize the canal abruptness by measuring the radius of curvature. By using the Schneider technique, two canals with the same angle of curvature would have quite various radii or abruptness of curvatures, which would have a dramatically different impact on file fatigue (15).

Pruett's method of analyzing canal geometry and curvature is more accurate since it considers the radius of curvature (r) in addition to the curvature angle (a). The radius of curvature is the circle's radius that corresponds to the canal path at its sharpest curve. The angle of curvature is the angle generated from the perpendicular lines from tangents intersecting at the circle center. The radius of curvature is independent of the angle. Consequently, two canals with equivalent degrees of curvature might have radii that vary greatly (15).

Either artificial simulated canals or extracted natural teeth can be used for cyclic fatigue testing. In the current investigation, we evaluated Reciproc Blue NiTi files cyclic fatigue resistance in two simulated canals with 45° and 60° curvature angles. Natural teeth may more accurately reflect the clinical conditions, however, because root canal morphology differs, it is hard to use natural canals and standardize the same curve regarding angle and diameter (32). That is why, to standardize cyclic fatigue testing, stainless steel simulated canals rather than natural teeth were utilized in the current investigation as in prior studies of a similar nature(33).

In the present study, to minimize the variables, temperature as a factor was not included in the study, cyclic fatigue resistance test was conducted at room temperature in accordance with previous studies(16,17,28), whereas other studies (18,33,34) have advocated the simulation of the environmental conditions such as the simulation of body temperature during fatigue testing to reflect clinical conditions. Keles et al.(33) claimed that there were no significant differences between room and intracanal temperatures in terms of cyclic fatigue resistance of the NiTi file systems, while Keskin et al.(34) stated that simulated body temperature was found to reduce the fatigue life of NiTi instruments.

Whereas many researchers have examined the cyclic fatigue resistance of several NiTi files only in one canal curvature ignoring the complex anatomy of the human teeth(12,22,34), in our study it was important to evaluate the cyclic fatigue resistance of Reciproc Blue instruments in two different canal curvatures because it is known that molar teeth have more complex anatomy with variable degrees of curvatures maybe even in the different roots within the same tooth (35).

The fatigue testing device manufactured to be used in the current investigation was very much like that of a study by Grande et al.(36) composed of a metal framework linked to a mobile Aluminum piece to hold the electric endomotor handpiece, and a stainless steel block with simulated canals.

The endomotor handpiece was installed over a portable device that permitted accurate and easy insertion of each file inside the simulated canal, to insure proper positioning and orientation of the file to the exact depth.

Grande et al.[36] stated that if the simulated canal is not in identical size and taper as the file, its trajectory would have less curvature during testing, which would affect the cycle fatigue test findings. Therefore, in the present investigation, artificial canals were built to simulate the size and taper of each file, allowing for a more optimal trajectory. Each simulated canal depth was milled to the maximal diameter of the instrument + 0.1 mm, permitting the file to operate smoothly inside the canal.

Two artificial root canals with angles of curvature of 60° and 45° and a radius of curvature of 5 mm were milled in the steel block. Before each file insertion, the artificial canals were flooded with synthetic lubricating oil to decrease the friction of the instrument with the simulated canal walls [16]. Tempered glass was placed over the artificial canals to keep the files from fleeing and to make it possible to observe the operating file in action.

There are two methods of testing cyclic fatigue resistance in laboratory studies, static and dynamic testing models [37]. Although tensile and compression stresses are usually located only at the maximal curvature point of the files, they may cause microcrack development on the files microstructure[38] with no signs of plastic deformity in static models. The area of these stresses advances through the entire file shaft in the case of dynamic models[33]. The dynamic model was previously reported to better represent the clinical conditions, delaying the microcrack development and extending the instrument lifetime[39].

One of the first dynamic testing devices that allowed for instrument vertical movement was developed by Dederich & Zakariasen [40]. Also, Ray et al. [41] used standardized axial movements during fatigue testing using their dynamic study designs. The stress interval before cyclic failure occurred, was lengthened by the axial movement during dynamic testing [40].

The distribution of the bending forces along the instrument, which prevents load localization on one point of the file, is the main factor that accounts for the longer lifetime of NiTi instruments in dynamic cyclic fatigue testing. Therefore, dynamic test designs using NiTi instruments must be viewed as giving more clinically relevant data and facts than static test designs due to their longer lifespan [39].

Nevertheless, dynamic testing also has many drawbacks, according to Hulsmann et al. [39]. Relying on the canal utilized to curve the instrument during dynamic testing, torsional fatigue may potentially impact the instrument's metallurgy in addition to cyclic fatigue, according to Dederich & Zakariasen [40]. In dynamic testing designs, it might be challenging to tell torsional and cyclic fatigue instrument fractures apart from one another. Additionally, standardizing the axial movement of the file with no side motion that causes torsional loads is difficult. Additionally, the results of dynamic tests may be distorted if an operating instrument moves laterally, creating a second bending point at the canal's entrance [39].

Interestingly, among the numerous papers on the cyclic fatigue resistance of NiTi files, dynamic fatigue testing investigations remain uncommon [41]. In addition, contrary to the dynamic cycle fatigue model, Keles et al. [33] found that the oscillations of the files are less throughout root canal preparation in real clinical settings. The NCF readings of the examined instruments are higher in the dynamic models, but the ranking order of the instruments is identical in both static and dynamic tests [(33)], suggesting that either one may be utilized for cyclic fatigue testing. Similar to the design of Plotino et al. [(25)], and Grande et al. [(36)], the static model was selected in the current investigation to evaluate the TTF values of Reciproc Blue R25 files in all tested groups.

Although the cyclic fatigue resistance of several rotation and reciprocating files has been evaluated in many studies using different kinematics [(33,34)], till present, no data are available on the effect of different kinematics on the cyclic fatigue resistance of Reciproc Blue file.

Thus, in the current investigation, we evaluated the cyclic fatigue resistance of Reciproc Blue instruments R25/0.08 using different kinematics and we found that all three of the tested reciprocation movements (150°CCW-30°CW, 210°CCW-30°CW, and 90°CCW-40°CW) yielded significantly prolonged time to fracture in comparison with continuous rotation motion in both simulated canal curvatures. Furthermore, there was a substantial variation in failure time between the three reciprocating groups in both canal curvatures, except the reciprocating groups A2B1 (150°CCW-30°CW with 60° canal curvature) and A3B1 (210°CCW-30°CW with 60° canal curvature), whose TTF values were nonsignificant when compared to each other. This is perhaps caused by the tiny difference in the CCW angle between them. Increasing the CCW angle, and therefore the angle of progression for each reciprocation cycle lowered the cyclic fatigue resistance, this is in accordance with Gambarini et al. [(42)].

Moreover, our results demonstrated that there was a significant alteration even between the highest reciprocation angle (210° CCW- 30° CW) in the more severe curvature 60° (A3B1) and the continuous rotation group in the less severe curvature 45° (A1B2) which means that cyclic fatigue resistance of the reciprocation groups gave better results in the more severe canal curvature than the rotation group had in the less severe canal curvature.

The results of the current study was in accordance with several previous studies such as Gambarini *et al*. [(42)] who examined the resistance to cyclic fatigue of K3XF files using reciprocation motion at different angles. The findings of that research showed that, all reciprocation groups displayed a significant increase in TTF under reciprocation motion than under continuous rotation.

Additionally, Arslan et al. [(43)] evaluated Reciproc files with various kinematics, and all reciprocation groups (150° CCW–30° CW, 270° CCW–30° CW, and 360° CCW–30° CW) resulted in a prolonged mean time to fracture in comparison with the 360° CCW continuous rotation movement.

However, the results of the current study were contradictory to others[(28,45)]. A previous study by Gundogar et al.[(28)] showed that HEDM instruments operated in continuous rotary motion had significantly more cyclic fatigue resistance than Reciproc Blue and WaveOne Gold instruments which were operated in reciprocation motions[(28)], However, these outcomes may be attributable to using a different assessment technique. Additionally, Pedullà et al. [(44)] claimed that the resistance to cyclic fatigue of HEDM rotary instruments is greater than that of Reciproc and WaveOne instruments. In this instance, the enhanced cycle fatigue resistance of HEDM instruments may be a result of the controlled memory wire (CM) and electric discharge machining (EDM) treatments employed during instrument fabrication. The difference might also be effortlessly clarified by the different assessment methods utilized in the various research (using NCF for cyclic fatigue evaluation vs. using TTF).

The distinction between reciprocating and continuous rotational motions regarding cyclic fatigue resistance is that more curvature deflection of the file during each cycle reduces the number of cycles necessary to cause file failure [43]. If the root canal restriction could induce only elastic deformity, a greater number of cycles would be required to cause instrument breakage. During one reciprocating motion, the file rotates CCW for a particular (in the current research variable) number of degrees and returns a certain number of degrees; hence, one rotary cycle (360º) is completed after more than one (depending on the angles) reciprocating cycle. The number of times a crack opens and closes influences its fatigue life [45]. Throughout one cycle, the crack opens and closes one time. More cycles result in a longer fatigue life since cracks shut and open more often. During a single reciprocation action, the file rotates counterclockwise and reverses clockwise for a specific degree, requiring a greater number (n) of reciprocating cycles to accomplish one complete rotation cycle (360 degrees). The greater the number of cycles, the longer the file lifespan [42].

According to our findings, all tested groups displayed a higher cyclic fatigue resistance at a 45° curvature angle in comparison with a 60° curvature angle. This result was in agreement with another research by Peng *et al.* [46] who claimed that at a 45° curvature angle, the cyclic fatigue resistance of NiTi instruments was significantly greater than their resistance in canals with 60° and 90° curvature angles [46]. Also, the same findings were confirmed by Lall *et al.* [47] who found that all tested groups had higher resistance to cyclic fatigue at 45° angle of canal curvature as opposed to 60° and 90° curvature angles [47].

Additionally, the findings of this research are in accordance with the results of former investigations that the cyclic fatigue resistance of NiTi instruments is greatly affected by the angle of the artificial canal curvature [32,46]. all reciprocation groups had greater resistance to cyclic fatigue than both rotation groups in both canal curvatures.

In accordance with several previous studies [23,46,48], there was no significant change between mean fractured segment lengths among all the tested groups in both canal curvatures, whose maximal area of stress coincided with the mid-point arc of the curvature, in accordance with Pruett et al [15]. This argues in favor of the accurate positioning of the tested files inside the canal.

Similar to Al-Obaida et al. [49] and Plotino et al. [25], the Time To Fracture has been chosen in the current investigation to examine the cyclic fatigue resistance of Reciproc Blue instruments. TTF is more reliable than the number of cycles to fracture, which is usually used in other studies [12,47]. NCF cannot be properly determined for reciprocation instruments operating in both CW and CCW directions [30].

Also, Ozyürek et al.[50] has chosen time to failure (TTF) for cyclic fatigue evaluation over the number of cycles to fracture (NCF) while comparing the resistance to cyclic fatigue of Reciproc Blue (RB), HyFlex EDM (HEDM), 2Shape (TS), and WaveOne Gold (WOG) NiTi instruments in various canal curvatures. They argued that it was inaccurate to compare rotation and reciprocation instruments using the number of cycles to fracture, as it was impossible to thoroughly determine this parameter in reciprocation instruments operating in forward and reverse angles due to the lack of agreement on the values reported by the manufacturers. They also stated that TTF is more clinically accurate since it reflects how files are used clinically, while NCF is more related to the mechanical quality of the instrument itself [51].

If the NCF values were considered in the present study, the Continuous rotation motion group A1 would have shown statistically greater resistance to cyclic fatigue than the reciprocation motion groups, especially the A4 (90ccw/40CW) group in both canal curvatures, contrary to what was previously reported for the same groups based on TTF values. These results highlight the need of using the appropriate assessment parameters for the tested instruments, as well as the requirement for test standardization.

And that was the reason for finding a non-significant correlation between the variables in all groups except for a highly significant correlation which was detected only between TTF and NCF in A2B1(150°CCW-30°CW with 60° canal curvature) and A2B2 (150°CCW-30°CW with 45° canal curvature) reciprocating groups. That might be caused by the fact that the number of strokes in the A2 group was three strokes, and the RPM value for Reciproc blue file is 300, so when applying the equation NCF= TTF* RPM, the values of the NCF are highly correlated with TTF values. However, to our knowledge, no former studies have examined the correlation between the three parameters (NCF, TTF, and FL) in cyclic fatigue resistance to compare.

Therefore, within the limitation of the present study, the null hypothesis was thus partially denied. The findings demonstrated that motion kinematics had a substantial impact on the cyclic fatigue life of the NiTi files that were examined. Not only was there a substantial difference between reciprocation and continuous rotation but also a significant change between different reciprocating movements with different reciprocation angles in both tested canal curvatures.

One of the limitations of the current study is evaluating the cyclic fatigue resistance of Reciproc blue files at room temperature, therefore, further investigations are required to evaluate the behavior of the cyclic fatigue resistance of Reciproc Blue files in different kinematics at body temperature to better simulate the clinical conditions, as according to a recent systematic review (51), various heat-treated files are martensitic, and transform to a more austenitic state at body temperature resulting in a mixed martensitic, R-phase, and austenitic structure. The martensitic to austenitic conversion is not complete at body temperature, but a considerable proportion is already austenitic. However, the crystal lattice of conventional NiTi instruments is almost identical at room and body temperatures; nevertheless, literature reports that at body temperature, cyclic fatigue resistance is reduced (52).

Also, further clinical researchers are needed to examine the behavior of the cyclic fatigue resistance of Reciproc Blue instruments in different kinematics using a dynamic testing method, In the present study, static testing of samples was undergone in simulated steel block artificial canals. Also, the simulated canals differ from natural teeth which better represent the clinical conditions. Additionally, samples were evaluated in only two canal curvatures, while the actual anatomy of the human teeth is very variable and complex and cannot be standardized.

Therefore, further investigations and research are needed to completely evaluate the behavior of the Reciproc Blue file using different kinematics in more complex canals like severe 90° angle of curvature and bayonet double curved canals. Also, investigations are required for the comparison of the superior cyclic fatigue resistance abilities of Reciproc Blue with the more recently introduced files such as Trunatomy, Edge Taper platinum, and Rogin Sup-taper blue and gold NiTi files.

Additionally, more studies are required to analyze the cyclic fatigue resistance of Reciproc blue files in different kinematics comparing both static and dynamic testing methods, as well as further research into the definition and measurement of speed in a reciprocating motion should be done.

CONCLUSION

Within the limitations of the current study, it was concluded that:

Movement kinematics have a substantial effect on the cycle fatigue life of the examined Reciproc Blue files. All reciprocation movements (150° CCW–30° CW, 210° CCW–30° CW, and 90° CCW–40° CW) resulted in a mean time to failure that was longer than that of the continuous rotating motion. In both canal curvatures, there was a substantial difference in the time to fracture between the three reciprocation groups. The cyclic fatigue resistance of NiTi instruments is decreased by increasing the CCW angle and, subsequently, the angle of progression for each reciprocating cycle. At 45° angle of curvature, all tested groups demonstrated higher cycle fatigue resistance than at a 60° angle of curvature.

Declarations:

Ethics Approval

All experimental protocols were independently reviewed and approved by the Research Ethics Committee (REC) of the Faculty of Dentistry, Suez Canal University (approval number 166/2019).

Consent for publication

Not applicable

Data availability

The datasets generated during this study are included in this article.

Competing interests

No potential conflicts of interest.

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Authors' contribution

Professor Marwa Sharaan and associate professor Dalia Abdallah contributed to the study conception and design, supervision, reviewing, and editing. Amira ElOzairy contributed to the cyclic fatigue testing procedures and writing the original draft. All authors read and approved the final manuscript.

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