

# Comparison of Cyclic Fatigue Resistance of Five Nickel Titanium Rotary File Systems with Different Manufacturing Techniques

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## Abstract

**Objectives:** The purpose of this study was to evaluate the resistance to fatigue failure of five different nickel-titanium rotary files in three different curved trajectories.

**Materials and Methods:** A total of 150 Neoniti A1, RaCe 25.06, Mtwo 25.06, Twisted file 25.06 and ProTaper Next X2 files with the tip size of 25 were tested (n=30 for each group). Three groove types simulating curved canals were used differing in radius, arc length and position of the arc, each measuring 1.5 mm in width, 20 mm in total length and 2.5 in depth. Resistance to cyclic fatigue was determined by counting the numbers of cycles to failure. Furthermore, the fragment length of the fractured tips and angle and radius of curvature formed by each file in each trajectory were evaluated. The data were analyzed by t-test, one way ANOVA and Tukey's HSD test.

**Results:** Neoniti showed the highest and RaCe showed the lowest number of cycles to fracture (NCF) values ( $P < 0.05$ ), indicating the highest and lowest fatigue resistance, respectively. The highest and lowest curvature angles were seen in RaCe and Neoniti, respectively. Regarding the radius of curvature, Twisted file had the lowest and Neoniti had the highest values. The mean NCF of all rotary files was lower in the more coronally curved trajectory.

**Conclusion:** The fatigue resistance of the evaluated rotary files was lower in more coronally located curvatures. Neoniti exhibited the highest and RaCe exhibited the lowest fatigue resistance compared to other evaluated files.

**Key words:** Fatigue; Dental Instruments; Fracture; Nickel; Root Canal Preparation; Titanium.

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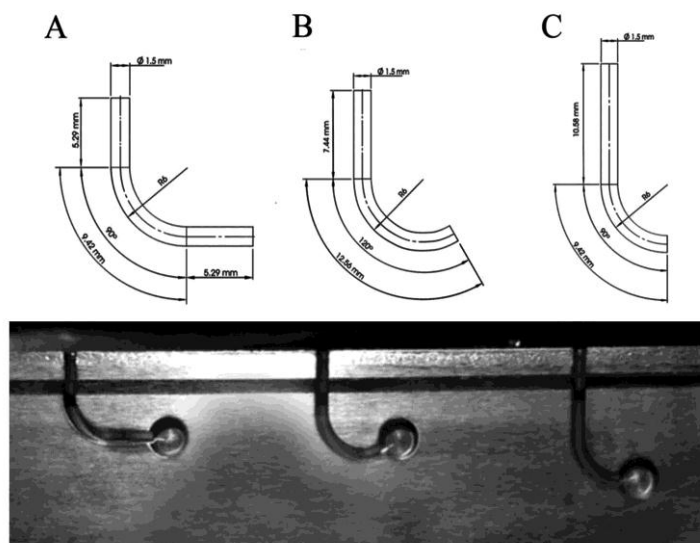
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## INTRODUCTION

The use of nickel-titanium (NiTi) rotary instruments for root canal system preparation has increased due to their undeniably favorable qualities; however, unexpected fracture is an important disadvantage of these instruments [1-3]. Controversy remains regarding the contribution of torsional fracture, fatigue

fracture and the combination of both to the separation of NiTi rotary instruments [4]. Some have implicated fatigue fracture to be a main reason for the separation of endodontic files in the clinical setting [2,5,6]. Fatigue fracture occurs due to repeated compressive and tensile stresses accumulated at the point of maximum flexure of an instrument rotating in a curved



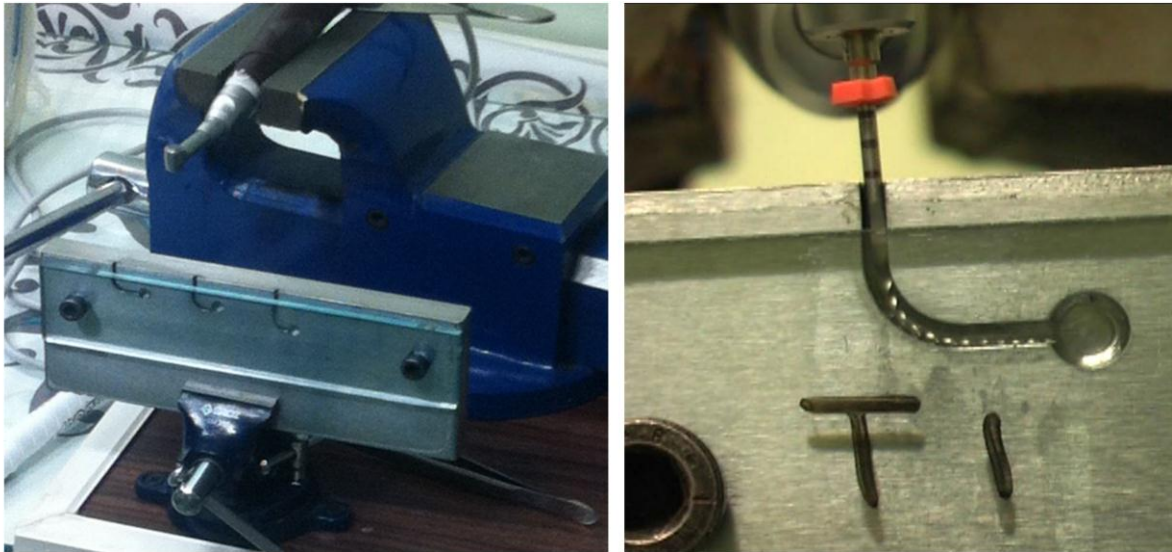
**Fig. 1.** Three types of trajectories designed for this study. A. Trajectory with curvature located in the middle third. B. Trajectory with curvature located in the apical third. C. Trajectory with curvature located in the apical third with smaller arc length.

canal without the instrument being bind to the root canal [5]. It should also be noted that controversy exists regarding the effect of un-retrieved separated files in root canals on the outcome of endodontic treatments [7]. Considering that the retrieval of separated instruments from the root canal system is very difficult and in some cases impossible and that un-retrieved fractured files may have an adverse effect on the outcome of endodontic treatments, overcoming or reducing the risk of this problem is of high clinical significance.

Neoniti (Neolix, Châtres-la-Forêt, France) is a newly introduced NiTi rotary system with a non-homogeneous rectangular cross section and multiple taper in a single instrument; it consists of one C1 and three A1 (with #20, #25 and #40 tip sizes) files. The taper in the A1 #25 file is 0.08 from D0 up to D5; whereas from D5 to D16 the taper is 0.04. It is manufactured using a newly developed wirecut electrical discharge machining (WEDM) process. The manufacturer claims that this manufacturing process is highly precise down to the micron, oil-free and clean and stress is limited to the metal surface during this process. Furthermore,

it produces a rough surface, resulting in abrasive properties that enhance the speed of root canal preparation. Moreover, the manufacturer claims that these files undergo appropriate heat treatment that results in high flexibility and shape memory of this system. ProTaper Next (Dentsply, Tulsa Dental Specialties, Tulsa, USA) is another newly marketed rotary file system made of M-Wire NiTi with a rectangular cross-sectional design. It also has multiple tapers in a single file [8].

Twisted file (SybronEndo, Orange, CA, USA) is manufactured by twisting a NiTi wire with a triangular cross-section and R-phase crystalline structures created by heating and cooling. After completion of twisting, the file is heated and cooled again to maintain its new shape while converting back into its austenite crystalline structure [9]. Mtwo (VDW GmbH, Munich, Germany) and RaCe (FKG Dentaire, La-Chaux-de-Fonds, Switzerland) rotary instruments are two routinely used systems for root canal cleaning and shaping. Mtwo instruments have an italic 'S' cross-section with two cutting edges resembling that of the S-file.



**Fig. 2.** Hand-piece stabilized on a holder (left image). Twisted file placed in the trajectory of group A (right image)

RaCe instruments have a triangular or Square-shaped cross-section and alternating cutting edges. Considering that no research has been done regarding the mechanical properties of Neoniti rotary files, the aim of this study was to compare the cyclic fatigue resistance of Neoniti A1 #25, RaCe 25/.06, Mtwo 25/.06, Twisted file 25/.06 and ProTaper Next X2 file.

### MATERIALS AND METHODS

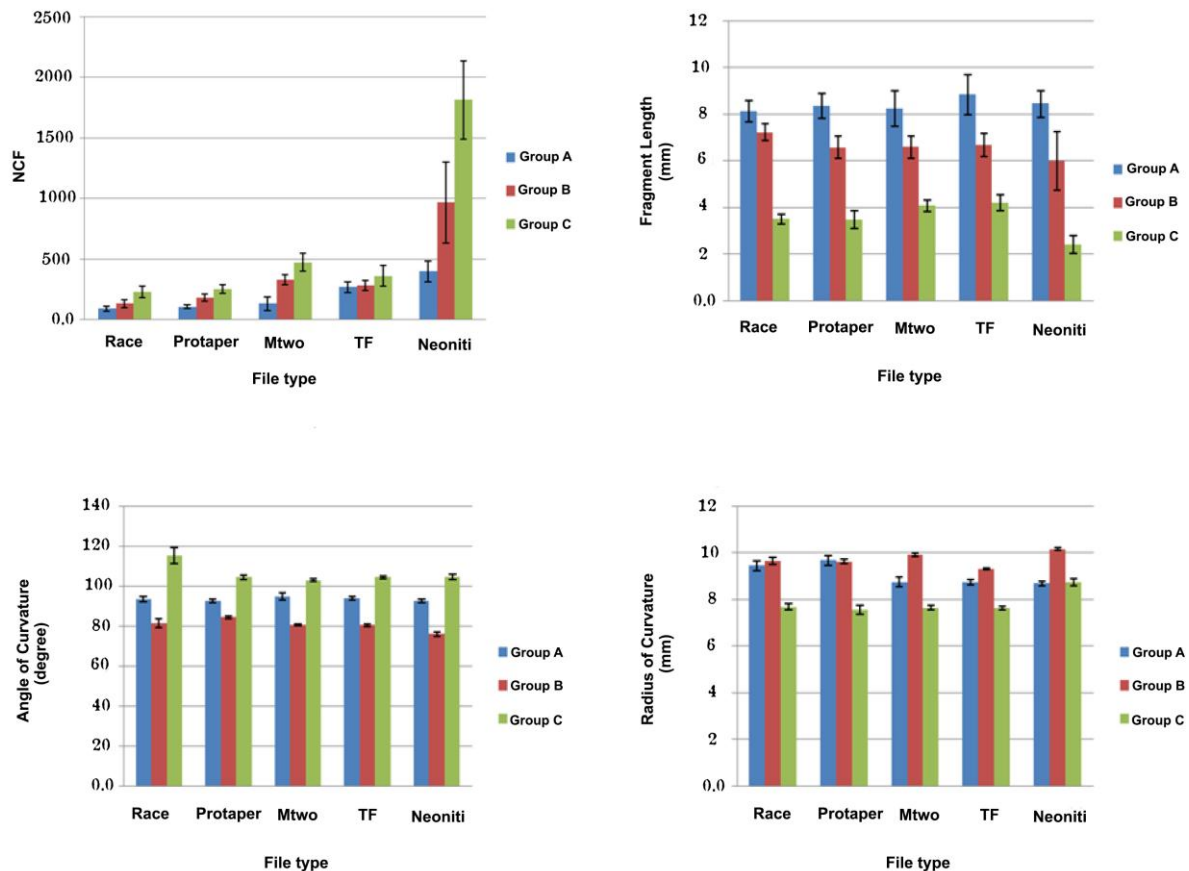
Artificial grooves simulating three canals measuring 1.5 mm in width, 20 mm in length, and 2.5 in depth with a U-shaped cross-section were machined into 316L stainless steel blocks by computer-assisted milling and hardened with polished chrome plating.

Three types of trajectories were designed according to the following parameters: group A: A straight cervical segment measuring 5.29 mm with an arc length of 9.42 mm, a curvature radius of 6 mm, a straight apical segment measuring 5.29 mm, and the arc in the middle portion of the canal; group B: A straight segment measuring 7.44 mm with an arc length of 12.56 mm, a radius of 6 mm, and the arc in the apical portion of the canal; group C: A straight cervical segment measuring 10.58 mm

with an arc length of 9.42 mm, a curvature radius of 6 mm, and the arc located in the apical portion of the canal [5]. A 4-mm-thick glass was screwed in front of the simulated canals to prevent the instrument from slipping out (Fig. 1). Comparison between trajectories A and C was done to evaluate the influence of the arc location (i.e. in the apical vs. the middle portion of the canal) on the NCF of rotary instruments. Comparison between trajectories B and C was done to evaluate the influence of the arc length (i.e. 9.42 mm or 12.56 mm) on the NCF of rotary instruments. Five types of rotary files with a similar tip size were used and evaluated in this study:

1. Neoniti A1 #25
2. RaCe 25.06
3. Mtwo 25.06
4. Twisted file 25.06
5. ProTaper Next X2 file

The hand-piece of an endodontic electromotor (X-Smart; Dentsply Maillefer, Ballaigues, Switzerland) with a reduction ratio of 1:20 was fixed above the block so cyclic fatigue could be assessed in a static mode (Fig. 2). After putting a glass slab on the block and fixing the hand-piece to the block with the file in it, the



**Fig. 3.** The mean ± standard deviation of (A) number of cycles to fracture (B) fragment length (C) angle of curvature and (D) radius of curvature of experimental subgroups.

instruments (n=10 from each subgroup) freely rotated in a “static” mode (i.e., without any pecking movement). The rotational speed and torque suggested for all evaluated rotary instruments by their manufacturers were similar except for that of Twisted file. To standardize the study, 300 rpm speed and 2 N.Cm torque was applied.

Liquid paraffin (Kimiagar Toos, Mashhad, Iran) was used as lubricant during the file rotation and it was applied on the canal walls by a micro-brush. The instruments were used until fracture occurred and the time to fracture was recorded in seconds by two methods: (A)

Direct visualization with a ×2.5 loupe (Heine HR binocular loupes, Heine Optotechnik, Herrsching, Germany) and listening (B) playing captured videos by Corel Video Studio ProX2 software (Corel Corp., Ottawa, Canada). The NCF was calculated using the following formula:  $NCF = \text{Time (seconds) to failure} \times \text{rotational speed}/60$  [4,10].

The exact angle and radius of the curvature in which each file was constrained in, were calculated from the snap shots taken from the files while rotating in the trajectories as measured by Pruett et al. [10].

Fractured tips were evaluated using a

stereomicroscope (model LA-SZM45-B1, Nanjing Sunny Optical Instrument Co., Ltd., Nanjing, China) at  $\times 7$  magnification and AM423X dinoEye digital eyepiece and RL-L64 LED light source (LED model). Images were saved in JPEG format by Dinocapture 2.0 software and the length of the fractured file tips was measured. The t-test was used to evaluate the mean time of fracture. One-way ANOVA and Tukey's HSD test were used for inter- and intra-group pairwise comparisons of NCF, separated fragment length, angle and radius of curvature; the significance was determined at the 95% confidence level.

## RESULTS

### *Number of cycles to fracture:*

The overall mean time of fracture calculated visually and on the captured film was  $82.02 \pm 91.09$  seconds and  $80.52 \pm 89.53$  seconds, respectively. The difference seen between the two different methods of calculation was not statistically significant ( $P=0.059$ ). The mean, minimum and maximum values of NCF for each group are shown in Table 1. According to the results of the current study in all curve types Neoniti showed the highest and RaCe showed the lowest NCF values ( $P<0.05$ ), indicating the highest and lowest fatigue resistance, respectively. In group A, a significant difference was seen in the NCF among the evaluated files ( $P<0.001$ ). The NCF values from the lowest to the highest were as follows (Fig. 3):

RaCe < ProTaper < Mtwo < Twisted file < Neoniti. Among the subgroups, Neoniti and Twisted file showed a significant difference when compared with each other ( $P<0.001$ ). Furthermore, both Neoniti and Twisted file showed significant differences when compared to other subgroups ( $P<0.001$ ).

In groups B and C, the NCF values from the lowest to the highest were as follows (Fig. 3): RaCe < ProTaper < Twisted file < Mtwo < Neoniti. In groups B and C, a significant difference was seen in the NCF among the

evaluated files ( $P<0.001$ ). RaCe, ProTaper and Twisted file showed no statistically significant differences ( $P>0.3$ ); Twisted file and Mtwo had no statistically significant difference either ( $P>0.4$ ); whereas, Neoniti had a statistically significant difference with all other groups ( $P<0.001$ ).

### *Separated fragment length:*

The mean length of separated fragment of instruments in each subgroup is shown in Table 2.

Overall, the fragment length of separated instrument in group A was significantly longer than that in group B; furthermore, these values in group B were significantly longer than those in group C. In group A, no statistically significant difference was seen ( $P>0.1$ ). The Twisted file separated fragments were the longest while the RaCe separated fragments were the shortest. In groups B and C, significant differences were seen in the separated fragment length of different groups ( $P<0.001$ ). Neoniti had the shortest separated fragment length. In group B, the longest separated fragment length was seen in RaCe; whereas, in group C, the longest separated fragment length was seen in ProTaper. In group B, ProTaper, Mtwo and Twisted file had no significant difference with all other file types ( $P>0.2$ ); whereas, RaCe had a statistically significant difference with Neoniti ( $P=0.003$ ). In group C, Neoniti had a statistically significant difference when compared to all other file types ( $P<0.001$ ); whereas, Twisted file and Mtwo had no statistically significant difference ( $P=0.4$ ). Furthermore, RaCe and ProTaper had no statistically significant difference either ( $P=0.9$ ).

### *Angle and radius of curvature:*

The mean angle and radius of curvature of each subgroup are shown in Table 2. Overall, the highest and the lowest curvature angles were seen in RaCe and Neoniti, respectively. Regarding the radius of curvature, Twisted file had the lowest and Neoniti had the highest values (Fig. 3, Table 2).

**Table 1.** The mean  $\pm$  standard deviation (SD), minimum and maximum NCF values of each subgroup. Groups with statistically significant differences are shown with similar symbols (alphabets or numbers).

	Group A			Group B			Group C		
	Mean $\pm$ SD	Minimum	Maximum	Mean $\pm$ SD	Minimum	Maximum	Mean $\pm$ SD	Minimum	Maximum
<b>RaCe</b>	91.75 $\pm$ 19.6	65.60	125.55	133.32 $\pm$ 31.7	80.80	201.00	228.21 $\pm$ 46.8	165.80	316.10
<b>Significance</b>	A,G			a,e			4,6		
<b>ProTaper</b>	108.80 $\pm$ 16.7	90.35	136.45	183.70 $\pm$ 29.3	135.00	220.85	255.42 $\pm$ 36.9	170.35	301.00
<b>Significance</b>	B,F			b			3,5		
<b>Mtwo</b>	133.58 $\pm$ 54.7	60.05	201.40	333.28 $\pm$ 41.6	290.85	420.50	475.60 $\pm$ 73.1	375.85	575.50
<b>Significance</b>	C,E			c,e			2,5,6		
<b>TF</b>	270.80 $\pm$ 43.7	205.85	315.85	283.16 $\pm$ 103.4	70.60	481.05	362.73 $\pm$ 85.7	190.25	480.50
<b>Significance</b>	D,E,F,G			d			1		
<b>Neoniti</b>	400.26 $\pm$ 85.6	265.10	530.70	966.68 $\pm$ 333.3	700.30	1466.25	1812.39 $\pm$ 322.6	1395.70	2381.20
<b>Significance</b>	A,B,C,D			a,b,c,d			1,2,3,4		

**Table 2.** Fragment length and angle and radius of curvature of each subgroup. Groups with statistically significant differences are indicated with similar symbols.

	Fragment length(mm)			Angle of curvature (degree)			Radius of curvature (mm)		
	Group A	Group B	Group C	Group A	Group B	Group C	Group A	Group B	Group C
<b>RaCe</b>	8.1 ± 0.4	7.2 ± 0.4	3.5 ± 0.2	93.4 ± 1.1	81.5 ± 2.2	115.1 ± 3.9	9.4 ± 0.2	9.6 ± 0.1	7.6 ± 0.1
<b>Significance</b>		A	4,6,8		A,B	1,2,3,4	A,B,C,D	d,h,j	4
<b>ProTaper</b>	8.3 ± 0.5	6.6 ± 0.5	3.5 ± 0.4	92.6 ± 0.95	84.3 ± 0.5	104.3 ± 0.9	9.7 ± 0.2	9.6 ± 0.1	7.5 ± 0.2
<b>Significance</b>			3,5,7	b	A,C,D,E	1,5	A,E,F,G	c,g,i	3
<b>Mtwo</b>	8.2 ± 0.8	6.6 ± 0.5	4.0 ± 0.2	94.8 ± 1.7	80.5 ± 0.6	102.9 ± 0.5	8.7 ± 0.2	9.9 ± 0.1	7.6 ± 0.1
<b>Significance</b>			2,7,8	a,b	C,F	2,6	B,E	b,f,i,j	2
<b>TF</b>	8.8 ± 0.8	6.7 ± 0.5	4.2 ± 0.3	93.6 ± 0.9	80.4 ± 0.7	104.3 ± 0.5	8.7 ± 0.1	9.3 ± 0.0	7.6 ± 0.1
<b>Significance</b>			1,5,6		D,G	3,7	C,F	a,e,f,g,h	1
<b>Neoniti</b>	8.4 ± 0.6	5.9 ± 1.3	2.4 ± 0.4	92.6 ± 0.9	75.9 ± 1.1	98.8 ± 3.8	8.7 ± 0.1	10.1 ± 0.1	8.7 ± 0.1
<b>Significance</b>		A	1,2,3,4	a	B,E,F,G	4,5,6,7	D,G	a,b,c,d,e	1,2,3,4

In group A, the angle and radius of curvature showed significant differences ( $P < 0.001$ ). Neoniti and ProTaper showed the lowest and Mtwo showed the highest angle of curvature. In groups B and C, the angle and radius of curvature also showed significant differences ( $P < 0.001$ ). The highest and the lowest angle of curvature in group B belonged to ProTaper and Neoniti, respectively; whereas, in group C the highest and the lowest values were seen in RaCe and Neoniti, respectively (Fig. 3, Table 2). In group A, Neoniti showed the lowest radius of curvature; whereas in groups B and C it showed the highest values (Fig. 3, Table 2).

## DISCUSSION

Different types of rotary files exhibit differences in resistance to fatigue failure due to differences in various determinants such as their manufacturing process [11,12], structural characteristics and geometric designs [13], surface texture [13,14], the type of curve they are introduced into [5] and the method used for fatigue failure calculation. Two methods for calculating the time of fracture were evaluated in this study. Most previous studies only used direct visualization. According to the results of this study, no significant difference was seen between the fracture time estimated by direct visualization and watching a captured video clip. When reviewing the captured video clips, the time of fracture can be determined more precisely and easily due to lack of eye strain.

Fatigue failure can be evaluated in two different modes of "static" and "dynamic". In the dynamic mode, the hand-piece is promoted in a back-and-forth axial motion while the instrument is driven in a full rotational movement inside the trajectory. This model is more similar to clinical conditions in which rotary files are used; but to standardize the amplitude and speed of the axial movement of the hand-piece, a device must be designed. It should be noted that the fatigue resistance of rotary files may be higher when used in the dynamic mode due to the axial movement,

which prevents stress concentration in the same area allowing stress distribution along a larger portion of the instrument [15]. Conducting another research that compares the fatigue failure of these rotary instruments in the dynamic mode is suggested.

Three ways for improving the longevity of endodontic files have been suggested which include the following: (I) Thermal treatments before machining; (II) Choosing machining conditions adapted to the NiTi alloy and (III) electro-polishing [16].

This study compared the cyclic fatigue resistance of different types of NiTi rotary files with different manufacturing techniques and different improvement strategies. Twisted files are formed by twisting a triangular blank in combination with heat treatment and special surface conditioning, which conserves the natural grain structure. RaCe files are developed by a grinding process, which is followed by electro-polishing. ProTaper Next is manufactured from M-Wire NiTi. Mtwo is a conventional NiTi rotary file developed by a grinding process. Neoniti is manufactured using a newly developed WEDM process.

The mean NCF of all rotary files was lower in group A compared to groups B and C implying that the resistance to fatigue failure is lower in files used in root canals exhibiting a more coronal curvature than apically placed curvatures. In more coronally located curvatures, the portion of the instrument situated in the critical stress concentration point has a greater diameter and undergoes higher levels of metal fatigue [5,17] opposed to when the arc is located in the apical portion. Also these values were higher in group B in comparison to group C indicating that the shorter the length of the arc of curvature the higher the resistance of the file used in that trajectory to fatigue failure.

Controversy remains regarding the effect of electro-polishing on the fatigue failure of rotary files. Some studies have shown that electro-polishing improves the instrument's working



properties such as resistance to failure by producing a smooth and homogeneous protective surface oxide layer with less defects and residual surface stress [11,12]; whereas, Herold et al. [18] inferred that electro-polishing did not prevent the development of microfractures and Barbosa et al. [19] concluded that electrochemical polishing had no influence on the resistance to fracture of the rotary instruments tested. According to the findings of our study RaCe had the lowest NCF values in comparison to all other experimental rotary files in all canal types evaluated. Mtwo files are expected to show lower fatigue resistance than files undergone electro-polishing, such as RaCe, due to the crack-like surface features created subsequent to their machining manufacturing process [14,20]. On the contrary, the Mtwo group exhibited higher NCF values than RaCe, although the difference was not statistically significant. In addition, while M-wire alloys are considered to be more flexible and more resistant to fatigue than conventional NiTi alloys [21], Mtwo showed no statistically significant difference when compared to ProTaper Next. Gambarini et al. [12] also concluded that instruments made of M-wire alloy did not show higher resistance to fatigue when compared to instruments produced by the traditional NiTi. Further research is required regarding the different factors involved in this matter.

Twisted files showed significantly higher NCF values than RaCe, ProTaper Next and Mtwo in curvatures located in the middle third of the trajectory; whereas, in more apically located curvatures no significant difference was seen between the aforementioned files. These results are in accordance with previous studies [11,22]. Overall, Neoniti showed the highest NCF values in all curve types evaluated. This may be due to the unique manufacturing process and heat treatment of this file. Further research regarding the physical and mechanical properties of this newly marketed file is required. It should be noted that there is a slight

inconsistency between the shape of the files and that of the trajectory they are rotating in. The files do not always precisely fit into the trajectory's shape.

This was seen when evaluating the angle and radius of curvature that each rotary file formed in the trajectories. It is unclear whether the slight differences seen in the angle and radius of curvature between rotary file types have a clinically significant effect on the resistance to fatigue failure of the evaluated files. For instance, while Neoniti files used in the group A trajectory had a similar angle of curvature and shorter radius of curvature compared to other files in group A, this file had the highest NCF values. It should be noted that lower fatigue resistance is expected in shorter radius of curvatures [10].

In group C, although RaCe files showed the highest angle of curvature, these files exhibited the lowest NCF values. Furthermore, Neoniti files in this group exhibited the highest resistance to fatigue even though they had the lowest angle of curvature. Further research is required regarding the clinical impact of slight differences in the angle and radius of curvature on the resistance to fatigue failure of endodontic rotary files.

Finally it should be noted that in clinical conditions, rotary files are used in a dynamic mode, endure torsional stresses and cyclic fatigue at the same time and are bind to the root canal walls; therefore, their fatigue resistance may be different from the results of this study. Further research is advised.

## **CONCLUSION**

The fatigue resistance of the evaluated rotary files was lower in more coronally located curvatures. Neoniti exhibited the highest and RaCe exhibited the lowest fatigue resistance compared to other evaluated files.

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