Summer 5-2-2024

Dynamic cyclic fatigue resistance of RACE EVO in S-shaped canal with different angles of access: An in vitro study

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Original Article

Dynamic cyclic fatigue resistance of RACE EVO in S-shaped canal with different angles of access: An *in vitro* study

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Abstract

Introduction: Nickel–titanium instruments annually undergo improvements to enhance the cyclic fatigue lifespan, especially with challenging canals. This study examines RACE EVO instrument in an S-shaped double-curvature canal in different angles of insertion 0°, 20°, and 40° to investigate the behavior of the heat-treated instruments in challenging canals.

Materials and Methods: A total of 30 instruments were assigned to three groups (Group 0°, Group 20°, and Group 40°). RACE EVO instruments were tested in artificial canals. The canals had two curvatures: an apical one which its parameters are 70° angle and 2 mm radius and a coronal one which its parameters are 60° angle and 5 mm radius. The test was done using a cyclic fatigue apparatus. A statistical study was done by one-way analysis of variance groups, and Tukey's honestly significant difference/Tukey–Kramer with a level of significance (α) was adjusted to 0.05.

Results: The time until failure was reduced by the increase in the angle of insertion; however, Group 20° and Group 40° were not significantly different. All the instruments were broken apically. The scanning electron microscopic analysis showed typical characteristics of cyclic fatigue failure.

Conclusions: Increasing the inclination during the insertion reduced the resistance of the RACE EVO instruments to cyclic fatigue failure despite the surface heat treatment of the instrument.

Keywords: Dental instrument, fatigue fracture, nickel–titanium alloy, root canal preparation, scanning electron microscopy

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Submission: 29-11-23 **Revision:** 11-01-24 **Acceptance:** 11-01-24 **Web Publication:** 02-05-24

INTRODUCTION

Nickel–titanium rotary instruments have been used extensively for root canal preparation. Despite, their several benefits, there remains a major clinical concern, which is their reported sudden fracture without alert.[1-4] Fracture can happen without any noticeable flaws of deformation. Rotary instruments fracture under two conditions: torsional fracture and cyclic fatigue.[5] Former studies have proved that cyclic fatigue is the main reason of instrument separation.[3,4]

Root canal preparation in tight, curved canals is challenging even for expert endodontists. The intensity of curvature of the canal is a principal cause in fractures caused by cyclic fatigue.[5] In clinical situations, two curves can be existed

Access this article online	
Quick Response Code:	Website: www.saudiendodj.com
	DOI: 10.4103/sej.sej_228_23

How to cite this article: Ayad OE, El Seoud MA, Kataia EM. Dynamic cyclic fatigue resistance of RACE EVO in S-shaped canal with different angles of access: An *in vitro* study. Saudi Endod J 2024;14:212-7.

in the same canal, which is one of the most challenging clinical situations.[6] Furthermore, the access inclination/accessing slopes of the instrument into the canal can make an additional curvature besides the anatomical ones already present.[7] The entry of the instruments into canals is not always at an angle of 0°. Inclined insertion may be mandatory due to different clinical variables such as the position of the tooth or due to the presence of old restorations.[8,9] The access cavity type may also affect the angle of insertion of the instrument. The recent access cavities may cause the inclination of the NiTi instrument compared to the traditional ones.[9] The inclination of the instrument during the root canal preparation creates different stresses on these instruments.[8]

In the previous few years, developments in design, alloys, and manufacturing processes have been done to increase the fractural resistance of NiTi rotary instruments. Heat treatment is one of the strategies used by the manufacturer for this reason. Studies have proved that thermal treatments enhance the cyclic fatigue lifespan.[10-12]

However, the resistance of these instruments to cyclic fatigue failure in the presence of both the double curvature of the canal and the inclined insertion of the instrument to this canal was not probably evaluated by the literature. The predictability of instrument's fracture would allow the avoidance of such unpleasant situations which compromise the outcome of the treatment. Therefore, this study was conducted to evaluate the effect of combination between the double curvature of the root canal and the increase in the angle of insertion of the instrument into the root canal on the time until instrument's fracture and the length of the separated part of the instrument.

MATERIALS AND METHODS

This study received approval from the Research Ethical Committee of The British University in Egypt, number 21–002.

Sample calculation and classification

A total of 30 RACE EVO instruments (FKG Dentaire, La Chaux-de-Fonds, Switzerland) ISO size #30, taper 0.04, and length of 25 mm were divided into three groups ($n = 10$) according to the angle of insertion of the instrument [Figure 1]. All the instruments were examined for surface flaws and distortions under magnification 40× by EXTARO® 300 Microscope (Zeiss, Jena, Germany), and none of the instruments were excluded. The statistical calculation of sample size was done using G*Power Program utilizing α-type error of 0.5 and β-power of 0.95 and an N2/N1 ratio of 1. The mean and standard deviation are taken from a previous study.[13]

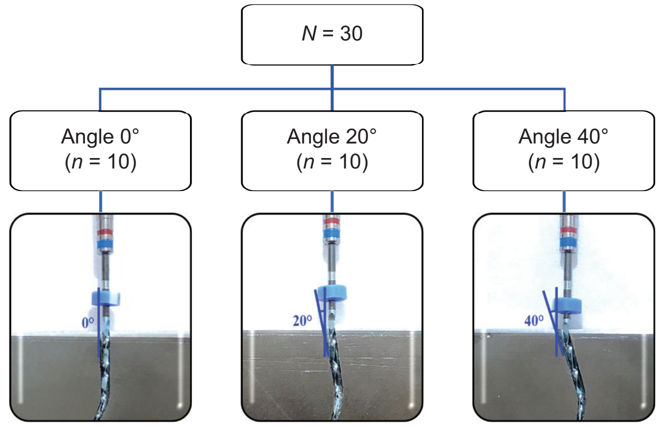

Figure 1: Samples' classification in groups

Cyclic fatigue test

The cyclic fatigue test was done in three artificial stainless-steel canals differing in the angle of insertion (0°, 20°, and 40°) [Figure 2]. Each canal has two angles [Figure 3]; the first angle was 60° with a radius of 5 mm and distanced 8 mm from the apical end of the instrument. The second one was 70° with radius of 2 mm and distanced 2 mm from the apical end of the instrument.[6] The angles of the canal were measured using Pruett's *et al.* method.[5]

The cyclic fatigue test was conducted via a special custom-made device made of aluminum shown in Figure 4 to allow a repeatable relation between the block which contains the artificial stainless-steel canals and the used E-Connect Pro endodontic handpiece (Eighteeth, Changzhou, Jiangsu, China) and to allow vertical movement of the endodontic handpiece to simulate the clinical pecking motion (1.5 mm/0.5 s upward and 1.5 mm/0.5 s downward).[14]

The device has an Arduino Uno board which is connected to dynamic movement regulator, and it is also connected to a laptop with a program to control the range of axial movement. This setup was inserted into a glass tub filled with water to a level covering the artificial canal block. The temperature of the water was set to 35°C ±0.5 by a heater to simulate the canal temperature.[15] The instruments were allowed to continuously rotate inside the artificial canals at a speed of 800 rpm and a torque of 1.5 Ncm as recommended by the manufacturer. The time of rotation of the instrument inside the canal until it fractured was video recorded. The time for all 30 instruments was calculated in seconds by video editing software Adobe Premiere (Adobe, California, US) to exclude any human

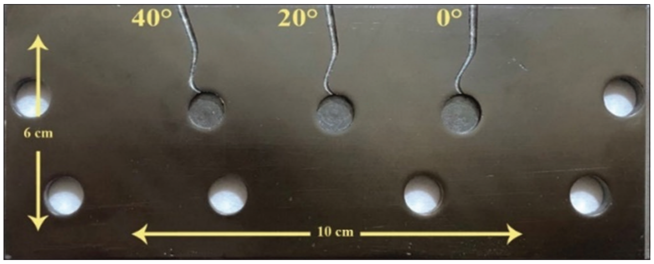

Figure 2: The stainless-steel block of the three S-shaped canals used in this study

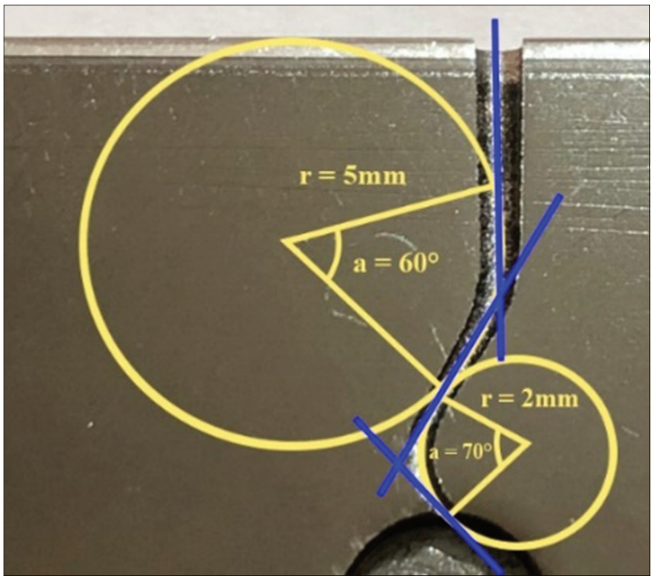

Figure 3: The S-shaped artificial stainless-steel canal showing the angles and the radii of the double curvature

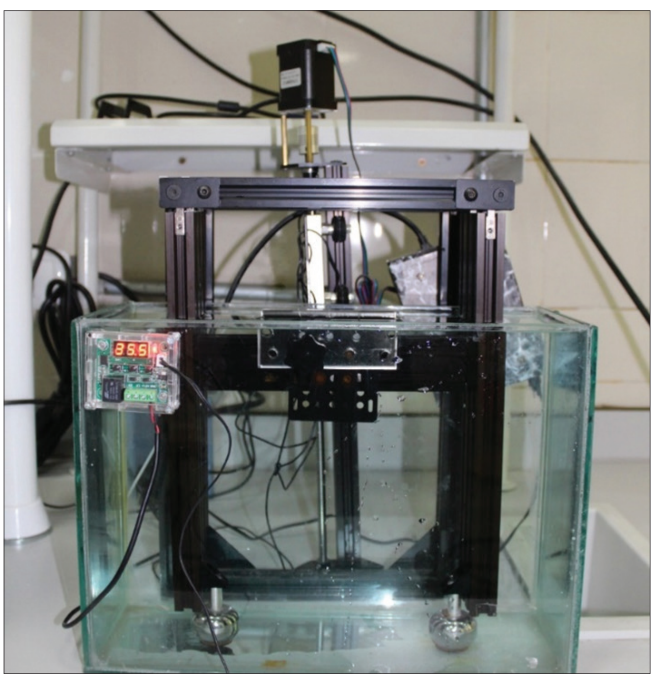

Figure 4: The cyclic fatigue device used in the study

error, and the separated fragments were measured in millimeters by an endodontic ruler.

Scanning electron microscopy

The fracture surfaces of two random fragments from each group were examined under Thermo Scientific™ Quattro S scanning electron microscope (Thermo Fisher Scientific, Waltham, Massachusetts, United States) using two magnifications ×500 and ×2000.[16-18]

As the separated parts were extremely short and cannot be easily handled, the other part of the instrument rather than the separated part was selected for the scanning electron microscopy. The instruments were reduced from the other side (the handle side) rather than the fractured side to a length <8 mm with preservation of the fractured surface untouched and were fixed into a piece of putty consistency addition silicone to compensate with the required measurements of the scanning electron microscope.

The samples were assigned to ultrasonic cleaning in 70% alcohol for 20 min to eliminate any impurities on the fractured surface and then allowed to dry into laminar flow unit before they were viewed under scanning electron microscope.

Statistical analysis

These are tests' names used in all studies no study mentioned the meaning of it in text but the meaning of thetests One-way Anova is a test used when there is one independent variable it uses specific equation todetermined if there is a significant difference or not. The Tukey is also a test used to determineif there is a significant difference in between the groups as it compare each group with the other groups for moreinformation it will need a statistical analysist, or you can see it on the website of Graphpad.

RESULTS

The time until fracture decreased by the increase in the angle of insertion. The longest time was shown in Group 0° with no significant difference between the two other groups ($P < 0.05$).

Regarding the length of the separated part, there was no statistically significant difference between all the tested groups. Two instruments from Group 40° fractured coronally at the level of the insertion, but they were excluded and replaced by two new instruments.

The mean, standard deviation, and P value for both the time and the length of the fractured part can be observed in Table 1.

Table 1: The mean, the standard deviation, and the *P* value of the length of the separated part and the time until fracture of all the groups 0°, 20°, and 40°

	Group 0°	Group 20°	Group 40°	*P*
Time until fracture, mean±SD	129.5±17.41[A]	80.93±17.31[B]	76.90±13.98[B]	<0.05
Length of the fractured part, mean±SD	1.75±0.5401	2±0.5270	1.95±0.4972	>0.05

SD: Standard deviation

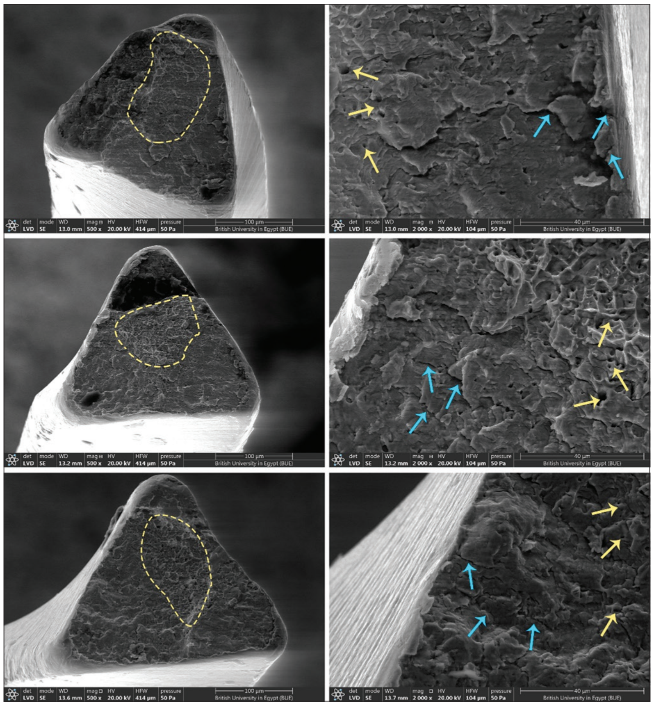

Figure 5: Scanning electron microscopy pictures of the separated parts of the instruments showing the ductile mode of fracture with central fibrous area characterized by the microvoids and dimples represented by the yellow arrows and peripheral smooth area characterized by multiple cracks represented by the blue arrows. The cutting side of the instrument showed smooth surface with no contaminants or microcracks due to the surface heat treatment

The scanning electron microscopy showed a large fibrous area with microvoids and dimples on the center of the fractured surface and fatigue striations and multiple microcracks at the periphery with no difference among all the samples from all the tested groups [Figure 5].

DISCUSSION

Heat-treated instruments proved to have high cyclic fatigue resistance even in double-curvature S-shaped canals, which is claimed to exist in 10.6% of the permanent teeth.[16,19-25] Recently, there are calls for adopting conservative access cavity designs instead of the straight access to the canal. Hence, if this is combined with a double-curved canal, it would be an extremely challenging situation for the preparing instrument.[5,7] The newly introduced RACE EVO instruments which proved to overperform the traditional RaCe instruments were investigated in this study to assess the combination between a double curvature and an inclined insertion.[17,26,27]

The results revealed that the cyclic fatigue endurance of the instrument was reduced when the degree of insertion angle increased which agreed with several studies.[13,18,28-30] It was found that Group 0° had a significantly longer time to fracture, and there was no statistical difference between Group 20° and Group 40°. This came in agreement with La Rosa *et al.*, who confirmed a remarkable decrease in the cyclic fatigue resistance from angle 0° and angle 20°.[29] Moreover, research by Pedullà *et al.* showed that angle 10° had significantly inferior cyclic fatigue resistance when compared to angle 0° when the canal radius was 3 mm, whereas angles 0° and 10° showed equivalent results when the radius was 5 mm.[28] This indicates that the difficulty of the canal (radius and curvatures) has a profound influence on the cyclic fatigue resistance, especially when it is combined with an inclined insertion.

Therefore, it can be stated that the reduction in cyclic fatigue resistance of the instruments in angles (20° and 40°), despite the heat treatment may be because of the high stress associated with excessive inclinations, thus reducing the benefits derived from the thermal treatment.[6] Further studies comparing heat-treated instruments to conventional ones in the same conditions are necessary to evaluate the effect of the heat treatment on the cyclic fatigue resistance of the instrument in such rough conditions, as in some studies, it was mentioned that the cyclic fatigue resistance of the rotating instruments was not improved by the blue and R-phase heat treatments.[31]

In research by La Rosa *et al.*, the cyclic fatigue endurance of the instruments was not significantly reduced from angle 0° to angle 20°, which disagreed with our results.[32] This difference may be due to the different conditions in both studies, as in the current study, the canal is more challenging having double curvatures and one of them is of a smaller radius than the radius of the canal used in La Rosa *et al.*'s (2021) study which also had only one curvature.[32] Moreover, the difference in the cross-section between the tested instruments in both studies may have affected the outcome as it was also confirmed by another study that the cross-section played an influential role in increasing the cyclic fatigue resistance.[33]

Regarding the length of the separated part of the instrument, all the tested groups were not significantly different. This coincided with other studies that showed similar results for angles 0° and 20° regarding the length of the separated part.[28,30,32] It also agreed with a study by Corsentino who reviewed the cyclic fatigue endurance of the instruments with the conservative access cavity and truss access cavity showing no difference between the two access cavities regarding the length of the separated part.[34]

The length of the fractured part ranged between 1 and 2.5 mm for all groups. This agreed with other studies which confirmed that the length of the separated part of the instrument was not affected by the angle of insertion, but rather it was afflicted by the radius of the canal.[28,30] Another study which reviewed the cyclic fatigue endurance of the instrument in different radii or angles ensured that the length of the separated part was influenced by the radius of curvature.[21] Moreover, studies of S-shaped canals suggested that fractures occurring at the apical curvature may be due to the sudden curvature and that the cyclic fatigue fracture of the instruments was afflicted by the canal's angle and/or radius.[6,35] Further studies comparing this canal with different canals (different angles and radii) with the same angles of insertion are needed to confirm which is the most influential factor regarding the length of the separated part.

In this study, two instruments in Group 40° were fractured coronally and were excluded from the study. A similar situation occurred in Pedullà *et al.*, and they attributed this to the possibility of uneven heat treatment along the surface of the instruments.[13] This opinion is supported by the results of the present study as the scanning electron microscopic pictures of the coronally broken instruments demonstrated roughness of the cutting surface near the handle with more irregularities than the cutting surface at the apical part of the instrument. This has also been confirmed by other studies that compared the apical curvature with the coronal curvature, claiming that the instrument tolerance to the cyclic fatigue reduced with the coronal curvature because of the flaws such as microholes, metal strips, longitudinal grooves, and milling marks that were shown to be larger near the shank of the instrument.[36] More research is needed to study the instrument shanks under the scanning electron microscope before and after the fracture and evaluate the reason of the coronal fracture of the instrument as this study lacks to scanning electron microscopic picture of the instrument prior to the test.

By examining the fractured surface of the instrument, on the periphery, there were multiple fatigue striations and microcracks, while in the center of the surface, there was a large fibrous area of microvoids and dimples indicative of ductile fracture. It was confirmed that these features are characteristic to cyclic fatigue failure as found in multiple cyclic fatigue failure studies even those which evaluated RACE EVO instruments.[26,27,37]

The limitation of this study is that the design of the study could not completely exclude the lateral forces exerted on the instruments during the rotation, so it could not solve the problem of the cyclic fatigue tests to completely exclude the torsional fatigue.

CONCLUSIONS

Considering the outcomes of this study, the cyclic fatigue resistance of RACE EVO instruments was negatively affected by merging an inclined insertion with an S-shaped double curvature. All the instruments in the tested groups fractured apically at the 70° angle with the 2 mm radius of curvature which is the most aggressive curvature in the tested canal. Reducing the speed of the endodontic handpiece is recommended in cases of difficulty to achieve straight-line access especially with the presence of challenging anatomy such as S-shaped double curvature.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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