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FLEXURAL BEHAVIOR AND THERMAL ANALYSIS OF TWO POST-MACHINED GLIDE PATH FILES WITH DIFFERENT KINEMATICS IN ARTIFICIAL DILACERATED CANAL

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KEYWORDS

Flexural fatigue, Austenite Finish temperature, glide path, R-Motion glider, Easy path.

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ABSTRACT

Introduction: Rotary glide path files save time and effort exerted with manual glide path files, they also minimize the stress created upon the preparation files. They should exhibit resistance to fracture as they negotiate tight and curved canals at the beginning of the preparation especially in severly curved canals. Aim: To evaluate the flexural fatigue resistance of post-machined heat-treated files with different kinematics in artificial dilacerated canals and to correlate their austenite temperature with the results of the time taken to fracture. Materials and methods: An artificial root canal was machined in a stainless steel block simulating a dilacerated canal with a 90° angle of curvature and 2-mm radius of curvature, length of the canal was 18 mm and the apical size of the canal was ISO 18 (diameter of 0.18 mm) with center of curvature is 4 mm from the apex and tapered coronally Results: The flexural fatigue behavior of R-Motion glider showed higher resistance to cyclic fatigue failure (237s) than Easy Path (90s) expressed by the significantly longer time needed to fracture the R-Motion although the austenite finish temperature of Easy Path was higher than R-Motion Glider. Conclusions: Reciprocating glide path files had superior flexural fatigue resistance than the rotating glide path regardless of the austenite finish temperature.

INTRODUCTION

Nowadays, Nickel-Titanium (NiTi) files suggested by Walia et al. in 1988 as an alternative to stainless steel hand files because it had two to three times more elastic flexibility during bending and torsion, as well as excellent resistance to torsional fracture. Inventors of these NiTi rotary files are continually trying to improve the design of files and the manufacturing process such as electropolishing, heat treatment, and certain modifications to the inherent metallic and surface properties in order to enhance performance, durability and safety[1] .

NiTi instruments have the capability to undergo a phase transformation, from austenite to martensite, with application of temperature or stress, giving rise to properties such as superelasticity and shape memory. A temperature-induced martensitic transformation is created when changes in the crystalline structure occur when the NiTi alloy is cooled through a critical transformation temperature range

(TTR). The shape memory effect is resulted when this deformation is reversed to its austenitic phase by heating the alloy above the TTR. Stress-induced martensitic transformation occurs as austenite transforms to martensitic NiTi with the application of stress, creating a superelastic NiTi. NiTi returns back to austenite when the stress is relieved. These Phase transformations are associated with changes in physical & mechanical properties of the alloy[2]. Differential Scanning Calorimetry (DSC) is a thermoanalytical method that has been used to evaluate phase transformations of current NiTi endodontic instruments. This is achieved by analyzing the amount of heat required to increase the temperature of a file sample versus a blank reference measured as a function of temperature. Transformations are revealed as endothermic peaks on the heating DSC curves and as exothermic peaks on the cooling DSC curves. This allows us to gain a detailed information about which phase of the NiTi alloy exists at a given temperature [3].

Flextural fatigue failure is the mode of failure caused by the occurrence of repetitive tension and compression forces along the instrument body as a result of being operated in a curved root canal, the instrument resistance to this failure can be measured by simulating the condition using a curved artificial canal where the instrument can be activated in a manner similar to the intra-canal condition, and recording the time needed to cause failure[4].

Creating a glide-path files are a technological challenge. They considered the first to penetrate narrow, curved and often calcified canals. They need to be thin and flexible, but also resistant to fracture inside the root canal. Creating a file which would fulfill all these requirements and create a safe glide-path file is not easy.

Endostar EP Easy Path is a novel rotary file introduced in the endodontic market for creating a glide path, which is a guideway for larger shaping instruments.it is heat-treated NiTi with the AMBER HT-technology gives it the extreme flexibility and resistance to flextural fatigue. I addition, it has modified NiTi S-shaped file with two cutting edges provides efficient cutting and debris transportation out of the canal. The non-cutting tip of EP with #14/.04 file ensures a safe passage down the canal in minimally invasive way[5]. R-Motion glider are reciprocating instruments with tip size with #15/.03 and rounded triangular cross-section with sharp cutting edges and thinner core size to reduce the screwing effect, during root canal preparation [10]. This unique design provides the perfect combination for high cutting efficiency down to the apex, while preserving dentine[6].

This study aimed to evaluate the flexural fatigue behavior and phase transformation temperature of those two glide path files at body temperature, the null hypothesis is that there will be no significant difference between the behavior of the two files.

METHODOLOGY

1. Artificial canal fabrication.

An artificial root canal was machined in a stainless steel block by computer-assisted milling and hardened via polished chrome plating simulating a canal with a 90° angle of curvature and 2-mm radius of curvature guided by Schneider method[7], length of the canal was 18 mm and the apical size of the canal was ISO 18 (diameter of 0.18 mm) with center of curvature is 4 mm from the apex and tapered coronally as shown in **Figure (1a-b),** the artificial canal was slightly larger than the size of the instruments in order to assure that there were no torsional stresses acting on the instrument, and the resulted failure was merely caused by flexural fatigue, the external aspect of

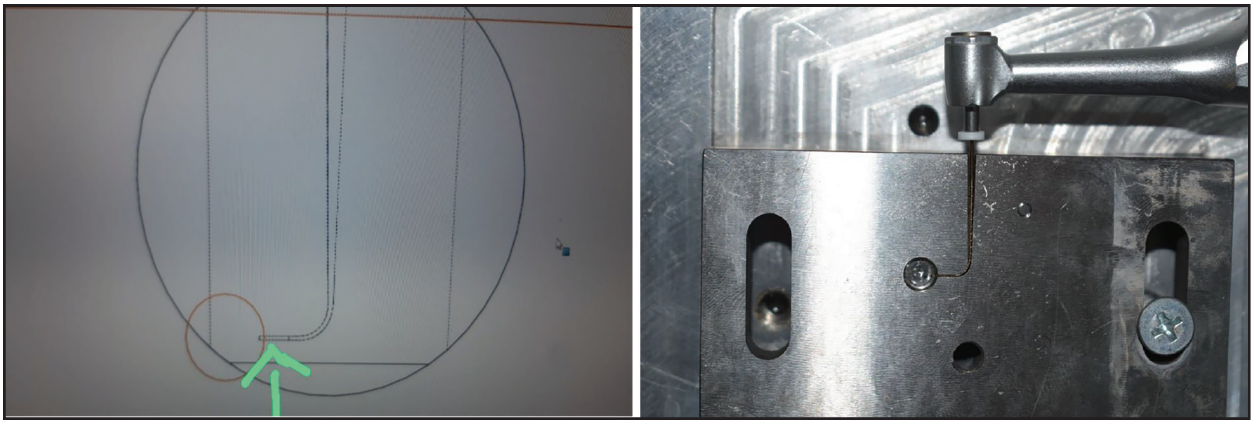

Fig. (1) (1a-b): Artificial 90° stainless-steel canal and motor holder on the metallic board.

the canal was covered by a glass cover to permit visual control on the instrument throughout the test and allow accessibility to record the actual moment of fracture. The stainless-steel block was fixed to a metallic board which the motor was also fixed to by a motor holder, to determine where the position of the instrument in the canal was controlled and standardized for each specimen, tip of the file reach the end of the canal, long axis of the file was with the long axis of the file so there were no stresses on the instrument except the flexural loads of the canal curvature, **Figure (1a-b),**

2. Samples preparation and grouping.

In order to evaluate flexural fatigue resistance, forty new files (Endostar Easy Path, Poldent & R-Motion glider, FKG Dentaire*)* were included in the experiment, they were divided into 2 main experimental groups (n=20).

Samples were grouped according the brand into three groups as following: -

- **Group. A**: Endostar Easy Path
- **Group. B**: R-Motion glider

Each group was later subdivided into two subgroups, subgroup 1: flexural fatigue resistance at body temperature n=18; subgroup 2: Differential Scanning Calorimetric analysis (DSC) n=2.

3. Evaluating the flexural fatigue resistance.

Flexural fatigue resistance test was planned to be conducted at body temperature in order to simulate the clinical conditions of intra-canal temperature (37˚C) making the results more realistic and reflecting the actual behavior of the samples at the clinical situation.

Table (1) *Torque, speed and reciprocating angles for each system as instructed by the manufacturers.*

	Torque	**Speed**
R-Motion glider	170˚ counterclockwise and 50˚ clockwise	
Endostar EP Easy Path	1.5 N.cm	350 rpm

a) Flexural fatigue resistance at body temperature.

To conduct flexural Fatigue Resistance test at body temperature (37˚C±1), a special glass container was fabricated and occupied with distilled water where the stainless-steel block was inserted vertically so that the instrument and the artificial canal were immersed in the water, its temperature was meticulously monitored by an electronic thermostat, samples were tested as follow; Synthetic oil (WD-40) was applied inside the artificial canal for lubrication, X-Smart™ Plus motor fitted with 6:1 reducing handpiece (Dentsply Sirona, Ballaigues, Switzerland) secured the motor holder on the metallic board, each sample was mounted in the handpiece and then inserted in the artificial canal to the length, operated based on manufacturer's recommendation -as shown in Table. 1- until the tip of the file is separated. Time to fracture (TF) was calculated for each file using a digital stop watch with the support of the recorded video of the file operating throughout the procedure.

For all samples, Number of Cycles to Failure (NCF) was measured by multiplying time to fracture (in seconds) by the operating speed of the instrument (per second) regardless the difference in reciprocation angles.

The mean and standard deviations of Time to Fracture (TF) and Number of Cycles to Failure (NCF) were recorded for each system, tabulated and statistically analyzed.

b) *Differential Scanning Calorimetric analysis (DSC).*

DSC analysis is a way to explore the characteristics of a material by measuring the energy changes as a function of heating, cooling or holding at a certain temperature. The principle of DSC device was to subject the thermal changes on two objects, the first object was named a reference which was an empty aluminum pan which its behavior to thermal cycle is previously known, the other object was the tested sample which its response to thermal changes was to be inspected. The amount of energy needed to raise the temperature of each object was measured by a special sensor, the relative difference in heat flow between the sample and the reference in then calculated by the device application.

For studying NiTi alloys properties, thermal cycle of cooling and heating was accomplished in order to detect the abrupt changes in the heat flow weather they were endothermic or exothermic physical reactions which was evidence to a phase transition or transformation of the crystal lattice of the NiTi alloy, the locations of such transitions on the scale of temperature was the key tool for understanding the features of the instruments and corelating to their mechanical behavior.

In the current study, DSC analysis was carried out in two samples from each of the test groups (n=2). about 3 to 5 fragments from the active part of new unused files were cut using a special wire cutter, each fragment was about 7-10 mg in weight following the guidelines from the American Society for Testing and Materials guidelines (ASTM International 2004).

Tested Samples were then exposed to chemical conditioning step before performing the test, a mixture of 45% nitric acid, 25% hydrofluoric acid and 30% distilled water was used as a chemical bath for 2 minutes, and then each fragment was mounted in an aluminum pan, while another empty pan served as a control sample, the thermal cycles were performed under a gaseous nitrogen (N_2) atmosphere with temperatures ranging from -60 to 70°C, cooling/heating rate will be 10 C/min^{-1}.

As the thermal cycle was being performed, the DSC sensor and software were detecting the needed energy to carry out the cycle and measuring the enthalpy changes in relation to temperature, the data was recorded in the form of a graph which was interpretated with the assistance of a dedicated software (Universal V4.5A TA instruments) to detect the phase transformations, the onset and the offset temperature of each transformation period.

Transformation temperature charts were created and tabulated, for each sample group, austenitic start (A_s), austenitic finish (A_f), by understanding those temperatures and corelate them with the results of flexural fatigue resistance, we gain a clear vision and valuable information about the metallurgical characteristics, and therefore, we also get to know more about the mechanical and clinical behavior of the instruments.

Statistical analyses

The statistical analysis was performed for comparison between two different files systems. Data were collected, checked, revised, and organized in tables and figures using Microsoft Excel 2016. Data were subjected to outliers' detections and normality statistical test to detect whether the data are parametric or nonparametric Using Shapiro-Wilk at 0.05 level. Data was analyzed for descriptive statistically both graphical and numerical description. Inferential statistics for evaluating and comparing between two different filesystems were performed by independent t-test. Data analyses were carried out using computer software Statistical Package for Social Science SPSS (IBM-SPSS ver. 28.0 for Mac OS) (Knapp, 2017).

RESULTS

Cyclic fatigue

Results of cyclic fatigue in terms of time taken to fractures (seconds) was presented in Table (2) and Figure (2). The easy bath file system showed a lower significant time to fracture with mean of 93 seconds, however, R motion recorded an average time to fracture of 237 seconds .The difference between two file systems was highly significant ($p<0.001$) as revealed by independent samples t-test.

Table (2) *Results of cyclic fatigue in terms of time taken to fractures (seconds).*

File system	Time taken to fracture		
	Mean	SD	SE
Easy path	93	0.045	0.014
R motion	237	0.647	0.204
***p*-value**		<0.001***	

, **, * significant at p<0.05, <0.01, 0.001; ns, nonsignificant at p>0.05*

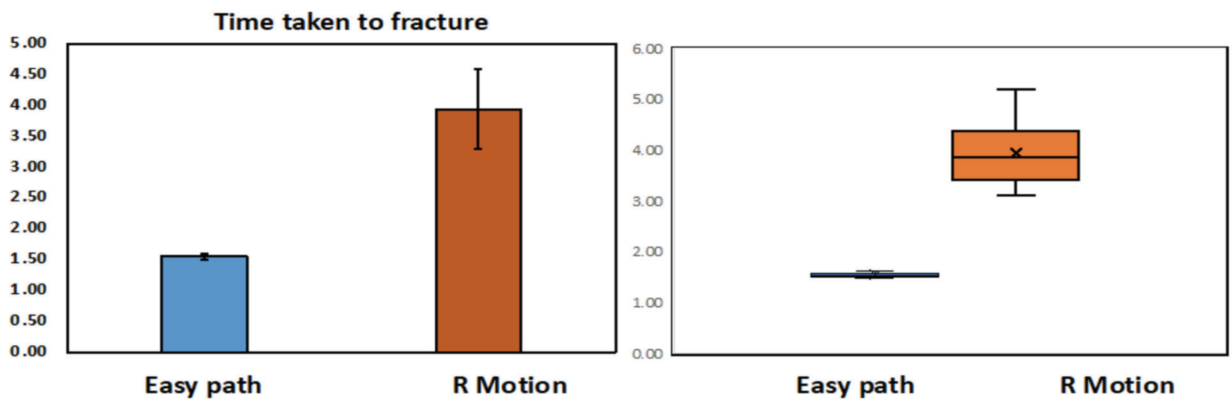

Fig. (2) Bar chart and boxplot presenting the cyclic fatigue in terms of time taken to fractures (seconds).

Austenite finish temperature

Results of DSC in terms of Austenite finish temperature (^{o}C) AF was presented in Table (3). The easy bath file system showed a higher AF@ values with an average of 40.30±0.04 seconds, however, R motion recorded an average AF@ of 37.49±0.10. The difference between two file systems was highly significant (*p*<0.001) as revealed by independent samples t-test.

Table (3) *Results of DSC in terms of AF was presented in terms of mean, standard deviation and standard error.*

File system	Austenite finish temperature AF©		
	Mean	**SD**	**SE**
Easy path	40.30	0.04	0.01
R motion	37.49	0.10	0.03
***p*-value**	<0.001***		

, **, * significant at p<0.05, <0.01, 0.001; ns, nonsignificant at p>0.05*

Interaction between variables

The relationship between study variables using Pearson's correlation coefficients presented in Table (4) showed significant increase in R motion in Time to fracture and AS ^{o}C i.e. positive correlation. However, AF in R motion decreased significantly than easy path.

Table 3. *Pearson's correlation matrix showing the interrelationships between study variables.*

		Group	**Time to fracture**	**AS©**	**AF©**
Group	r	1	0.940**	0.871**	-0.999**
	p		<.001***	<.001***	<.001***
Time to fracture	r	0.940**	1	0.845**	-0.948**
	p	<.001***		<.001***	<.001***
AS©	r	0.871**	0.845**	1	-0.866**
	p	<.001***	<.001***		<.001***
AF©	r	-0.999**	-0.948**	-0.866**	1
	p	<.001***	<.001***	<.001***	

DISCUSSION

Rotary glide path preparation save the time and effort spent with the manual files, however, these files should possess high resistance to fracture as they are the first files used for negotiation of the narrow canals, also they should be flexible to slide into curved canals without transportation[8], as it has been shown that files with tip size as small as 0.15mm could result in root canal transportation[9]. Therefore, the aim of this study was to evaluate the flexural fatigue resistance of post-machined heat-treated files with different kinematics and to correlate their austenite temperature with the results of the time taken to fracture.

Cyclic fatigue resistance could be carried out either at room temperature or at body temperature, indeed carrying the test in body temperature is more clinically relevant[10], moreover the time to fracture was the method of testing instead of the number of cycles to fracture as we are comparing a rotary glide path file with a reciprocating glide path file[11]. The test was carried in an artificial canal for standardization of the experiment settings for both files. The artificial canal had a severe curvature of 90° with small radius 2mm to resemble a dilacerated canal as it represents the greatest challenge during negotiation and preparation clinically[12].

In the present study, we rejected the null hypothesis due to the significant difference in cyclic fatigue and differential scanning calorimetry results for the two files. The flexural fatigue behavior R-Motion glider showed higher resistance to cyclic fatigue failure (237s) than Easy Path (90s) expressed by the significantly longer time needed to fracture the R-Motion. This comes in harmony with other study that showed that the reciprocating motion prolongs the time needed to failure compared with the rotation motion[13–16]. This could be attributed to the release of the generated stresses on the file by reversing the motion during reciprocation in comparison with the buildup of internal stresses during continuous rotation[17]. On the contrary, studies that focused on the effect of the cross-section design on the flexural fatigue resistance have documented superior time to fracture for the S-shaped cross section rotary files compared with the convex triangle, nevertheless those studies focused only on the effect of cross section and standardized the other variables such as the kinematics of the tested instruments[18,19]. The remarkably decreased time to fracture of both files was logically expected and could be linked to the angle and radius of curvature of the simulated artificial canal that mimicked a dilacerated root. Rotary files most often fracture in those canals, moreover most studies compared flexural fatigue failure in artificial canals with two different angles, revealed an inversely proportional relationship between the angle of curvature and the flexural fatigue failure[20], and a direct proportion with the radius of curvature[21].

Although some studies showed that heat treated wires with reflected gold color are more resistance to fatigue failure than heat treated wires with reflected blue color[22,23], those colors are a result of the titanium oxide arising from the post-machined heat treatment, the thickness of this layer is thicker in the gold alloy than the blue alloy[24], this was documented in previous studies which compared blue wire and gold wire of the same kinematics that is why the results of the DSC in the current study displayed an AF temperature that is higher significantly for the Easy Path (40.30±0.04) than R-Motion Glider (37.49±0.10). The AS and AF temperature of R-Motion Glider and Easy Path files were not specified by the manufacturer nor described in the previous literature. By correlating the results of the DSC with the results of the cyclic fatigue, the higher AF showed have reflected higher resistance in cyclic fatigue which did not occur in our study. This could be explained by the various factors that manipulate the cyclic fatigue collectively including the cross section of the file, the taper, the size of the instruments, the speed and torque of the file, the pitch, the kinematics and the phase transformation temperatures[25]. The interaction of all these variables constitutes the flexural behavior of the file, therefore the present results for one of these variables which is phase transformation temperature of the tested files did not correlate with the fatigue failure of the same files in comparison to each other.

Results of the DSC disclosed an austenite start and finish temperature of R-Motion glider slightly different from the preparation file R-Motion with a higher Af for the glider (37.49°C) than R-Motion in one study (35.09°C)[26] and 32.52°C in another study[27] meaning that the file is in a mixed state during canal preparation which could be needed to provide flexibility to the file during negotiation of curved canals and to provide greater resistance to flexural fatigue.

CONCLUSIONS

Easy Path rotary files had a higher AF temperature than R-Motion glider, however the latter demonstrated superior flexural fatigue resistance at body temperature. The austenite finish temperature negatively correlated with the results of the flexural fatigue failure due to the kinematics factor.

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