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EVALUATION OF DYNAMIC CYCLIC FATIGUE RESISTANCE OF THREE DIFFERENT ROTARY NICKEL TITANIUM SYSTEMS. (INVITRO STUDY)

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ABSTRACT

Background: Mechanical preparation that is fast, safe, and effective without affecting the natural morphology of the canal is made possible with nickel-titanium (Ni-Ti) instruments due to their low modulus of elasticity and excellent flexibility. They exhibit unique property of shape memory and super elasticity, but unfortunately these rotary instrument shows unexpected fracture because of cyclic fatigue or/and torsional overload.

Aim of the work: The objective of this investigation was to evaluate the dynamic cyclic fatigue performance of three rotary file systems: “Protaper Next,” “edgx7,” and “Trunatomy.”

Materials and methods: Dynamic cycle fatigue was tested with 30 files from these systems utilizing a specific instrument. The number of cycles to fracture NCF was calculated using a given function. By scanning representative samples from all the previous groups of files using SEM, we were able to evaluate the mode of fracture. Tukey’s Post Hoc and one-way ANOVA were used to determine group differences.

Result: ANOVA illustrated that there was significant distinction amongst the three groups (P=0.0001). The fatigue resistance was highest in Edgex3, then in Trunatomy prime, as well as lowest in Protaper next x2.

Conclusion: The dynamic cyclic fatigue resistance of the EdgeX3 was the greatest due to the fire wire technology followed by the Trunatomy prime and then Protaper next x2 showed the least.

KEYWORDS: Cyclic fatigue resistance; Nickel Titanium; Endodontics; protapernext; fractrographic analysis.

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INTRODUCTION

The low modulus of elasticity and great flexibility of Ni-Ti instruments allow for mechanical preparation that is quick, safe, and effective without altering the canal's original morphology. Despite their remarkable form memory and super elasticity, these rotating instruments are prone to unexpected fractures caused by cycle fatigue and torsional strain. Iatrogenic errors, such as ledging, transportation, zipping, as well as perforation, are most commonly seen in curved canals, so researchers are working to develop rotary systems with improved shaping ability, cyclic fatigue resistance, geometry, thermomechanical treatment, as well as motion kinematics[1].

The two most important characteristics for assessing the performance of Ni-Ti files are torsional failure and cyclic fatigue resistance[2]. On the one hand, torsional failure happens when a metal twists on its longitudinal axis at one end while the other end remains fixed, and cyclic fatigue occurs when a metal rotates around a curve as a result of repeated compressive and tensile stresses created around the maximum flexure until fracture occurs. It is challenging to predict fracture due to cyclic fatigue, which causes invisible indications of irreversible plastic deformation during clinical usage[3].

This study's objective was to assess dynamic cyclic fatigue resistance in a simulated artificial canal using three distinct ProTaper Next rotary nickel titanium (NITI) files. TruNatomy and Edge File X7 together.

An M-Wire called Protaper Next (PTN) (Dentsply Maillefer, Ballaigues, Switzerland) uses heat treatment to increase the instrument rotary file system's flexibility. The system is constructed with varying tapers (variable tapers) on a single file, and it comes in a variety of sizes. In addition to swaggering motion that lessens the screw-in effect, the ProTaper Next system has a bilateral asymmetrical off-centered rectangular cross section that is offset from the primary axis of rotation.[4].

Edge file X7(Edge Endo; Albuquerque, New Mexico, United States) is a Ni-Ti file which has a constant taper with parabolic cross section, electro polished file for more strength, manufactured by a process called "FireWire™" Ni-Ti alloy annealed heat treatment which potentially improves flexibility and resistance to fatigue.[5]

In contrast to the conventional 1.2-millimeter NiTi wire, the Trunatomy file (TRN) (Dentsply Maillefer, Ballaigues, Switzerland) is constructed using a one-of-a-kind 0.8-millimeter NiTi wire that has an off-centered parallelogram cross-section to which a specific heat treatment is applied to the material. It has been asserted that TruNatomy possesses a flexible prebending capability, possesses four times greater elasticity as well as fatigue resistance in comparison to file systems that are manufactured utilizing conventional heat treatment, and demonstrates a reduced risk of separation as a result of its enhanced resistance to cyclic fatigue [6].

The null hypothesis suggests that there is no distinction in dynamic cyclic fatigue resistance among ProTaper Next, EdgeFile X7, in addition to TruNatomy.

MATERIALS AND METHODS

Methods:

Sample selection and classification:

Based on their file system, thirty files were chosen for this research and then separated into three categories. Each group was tested at intracanal temperature.

Group 1 (n=10): was tested by protaper next X2 with; tip size #25, taper of 0.06. Group 2 (n=10): was tested by Edge X3 file with tip size #25, taper of 0.06. Group 3 (n=10): was tested by truNatomy prime with tip size #26, taper of 0.04. All the three tested group are in length of 25mm.

The instructions provided by the manufacturer were followed for the use of each file. The speed and torque for protapernext X2 and edgeX3 are 300 rpm and 2.5 Ncm, while for truNatomy prime is 500rpm and 1.5Ncm.

The cyclic fatigue testing device:

The cyclic fatigue testing device that M. EL-Wakeel devised and manufactured is shown in (figure (1)). The artificial canal block designed with computer numerical control (CNC) milling machine XKT CNC double-sided boring and milling machine (Weihai Huadong Automation Co., Ltd) drawn by using SOLIDWORKS® CAD and the milling from stainless-steel with two artificial canals (figure (2)). One canal was made with a 0.35mm tip size and taper 0.06 for PTNX2 and Edgex2, and the other canal was made with a 0.36 mm tip size as well as taper 0.04 for TRN prime. It was possible to achieve free rotation by increasing the depth of the canal by approximately 0.5 millimeters from the maximum diameter of the file. This was done during the machining process. The center of the curve was situated five millimeters away from the tip of the file. The canal's width was designed to exceed the original file size by 0.1 millimeters. This was executed to facilitate the file's unrestricted rotation within the artificial canal. The total length of the canal is 17mm with 6mm radius consistent with the method of ***Pruett et al.***[7]- and 45-degree angle of curvature. The straight part of the length 12mm. The block was covered by a transparent acrylic sheet fixed in place to prevent slipping out of the file from the artificial canal and to secure the separated part to be retrieved. Moreover, it allows observation of the rotating file and detection of the fracture.

The device was equipped with a custom-made liner actuator that could control the axial movement, allowing for up and down movement with an amplitude of 3 mm/1 sec (1.5 mm in each direction). This allowed for the simulation of pecking motion, as seen in clinical practice. The temperature was controlled by use of a specially constructed water bath. The test was conducted in an environment with distilled water at an intra-canal temperature of 35 °C ±1 °C, with the help of an aquatic thermostat linked to the heat control system and a digital thermometer for measurement. Every one of the examined files within the artificial canal is positioned at the same distance in an accurate and dependable way. All files were rotated using e-connect pro end motor (Eighteeth Medical, Changzou,China) With 16:1 reduction contra-angle rotary hand piece.

Careful observation by the operator was maintained as the file rotated in the canal until it broke. An accurate digital timer, which had to be operated by hand, was used to record the time to fracture. In order to ensure that no human mistake

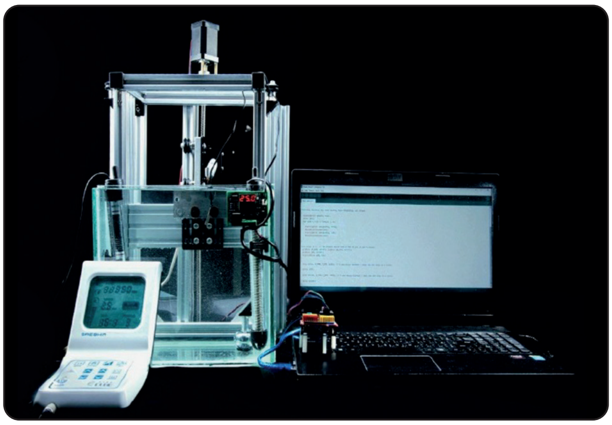

Fig. (1) Dynamic cyclic fatigue testing device

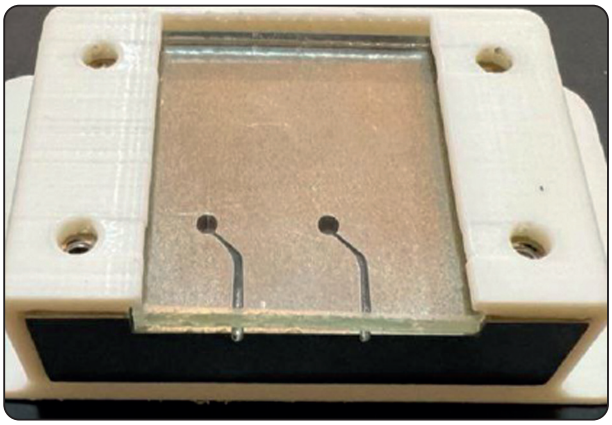

Fig. (2) Stainless steel block with a clear acrylic sheet occurred, multiple video recordings were made at the same time and subsequently compared to determine the exact moment when the files were separated.

Cyclic fatigue testing calculation:

The time to fracture (Ttf) was measured in seconds using a chronometer timer set to 1/100. Both the motor and the stopwatch were turned on simultaneously. Time halted when observable evidence of instrument breakdown was detected. The following equation was then utilized in order to achieve the subsequent computation of the number of cycles to fracture (NCF).[7-10]

NCF = revolution per minute (rpm) X time (seconds)/60.

The length of the fractured fragments (FL) in mm was measured using a caliper

Scanning electron microscopy analysis:

At the nano institute of science and technology - kafr-elsheikh university, two broken pieces from each group were analyzed using a scanning electron microscope (SEM) (JEOL.Model JSM- IT 100 lv series, Tokyo, Japan). This allowed us to identify the file types that had fragmented. The broken surfaces were photographed using a 10kv excitation voltage in top views at two different magnifications (150x and 3000x). In order to improve the appearance of these samples, gold sputtering was utilized.

Statistical analysis:

The statistical analysis was carried out using SPSS 20®, Graph Pad Prism®, as well as Microsoft Excel 2016 from IBM, Graph Pad Technologies, and Microsoft Co-operation, respectively, all located in the USA. The mean and standard deviation were applied to display all quantitative data, which are considered normal data. Shapiro-Wilk and Kolmogorov tests were utilized for the purpose of examining normalcy. Tukey's Post Hoc test for multiple comparisons relating cycle fatigue after a one-way ANOVA test for comparisons among all groups.

RESULTS

All results were presented as:

Normality test.

Cyclic fatigue.

Length of the fractured instrument

Fractoraghic analysis

Normality test:

A normality test and a Shapiro-Wilk test were used to examine the provided data. The findings demonstrated that the data came from a normal distribution (parametric data) regarding cyclic fatigue in all groups, as the P-value was below 0.05, indicating that the level of significance was insignificant.

Dynamic cyclic fatigue:

Table 1 and figure 3 show the means and SD of cycle fatigue for each group of participants. The cycle fatigue test was expressed in seconds using the time to fracture (TtF) metric. There was also an expression for the cyclic fatigue test that used the number of cycles to failure (NCF). The One-Way ANOVA test was employed to conduct an intergroup comparison, which demonstrated a significant variance among the groups (P=0.0001), as: the Group I (5.79 ± 1.57) the lowest resistance to cyclic fatigue test, then group III (9.68 ± 0.41), while GII (16.82 ± 1.83) was significantly the highest resistance to cyclic fatigue.

Length of fractured instruments:

No significant variance found among any of the studied groups (6±0.5mm)

TABLE (1) Comparison between groups regarding cyclic fatigue test:

	Mean	Standard Deviation	P
Group I Protaper next files	5.79 [a]	1.57	
Group II Edge X7 files	16.82 [b]	1.83	0.0001*
Group III TruNatomy files	9.68 [c]	0.41	

Significant difference as $P \leq 0.05$. Means with various superscript letters showed significant differences ($P \leq 0.05$). Means with the same superscript letters were not statistically different ($P > 0.05$).

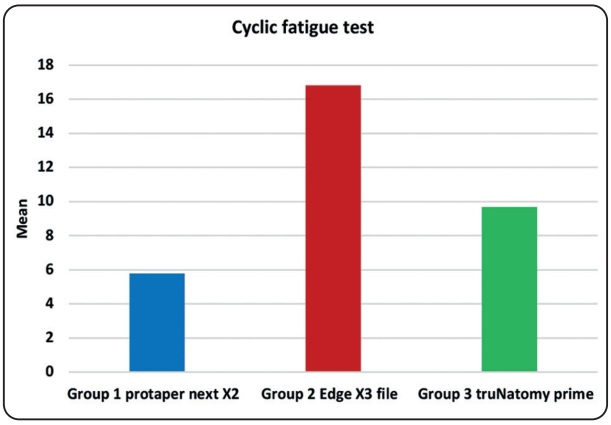

Fig. (3): bar chart showing Comparison between groups regarding cyclic fatigue test.

Fractographic examination:

The analysis of the fracture surface imperfections of the endodontic rotary instruments by SEM have showed several features of ductile fracture such as dimples inside the overload zones, fatigue striations, crack initiation (starts at cutting edges), micro-voids and micro-voids coalescence (figure 4). During plastic flow, micro voids expand and eventually combine to form bigger voids. These gaps experience substantial necking in the last phases of collapse, resulting in the distinctive dimpled texture. The consolidated micro voids will become longer when shear loads are present.

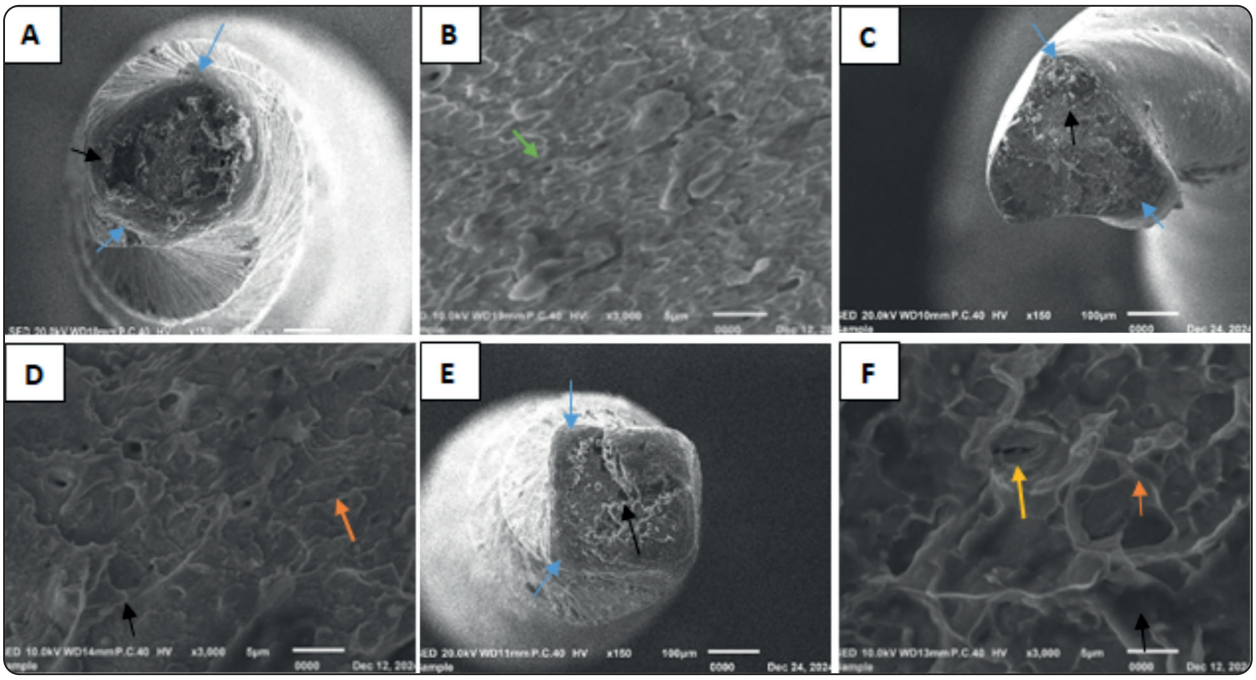

Fig. (4) Scanning electron micrographs of the fractured surfaces of separated fragments (top views) after cyclic fatigue test. (a), (c) and (e) depict variations in geometric and flute designs for the cross sections of PTN, EdgeX3 and TRN respectively with obvious damaged working edge flutes at 150x magnification.(b), (d) and (f) at 3000x magnification of PTN, EdgeX3 and TRN respectively. Red arrow (fatigue striations). Green arrow (microvoids). yellow arrow (voids coalescence). blue arrows (crack initiation) black arrow(dimples)

DISCUSSION

Various flexible NiTi instrument have been developed by ***Buehler et al.***[11] in 1963 at the Naval Ordnance Lab. These files have a significant risk of separation, such as torsional and cyclic fatigue failure, yet they are extensively employed because they have certain advantages over stainless steel files, such as improving flexibility and elasticity and producing less iatrogenic defects. When tension and compression cycles are generated at the point of maximal flexure and the material freely spins in a curve, a fracture can be formed by cyclic fatigue.

A wide range of complex interdependent characteristics were utilized in order to evaluate the fracture resistance of the instruments. These parameters included the angle as well as radius of curvature, the speed and torque of the rotary files, in addition to the single or double curvature of the artificial canal. Various methods have been employed to reduce the frequency of fractures, such as heat treatment, surface treatment, file shape adjustment, alloy property enhancement, as well as file motion modification. ***Gambrini et al.***[12] claimed that fatigue resistance is affected by cross sectional design, rotational speed and torque rather than file dimensions.

The extracted tooth, which exemplifies the clinical condition, serves as an effective model for discerning the intrinsic physical characteristics of Ni-Ti files; however, given that no two root canals are identical and the morphology of the root canal alters post-instrumentation, the tooth can only be utilized once. In order to standardize the circumstances and minimize the impact of failures other than cyclic fatigue, the non-tooth model was selected. Since there are no extraneous factors, like dentin and debris, in this controlled and repeatable setting, the test and results are more indicative of the file's intrinsic properties.

An instrument's resistance to fracture as a result of metal fatigue accumulation brought on by tension/compression cycles at the point of maximal flexure is the variable in this study that is not typical of a clinical scenario where multiple factors act simultaneously to cause a fracture. Because of this, it could be challenging to correlate the laboratory test results with the clinical state. This lab test is a pure mechanical test to elicit only one attribute of the instrument (resistance to cyclic fatigue), however it is crucial to assess the mechanical properties of endodontic instruments in order to provide the clinician with reliable information.

Three stiff stainless-steel pins in a pegboard are one example of an experimental design that was created to be used as a block without any defined testing standards. The use of loose-fitting instruments within the groove may be a limitation of tempered steel rod[13,14] and block assemblies[15,16].

This study's cyclic fatigue testing system circumvents the limitations of laboratory investigations by simulating the instruments' sizes and taper in artificial canals. ***Pruett et al.***[7] measured the radius to be 6 mm, and **Schneider's** method[17] estimated the angle of curvature to be 45 degrees, suggesting that these various Ni-Ti rotary instruments may follow an accurate and repeatable trajectory.

This study compared three different rotary files with different tapers and different surface treatment without standardization of these items same as other studies[9,18,19].

In order to prevent the canals from wearing down while being instrumented, they were machined from a block of stainless steel. The rotating instrument can be seen through a glass cover placed above the St-St block. This helps to maintain an exact and repeatable trajectory, as glass is more resistant to wear than Ni-Ti files. The width of the artificial canal is 0.1 mm above the instrument's tip diameter, enabling free rotation of the file, and its depth is 0.5 mm above the maximum diameter of each file. This model is designed by ***Plotino et al.***[14].

The test was performed at intra-canal temperature 35°C±1°C because these files are manufactured by thermo-mechanical treatment. The aqueous media decreases the friction of the instruments with the canal walls decreasing the stress on the instrument, as result lubrication of the canal to prevent rising in temperature recommended by many authors[20].

Pedullà et al.[21] claimed that Heating can cause the martensite phase to transition into the more rigid austenite phase, which is more prone to fatigue failure, whereas the martensite phase shows a notable improvement in flexural strength. The temperature of the solution used to prepare the root canals and the interaction between the irrigant and Ni-Ti files might lead to variations in canal temperature. An important consideration in cyclic fatigue investigations is the environmental temperature to which Ni-Ti files are subjected.

Researchers have used static and dynamic testing to examine cyclic fatigue resistance. Rotating endodontic files made of Ni-Ti alloy until they break is a common component of static cyclic fatigue testing models. After that, the maximal curvature angle of the canal is the primary focus of the tension and compression cycles, which results in the file's failure. The dynamic model, on the other hand, mimics the clinical condition by simulating pecking motion caused by axial movement, making it the preferred choice. In this study although the dynamic model accurately approximates brushing or pecking motions in clinical practice more than the static model. Because the up and down motion is regulated manually, the magnitude of the axial motions is unlikely to be constant and reproducible in clinical practice, which is a restriction.

This study's results indicate an significant distinction in cyclic fatigue resistance across the three assessed NiTi instruments (P=0.0001). The EdgeX3 demonstrated the greatest resilience to cycle fatigue, followed by TRN, while PTN exhibited the least resistance.

Although the files analyzed were all about the same length and tip size, their different tapers necessitate careful interpretation of the data.the result of the current study in conrast to Previous studies by ***Faus-Llácer et al.***[18] that have shown that reduced instrument taper and core mass improve cyclic fatigue resistance,this is due to the firewire technology of Edgex3 (with 6% taper) that shows the superior file performance regarding the cyclic fatigue resistance same as ***Sinha et al.***[22] that reported that Edgex3 is more resistance than hyflex cm, hyflex EDM and twisted files. The parameters of TRN files were selected in accordance with the manufacturers' recommendations, resulting in higher velocities and lower torques than Edgex3 (500 versus 300 RPM as well as 1.5 versus 3 N-cm, correspondingly). ***Almohareb et al.***[23] have demonstrated that cyclic fatigue resistance is adversely affected by increased rotational speed. They also concluded that Edge taper platinum (taper6%) is more resistant than TRN (taper4%) despite having a greater taper and a lower rotational speed than TRN.

There have been more studies that have examined the cyclic fatigue resistance of various file tapers [24]. ***Topçuoğlu et al.***[25] reported that ProTaper Next exhibited lower cyclic fatigue resistance than Edgex7, which is in agreement with our results.

PTN x2 files have a large core mass in addition to the variable regrssive taper (6%)with a rectangular cross section that are considered the causes of showing the least cyclic fatigue resistance.Edgex3 exhibited the highest NCF because of the firewire technology, heat and cryogenic treatments not only improve the performance but also decrease the shape memory effect, which is an advantage over the traditional, although theses files have taper larger than TRN prime in addition to tip diameter (0.25) lessr than TRN(0.26), stating that NiTi endodontic rotary files' resistance to dynamic cycle fatigue is unaffected by the taper as well as apical diameter.

The Edge x3 group had the greatest cyclic fatigue resistance and the longest time to fracture.

This corroborated the findings of previous research conducted by ***Gambrini et al.***[26]**,** ***Drukteinis et al.***[27]and ***Bueno et al.***[28] that confirmed the greatest resistance of Edge files over wave one gold and genius files. In comparison to instruments manufactured using M-wire technology, Edge X7 instruments exhibited superior resistance to cyclic fatigue due to their electro-polished construction and specialized thermal "Fire-wire" annealed heat treatment.

Consistent with previous investigations by ***Riyahi et al.*** [29]***,*** as well as ***Peters et al.*** [30]***,*** the TRN had greater resistance to cycle fatigue than PTN. TRN prime (with a tip size of #0.26) exhibits greater resistance than PTN (#0.25) in the cyclic fatigue test, even though the resistance falls as the diameter of the tip increases. TRN designs are characterized by using a thinner Ni-Ti wire (0.8 mm) instead of a thicker one (1.2 mm), which results in a more streamlined shape and reduced core mass. Additionally, TRNs are operated at faster speeds with less torque. Because of its enhanced flexibility and resilience to cyclic fatigue, one of the purported benefits of TRN files is a decreased likelihood of separation.

In this investigation, the average length of the broken file segment (FL) in millimeters was documented to assess the proper placement of the instrument within the canal's curve and to ascertain if comparable forces were applied. All of the devices failed at or close to the point of greatest stress, which is the center of curvature, because there was no significant disparity in the results. The findings were consistent with those of prior investigations[8,31,32].

The incremental crack propagation induced by the cyclic stresses generated as the file is rotated in a curved root canal is what causes the cyclic fatigue fracture. The micro-cracks begin at microstructural flaws like surface irregularities or voids, which operate as sites of least resistance. From there, they propagate along certain crystallographic planes, eventually breaking the material. A SEM was used to analyze two specimens of cracked files at magnifications of 150x each. This allowed the researchers to see the file cross-section as well as the locations of crack start, which were visible up to the curved section. Here, during the stage of dissolution. Using a different magnification of 3000x, we can identify the fracture mode. This analysis facilitated the identification of failure origin and fracture pattern in the area of the greatest stresses. The configuration of the file flutes, canal curvature and radius are the most likely factors that act as stress concentration for fracture.

Because SEM offers superior resolution and depth of field, it was utilized. Image analysis revealed ductile fractures, a result of gradual material tearing; these fractures showed a dimpled surface, a result of the expansion of metal voids, and a noticeable plastic deformation. In comparison to standard Ni-Ti wires, the grain size of M-wire is significantly smaller. It is believed that the 100 nm size of the martensite grains in M-wire will help to decrease the onset of cracks along grain boundaries.[33] In every case of tired metal, the fractographic outline will go from the site of the crack to an area with fatigue striations and, finally, a dimple rupture [34]. Every single one of those characteristics pointed to a ductile fracture in the cyclic fatigue test. hence, cyclic fatigue resistance is not a null hypothesis.

CONCLUSION

Within the limitation of this research, it was concluded that:

The cyclic fatigue resistance of the EdgeX3 was the greatest followed by the TRN prime and then PTN x2 showed the least.

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