Research Article

Cyclic fatigue of advanced heat-treated nickel-titanium rotary files in simulated canals with single or double curvatures

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Abstract: Background: Fractures of endodontic files are one of the serious concerns affecting root canal treatment prognosis. Recently, countless innovations have been presented to optimize their microstructure and flexibility, reflected in different commercial brands. However, their performance has not been evaluated in complex root canals. Aim: To evaluate and compare the resistance to cyclic fatigue of three rotary endodontic files utilizing artificial canals designed with different angles and radii of curvature. Materials and Methods: sixty rotary instruments of the following types were used. Group I: Edge endo X7; Group II: Luster dent pliancy total solution; and Group III: Race Evo FKG. Instruments in each group were constrained into two subgroups (n=20) to be examined in artificial canals having a single curvature or a double curvature. The cyclic fatigue resistance of each rotary file was tested, where the number of cycles to fracture (NCF) and the fractured segment length (FL) were recorded. Results: In both single and double curvature canals, the Edge endo X7 files (9162.50 ± 441.14 and 2210.00 ± 341.07, respectively) demonstrated significantly higher resistance to cyclic fatigue than did the Race Evo FK (3866.66 ± 410.99 and 1825.00 ± 230.17, respectively) and Luster dent pliancy total solution (7077.77 ± 1001.84 and 1257.77 ± 126.95, respectively). However, in the double canal tests, the Luster dent pliancy total solution had a greater mean NCF than the Race Evo FK. In relation to the FL, there was no statistically significant difference between any of the groups, and only the edge of the Endo X7 file was significantly different between single- and double-curvature canals (P = 0.058). Conclusion: The Edge Endo X7 rotary file demonstrated greater cyclic fatigue resistance than did the Race Evo FKG and Luster dent pliancy total solution.

Keywords: Edge endoX7, luster dent pliancy total solution, Race Evo FKG, Double canal curvature, Cyclic fatigue

Introduction

During root canal treatment, endodontic instruments are subjected to high stress and cyclic fatigue, especially at the root canal curvature, which subsequently leads to canal blockage and instrument fracture. The extent of curvature is a significant variable that can lead to instrument fatigue and fracture [(1)]. The

fracture resistance of NiTi instruments is influenced by many factors, including manufacturing methods, alloy composition, flute design, and cross-sectional geometry [2,3]. Thermomechanical technology has been applied to improve the transformation behavior and microstructure of NiTi rotary files, enhancing the instrument performance during root canal preparation including cyclic fatigue resistance [4-7]. One of the most effective methods for modifying the transition temperature of NiTi alloys is thermal processing. The NiTi Edge endo X7 file, a recently introduced rotary system made by heat-treating firewire NiTi, has been stated to effectively increase fatigue resistance and flexibility due to changes in transformation behavior. This is accomplished to improve the resistance of the file to cyclic fatigue. This file has a parabolic cross-section and is part of a rotation multiple file system, which improves the cutting efficiency, and strength of the file and increases its fracture resistance [8,9].

High-quality Lusterdent Pliancy Rotary Files are manufactured using a unique French Ni-Ti alloy, CM-Wire Heat Activation, and advanced metallurgical techniques with a rectangular cross-section multivariable taper. High flexibility is achieved through the use of proprietary Control Memory Ni-Ti technology. Cutting efficiency and flexibility have also been improved by the progressive taper design of files, which is beneficial, particularly for curved canals, double-curved canals, tiny canals, and calcified canals [10]. To the best of the author's knowledge, there are no available studies in the literature evaluating the cyclic fatigue resistance of Luster dent pliancy total solution.

Race Evo is a heat-treated instrument for minimally invasive root canal preparation. With a triangular design of the file cross-section, alternating cutting edges, and a rounded file tip, these new electropolished files are impressive [11,12].

Insufficient data are available concerning the resistance of the Edge Endo X7, Luster Dent Pliancy Total Solution, and Race Evo FK files to cyclic fatigue. Hence, it is of utmost importance to perform tests on newly introduced NiTi instruments to gather reliable information that can aid dentists in optimizing the results of root canal treatments. This in vitro investigation sought to quantify the cyclic fatigue of the Edge endo X7, Luster dent pliancy total solution, and Race evo FK files in simulated canals featuring single and double curves. The null hypothesis suggests that; there is no significant discrepancy in the cyclic fatigue resistance of the three heat-treated NiTi rotary file types (Edge endo X 7, Luster dent pliancy total solution, and Race evo FK) within both single and double curvature canals.

Materials and Methods

Instruments and grouping

In this study, three types of NiTi rotary instruments were used (Table 1). Edge endo X7 (EdgeFile X7 (EdgeEndo, Albuquerque, NM, USA), Luster dent pliancy total solution (Lusterdent Médical Instrument Co., Ltd., Paris, French), and Race evo FK (FKG Dentaire SA, La Chaux de Fonds, Switzerland) instruments with a size of 25 and 0.06 tapering were checked for any sign of defect or deformity with a stereomicroscope (Meiji Techno Co. Ltd., Tokyo, Japan) under x20 magnification, where none of the instruments were discarded.

Table 1: Characteristics of rotary file instruments

Files	Cross section design	materials and manufacture design
Edge endo x7	triangular parabolic	Heat treating firewire
Luster dent pliancy	rectangular cross-section	CM-Wire heat activation
Total solution	multivariable taper	
Race Evo FK	triangular cross section with alternating Cutting edge and rounded files tip	Electropolished files

Sixty NiTi rotary files were employed in this experiment and assigned to three groups (N = 20 for each)[1]. Group I: Edge endo X7 size 25/0.06; Group II: Luster dent pliancy total solution; and Group III: Race Evo

FKG. Then, according to canal curvature (single or double curvature), each group was subdivided into two subgroups (N = 10 for each subgroup).

Cyclic fatigue test procedure

A cyclic fatigue test was performed on all the files using a specially produced custom-made stainless-steel block with a single or double curvature canal. The canals were 3D drawn in AutoCAD 2018 and then transferred to DWG, DXF 2005 file extension in order to be understood and constructed by an electrical discharge wire cutting machine. Two slices of stainless steel (316) (S.S) were used to manufacture the artificial canals. The first one is a 1.5 mm thickness S.S. sheet, in which the canal milled. The second slice was used to provide adequate thickness to the block. Then, four screws joined the two parts [13]. A double curvature canal was designed with 90° coronal curvature and a 5 mm radius, and the apical curvature angle was 70° with a 2 mm radius. The center of the coronal curvature was created about 8 mm away from the canal's end with a 5.25 mm curve length, whereas the center of the apical curvature was created 2 mm away from the canal's end, and the curve length was 2.4 mm. The single curvature canal was 60° with a 5 mm radius, and the curve length was 5.25 mm with the center of curvature 5 mm away from the canal's end. The working length of the two artificial canals was 18 mm, with an inner canal diameter of 1.5 mm (Figure 1) [1]. The canals were covered with tempered glass to prevent slipping out of the tested files and to make it easier to see fractures through the cover when instrument separation occurred.

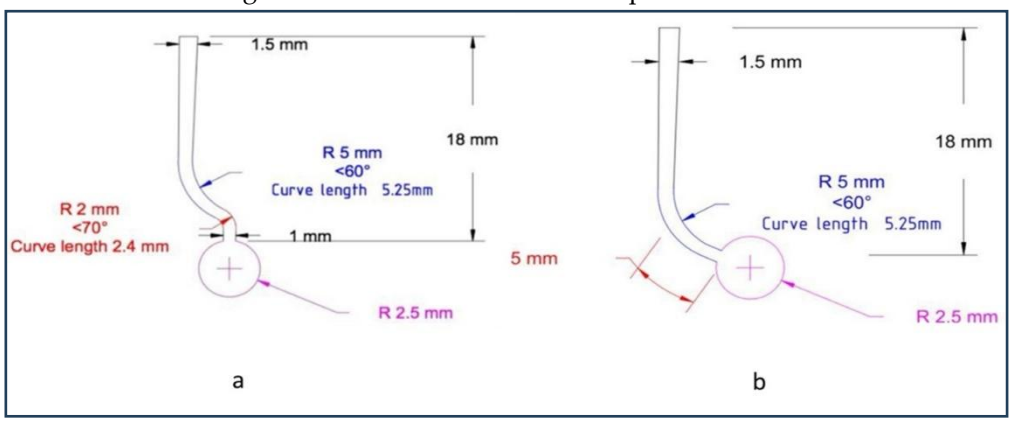

Figure 1: (a) Double curved artificial canal and (b) single curved artificial canal (adapted from [1])

The electric motor handpiece (Motopex, Woodpecker, Guilin, China) was mounted on a surveyor, keeping it at a stable position during an operation to allow precise settlement of each rotary file inside the artificial canal, with the same insertion depth of the instrument each time (Figure 2).

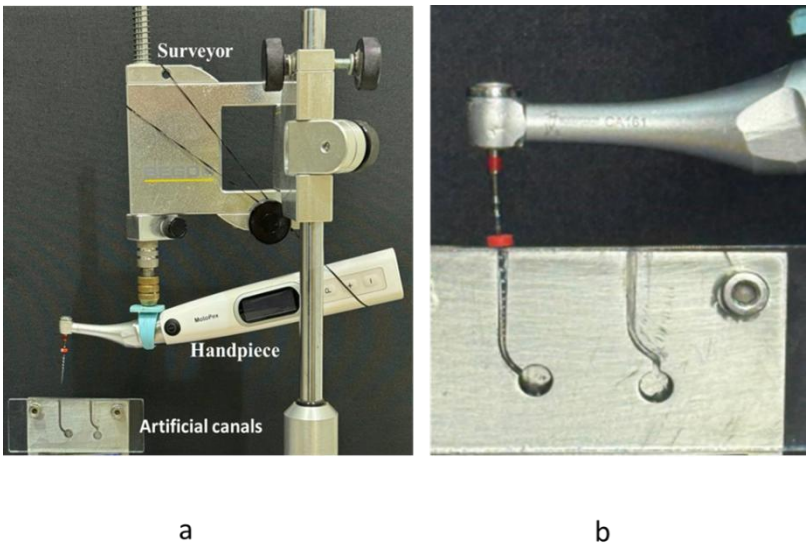

Figure 2: (a) Dental handpiece mounted on a surveyor with a file positioned inside the block; (b) magnified view of the artificial canal.

The files were examined in static mode, where the canal was loaded with oil (Iranoil, Tehran, Iran) at room temperature. Each file positioned in the handpiece was rotated at a clockwise continuous rotation, at speed and torque following the manufacturer's recommendations: Edge endo X7 and Luster dent pliancy total solution rotated at a speed of 300 rpm and torque of 3 N-cm and 2 N-cm, respectively), while Race Evo FKG rotated at a speed of 800 rpm and torque of 1 N-cm. The files were rotated until fracture. The required time to a file fracture was determined by a 1/100 s chronometer. For the NCF calculation, the time required to fracture was multiplied by the number of rotations per minute. The lengths of the fractured fragments of each file were recorded with the aid of a digital caliper (Mitutoyo, Kawasaki, Japan).

Statistical analysis

The statistical analysis was achieved using SPSS version 21 software (IBM-SPSS Inc., Chicago, USA). The normal distribution of the data was performed using the Shapiro–Wilk test. The level of significance was set at 0.05. The NCF and FL data were statistically analyzed by applying one-way ANOVA, the post hoc Tukey test and an independent t-test was applied for data comparison between single- and double-curved canals.

Results

Table 2 and Figure 3 display the mean and standard deviation values of the NCFs. Edge Endo X7 showed the highest NCF value in single- and double-curved canals (9162.50 ± 441.14 and 2210.00 ± 341.07 respectively). The Race evo FK files had the next highest NCF values in single-curved canals (7077.77 ± 1001.84), followed by the Luster dent pliancy total solution (3866.66 ± 410.99). The values of the NCFs in tested groups of single-curved canals were found to be in the following order: Edge Endo X7 > Race evo FK > Luster dent pliancy total solution.

In the double-curved canals, the Luster dent pliancy total solution recorded the second highest resistance (1825.00 ± 230.17) after the Edge endo X7, while the Race evo FK files showed the lowest values (1257.77 ± 126.95). The values of the NCFs in tested groups of double-curved canal were found to be in the following order: Edge Endo X7 > Luster dent pliancy total solution > Race evo FK. Across all file groups, there was a statistically significant difference in the NCF in the canals group according to the single and double curves (P > 0.05). In relation to the effect of canal curvature, and as revealed by the independent sample t-test, all tested file systems expressed significant differences in NCF values between single and double-curved canals in each main group (P = 0.000).

Table 2 and Figure 4 display descriptive statistics as the means and standard deviations of the fractured segment lengths (FLs). Race evo FK files showed the lowest fragment length among the tested files in the single curve canals (2.65 ± 0.40 mm). Fracture segment length for the Edge endo X7 and Luster dent pliancy total solution groups were nearly the same in single curve canals with mean values of FL 3.08 ± 0.24 mm and 3.11± 0.34 mm, respectively. In double-curvature canals, Rase evo FK also demonstrated the lowest FL among tested files as in single ones (3.46 ± 0.42 mm). However, the same order was seen between the remaining files as in single curvature canals with a mean value of FL was 4.05± 0.99 to Edge endo X7 and 4.45 ± 0.30 to Luster dent pliancy total solution. Between the single- and double-curvature canals in each group, there was a statistically significant difference in the FL between all the tested file systems, and FLs in the double-curved canal were higher than those in the single-curved canal. However, statistical analysis for FL in both single and double-curved canals expressed no significant differences among the three groups ((P > 0.05), with a place of curvature located nearly at the center of the canal curvature.

Table 2: Mean and standard deviation (SD) for the number of cycles to fracture (NCF) and lengths of broken fragments (FLs) for the groups in mm.

Groups	Number of cycles to fracture (NCF) Mean ± SD		Fracture length(FL) in mm Mean ± SD	
	Single	double	single	double
Edge endo x7	9162.50 ± 441.14 aA	2210.00 ± 341.07 aB	3.083 ± 0.24aA	4.05 ± 0.99aB
Luster dent pliancy	3866.66 ± 410.99 bA	1825.00 ± 230.17 bB	3.11 ± 0.34aA	4.45 ± 0.30aB
Race Evo FK	7077.77 ± 1001.84 cA	1257.77 ± 126.95 cB	2.65 ± 0.40aA	3.46 ± 0.42aB

Different lowercase letters within each column reflect significant differences, while different uppercase letters within each row reflect significant differences.

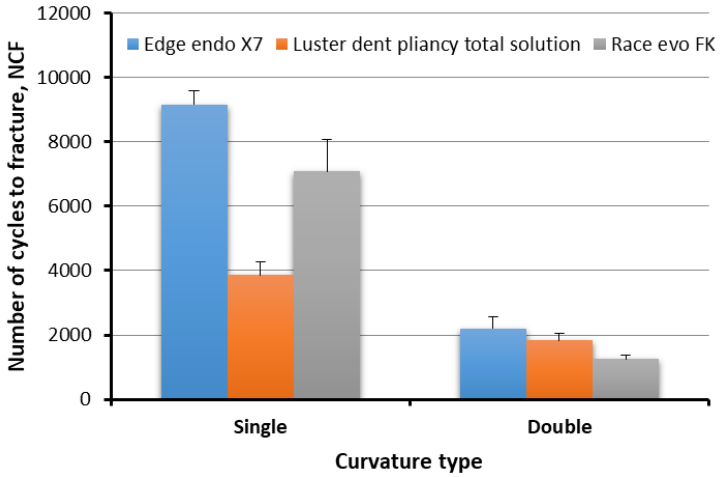

Figure 3: Bar chart showing the mean and standard deviation of the number of cycles to fracture (NCF) for the groups

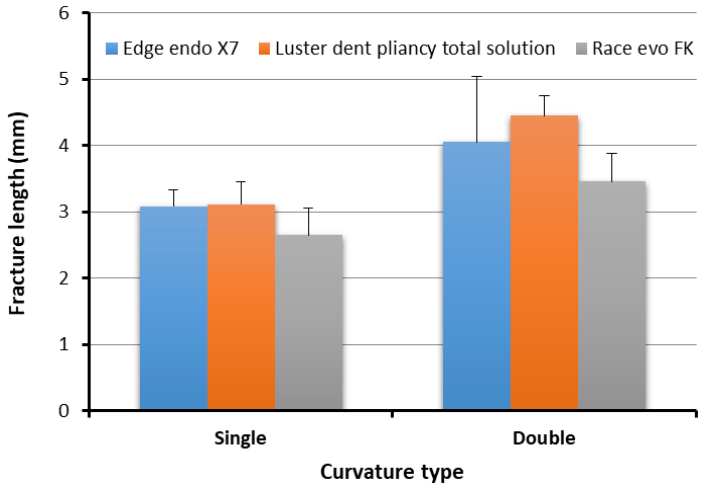

Figure 4: Bar chart showing the mean and standard deviation (SD) for the lengths of the broken fragments (FLs) for the groups in mm.

Discussion

During root canal therapy, a catastrophic accident known as an endodontic file fracture might occur. Although NiTi files are more flexible and torsion-resistant, breakage remains a serious concern with these files, especially after extended use [13]. The primary cause of NiTi file fractures during root canal preparation

is cyclic fatigue [14,15]. If file breakage prevents adequate cleaning and shaping of the root canal system, the treatment prognosis may be affected [16]. Consequently, numerous innovations have been developed to improve the cyclic fatigue resistance of file systems, including modifications in file configuration (cross-sectional design, tapering), metallurgy design, and surface and heat treatment for NiTi alloys [13]. Previous literature has also demonstrated that the cyclic fatigue resistance of files is influenced by the angular curvature and radius of the root canal [17,18]. Thus, this study aimed to assess and compare the cyclic fatigue resistance of three newly developed rotary files at different canal curvatures with variable radii of curvature. Firewire (Edge File X7), CM-wire heat activation (Luster dent pliancy total solution), and heat-treated technology (Race evo FKG) rotary files were examined in this study to determine whether different manufacturing processes, kinematics, or alloys impact the resistance to cyclic fatigue if endodontic files are manufactured with different alloys.

In this study, artificial root canals were used instead of naturally extracted teeth because they were not anatomically standardized; thus, any other possible confounding factors were eliminated, and variables other than the cyclic fatigue variable were ruled out [9,19,20]. The stainless-steel material used to make the canals prevented frequent wear, ensuring that each file followed the same path. To accommodate the various sizes and tapers of the files used, the artificial canal was designed to be 2 mm deep, allowing the files to rotate freely within the canal [21].

The stainless-steel inspection block is covered with a glass surface, which allows the instrument visualization while working in the root canal and when the file is broken. Additionally, this design also helps keep the oil in the canal for a long time, prevents the file from slipping out of the canal, and prevents loss of debris [22,23].

The size and taper of the tested file were the same for each group (0.25 mm with 6% taper) because size 0.25 mm size is the mutual size among the three manufactural of the files that were used in this study for making standardization in the size and jeopardizing the errors in results. In addition, according to the previous study "that Apical size equivalent to #25 with a minimum taper of 0.6 facilitates sufficient irrigation with fine irrigation needles while preventing coronal overpreparation and shaping errors in highly curved canals" [24]. Additionally, the static cyclic fatigue test was used instead of the dynamic test since the latter test cannot represent the mechanical behavior of NiTi files [25].

According to the current study findings, in both single and double-curvature canals, Edge Endo X7 files demonstrated significantly greater resistance to cyclic fatigue. In a single-curved canal, Race Evo FK had the second highest value, followed by the Luster dent pliancy total solution. However, in the double canals, the Luster dent pliancy total solution had a greater mean NCF than did the Race Evo FK. Therefore, the null hypothesis was rejected because of the significant differences among the tested groups regarding their cyclic fatigue resistance.

The major components influencing the cyclic fatigue resistance of files include the file taper, size, cross-sectional plan, fabrication procedures, and materials [26,27]. During the cyclic fatigue test, the point of greatest stress may affect the fatigue life of the NiTi rotary files. The fatigue resistance decreases with increasing metal volume [17].

There were distinctions between the edge file and the luster file. The triangular cross-sectional design at the edge differs from the rectangular shape with 4 cutting edges in the luster pliancy [28-29]. The file cross section was responsible for changing the stress distribution in the rotary instrument when twisted or strained [30]. A finite element analysis showed that the triangular cross-section design exhibited greater cyclic fatigue resistance than did the square cross-section design of the file [32]. This was explained by the fact that the file with the triangular cross-section had less metal mass than the one with the square cross-section and comparable diameter [25,36]. As a result, in this study, the greater resistance to cyclic fatigue may be caused by the lower metal mass of the edge's triangular cross-section as opposed to the higher metal mass of the pliancy file's rectangular cross-section. This result was consistent with earlier research showing

that files made from small cross-sections and thermally treated alloys showed increased resistance to cyclic fatigue [33-37]. Additionally, the cross-sectional design may influence how the file blade engages with the canal wall and generates stress, which is beneficial for lowering torsional stresses [39]. The fatigue resistance of rotating instruments can be impacted by the mass of the metal [40]. Furthermore, EdgeFile X7 features a constant taper, while Luster dent plasticity total solution and Race Evo FKG incorporate a variable regressive taper design, resulting in a large dimension of its coronal part, even though the nominal size of the tested instruments was the same (25/.06). As a result, there were differences in the tested systems' engagement within the root canal walls [38,42].

Generally, there are similarities between Edge and Race because both of them have triangular cross-sectional designs. The specific mechanical properties of the Edge Endo X7 files could be a possible reason for their superiority compared to the other two files. The X7 Edge File instrument can be deformed by light pressure and does not recover its original shape when heated to 125°C. Therefore, it can be proposed that the Edge endo X7 files have a martensite/austenite composition, with a higher percentage of the former. This information may help to explain why the file performed better than the other tested files [8].

The Race Evo FKG instrument demonstrated the second-highest resistance to cyclic fatigue in single curvature canals. This might be attributed to the high flexibility resulting from heat treatment during the manufacturing process of Race Evo [12]. Furthermore, the Race Evo instrument has more martensite phase at ambient temperature [9]. It was recorded that in the martensitic crystallographic state, as opposed to the austenitic state, NiTi alloys exhibited greater flexibility and resistance to cyclic fatigue [43-45]. This result agreed with that of Basturk et al. [11], who reported that the Race Evo instrument was highly flexible with high cyclic fatigue resistance after the R-Motion file. It appeared that in the single-curvature canal, the file configuration affected the CFR, where higher values were recorded with the X7 Edge File and Race Evo with their triangular cross sections, while the metallurgical properties affected the results in the double-curved canal. Nevertheless, in the double curvature canal, all the tested files showed less CFR. Some previous literature supported this finding that cyclic fatigue resistance was greater in canals with double curvature than in canals with single curvature [5,36]. However, the Luster dent pliancy total solution exhibited the second highest cyclic fatigue resistance, following that of Edge endo X7. This may be due to the manufacturing process as it is made of CM wire alloy and the EDM process during manufacturing [9]. Because rotational speed tends to shorten the time to fracture, it was claimed that it has a significant impact on cyclic fatigue [46-48]. The impact of heat generation by friction and a possible phase transition that is reliant on the austinite final temperature [49,50]. This might explain the reduced CFR of Race Evo FKG, which was exuded in the double-curved canal.

Statistical analysis of FL in single and double-curved canals did not reveal any significant difference between the file systems ($P > 0.05$), and the position of the fractures was at the center of the curvatures. This finding suggests that the tested instruments were correctly positioned within the artificial canals, resulting in similar induced stresses [51]. To the best of our knowledge, there are no published studies comparing the cyclic fatigue resistance of Edge endo X7, Luster dent pliancy total solution, and Race Evo FKG files, making it challenging to justify and compare their performance. As a limitation, this study cannot perfectly replicate a clinical setting. Second, a single kind of curvature radius has been used, even though in real-world applications, different canals have different curvatures and different radii of curvature. Third, instead of using the pecking motion found in the dynamic test, this study employed a static cyclic fatigue test. Fourth, unlike oral conditions, this study was conducted at room temperature. Fifth, the study was conducted using artificial steel canals rather than real teeth, which makes it impossible to replicate real-world clinical settings.

Conclusion

Within the limitations of this in vitro study, the results suggested that the resistance to cyclic fatigue of rotary endodontic files may be influenced by various internal factors, such as file alloy properties, cross-sectional design, taper, and kinematic characteristics. Furthermore, some external factors might also affect

the cyclic fatigue resistance of endodontic files, such as the temperature, curvature, and radius at which the instrument is activated. Based on the findings, it can be concluded that among the tested files, Edge File X7 instruments exhibited greater resistance to cyclic fatigue in both single and double-curvature canals compared to Race Evo FKG and Luster dent pliancy total solution.

Conflict of interest

The authors have no conflicts of interest to declare.

Author contributions

SAR and WAK; study conception and design. MAA, SJH; data collection. AAA, RA; Methodology. SAR, AIA, and RAA; statistical analysis and interpretation of results. SJH, AA, AAA, and RA; Writing - review & editing. Supervision; AA, AAA, and SAR. All authors reviewed the results and approved the final version of the manuscript to be published.

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Informed consent

Informed consent was obtained from all individuals (or their guardians) who participated in this study.

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الاجهاد الدوري للمبارد الدوارة الحديثة المعالجة بالحرارة من النيكل والتيتانيوم في القنوات المحاكاة ذات الانحناءات المفردة أو المزدوجة

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المستخلص:

خلفية: كسور المبارد اللبية هي واحدة من المخاوف الخطيرة التي تؤثر على تشخيص علاج قناة الجذر. في الآونة الأخيرة، تم تقديم عدد لا يحصى من الابتكارات لتحسين بنيتها الدقيقة ومرونتها، وهو ما ينعكس في العلامات التجارية المختلفة. ومع ذلك، لم يتم تقييم أدائها في القنوات الجذرية المعقدة. الاهداف: تقييم مقاومة الاجهاد الدوري لثلاثة مبارد علاجية دوارة باستخدام قنوات صناعية مصممة بزوايا وأقطار انحناء مختلفة. المواد والطرق: تم استخدام عشرين أداة دوارة من الأنواع التالية. المجموعة الأولى: Edge EndoX7؛ المجموعة الثانية: Total solution Luster dent pliancy ؛ والمجموعة الثالثة: Race Evo FKG. تم تقسيم الأدوات في كل مجموعة إلى مجموعتين فرعيتين لفحصها في القنوات الاصطناعية ذات انحناء واحد أو انحناء مزدوج. تم اختبار مقاومة الاجهاد الدوري لكل مبرد دوار، حيث تم تسجيل عدد دورات الكسر (NCF) وطول القطعة المكسورة (FL). النتائج: في كل من قنوات الانحناء الفردية والمزدوجة، أظهرت ملفات Edge endo X7 (9162.50 ± 441.14 و2210.00 ± 341.07، على التوالي) مقاومة أعلى بكثير للإجهاد الدوري مقارنة بملفات Race Evo FK (3866.66 ± 410.99 و1825.00 ± 230.17، على التوالي) و Total solution Luster dent pliancy (7077.77 ± 1001.84 و1257.77 ± 126.95 على التوالي). ومع ذلك، في اختبارات القناة المزدوجة، كان Luster dent pliancy متوسط NCF أكبر من Race Evo FK. فيما يتعلق بـ FL، لم يكن هناك فرق ذو دلالة إحصائية بين أي من المجموعات، وكانت حافة ملف Endo X7 فقط مختلفة بشكل كبير بين القنوات ذات الانحناء الفردي والمزدوج (P = 0.058). الخلاصة: أظهر المبرد الدوار Edge Endo X7 مقاومة أكبر للإجهاد الدوري مقارنة ب Race Evo FKG و Luster dent pliancy