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Original Article

Assessing the Cyclic Fatigue Performance of Different Nickel Titanium Rotary Endodontic Files in Simulated Curved Canals: An *in –vitro* Study

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Abstract

Nickel-titanium (NiTi) rotary endodontic instruments have significantly improved root canal treatment due to their superior flexibility and fracture resistance. However, their effectiveness can be compromised in curved root canals, where they are susceptible to cyclic fatigue, leading to instrument breakage and potential complications. This study aimed to evaluate the cyclic fatigue resistance of three different NiTi rotary endodontic instruments using a static testing apparatus. Thirty-six files, twelve each of Orodeka Plex V, Super Flexi Files Gold, and Fury L60, were subjected to a 45-degree curvature with a 5-mm radius. Each file was rotated at 300 RPM with a 2 N/cm torque until fracture. The number of cycles to fracture (NCF) was recorded for each instrument. The significance level was set at $p \leq 0.05$. Statistical analysis revealed significant differences in cyclic fatigue resistance among the three groups, with Fury L60 demonstrating the highest resistance, followed by Super Flexi Files Gold and Orodeka Plex V. However, no significant differences were observed in fragment fracture length among the groups. In conclusion, Fury L60 exhibited the highest resistance to cyclic fatigue among the tested NiTi instruments. All instruments fractured at the midpoint of the curvature, with consistent fragment lengths.

Keywords: *NiTi alloy rotary endodontic files, Cycle Fatigue, Simulated curved canal.*

Introduction

Endodontics has undergone significant advancements, evolving from carbon steel alloy instruments to stainless steel and eventually to nickel-titanium (NiTi) rotary instruments. While stainless steel instruments improved upon the corrosion and rust issues of carbon steel, they still faced challenges such as perforations, zips, and ledges, which could compromise root canal treatment success [1–3]. Nickel-titanium (NiTi) alloy instruments were introduced in the 1960s by Sir William Buehler and Frederick Wang at the Naval Ordnance Laboratory, Maryland, to address the limitations of previous materials. NiTi's unique shape memory and superelastic properties allow endodontic NiTi files to be 2-3 times more flexible than traditional instruments, making them ideal for navigating curved root canals [1,4,5]. These advancements have made the cleaning and shaping procedure more efficient and straightforward [6].

Despite the advantages of rotary NiTi instruments, concerns persist regarding their potential to fracture within the root canal system during endodontic treatment. Fractures can occur unexpectedly, even in instruments without visible defects or previous permanent deformation. The presence of a fractured instrument in a treated tooth is both undesirable for the dentist and patient, often requiring complex removal procedures, including potential surgical intervention. Two primary modes of fracture for rotary NiTi instruments are cyclic fatigue and torsional failure, with cyclic fatigue being a particularly significant clinical concern [7–10]. Flexural fatigue occurs when an endodontic file rotating in a curved canal is subjected to repeated cycles of compression and tension at the point of maximum curvature. This repeated stress can eventually lead to file fracture [1,5]. The stress on a file during canal preparation is greatly impacted by the operator's handling, usage method, and the complexity of the root canal [9]. The stress behavior of NiTi files, and consequently their propensity to fracture, is greatly influenced by factors such as file geometry, alloy composition, and manufacturing methods [9]. Various manufacturers have introduced innovative NiTi rotary systems, each with unique geometric designs and thermomechanical processes aimed at enhancing mechanical characteristics [3,11].

Orodeka Plex V (Orodeka Plex V; Orodeka Medical Equipment CO, JiNing, China) was introduced on the market with the claim that it is manufactured using heat-treatment technology. These files are made from a special metal alloy called CM wire alloy. This alloy has a unique property that allows it to bend and return to its original shape. This is helpful for navigating curved root canals without damaging them. The files have a triangular convex modified shape that helps remove debris from the root canal. They also have a non-cutting tip that helps prevent damaging the root canal walls. The files have three sharp blades that cut away debris. The blades are designed to get progressively sharper towards the tip, which helps remove debris and prevents the file from getting stuck. Super Flexi Files Gold (SUPER FLEXI FILES GOLD; Shenzhen Rogin Medical CO, China) are special tools used by dentists during root canal procedures. They're a simple but effective system for cleaning curved canals. Here's what makes them special: Flexible; Made from a special metal alloy (CM wire alloy) that bends easily, allowing them to follow the curves of your root canals without breaking. Square-shaped; this shape helps them efficiently scrape and clean the walls of the canal. Non-cutting tip; the tip is designed not to cut, but to safely guide the file into the canal without damaging the root.

Overall, Super Flexi Files Gold are designed to clean curved canals gently and effectively Fury L60 (FURY L60; Mighty Medico CO, Changzhou, China) was introduced with Patented Alternating Flat Surface for Removes debris efficiently; the unique design pushes debris upwards, preventing it from going deeper into the root canal. No "screw-in" effect; It doesn't twist and get stuck in the canal. Good balance of cutting and flexibility; the special S-shape design provides both sharp cutting and flexibility. Flexible; the alternating flat surfaces make it more flexible because there's less metal in the core. Gentle on the root; the design allows the file to navigate the root canal smoothly and safely. Smooth feeling; the alternating flat surfaces and asymmetrical shape create a smooth sensation during use. In simpler terms, this file is designed to clean root canals effectively without damaging those. Nickel-titanium (NiTi) files are commonly used dental instruments for root canal procedures. Despite manufacturers' claims of their durability, further research is necessary to confirm their resistance to breakage. This study aimed to compare the cyclic fatigue performance of various NiTi alloy endodontic rotary files. The null hypothesis assumes that there is no significant difference in the cyclic fatigue resistance among these files.

Methods

Sample size calculation was performed using G*Power version 3.1.9.7 based on the results of a previous study [5,12]. A power analysis was designed to have adequate power to apply a two-sided statistical test to reject the null hypothesis that there is no difference between groups. By adopting an alpha level of (0.05) and a beta of (0.1), i.e. power=90% and an effect size (d) of (0.6509) calculated based on the results of a previous study. The predicted sample size (n) was (36), i.e., 12 files per group. To detect for different between groups as regard number of cycles to fracture. A total 36 experimental rotary NiTi files were divided in 3 groups namely Group I Orodeka Plex V (Orodeka Plex V; Orodeka Medical Equipment CO, JiNing, China), Group II Super Flexi Files Gold (SUPER FLEXI FILES GOLD; Shenzhen Rogin Medical CO, China) and Group III Fury L60 (FURY L60; Mighty Medico CO, Changzhou, China). Each group comprised of 12 experimental rotary files were kept standardized of 25mm length, 4% taper and ISO size 25 (Figure 1). All these files were tested in a simulated constructed apparatus with angle of curvature 45° and radius of curvature 5 mm. A static model for cyclic fatigue testing was conducted in a custom –made device that allowed for a reproducible simulation of instruments confined in a curved canal. All the files were placed in the simulated canal of over length 20mm.

To reduce file friction with artificial canal walls, high-flow synthetic lubricating oil (Ravenol, TSI, Teilsynthetisches Motorenol, Germany) was applied and the free canal surface was covered with tempered glass to prevent the instruments from slipping out and to allow observation of the instruments. The dental handpiece was constructed on the custom-made plastic frame and metal block for precise and reproducible insertion of each instrument into the canal. Each file was then allowed to rotate at 300 rpm and 2 N/cm torque preset in Endo Smart Endo endomotor with transmition ratio 1:1 (Guilin Woodpecker Medical Instrument Co, Guangxi, 541004, China). The time to fracture was videos recorded and stopped as soon as a fracture was detected visually and/or audibly using a digital stopwatch 1/100-s with accuracy ±0.01s (Casio Stopwatch HS-3, CO., LTD. China) and registered to the nearest integer second (Figure 2). Number of cycles performed by a file until fracture was calculated by the following formula: No. of cycles performed by experimental file until fracture=300/60 x Time taken till fracture (in sec.). The length of the fractured fragments was measured in millimeters used a digital caliper with accurate to ±0.01mm (ROHS NORM 2002/95/EC, Qingdao Preco Imp. & Exp. Co., Ltd. China) (Figure 3). Values were presented as mean and range values. Data were explored for normality using Kolmogorov-

Smirnov test of normality. The results of Kolmogorov-Smirnov test indicated that data recorded values were normally distributed. Therefore, one way analysis of variance (ANOVA) test was used to compare between groups, followed by Tukey's post hoc test for pairwise comparison. The significance level was set at $p \leq 0.05$. Statistical analysis was performed with SPSS 23.0 (Statistical Package for Scientific Studies, SPSS, Inc., Chicago, IL, USA) for Windows.

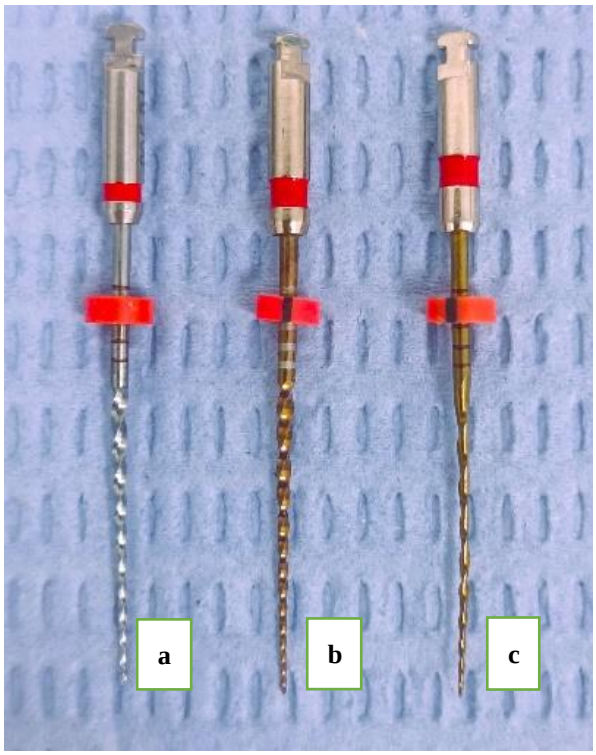

Figure 1. NiTi rotary files (a) Group 1-Orodeka Plex V, (b) Group 2- Super Flexi File Gold and (c) Group 3- Fury L60.

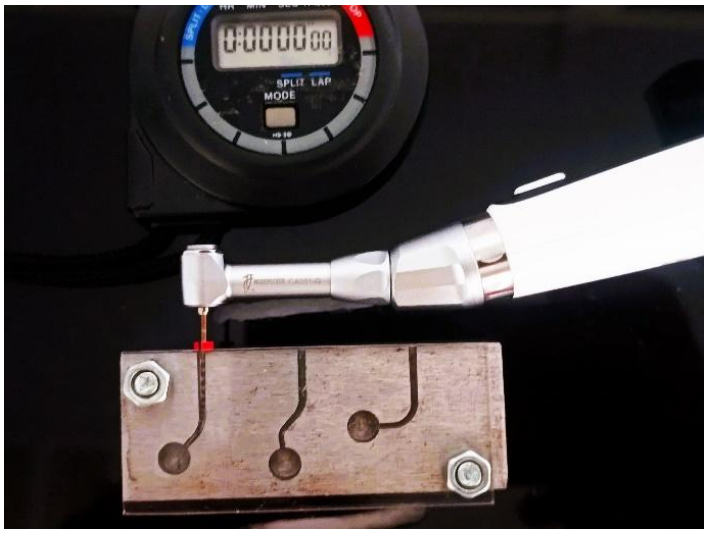

Figure 2. Setup of custom fabricated cyclic fatigue device.

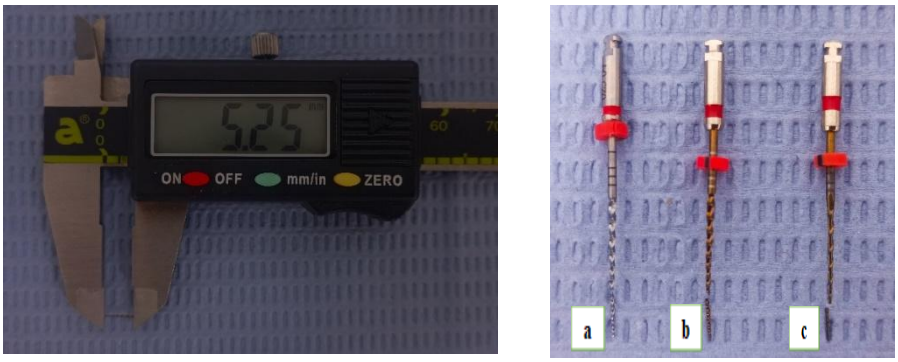

Figure 3. Right picture shows separated NiTi rotary files (a) Orodeka Plex V, (b) Super Flexi File Gold, and (c) Group 3- Fury L60. Left picture show fragment fracture length measured with digital caliper.

Results

Table 1 present the number of cycles to fracture (NCF) for three groups of experimental dental files. Group III (Fury L60) exhibited the highest mean NCF (3650.75 ± 137.71), followed by Group II (Super Flexi Files Gold) and Group I (Orodeka Plex V). Statistical analysis (ANOVA) revealed significant differences among the groups (P = 0.001). Subsequent Tukey's post hoc tests indicated multiple significant differences between Groups I, II, and III. Table 2 show the fragment fracture length of the same three groups. Group II had the longest mean fragment fracture length (5.04 ± 0.19), followed by Group I and Group III. However, no statistically significant differences in fragment fracture length were found among the groups (P = 0.886) using ANOVA or Tukey's post hoc tests.

Table 1. mean±SD values, results of ANOVA and post hoc tests for the comparison between different groups regarding number of cycle fatigue.

Groups	N	Mean	±SD	±SE	95% C.I. for Mean		Min.	Max.	F-test	p-value
					Lower	Upper				
Group I (Orodeka Plex V)	12	1738.25C	59.40	17.15	1700.51	1775.99	1620	1815	1785.782	0.001*
Group II (Super Flexi Files Gold)	12	1866.00B	23.55	6.80	1851.04	1880.96	1824	1902		
Group III (FURY L60)	12	3650.75A	137.71	39.75	3563.26	3738.24	3399	3810		

SD: Standard deviation; SE: Standard Error; Min.: Minimum; Max.: Maximum C.I. Confidence Interval Tukey's post hoc: Means sharing the same superscript letter are not significantly difference.

Table 2. mean±SD values, results of ANOVA and post hoc tests for the comparison between different groups regarding Fragment Fracture Length.

Groups	N	Mean	±SD	±SE	95% C.I. for Mean		Min.	Max.	F-test	p-value
					Lower	Upper				
Group I (Orodeka Plex V)	12	5.02	0.16	0.05	4.92	5.13	4.75	5.30	0.122	0.886
Group II (Super Flexi Files Gold)	12	5.04	0.19	0.06	4.92	5.16	4.75	5.31		
Group III (FURY L60)	12	5.00	0.17	0.05	4.89	5.11	4.75	5.30		

SD: Standard deviation; SE: Standard Error; Min.: Minimum; Max.: Maximum C.I. Confidence Interval Tukey's post hoc: Means sharing the same superscript letter are not significantly difference.

Discussion

This study aimed to evaluate the cyclic fatigue behavior of various NiTi rotary instruments, a property not typically provided by manufacturers [13]. Evaluation of the mechanical properties of new NiTi rotary instruments and their impact on instrument performance is mandatory for clinicians in order to pick the best system for each case and improve clinical endodontic results [14]. The results of our study lead to the rejection of the null hypothesis, as there were significant differences in the cyclic fatigue between the tested systems. A significant concern during root canal treatment is the risk of instrument fracture. While several factors can contribute to this, cyclic fatigue has been identified as a primary cause, particularly when rotary files are used in curved canals [8,15,16]. Recent advancements in NiTi technology and manufacturing have resulted in a new generation of instruments with improved flexibility and increased resistance to cyclic fatigue [11].

Schneider's work on measuring canal angulation has aided in assessing complexity and favorable outcomes [5,17]. The present study used a 45° angulation to replicate a challenging canal, as curvature beyond 30° is considered highly difficult by the AAE standards, which similar to the previous study [18]. To ensure standardized experimental conditions and minimize the influence of extraneous variables, the cyclic fatigue test in this study employed a stainless-steel block with a single-curved artificial canal [19,20]. While natural teeth are preferred for evaluating NiTi file cyclic fatigue resistance in simulated clinical settings, their anatomical variability makes standardization challenging [21]. Simulated canals are particularly valuable for studying complex canals, as it is nearly impossible to find a sufficient number of human teeth with consistent canal lengths, curvatures, and diameters [19,20]. Furthermore, natural teeth undergo changes during root canal filling, potentially affecting test results. Therefore, extracted teeth are not ideal for cyclic fatigue testing of NiTi instruments. However, results from studies using artificial canals must be cautiously extrapolated to clinical conditions due to differences between stainless steel and dentin [22].

Cyclic fatigue tests can be conducted using static or dynamic models. This study employed a static model due to the challenges of standardizing axial movement without inducing lateral movement and torsional loads in dynamic models [23]. Distinguishing between torsional and cyclic fatigue fractures is difficult in dynamic test designs [23]. Despite the limitations of simulated canals, they allow for standardized comparison of different instruments [24]. All instruments in this study fractured at the same point, enabling a better understanding of the influence of design features and pre-treatments on cyclic fatigue [24]. Dynamic testing may be more prone to procedural errors, such as variations in axial motion amplitude and insertion angle, which can affect results [23]. Additionally, maintaining a precise trajectory during dynamic testing can be challenging, potentially leading to variations in bending and geometric properties and subsequent changes in the instrument's path within the canal [25–27].

A metal canal space is filled with a lubricant like synthetic oil or other solutions to reduce the friction of the file, thus preventing torsional load. In the present study, we used constant rotational speed settings for each instrument which similar is to previous studies [1,3,28]. However, some authors reflect that the rotational speed was not a significant factor concerning instrument fracture, others consider it to be critical [29]. Clinically, the fatigue of an instrument may be related to the degree of flexure when placed in a curved root canal especially when these curves are more prominent, the instrument submits to greater cyclical fatigue, and thus its life expectancy is lower [29]. Pruett et al stated that cycles to failure were not affected by speed on the conditions of artificial metal canals and it may be specified that the curvature of the canal is a factor that is much more important than rotational speed when it comes to the fracture of instruments [30]. Therefore, it remains unclear whether or not rotational speed affects the resistance to cyclic fatigue of NiTi alloy endodontic rotary files. Yared et al. have found that rotational speed does indeed influence the prevalence of fracture in NiTi alloy endodontic rotary files [31,32].

This study compared the cyclic fatigue resistance of three endodontic file systems. Fury L60, characterized by its patented alternating flat surface and S-shaped design, demonstrated the highest resistance to cyclic fatigue (3650.75 ± 137.71). Despite being manufactured from CM wire alloy, Super Flexi Files Gold exhibited greater fatigue resistance (1866.00 ± 23.55) than Orodeka Plex V (1738.25 ± 59.40). The higher flexibility and fatigue resistance of Super Flexi Files Gold may be attributed to its cross-sectional design and CM wire alloy composition. Due to the novelty of this research, direct comparisons with other studies are currently unavailable.

The instruments were fractured at the point where the most flexure was accumulated, which corresponded to the curvature's midpoint. Our findings are consistent with those of previous research [33–35]. There was no significant difference in the mean length of the broken fragments of all experimental instruments in the same curvature. The FL at single canal curvatures was 5 mm. The fractured fragment of the file was at the center of the curvature or just

below this point, which confirms the positioning of the files in a precise trajectory. All the fractures revealing a narrow area of maximum flexure across file groups [30,33]. Besides that, the separation of unbound instruments in the region of the most severe canal curvature would be considered a result of cyclic fatigue with any instrument system [30]. Fractured instruments showing a ductile fracture was occurred due to the accumulation of metal fatigue [36]. Furthermore, the length, type, and position of separating endodontic instruments affecting the removal procedures for them from challenging curved root canals in clinical manners [37]. Further research is needed to establish a definitive relationship between file design, material composition, and cyclic fatigue resistance.

Conclusions

The analysis of the provided data reveals significant variations in cyclic fatigue resistance among different endodontic file systems. The Fury L60 demonstrated the highest resistance, likely attributed to its unique design features. Surprisingly, Super Flexi Files Gold, despite being made from CM wire alloy, exhibited greater fatigue resistance than Orodeka Plex V. This underscores the crucial role of cross-sectional design and manufacturing processes in determining the cyclic fatigue performance of endodontic files. All instruments fractured at the midpoint of the curvature, resulting in consistent fragment lengths. Fracture analysis revealed a narrow area of maximum flexure across all file groups, suggesting that cyclic stress concentrates at the point of maximum curvature. These findings provide valuable insights into the factors influencing the durability and performance of endodontic rotary files. Understanding these factors will aid in the development of more resilient and reliable instruments, ultimately improving the efficiency and safety of endodontic procedures.

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