A comparative evaluation of cyclic fatigue resistance of FlexiCON (Edge Endo) files in rotary versus reciprocating motion at various curvatures – An in vitro study

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Abstract

Aim: The aim of the study to compare the cyclic fatigue resistance of FlexiCON (Edge Endo) files in rotary versus reciprocating motion in coronal, middle, and apical curvature of the simulated artificial canal.

Materials and Methods: A total number of 36 new files, 25 mm length of ISO size 25 at the tip and a taper of 0.06, were used for the study and divided into two groups of 18 files each. Group I: FlexiCON X3, was used in a rotary motion and Group II: FlexiCON X1, was used in a reciprocating motion. Cyclic fatigue testing was conducted in a custom-made device that allowed for a reproducible simulation of a curved canal. The canal system, which comprised two adjustable stainless steel blocks, had a 60° angle of curvature and 3 mm width. The groups were further divided into three subgroups with six files in each, representing apical curvature (Group Ia/IIa), middle curvature (Group Ib/IIb), and Coronal curvature (Group Ic/IIc). Using X-Smart plus motor, files were used in rotary and reciprocating mode and the number of cycles to failure was recorded.

Statistical Analysis: Data were analyzed using ANOVA and Post hoc followed by Dunnett’s test and unpaired t-test using Statistical Package for the Social Sciences 16 version.

Results: FlexiCON X1 reciprocating files showed the maximum cyclic fatigue resistance at coronal curvature (1936.50 ± 1.09) followed by middle (1514.50 ± 1.07) and apical curvature (1487.50 ± 6.75), while FlexiCON X3 rotary files showed the maximum cyclic fatigue at the middle curvature (1106.00 ± 4.21), followed by coronal (920.00 ± 1.16) and apical curvature (757.00 ± 5.34). The statistical analysis revealed a statistically significant difference (P = 0.001) between the two groups.

Conclusion: FlexiCON X1 reciprocating files showed better cyclic fatigue resistance at coronal, middle, and apical curvature compared to FlexiCON X3 rotary files.

Keywords: Canal curvature; cyclic fatigue; FlexiCON; reciprocation

INTRODUCTION

The success of endodontic treatment relies on shaping of the root canal system by eradicating bacteria which facilitates adequate chemical irrigants to disinfect the root canal system and create space for root canal filling.[1] 1980’s...
saw the new era of endodontic instruments developed from nickel–titanium (NiTi) alloy that has improved the mechanical preparation of root canal space, avoiding problems associated with stainless steel instrument such as ledges, zipping, stripping, perforation, and root canal transportation.\cite{2} The significant advantage of NiTi alloy is its unique ability to negotiate curvatures during continuous rotation without undergoing the permanent plastic deformation; hence, preparations are self-centered in the canal which helps to maintain the original root canal configuration.\cite{3}

Ferreira et al. identified two modes of fracture for a rotary NiTi file: torsional fatigue and cyclic fatigue. Torsional fatigue occurs when the tip of the instrument binds in the root canal, while the file continues to rotate.\cite{3} This is accompanied by an apparent deformation of a file, and the separation occurs as a result of slippage between the planes of its crystalline boundaries, mainly due to the excessive forces of torsion.\cite{4} Another fracture may take place across the grain of the metal with little or no apparent deformation. This type of fracture can be seen as a result of fatigue, most often caused from the excessive stresses of the repetitive compression and tension that occurs during rotation of a file around a curvature. On the inside of the curvature of a canal, a rotating file is compressed, and the outside of the curvature, the file undergoes tension. This is the cause of cyclic fatigue.\cite{5}

There are several factors that can affect cyclic fatigue resistance of a file. These are the radius of curvature, angle of curvature of the canal, the length of the arc, the diameter, and the design of the instrument.\cite{6}

Most of the file systems that are available use continuous rotational movement with a mechanical handpiece. Continuously rotating active files have an advantage that they have a greater efficiency in smaller diameter and more curved canals, but this must be balanced with the potential risks associated with torque and cyclic fatigue resistance.\cite{3} Rotary instrumentation has the ability to collect and remove debris from the canal system in coronal direction, it also provides greater taper in canal preparation.\cite{7}

Reciprocating movement NiTi instruments were developed with an advantage of increasing performance and safety. The lower stress induced by reciprocating motion enables the endodontist to use a single NiTi instrument to prepare the entire root canal system.\cite{3} If the instrument becomes stuck in the dentin or root canal filling material, the motor switches its movement to reciprocation movement due to increased stress. The reciprocating motion is based on a counterclockwise (CCW) motion (cutting direction) and a clockwise (CW) motion (release of the instrument).\cite{8}

Conventional austenite files are well known only for their superelasticity. Recently, with the introduction of FireWire technology, annealed heat-treated NiTi alloy has been developed with increased cyclic fatigue resistance and torque strength due to superelasticity and shape memory property. In this study, annealed heat-treated NiTi alloys which are manufactured using FireWire technology, namely FlexiCON files X3 (rotary) (Edge Endo; Johnson city, Tennessee, USA) and FlexiCON X1 (reciprocating), were used.\cite{9} According to the manufacturer, the parabolic cross-section of the file combines high efficiency and flexibility while being safe and resistant to fracture in curved canals.

As the root canal curvature poses a significant challenge to clinical endodontic practice, the aim of this study was to compare the cyclic fatigue resistance of FlexiCON files in rotary versus reciprocating motion in coronal, middle, and apical curvature of the root canal. The study hypothesis was that reciprocating files would show more cyclic fatigue resistance than rotary files.

**MATERIALS AND METHODS**

A total number of 36 new FlexiCON (Edge Endo; Johnson city, Tennessee, USA) files, 25 mm long, were selected and divided randomly into two groups – Group I: FlexiCON X1, $n = 18$ (rotary motion) and Group II: FlexiCON X1, $n = 18$ (reciprocating motion). The rotary and reciprocating instruments had an ISO size 25 at the tip, a taper of .06. All files were checked free of defects or deformities, under a stereomicroscope at ×20 magnification.

**Cyclic fatigue testing**

Cyclic fatigue testing was done on a static custom made device which consists of stainless steel artificial canal with a 60° angle of curvature and 3 mm width. The groups were further divided into three subgroups with curvature starting at 3 mm (Group Ia/Iia), 5 mm (Group Ib/Iib), and 7 mm (Group Ic/Ilc) representing apical, middle, and coronal curvature, respectively [Figure 1b]. This artificial canal was attached to a framework made of iron and wood to which support for handpiece was attached. The instruments

**Figure 1:** Cyclic fatigue testing device. (a) Assembly for the simulated artificial canal, (b) custom-made static model, (c) separated file
were activated using X-Smart plus – (Dentsply Maillefer, Switzerland) handpiece. The handpiece was attached using the testing device [Figure 1a]. All files were activated in the handpiece according to the manufacturers’ recommendation. The canal was lubricated using glycerin between each file to reduce friction. Using X-Smart Plus Motor, the files were used in rotation (ProTaper Next program) (300 rpm speed, torque 3–3.5) and reciprocative mode (WaveOne program) (170CCW, 50 CW), and time till fracture in seconds was recorded to evaluate cyclic fatigue resistance [Figure Ic].

The number of cycles to fracture (NCF) was calculated using the following formula:

\[
NCF = \text{The duration to fracture(s) } \times \text{rotating speed (rpm)/60.}
\]

**Statistical analysis**

The data were expressed in mean and standard deviation. Statistical Package for the Social Sciences (version 16.0) (SPSS Inc., Chicago, IL, USA) was used for the analysis. ANOVA and Post hoc followed by Dunnett’s test and unpaired t-test was applied to find the statistical significance between the groups.

**RESULTS**

The mean NCF values and intragroup comparison between the groups are tabulated in Tables 1 and 2.

Table 3 demonstrates the intergroup comparison at various levels.

Among Group I (FlexiCON X3), Group Ib (middle curvature) showed the maximum resistance to cyclic fatigue resistance of 1106.00 ± 4.21, followed by Group Ic (coronal curvature) with a value of 920.00 ± 1.16 and Group Ia (apical curvature) showed the least resistance to cyclic fatigue resistance with a value of 757.00 ± 5.34.

Among Group II (FlexiCON X1), Group IIC (coronal curvature) showed the maximum resistance to cyclic fatigue of 1936.50 ± 1.09, followed by Group IIb (middle curvature) with a value of 1514.50 ± 1.07 and Group IIa (apical curvature) showed the least resistance to cyclic fatigue resistance with a value of 1106.00 ± 4.21.

**DISCUSSION**

In this study, the cyclic fatigue resistance of Flexicon (Edge Endo) files was compared in rotary versus reciprocating motion in the coronal, middle, and apical curvature of the simulated artificial canal. The result obtained was in accordance with the hypothesis that the files in the reciprocating motion showed better cyclic fatigue resistance when compared to rotational motion.

Flexicon X1 reciprocating group with value of 1936.50 ± 1.09 showed better cyclic fatigue resistance when compared to other groups. According to You et al. and Neelakantan et al., cyclic and torsional fatigue was reduced in reciprocating motion when compared to rotary motion. Reciprocating motion prevents taper lock phenomenon by unsymmetrical repeating of CW (50 CW) and CCW (170 CCW) rotation. This movement is the modification of balanced force technique of canal preparation which enables the preparation of root canals with one single instrument.

At coronal curvature, Group Iic showed improved cyclic fatigue resistance among the subgroups with a value of 1936.50 ± 1.09. The improved cyclic fatigue resistance of FlexiCON X1 reciprocating files at coronal curvature might be because of thermomechanical annealed heat-treated Niti alloy.

At middle curvature, Group IIb showed cyclic fatigue resistance of 1514 ± 1.07. The diameter of the instrument at the point of maximum curvature influences the fatigue resistance.
life of endodontic file. Number of cycles to failure reduced, as the diameter of the instrument increased toward the middle third of the endodontic file.\textsuperscript{12}

Within the rotary group, at middle curvature, Group I b showed improved cyclic fatigue resistance with a value of 1106.00 \pm 4.21 s, and at coronal curvature, Group I c showed cyclic fatigue resistance of 920.00 \pm 1.16 s.

According to the literature, coronal curvature was more challenging when attempting to instrument the root apex using larger taper and size files.\textsuperscript{3} With the introduction of Annealed heat-treated files with FireWire technology, coronal and middle root canal curvature could withstand cyclic fatigue resistance. A study by Uygun \textit{et al.} showed heat-treated rotary files were more resistant at 5 mm and 8 mm from the tip.\textsuperscript{13} A study by Lopes \textit{et al.}, the NCF for Mtwo (Sweden and Martina, Padova, Italy) instruments within artificial canals increased with the shift in curvature from the middle to the apical canal position.\textsuperscript{14}

Apical curvature (Group IIa) showed the least resistance to cyclic fatigue resistance within the reciprocating and rotary group with a value of 1487.50 \pm 6.75 s and 757.00 \pm 5.34 s, respectively. As the radius of curvature decreases towards apical curvature, cyclic fatigue resistance also reduces.

Al-Sudanii \textit{et al.} compared the cyclic fatigue resistance of rotary files at coronal and the apical portions of the double curvature. The results showed that instruments were less resistant to cyclic fatigue in the apical portion of the canal compared with the coronal portion, as the apical curvature was more abrupt, with a radius of only 2 mm, whereas the coronal curvature had a 5-mm radius.\textsuperscript{15}

The superior performance of heat-treated alloy at coronal curvature might be due to the effect of annealing, internal stress relaxation, smaller grain size, presence of martensite phase, transformation behavior of conventional NiTi alloy to thermomechanical annealed heat-treated alloy, and cross-sectional design.\textsuperscript{16}

The inferior performance of heat-treated NiTi alloy at apical curvature occurs as fatigue accumulates very quickly in NiTi rotary instruments, and radius of curvature decreases apically consequently, fracture might occur after a very short time of use inside the apical curvature.\textsuperscript{15}

A study by Gambarini \textit{et al.} proved that the peculiar three-dimensional aspect of the crystalline matrix of the Fire-Wire alloy confers higher flexibility and cyclic fatigue resistance to the instruments. The use of artificial canals eliminates the differences like dentine hardness, canal length, and degree and radius of curvature. Standardization of the canal is necessary to avoid unexpected interferences which could invalidate the tests.\textsuperscript{17}

The width of the artificial canal system used is 3 mm which is greater than the maximum diameters of the files used, compromising the intimate adaptation of files to the canal system. According to Plotino \textit{et al.},\textsuperscript{18} cyclic fatigue occurs because of metal fatigue. The instrument does not bind in the canal, but it rotates freely in a curvature, generating tension/compression cycles at the point of maximum flexure until the fracture occurs.\textsuperscript{19}

The limitation of the study was that it was done on a simulated root canal of stainless steel, and hence, the exact clinical scenario cannot be expected due to several challenges in root morphology of natural tooth, as the simulated artificial canal is two dimensional, whereas in natural teeth, the canal curvature is three dimensional. Moreover, the frictional resistance to the file from a simulated curved stainless steel canal may be different from the frictional resistance from a naturally curved root canal.

**CONCLUSION**

Within the limitation of the study, it can be concluded that reciprocating file FlexiCON (Edge Endo) X1 showed better cyclic fatigue resistance when compared to rotary file FlexiCON (Edge Endo) X3. The development of heat-treated endodontic rotary and reciprocating files has revolutionized the modern endodontics facilitating excellent biomechanical preparation with reduced chances of cyclic fatigue and separation of endodontic files which was a challenge faced by endodontists in the instrumentation of curved and narrow canals.

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**Conflicts of interest**

There are no conflicts of interest.

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