Original Article

Cyclic Fatigue Resistance of Novel Rotary Files Manufactured from Different Thermal Treated Nickel–Titanium Wires in Artificial Canals

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ABSTRACT

Aims: The aim of this in vitro study was to compare the static cyclic fatigue resistance of thermal treated rotary files with a conventional nickel-titanium (NiTi) rotary file. **Subjects and Methods:** Four groups of 60 rotary files with similar file dimensions, geometries, and motion were selected. Groups were set as HyFlex Group [controlled memory wire (CM-Wire)], ProfileVortex Group (M-Wire), Twisted File Group (R-Phase Wire), and OneShape Group (conventional NiTi wire)] and tested using a custom-made static cyclic fatigue testing apparatus. The fracture time and fragment length of the each file was also recorded. Statistical analysis was performed using one-way analysis of variance and Tukey's test at the 95% confidence level ($P = 0.05$). **Results:** The HyFlex group had a significantly higher mean cyclic fatigue resistance than the other three groups ($P < 0.001$). The OneShape groups had the least fatigue resistance. **Conclusions:** CM-Wire alloy represented the best performance in cyclic fatigue resistance, and NiTi alloy in R-Phase had the second highest fatigue resistance. CM and R-Phase manufacturing technology processed to the conventional NiTi alloy enhance the cyclic fatigue resistance of files that have similar design and size. M-wire alloy did not show any superiority in cyclic fatigue resistance when compared with conventional NiTi wire.

Keywords: *cyclic fatigue, controlled memory wire, nickel–titanium, R-Phase wire, thermal treatment*

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Introduction

Nickel-titanium (NiTi) rotary files are widely used for root canal shaping. Improved flexibility of NiTi rotary files reduces canal transportation, particularly during the preparation of curved canals compared with conventional stainless steel hand files.[1] However, fracture and separation of NiTi rotary files are still major concerns during clinical use. Torsional failure and flexural cyclic fatigue are two mechanical deficiency resulting in these complications.[2]

Torsional fracture occurs when the tip of the file is engaged in root canal dentine while the other part continues to rotate. Moreover, flexural fatigue fractures occur due to repeated tension–compression cycles at the point of maximum flexure when the file rotates in a curvature.[3]

Many improvements including new manufacturing techniques have been developed to increase the cyclic fatigue resistance of NiTi files.[4] Novel thermomechanical processes applied to conventional NiTi wire optimizes the microstructure of NiTi alloy and therefore extends the files' life span. A special NiTi alloy termed M-wire (Dentsply, Tulsa, Oklahoma, USA) was developed by using this manufacturing technique. Its unique nanocrystalline martensitic microstructure leads to enhanced flexibility and more resistance to cyclic fatigue.[5] M-wire is currently used for the manufacturing of ProTaper Next (Dentsply, Maillefer, Ballaigues, Switzerland), ProFile Vortex (PV), (Dentsply), and Reciproc (VDW, Munich, Germany). R-Phase technology is another thermal treatment

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procedure that optimizes the microstructure and improves the fatigue resistance of the NiTi alloys. Both K3XF and Twisted File (TF) are manufactured from R-Phase alloy and developed by the same manufacturer (SybronEndo, Orange, California, USA). However, TFs are manufactured by twisting when the alloy is in the R-Phase and K3XFs are manufactured by grinding before R-Phase thermal treatment procedure.[6] A more recently introduced alloy is Controlled Memory (CM), (DS Dental, Johnson City, Tennessee, USA). CM technology aims to increase fatigue resistance of a conventional NiTi alloy with processing a special thermal treatment. The HyFlex CM (HY), (Coltene/Whaledent, Cuyahoga Falls, Ohio, USA), and Typhoon Infinite Flex NiTi (TYP CM; Clinician's Choice Dental Products, New Milford, Connecticut, USA) files were recently developed using CM technology.[7] The manufacturers claim that NiTi files made from CM wire are up to 300% more resistant to fatigue failure than files fabricated from conventional NiTi wire.

There have been limited studies evaluating the cyclic fatigue resistance of NiTi rotary files fabricated from all of these three innovative thermal processed alloys.[8] Therefore, the aim of the present study was to compare the cyclic fatigue resistance of rotary files of similar file dimensions, geometries, motion styles, and manufactured by three different thermal methods. For this purpose, M-wire alloy (PV), R-Phase wire alloy (TF), and CM-wire alloy (HY) were included in the present study and compared with conventional NiTi alloy [OneShape (OS), (MicroMega, Besancon, France)]. The null hypothesis is that there is no significantly difference between the tested files in terms of cyclic fatigue resistance.

Subjects and Methods

The study included four groups: PV, TF, HY, and OS files. Each group contained 15 files with ISO tip size 25 and a 0.06 taper. Before the static fatigue test, each file was controlled for any possible defects and deformation with a stereomicroscope (Leica MZ 12.5, Heerbrugg, Germany) under ×10 magnification. Total of 60 files were tested using a custom-made apparatus that was specially designed for this experiment by using a modification of the apparatus described by Larsen *et al*.[9] and Capar *et al.*[10] The apparatus consist of two main parts. First section was consisted of the stainless steel block part, which has an artificial canal with an inner diameter of 1.5 mm, a 60° angle of curvature and a curvature radius of 3 mm and has a flexiglass preventive cover that prevent fractured part of the file from slipping out. The latter section included hand piece holder part that positioned the hand piece in a precise relationship to the stainless steel block when testing file inside the artificial canal. These two mains part of the apparatus were attached to the steel base [Figure 1].

Static cyclic fatigue testing was performed for each file at 500 rpm continuous rotation. Working length was standardized to 16 mm for each file. During the testing, engine oil was used to reduce the friction between files and metal block. All files were rotated until fracture occurred and the time to fracture was recorded in seconds. The length of the fractured file tip was also measured with a digital micro caliper (Aydal, Istanbul, Turkey) and recorded.

Means and standard deviations of the fracture time and fragment length were calculated for each group. The data were subjected to the Shapiro–Wilk test to analyze the normality of the continuous variables. Due to parametric distribution of variables one-way analysis of variance and Tukey's test was performed at the 95% confidence level ($P = 0.05$). All statistical analyses were performed using SPSS software (SPSS Inc, Chicago, Illinois, USA).

Results

The mean values and standard deviations of fracture time and fragment length of each group are represented in Table 1. The HY group had significantly higher mean cyclic fatigue resistance than the other three groups ($P < 0.001$). TF group represented the second highest fatigue resistance. There was statistically significant differences between the TF and PV groups ($P = 0.0484$) and between TF and OS groups ($P = 0.016$). The OS files had the least fatigue resistance. In addition, there was no statistically significant differences between the OS and PV groups ($P = 0.206$). In terms of fragment length, no statistically significant difference was found among the tested groups ($P = 0.42$).

Table 1: Mean values (±standard deviation) for time to fracture in second(s) and fragment length of each group in millimeters (mm).

Groups	Time to Fracture* (s)	Fragment Length** (mm)
HY	137.3 ± 22.7[a]	5.5 ± 1.1
TF	80.3 ± 11.4[b]	4.9 ± 0.6
PV	74.1 ± 12[c]	5.3 ± 1.3
OS	62.9 ± 12.8[c]	5.2 ± 0.5

*Means with the different superscript lowercase letter are significantly different ($P < 0.05$) **There was no significant difference in the length of fracture fragment between files ($P > 0.05$).

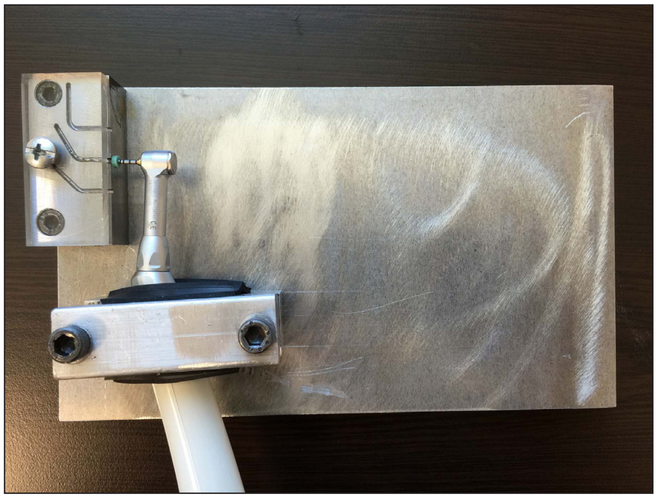

Figure 1: Custom-made apparatus, which was specially designed for this experiment.

Discussion

According to the manufacturers, new generation rotary files that are fabricated from thermo-mechanically treated alloys have enhanced cyclic fatigue resistance and flexibility. This claim should be experimentally verified by researchers to ensure awareness while selecting file system during clinical practice. Factors influencing the fatigue resistance include file design, cross-sectional geometry and diameters of core, tip size, and taper of the tested file.[11] Furthermore, radii and degree of curvature, rotation speed, torque, and movement kinematics (continuous, reciprocal, or adaptive) also perform an important role in the cyclic fatigue resistance of files.[12] In the study of Pérez-Higueras *et al.*,[6] it was mentioned that the speed and motion type (reciprocal or rotational) of files may also affect the cyclic fatigue resistance. For these reasons, standardization of these experiment variables is mandatory. Although, several studies compared the cyclic fatigue resistance of different NiTi rotary files, the files evaluated had different cross section, degree of taper, or different sizes.[9,10,13,14] Thus, in this study, the cyclic fatigue resistance of new-generation files PV, TF, and HY possessed the same cross-section geometry, motion type, taper, and tip sizes were compared with OS files *in vitro*. The cross-section geometry of PV, TF, and HY files is triangular. Each of these three systems have active cutting blades and variable pitch. Only OS files have variable cross-section over the entire length of the working part. (Near the tip region have triangular cross section with three cutting edges and have S-shaped cross section with two cutting edges in the middle and coronal part.) By this way, only one variable (the effect of manufacturing method on cyclic fatigue) could be compared. Furthermore, in the present study, standardized artificial canals (60° angle of curvature and a curvature radius of 3 mm) were included and same rotation speed (500 rpm), rotation type (continuous) were set to minimize the influence of variables. M-wire (PV), CM-wire (HY), and R-Phase wire (i.e., TF) files were tested versus conventional NiTi (OS), to check whether different manufacturing methods influenced the fatigue resistance of the endodontic files produced with different alloys.

In the present study, the same speed setting was used for each file. Cyclic fatigue behavior of the files using time to fracture data was compared. On contrary to the present assessment method, previous researchers used number of cycles to fracture for the failure of files.[9,10,13,15,16] Considering time to fracture assessment method may be more relevant clinically than number of cycles to fracture.[17-19]

According to the results of the current study, the null hypothesis was rejected. HY files were significantly more resistant to cyclic fatigue than other tested files fabricated from M-wire, R-phase wire, and conventional NiTi wire. It should be mainly related to CM manufacturing process including proprietary thermal treatment. HY files are manufactured by a unique process that controls the material's memory and these files are highly flexible and resistant to cyclic fatigue compared with other conventional and thermally treated files.[20] The superiority of CM files in terms of cyclic fatigue resistance was also proven in previous studies.[10,21,22] The present study supplemented a further addition revealing that CM wire is more resistant to cyclic fatigue than M-wire and R-phase files.

TF files had the second highest cyclic fatigue resistance among the compared groups. Time to fracture of the TF was significantly higher than PV and OS files. This could be attributed to manufacturing process including R-Phase technology. Moreover, special surface conditioning and twisting process of ground blank instead of grinding may have positively affected the TF files' performance in terms of fatigue resistance. Our findings are consistent with other researchers' reports those comparing the cyclic fatigue of TF files with conventional NiTi files.[4,23] In contrast to the results of the present study, a previous study comparing the cyclic fatigue resistance of rotary files including TF, ProFile GT Series X, EndoSequence, and Profile stated that ProFile GT Series X is significantly more resistant to cyclic fatigue than other files. The same study also compared TF 25/.06 file with Profile 25/.06 file, manufactured with conventional NiTi wire and showed no significant difference.[9] ProFile GT Series X and Profile were not used in our study; therefore, it not possible to make direct comparison between the two studies. In addition Profile, EndoSequence, TF, and

ProFile GT Series X are markedly different instruments with different cross sections. The difference in the file design may also influence to the conflicting results. The same study found that ProFile GT Series X files manufactured of M-wire alloy had significantly more cycles to failure than the other groups. However, ProFile GT Series X files had a #20 tip size, whereas the TF, EndoSequence, and ProFile all had #25 tip sizes. This difference in tip size may have favored ProFile GT Series X.

Endodontic files manufactured of M-Wire are expected to have higher resistance to fatigue than those made from a conventional NiTi wire because of its unique nano-crystalline martensitic microstructure.[5,24] However, the present findings for PV files in comparison with OS files showed similar cyclic fatigue resistance contrary to that was expected. Similar to our findings, some previous studies found that M-Wire files do not have better cyclic fatigue resistance compared with conventional NiTi rotary files.[4,15] These different results indicate that various factors, particularly design features of the files may influence the cyclic fatigue resistance more than manufacturing technology. PV files have a triangular cross section, three active cutting edges. However, OS files have three variable cross-section shapes throughout the working part, which change from three cutting edges near the tip region into two at the end of the working part. Moreover, according to Bouska *et al.*,[16] the changes in the designs of the files may also have lead to differences in cyclic fatigue resistance.

In the present study, the results showed no significant difference between the lengths of the fractured part. All tested files fractured ±0.5 mm below or above the point of maximum flexure of the shaft, corresponding to the center of the curvature [Table 1]. Our results are in agreement with previous studies.[4,13,25]

Within the limitations of this study, the HY files, which is made of CM-Wire alloy represented the best performance in cyclic fatigue resistance and TFs, which is made of NiTi alloy in R-phase, had the second highest fatigue resistance. CM and R-phase manufacturing technology processed to the conventional NiTi alloy enhance the cyclic fatigue resistance of files that have similar design and size. In addition M-wire alloy (PV) did not show any superiority in cyclic fatigue resistance when compared with conventional NiTi file (OS).

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Conflicts of interest

There are no conflicts of interest.

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