Cumhuriyet Dental Journal, 25(2):125-130, 2022
DOI: https://doi.org/10.7126/cumudj.1098476

Cumhuriyet Dental Journal

| cdj.cumhuriyet.edu.tr | Founded: 1998 Available online, ISSN: 1302-5805 Publisher: Sivas Cumhuriyet Üniversitesi

An Investigation of the Metal Fatigue of Different Nickel-Titanium Rotary Instruments After Prolonged Use

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Research Article

History

Received: 05/04/2022
Accepted: 16/05/2022

ABSTRACT

Objectives: This study aimed to compare the cyclic fatigue (CF) resistance of nickel-titanium (Ni-Ti) endodontic instruments from ProTaper (PTU), ProTaper Next (PTN), Wave One (WO), and Reciproc (RPC).
Materials and Methods: In our study, PTU, PTN, WO, and RPC rotary files were divided into the experimental and control groups containing an equal number of samples. The experimental group files were used in the shaping of 80 extracted human lower premolar and lower molar teeth. The experimental and control group kits were then placed in the test apparatus and observed until they fractured. Fracture times were recorded and statistically evaluated.
Results: In the one-to-one comparisons of the experimental and control group files, the differences between the fracture times of the experimental and control group files were found to be statistically insignificant in RPC, WO, PTU, and PTN X1 files, fracture time differences were statistically significant in all PTN X2 files. As a result of the pairwise comparison of the experimental and control groups, the difference between the experimental and control groups of the WO and RPC files used with reciprocal movement was found to be statistically insignificant.
Conclusions: The files used with the reciprocal movement were found to be safer in terms of metal fatigue when compared to the other files used with rotational movement after the preparation.

Keywords: Cyclic Fatigue, Ni-Ti Files, Wave One, Reciprocating Movement.

Farklı Nikel-Titanyum Kök Kanal Eğelerinin Uzun Süreli Kullanımı Sonrası Oluşan Döngüsel Yorgunluğunun Araştırılması

Süreç

Geliş: 05/04/2022
Kabul: 16/05/2022

ÖZ

Amaç: Bu çalışmanın amacı ProTaper (PTU), ProTaper Next (PTN), Wave One (WO) ve Reciproc (RPC) nikel-titanyum (Ni-Ti) endodontik aletlerin döngüsel yorgunluk (CF) direncini karşılaştırmaktır.
Gereç ve Yöntem: Araştırmamızda PTU, PTN, WO VE RPC eğeleri eşit sayıda örnek içeren deney ve kontrol gruplarına ayrılmıştır. Deney grubu eğeleri 80 adet çekilmiş insan alt premolar ve alt molar dişlerinin şekillendirilmesinde kullanılmıştır. Sonrasında deney ve kontrol grubu kitleri test düzeneğine yerleştirilerek kırılana kadar gözlemlenmiştir. Kırılma süreleri kaydedilerek istatistiksel değerlendirmeleri yapılmıştır.
Bulgular: Deney ve kontrol grubu eğelerinin bire bir karşılaştırmalarında deney ve kontrol grubu eğelerinin kırılma süreleri arasındaki farklılıklar RPC, WO, PTU, PTN X1 eğelerinde istatistiksel olarak önemsiz bulunurken, PTN X2, eğelerinin tümünde kırılma süreleri farklılıkları istatistiksel olarak önemli bulunmuştur. Deney ve kontrol gruplarının ikili karşılaştırılması sonucunda, resiprokal hareket ile kullanılan WO ve RPC eğelerinin deney ve kontrol grupları arasındaki farklılık istatistiksel olarak önemsiz bulunmuştur.
Sonuç: Resiprokal hareket ile kullanılan eğeler, rotasyonel hareket ile kullanılan diğer eğelerle preparasyon sonrası karşılaştırıldığında, metal yorgunluğu açısından daha güvenli bulunmuştur.

Anahtar Kelimeler: Döngüsel Yorgunluk, Ni-Ti Kök Kanal Eğeleri, Wave One, Resiprokal Hareket.

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How to Cite: Akpınar KE, Kutlu Cengiz G.(2022) An Investigation of the Metal Fatigue of Different Nickel-Titanium Rotary Instruments After Prolonged Use, Cumhuriyet Dental Journal, 25(2):125-130.

Introduction

With the use of nickel-titanium (Ni-Ti) files, significant improvements have been achieved in endodontics. The superelasticity of Ni-Ti files has enabled endodontic files to conform better to canal curvature, have more fracture resistance, and wear less, compared to stainless steel files.[1]

Despite the advantages of Ni-Ti files, their fractures are among the most significant concerns about Ni-Ti files. These fractures may occur without visible signs of previous permanent deformation.[2] Studies demonstrate that the incidence of clinically observed instrument fractures ranges from 0.9% to 21%.[3,4,5] The fracture of Ni-Ti files occurs in two ways, flexural (cyclic) fatigue (CF) and torsional forces. Cyclic fatigue occurs when the metal is subjected to repetitive stress and compression cycles, which causes its structure to deteriorate and, ultimately, fracture.[6,7,8]

Many factors (for example, the radius and degree of root canal curvature, and the design, manufacture, and use of the instrument) are believed to affect the CF resistance of canal files. However, manufacturers have recently attempted to improve the fracture resistance of Ni-Ti files by improving production processes, developing new alloys with superior mechanical properties compared to conventional Ni-Ti, and making changes in their kinematics.[9,10,11]

ProTaper Universal (PTU) (Dentsply Maillefer, Ballaigues, Switzerland) is a rotary file system with a variable conical shape. This design is expected to reduce buckling loads, internal fatigue, and possible fractures.[12] ProTaper Next (PTN) (Dentsply Maillefer, Ballaigues, Switzerland) was developed using the new M-Wire alloy. The design features include variable tapers and an off-centered rectangular cross-section.[13]

WaveOne (WO) (Dentsply Maillefer, Ballaigues, Switzerland), of which cross-sections are produced in a modified convex triangle form, enables the shaping of root canals with a single file. The WO file was produced with the M-wire technology that increases flexural fatigue resistance. In the reciprocal movement, the angle of the counterclockwise (CCW) movement is larger than the angle of the clockwise (CW) movement. The file performs the rotation with 120° CCW and 60° CW movements.[14] While the file performs the cutting procedure in its CCW movement, it becomes free in its CW movement. The full cycle is completed with three reciprocating movements. The conducted studies reported that this reciprocating movement prolongs the life of the file compared to continuous rotation.[15,16]

Reciproc files (RPC) (VDW, Munich, Germany) were produced with the M-wire technology like WO files and have the advantages of the M-wire technology. The files have an S-shaped cross-section, a non-cutting end structure, and two sharp cutting edges.[17,18] The files are designed to be used with a reciprocating movement and can be distinguished from other files by their unique design features. The spirals of the files are reversed, and this feature provides them with the ability to cut in the CCW movement. While the file performs the CCW rotation at a wider angle of 150°, it performs the CW rotation at a narrower angle of 30°.[19,20]

This *in vitro* study aimed to investigate the results of flexural fatigue, which might occur in the use of four different Ni-Ti files (PTU and PTN, which are used with rotational movement, and WO and RPC, which are used with reciprocating movement) in inclined root canals, and to conduct a comparative analysis of metal fatigue occurring after their use. Therefore, by learning to what extent Ni-Ti root canal files were affected by the preparation process, it was aimed to obtain information about fracture behaviors and determine the situations that should be considered.

Materials and Methods

The study was initiated after receiving the ethics committee approval dated 11/11/2018 and numbered 2018-11/05 from Cumhuriyet University Clinical Research Ethics Committee. The study was carried out at the Endodontic Clinic of the Faculty of Dentistry of Cumhuriyet University.

The first stage of our study includes the use of Ni-Ti files in artificial models simulating clinical conditions, while the second stage involves the exposure of unused files and files used in simulated models to fracture in the test apparatus and the calculation of the time to fracture.

Due to the risk of fracture of Ni-Ti root canal files, the root canal shaping process was performed on simulated patients. For this purpose, 20 simulated patients' mandibular models, each of which included lower premolar and lower molar teeth on the right and left sides, were created. During the model building process, the extracted teeth with completed root development, lower premolar teeth having a single root and a single canal, lower molar teeth having two roots and three canals (two canals in the mesial root, a single canal in the distal root), and teeth of which canals conformed to the criteria of curved root canals, were included in the study.

The prepared acrylic models were placed on simulated patients, and endodontic access cavities were opened. Digital radiographs (Trophy Trex, CCX Digital, Marne-La-Vallée, France) were obtained using K-file number 10 (Dentsply Tulsa, Oklahoma City, USA), and the working length of each tooth was determined and recorded. Rubber-dam (OptiDam Kerr, Bioggio, Switzerland) was applied to the models before starting the mechanical preparation of the root canals of the teeth on all models (Figure 1).

The experimental groups consisted of PTU (Group 1), PTN (Group 2), WO (Group 3), and RPC (Group 4) files. The files in each group were used in one lower premolar and one lower molar tooth (in four root canals). In the file changes, irrigation was performed with 2 ml of 5.25% NaOCl (Sultan Healthcare, USA).

Figure 1. The simulated patients used in our study and the rubber-dam applied state

Figure 2. Test apparatus used for the evaluation of flexural fatigue

The files used were then tested in the device simulating the root canal slope of 40° at the torque and speed values recommended by the manufacturers. During the preparation of the test apparatus, to minimize friction and to provide the standardization of each file at a certain angle, the test apparatus of Cheung and Darvell[21] was used by performing modifications (Figure 2).

For a more precise calculation of the fracture time of files, an electronic system was installed in the apparatus, and a stopwatch with a 1/100 precision was added. When the file contacts the pins, the circuit is completed, the circuit breaks as soon as the file fractures, and the stopwatch calculates the fracture time accurately by stopping at the same time. The time to fracture was recorded separately for each file. For each file group, the values in seconds that elapsed until the files fractured were multiplied by the files' number of rotations per second, and thus, the files' number of cycles to failure (NCF) was calculated.[22,23]

The control groups consisted of PTU (Group 5), PTN (Group 6), WO (Group 7), and RPC (Group 8) files. The files not used in the control group were placed in the test apparatus like the files in the experimental groups and subjected to fracture tests under air cooling at the torque and speed values recommended by the manufacturers. The time to fracture was recorded separately for each file, and the NCF values were calculated.

Statistical analysis

The data obtained from our study were analyzed using SPSS (Statistical Package for Social Science) version 22.0. In the data analysis, the Kolmogorov-Smirnov significance test of the difference between the two means in independent samples, analysis of variance, and Tukey's test were used when the parametric test assumptions were fulfilled, and the Kruskal-Wallis test and the Mann-Whitney U test were used when the parametric test assumptions were not fulfilled. The significance level was considered to be 0.05.

Results

In our study, the means of the NCF values for the experimental and control groups consisting of 4 different Ni-Ti file systems were presented in Table 1.

When the NCF values were compared in the comparison and statistical evaluation of the experimental and control group results of all groups, minimum values were observed in the experimental group.

Table 1. The means of the NCF values for the experimental and control groups consisted of 4 different Ni-Ti file systems in the study.

	PTU (Mean±SD)					PTN (Mean±SD)		WaveOne (Mean±SD)	Reciproc (Mean±SD)
	S1	S2	F1	F2	F3	X1	X2		
Experimental Group (n=10)	193.66 ±50.96	399.44 ±88.47	333.31 ±54.83	238.62 ±58.46	210.68 ±61.57	1459.65 ±777.54	1385.27 ±458.34	632.67 ±196.98	3928.25 ±1210.26
Control Group (n=10)	204.92 ±41.19	428.15 ±85.39	412.71 ±213.13	245.30 ±121.87	234.28 ±67.10	1821.88 ±489.58	2349.60 ±665.64	777.45 ±250.14	4831.63 ±894.85
RESULT	**P= 0.593**	**P= 0.470**	**P=0.280**	**P=0.878**	**P=0.423**	**P= 0.229**	**P= 0.001***	**P= 0.168**	**P= 0.082**

The mean NCF values of the files in the control group were found to be higher than the mean NCF values of the files in the experimental group. However, the difference in the NCF values between the experimental and control groups was found to be statistically insignificant for all file numbers ($p>0.05$). While the difference between the PTN experimental and control groups was statistically insignificant for the X1 file ($p>0.05$), the difference in the X2 file was statistically significant ($p<0.05$).

Discussion

The metal fatigue of Ni-Ti files can be evaluated in two different ways in the test apparatus torsional and flexural fatigue. In some studies, file fractures occurring due to CF were reported to be more than fractures caused by torsional stress.[24,25,26,27] For this reason, flexural fatigue, which frequently appears in clinical treatments and constitutes a risk factor for file fractures by shortening the life of files, was also investigated in our study.

The CF values of Ni-Ti files can be evaluated clinically with studies carried out on patients, as well as with studies carried out on extracted teeth. Furthermore, different studies have been conducted on the number of uses of files clinically or on extracted teeth. Gambarini [24] investigated flexural fatigue after the prolonged clinical use of thirty ProFile files. Twenty ProFile files, which constituted the experimental group, were used in a total of 10 teeth, including six to seven molars and three to four single-rooted teeth, and an average of 26.7 canals. In the study, in which Aydin *et al.*[28] evaluated flexural fatigue of used and new RaCe files, experimental group RaCe files were used clinically in the root canals of five molar teeth. Yared *et al.*[29] evaluated in their study the metal fatigue of ProFile files clinically after use in the preparation of 4 molar teeth. In another study, the same researchers evaluated the flexural fatigue of ProFile files after using them under conditions simulating clinical conditions.[30] They used the files in the preparation of the mesial canals of the extracted lower molar teeth. They performed the opening of the entrance cavity, the determination of the canal size, and all preparation processes by hand. As is observed in these studies, the use of files for the preparation process of root canals clinically on the patient or on extracted human teeth reflects stresses that will occur on the file most naturally. However, in the studies carried out with the use of extracted teeth by hand, the procedures are performed with direct vision and cannot adequately provide the clinical conditions. Therefore, transferring files to the test apparatus after their clinical use may provide more accurate results. However, it should be kept in mind that during clinical use, files may fracture even at first use. For this reason, in our study, we tried to transfer the clinical conditions to the laboratory environment. Acrylic mandibular models were obtained by using extracted teeth and placed on phantom heads. Thus, the preparation process was performed in vitro on simulated patients, in the working positions under clinical conditions, and under the same visual conditions.

In our study, the files were used at different speed values in line with the recommendation of the manufacturers. Therefore, the number of cycles per second of the files in different groups also differs. For this reason, the NCF values of the files were calculated after the fracture time was determined, and statistical evaluations were made over the NCF values. The NCF values of the files used with the reciprocal movement were calculated over the rpm values specified by the manufacturer without considering the kinematic differences, as in the study by Higuera *et al.*[31]

Nguyen *et al.*[32] evaluated the flexural fatigue of PTN, PTU, and Vortex Blue files in their study. Although Vortex Blue and PTU files are used with the crown-down technique, in PTN files, the apical shaping is performed first. Moreover, although the PTU file was produced from a conventional Ni-Ti alloy, the PTN file was produced with the M-wire technology. As a result, it was determined that the Vortex Blue file was more resistant to flexural fatigue than the PTN file, and the PTN file was more resistant than the PTU file. In our study, similarly to this study, the PTN file fractured at higher NCF values than the PTU file.

In a study, the researchers investigated metal fatigue differences between files by using files with different tapers, and they reported that the file with the highest taper fractured within the shortest time. They attributed this result to the increase in the tensile strength depending on the increase in the diameter of the file, even the curvature remained the same, and to the more free movement of the file with a small taper in the canal than the file with a large taper.[32,33] In our study, the NCF values of ProTaper files were evaluated within the group. Both in the experimental and control groups, among the finishing files of F1, F2, and F3, the file F3 with the highest apical diameter fractured at the minimum number of cycles, while the file F1 with the lowest apical diameter fractured at the maximum NCF value. These results are parallel with the results of other studies. Fife *et al.*[34] investigated CF, which occurred as a result of the prolonged continuous use of PTU files, and they reported that S1 files fractured in a shorter time than S2 files. In parallel with this study, in our study, when shaper files were compared, it was found that while the S1 file with the smallest apical diameter fractured at the least NCF value, the S2 file with the second smallest apical diameter fractured at the maximum NCF value. We think that this result is because the S1 file is the first file used and that files undergo more deformation due to the narrowness of the canal mouths.

When the NCF values of the PTN file were compared within the group, the difference between X1 and X2 files was not found to be statistically significant in both the experimental and control groups. However, in the statistical comparison of the files between the groups, while the difference between the groups for X1 files was found to be statistically insignificant, the difference between the groups for X2 files was found to be statistically significant in favor of the control group. As a result, after the preparation of one lower premolar and lower molar tooth, the X1 file was

not significantly affected by flexural fatigue, whereas the X2 file was significantly affected by it. We think that the X2 file, which was thick, was more affected by the user due to the accumulation of more internal stress and, thus, fractured in a shorter time. The studies on factors such as core thickness and cross-sections of root canal files reported that flexural fatigue resistance decreased, and torsional fracture resistance increased, as core thickness increased. Some researchers reported that files with a large diameter were more vulnerable to flexural fatigue than files with a small diameter due to internal stress accumulation.[24,32]

In our study, following the recommendations of the manufacturer, file S1 was used at the highest torque value, and file S2 was used at the lowest torque value. The studies have reported that the use of endodontic motors with low torque values increases the flexural fatigue resistance of Ni-Ti files. It is stated that the mechanical stress on Ni-Ti files is proportional to the torque of the motor, that the specific torque limit of the file is frequently exceeded when high torque motors are used, and thus, the risk of deformation or fracture due to mechanical stress increases.[24,33] In another study conducted by using different types of motors, the researchers stated that low torque-controlled motors were more reliable than other motors and reported that the slight pressure applied to the apical could reduce the risk of fracture.[34]

There have been many studies investigating the effect of the use of kinematics on instrument fractures.[35,36,37,38] In our study, RPC and WO files, which are used with reciprocal movement and produced with the M-wire technology, and also PTN files, which are used with rotational movement and produced with the M-wire technology, were used. Therefore, it was possible to compare the files produced with the same alloy technology but used in different kinematics.

Castello-Escriva *et al.*[14] compared the flexural fatigue resistance of PTU, WO, and Twisted File files and used each file in the proprietary movements and speeds recommended by the manufacturer. They performed statistical evaluations after calculating the NCF value of each file, and as a result, they found that the WO file used with reciprocal movement was more resistant to flexural fatigue than other files.

We think that this is caused by the fact that RPC and WO files are produced with the M-wire technology, which has been shown to provide the increased cyclic fatigue resistance to files in various studies, and the fact that the reciprocal movement, which occurs in CW and CCW, reduces the files' risk of screwing inside the canal, the compressive and tensile forces to which they are exposed, and the risk of cyclic fatigue. In our study, among the single-file systems, WO and RPC files, which are used with the same kinematics and have the same alloy technology, were compared, and it was observed that RPC fractured at a higher number of cycles than the WO file, which has the modified convex triangular cross-section, similar to the geometry of the PTU file. We think that these similar results are caused by the fact that, unlike the other two files, the RPC file has two cutting-edged S-shaped geometry and a smaller cross-sectional area and that its flexibility increases due to these properties.[39]

We think that this is caused by the fact that RPC and WO files are produced with the M-wire technology, which has been shown to provide the increased cyclic fatigue resistance to files in various studies, and the fact that the reciprocal movement, which occurs in CW and CCW, reduces the files' risk of screwing inside the canal, the compressive and tensile forces to which they are exposed, and the risk of cyclic fatigue.[40,41,42]

As a result, the M-wire technology can increase the flexural fatigue resistance of files. However, factors, such as the file design and the cross-section of files, also affect file fracture. In our study, when the flexural fatigue resistance of the Ni-Ti files produced conventionally and with the M-wire technology was compared, the files produced by the M-wire technology were observed to have more flexural fatigue resistance. It was observed that the flexural fatigue resistance of the Ni-Ti canal files we used decreased as their diameters increased. In our study, it was determined that the reciprocal movement reduced the compressive and tensile forces affecting the files inside the canal and the risk of screwing the files inside the canal and that the flexural fatigue resistance of the files used with reciprocal movement was higher compared to Ni-Ti files used with other rotational movements.

Conclusions

Instead of the direct use of large-diameter files in very narrow and curved canals, we find it safer in such canals firstly to use files with a low taper and then with a high taper, and to use files with reciprocal movement. Further studies, ex vivo or clinical, are highly recommended to verify the clinical efficacy of these instruments for shaping the root canal and for ways to minimize the risk of fracture.

Acknowledgements

None.

Conflicts of Interest Statement

None.

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