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Effect of Taper and Pitch on Nickle-Titanium File with Variable Cross Section to Its Cyclic Fatigue (In Silico Study)

Yustika Chrysandra
Department of Conservative Dentistry, Faculty of Dentistry, Universitas Gadjah Mada, Yogyakarta, Indonesia, yustikachrysandra@mail.ugm.ac.id

Tunjung Nugraheni
Department of Conservative Dentistry, Faculty of Dentistry, Universitas Gadjah Mada, Yogyakarta, Indonesia, drgtunjungnugraheni@ugm.ac.id

Wignyo Hadriyanto
Department of Conservative Dentistry, Faculty of Dentistry, Universitas Gadjah Mada, Yogyakarta, Indonesia

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ORIGINAL ARTICLE

Effect of Taper and Pitch on Nickle-Titanium File with Variable Cross Section to Its Cyclic Fatigue (In Silico Study)

Yustika Chrysandra, Tunjung Nugraheni*, Wignyo Hadriyanto

Department of Conservative Dentistry, Faculty of Dentistry, Universitas Gadjah Mada, Yogyakarta, Indonesia
**Correspondence e-mail to: drgtunjungnugraheni@ugm.ac.id*

ABSTRACT

The geometric design of an endodontic file includes cross-sectional shape, taper, and pitch. NiTi endodontic files of OneCurve (MicroMega) are made of two variations of cross-sectional shape, that is, double-s shaped and triple helix. Various kinds of modifications were made to increase the resistance of the NiTi endodontic files from fracture. Cyclic fatigue is the most common factor that causes a fracture of the endodontic file. **Objective**: The purpose of this study was to obtain a NiTi endodontic file design that has the best cyclic resistance value based on its taper size and number of pitch. **Methods**: This study used OneCurve endodontic file size 25.06, then scanned with MicroCT Scan and modified the geometric design. The number of file modifications was nine. Taper size modifications were 4%, 6%, and 8%; the number of pitch modifications was reduced by three, fixed, and added by three. Cyclic fatigue measurement simulations were carried out using the finite element method three times each. The result data were analyzed using a two-way ANOVA test and then continued with LSD. **Results**: The results of the statistical test showed that there was an effect of the size of the taper on the cyclic fatigue values. Endodontic files with a size of a taper 4% had the lowest cyclic fatigue value. **Conclusion**: The conclusion of this research was that the taper size affects the value of cyclic fatigue in continuous endodontic files made of nickel-titanium with variable cross sections. The number of pitch did not show a significant effect on the cyclic value.

Key words: cyclic fatigue, in silico, NiTi endodontic file, number of pitch, taper size

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INTRODUCTION

Root canal treatment has three main principles, namely endo access, biomechanical preparation (cleaning and shaping), and root canal filling.[1] When performing biomechanical preparations, endodontic instruments play an important role in the disposal of microorganisms. This instrument disposes of infected products and tissues mechanically and creates a chamber that facilitates antimicrobial irrigation solutions for infection control and optimal obturation material. Root canal cleaning and shaping greatly affect the success of root canal disinfection and filling.[2,3]

One of the instruments used in performing root canal preparation is the endodontic file. Endodontic files have undergone various developments from the basic metal materials used, including carbon steel, stainless steel, and nickel titanium (NiTi).[4] The single file system is a development of NiTi files to be able to perform root canal biomechanical preparation using one file. This single-file system aims to simplify instrumentation procedures, reduce stress, and prevent cross-contamination between patients. The main advantage of using this single file is the efficiency in performing root canal preparation.[5] NiTi instruments are increasingly popular in root canal treatment because of their ability to perform root canal preparation more easily, quickly and controllably in terms of speed as well as torsional strength. However, these NiTi-based files also have some limitations, such as when a straight file is placed in a very curved root canal, there is a risk of one of them being broken in the apical third.[6,7] The risk of fracture in NiTi file can be caused by cyclic fatigue. Cyclic fatigue occurs when the file rotates freely and does not contact the curved root canal wall and then undergoes repeated stress and compression cycles until it reaches its maximum point of flex and causes cracks in certain parts.[8]

The rigidity and flexibility of the file depend largely on its geometric design, including taper, helix angle, cross-section, tip size, and length. Various research and development of NiTi rotary instruments continue to be carried out to obtain the best efficiency and safety in order to prevent instrument breakage. The modifications of the instrument carried out were included in the development of its geometric design.[9] *One Curve* file from *MicroMega* creates a variable cross-sectional design that is claimed to have more optimal root canal cleaning capabilities. The cross-sectional shape in the apical third is triple helix, and the cross-sectional shape from middle to coronal is double S-shaped. *One Curve* file has a taper size of .06, and the number of pitch is 12.

This study modified the geometric design of the *One Curve* endodontic file which will be the number of pitch and the size of the taper in silico. The *taper* size of the One Curve endodontic file will be modified into groups of 4%, fixed, and 8%. The number of pitch is also modified by adding three, fixed, and reduced by three. The entire modification group was simulated to determine its cyclic fatigue value. The purpose of this study was to determine the effect of a number of pitch and size of taper on NiTi continuous endodontic file with variable cross-sectional shape to its cyclic fatigue.

Table 1. Physical properties of NiTi endodontic file material (*ANSYS 2020 R2).*

Parameter	Unit	Value
Density	kgm^-3	1500
Specific Heat		320
Initial Yield Strength	Pa	8.5E+08
Maximum Yield Strength (Ymax)	Pa	1.45E+09
Hardening Constant B		210
Gruneissen Coefficient		1.23
Modulus Young	GPa	50
Poisson Ratio		0.33
Bulk Modulus	GPa	49.02
Shear Modulus	GPa	1.8797

Table 2. Strain-life material NiTi alloy (*ANSYS 2020 R2).*

Parameter	Unit	Value
Strength coefficient	MPa	705
Strength exponent		-0.06
Ductility coefficient		0.68
Ductility exponent		-0.6
Cyclic strength coefficient	MPa	733
Cyclic strain hardening exponent		0.1

Table 3. S-N curve material alloy NiTi (*ANSYS 2020 R2).*

Number of cycles	Unit	Value
5000	MPa	900
12000	MPa	800
20000	MPa	720
120000	MPa	600

METHODS

The approval of this research is based on a letter from the Dental Ethics Commission of Universitas Gadjah Mada, Yogyakarta, with number 003/KKEP/FKG/UGM/EC/2022. This research type is experimental with Completely Randomized Design (CDR) in silico, which is carried out by computational simulation using Finite Element Analysis (FEA) methods. The subject of the study was a *One Curve* (*Micro Mega*) endodontic file with a tip size of 0.25 mm, *taper* size of 6%, and number of pitch was 12. The *One Curve* endodontic file was then scanned using a micro-computed tomography scanner (*nanoVoxel-4000*) conducted at the Scan Laboratory, Sanying Precision Instrument Co., Ltd., Tianjin, China. The scan results are then stored in the form of extension data.STL.

Extension data.stl was then remodeled (reverse engineering) to obtain a 3-dimensional design using Autodesk Inventor Professional 2018 software at the Dynamics Laboratory of the Department of Mechanical Engineering and Industry, Faculty of Engineering, Universitas Gadjah Mada. *One Curve* modification file modeling is done with *Computed Aided Design* (CAD) techniques. The number of file modifications is nine with the type of modification, namely the taper size of 4%, 6%, and 8%, and the number of pitch minus three, fixed, and plus three.

The entire modification group was then transferred to *ANSYS 2020 R2* software to simulate cyclic fatigue measurement using the FEA method. This simulation was performed by measuring the fatigue life on the file in the bending cycle loading at a rotary load of 1N. Material adjustment is carried out by inputting the value of physical properties (Table 1), strain life (Table 2), and S-N Curve (Table 3) of the material object to be analyzed into *ANSYS 2020 R2* software.

Each model is then meshed to be able to divide the integrity of geometric shapes into elements. Then the selection of solutions for simulating cyclic fatigue value tests is obtained in units of Number of Cycle to Fracture (NFC). Simulated cyclic fatigue value tests were performed 3 times per file type. Data from each test group were then performed Shapiro Wilk normality test. The next stage of analysis is the Levene test to see the homogeneity of variance. The data was then carried out a One-Way Analysis of Variance (ANOVA) test to determine the effect of variables on each group.

Table 4. The mean value and standard deviation of cyclic fatigue of continuous endodontic file made of NiTi variable cross-sectional design with different number of pitch and taper magnitude in Number of Cycle to Fracture (NCF) units.

	Fatigue cycle life (NFC)		
Taper	*Pitch*		
	Pitch 9	Pitch 12	Pitch 15
4%	689800±	633720±	387720±
6%	382540±	333850±	205950±
8%	167030±	172960±	129370±

Table 5. Shapiro-Wilk normality test results cyclic fatigue continuous endodontic file made from NiTi variable cross-section design with different taper sizes and number of pitch.

Group	Probability (P)
Size of *Taper* 4%	0.335
Size of *Taper* 6%	0.516
Size of *Taper* 8%	0.240
The number of *pitches* reduced by 3 (9)	0.807
Fixed *pitch* (12)	0.671
Number of *pitches* added by 3 (15)	0.559

Table 6. Cyclic fatigue ANAVA test results on NiTi continuous endodontic files, variable cross-sectional designs with different *taper* sizes and *pitch* counts.

	Sum of Squares	Free Degrees	Mean Squared	F	p
Size of *taper*	2633133360,889	2	1316566680.44	11.384	0.009*
Number of *pitches*	500737682,889	2	250368841.444	0.532	0.613

Table 7. LSD test results cyclic fatigue values of continuous endodontic files made from NiTi variable cross-section design with different *taper* magnitudes.

Taper (A)	*Taper* (B)	Average Difference (A-B)	p
4%	6%	26296.667*	0.024
	8%	41396.000*	0.003
6%	4%	-26296.667*	0.024
	8%	15099.333	0.136
8%	4%	-41396.000*	0.003
	6%	-15099.333	0.136

RESULTS

The value of the cyclic fatigue simulation results carried out is a unit of the number of cycles or rotations from the file to a fracture or called the Number of Cycle to Fracture (NCF). The greater the number of NCFs means that the cyclic fatigue value is lower. The first, second, and third simulation results of each group had the same cyclic fatigue values. The mean value and standard deviation of the endodontic file cycle can be seen in Table 4.

The data obtained from each group were then tested for normality using Shapiro-Wilk and obtained a distribution of normally distributed data with the results of the normality test having a significance value of $p > 0.05$ contained in Table 5. The data then continued the homogeneity test using Levene's Test and obtained a significance value of 0.058 in the taper group and 0.588 in the pitch group ($p > 0.05$), thus showing that the variance of the data was homogeneous.

The results of the One-Way ANOVA test were conducted to determine the effect of the number of pitch in the 9, 12, and 15 groups on cyclic fatigue and the effect of size taper in the 4%, 6%, and 8% groups on cyclic fatigue. Table 6 shows the results of the single-line ANAVA test in the large taper group (4%, 6%, 8%) and obtained a significant difference of 0.009 ($p < 0.05$). These results show that there is a significant effect of taper on cyclic fatigue. Data on groups of size taper were then tested post hoc LSD, which can be seen in Table 7. LSD test results showed significant differences in cyclic fatigue values between the 4% and 6% taper size groups, as well as between the 4% and 8% taper size groups (Figure 1 and 2). The results of the One-Way ANOVA test in the number of pitch groups (9, 12, 15) did not have a significant difference of 0.613 ($p > 0.05$). The results showed no effect of pitch amount on cyclic fatigue.

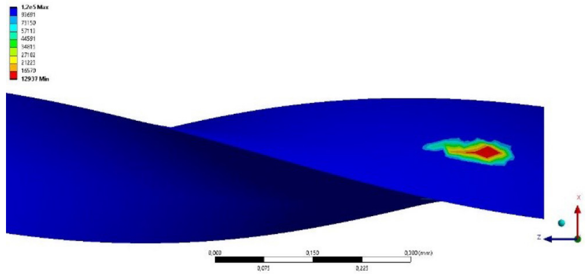

Figure 1. The simulation results of cyclic fatigue values of the group number of *pitch* 15 and taper size 8%.

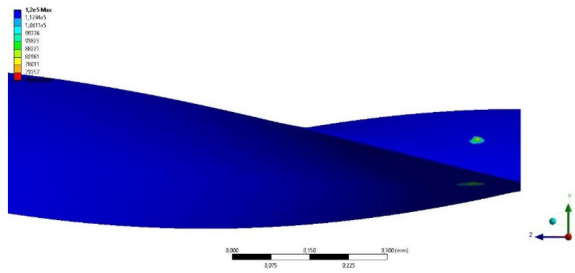

Figure 2. The simulation results of cyclic fatigue values of the group number of *pitch* 9 and taper magnitude 4%.

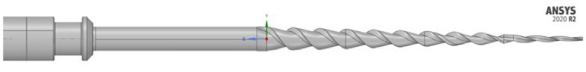

Figure 3. The three-dimensional of modified One Curve endodontic file created with CAD technique.

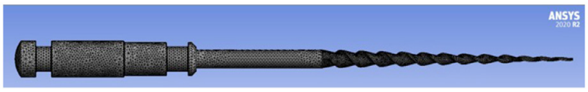

Figure 4. Three-dimensional file was exported to ANSYS 2020 R2 software.

To determine the cyclic fatigue value, the combination of the group of the number of pitch and the size of the taper is carried out a descriptive statistical test. The results of the descriptive statistical test of cyclic fatigue values were obtained by combining groups of the number of pitch and taper sizes that had the highest cyclic fatigue values were the number of pitch 15 and the size of the taper 8%, it had 12,937 NCF (Figure 3). The combination of the number of pitch and the size of the taper that has the lowest cyclic fatigue value is the number of pitch 9, and the size of the taper is 4%, which is 68,980 NCF (Figure 4).

DISCUSSION

This study tested the cyclic fatigue value of NiTi continuous endodontic files with variable cross-section design using simulation through finite element analysis (FEA). The addition and reduction of the number of pitch by three in the ANAVA test results did not show significant results. In this study, the reduction and addition of the number of pitche*s* by three did not affect the flexibility of the file. The addition of 3 pitches does not affect the volume of the file enough so that the cyclic fatigue value is not significant. The results of this study are in accordance with several previous studies that modified the addition and subtraction of the number of pitches by 1 and which compared modifications to pitch lengths of 2 and 3 mm or about 1 to 2 the number of pitch. Both studies showed that statistically, there was no difference in cyclic fatigue, only an upward trend in cyclic fatigue in files with a greater number of pitches.[10,11]

The results of the one-way ANAVA test showed that there was a significant effect of taper on cyclic fatigue in continuous endodontic files made from NiTi with variable cross-section design. The results of statistical analysis in this study showed that files with a large taper of 4% had the lowest cyclic fatigue value compared to large files of taper 6% and 8%. Taper in endodontic files will add dimension to a file, so that the stiffness of the file body will increase and affect both flexibility and torsional properties.[12] A large taper size will result in a thick core mass that increases torsional resistance but cyclic resistance will decrease.[13] The results of this study are in accordance with research that states that increasing the diameter of *the taper* and apical will decrease resistance to cyclic fatigue.[14]

The results of the descriptive test analysis showed that the modification of the endodontic file made from NiTi with a variable cross-sectional design that has a number of pitch 9 and size taper of 4% has the highest value of cycle number to cyclic fatigue of 68,980 NCF. Cyclic fatigue value of 68,980 NCF indicates that if the file is used with a rotating speed according to the manufacturer's instructions of 350 rpm it can last up to 197 minutes. Continuous endodontic file made from NiTi, a variable cross-section design with number of pitch 15 and size taper of 8%, had the lowest cyclic fatigue value of 12,937 NCF. A cyclic fatigue value of 12,937 indicates that if the file is used with a rotating speed according to the manufacturer's instructions of 350 rpm it can last up to 36 minutes.

A smaller amount of pitch and smaller taper size will increase the flexibility of the endodontic file.[15] Modifications to the number of pitch and size of taper need to be studied for future research, so that the level of flexibility required can be known while still having the best torsional resistance and cutting ability in continuous NiTi *endodontic files*. In general, the more flexible a file is, the higher the resistance to cyclic fatigue. Resistance to cyclic fatigue depends not only on the diameter and size of the core but also on the influence of the overall design and quality of the material.

The FEA method has many advantages, including being able to modify a design and provide accurate test results, but this method has a limitation, which is that it cannot perfectly describe clinical conditions. Continuous NiTi endodontic files used to perform root canal preparation will experience increased temperatures on the file surface. An increase in temperature will cause a changing phase in the endodontic file made from NiTi so that it will affect its flexibility. This condition cannot be simulated using FEA method.

The number of pitch and size of the taper play an important role in influencing the cutting efficiency of endodontic files. The variable cross-sectional shape of the *OneCurve* file has the advantage of good cutting efficiency, especially in the apical third, which is the triple helix shape. The triple helix cross-sectional shape has a larger cutting surface so that the cutting efficiency on the root canal wall increases. The cross-sectional shape in the middle third to coronal of the *OneCurve* file is double-s.

The double-s cross-section increases resistance to cyclic fatigue in root canals that have high curvature because the metal mass of this cross-sectional form is lower. The combination number of pitch 9 and size of taper 4% with this variable cross-sectional shape can help provide cutting efficiency by having good cyclic resistance.[16]

CONCLUSION

Based on this study, it can be seen that continuous NiTi endodontic file with variable cross-sectional shapes that have a smaller taper size have a lower cyclic fatigue value than larger taper sizes. There was no effect of pitch amount on NiTi continuous endodontic files with variable cross-section design on cyclic fatigue values.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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None.

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