Influence of Artificial Canal Lubricants on the Lifespan of One Curve File under Static and Dynamic Test Modes

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Abstract

Aim: This study was designed to determine the lifespan of One Curve (OC) heat-treated nickel-titanium (NiTi) rotary files operating understatic and dynamic fatigue conditions using intracanal lubricants such as oil or sodium hypochlorite (NaOCl).

Materials and Methods: The OC files were tested using an artificial zirconia canal. They were tested in air without any intracanal lubricant under static (Group 1) and dynamic (Group 4) modes, and after filling the canal with either oil (Group 2 and Group 5 under static and dynamic modes respectively) or 1% NaOCl (Group 3 and Group 6 under static and dynamic modes respectively). One Curve files were rotated freely in the canal at a speed of 350 rpm (continuous clockwise) under static mode until file failure occurred through fracture. In case of dynamic testing, the instruments were rotated at the same conditions in the canal, but with an additional back and forth movement until fracturing. The number of cycles to fracture (NCF) was recorded and statistically analyzed using One Way ANOVA and Bonferroni tests.

Results: Testing of the file in air demonstrated the lowest fatigue resistance, where the static test mode (NCF: 560 ± 8.25) was the worse than the dynamic mode (NCF: 636.81±14.49). On the other hand, the instruments tested under both static and dynamic modes in oil as an intracanal lubricant showed improved lifespan in terms of NCF (1193.89±7.96 and 1351.39 ± 7.06) compared to the same modes in NaOCl lubrication (878.89 ± 8.59 and 1093.82±39.08). Regardless of intracanal lubricant, the dynamic groups produced better results than the static ones. In terms of fractured length, significant differences were identified between the groups except between Group 2 and Group 6.

Conclusions: Type of intracanal lubricant demonstrated a more influential effect on the file lifespan than the mode of cyclic fatigue (CF) test. The dynamic CF test utilizing oil intracanal lubricant resulted the best improvement in the file lifespan.

Keywords: Endodontic Nickel-Titanium file, One Curve, Cyclic Fatigue, Static, Dynamic, Intracanal lubricant, NaOCl, Oil

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1. Introduction

For mechanical root canal preparation, the nickel-titanium (NiTi) rotary files have become an essential tool mainly due to their super flexible property. However, they may undergo premature failure (1) during the treatment. The CF is reported as the primary cause of the failures of NiTi files. It occurs as a consequence of continuous rotation where repeated tensile and compressive stresses accumulate at the point of maximum flexure of the rotary instrument rotating files in a curved canal (2, 3). Cyclic fatigue resistance (CFR)is defined by the number of cycles that an instrument can bear endure under a particular loading condition until the fracture occurs determines its CF resistance, which and this can be evaluated either by static or dynamic tests. In the former, the endodontic files rotate continuously in either clockwise or anticlockwise at a fixed length in the canal without axial movement, while in the dynamic mode, the rotary files are moved back and forth (pecking motion) inside the root canal(4-6). Different test modes for CFR are presented schematically in Figure 1.

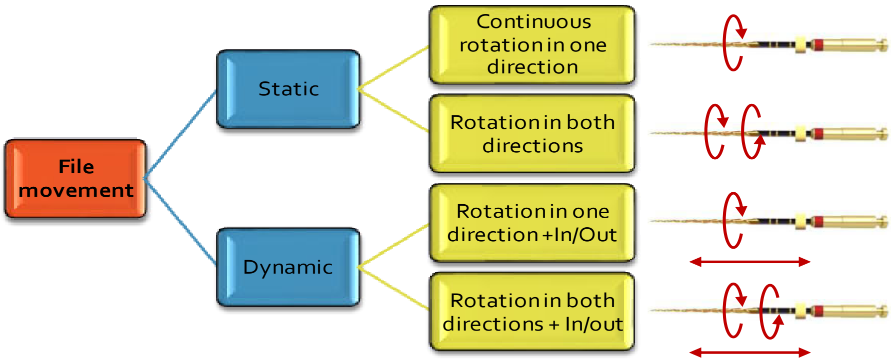

Figure 1. Static and dynamic testing conditions used for CFR of endodontic files

It has been identified that chemical composition of NiTi alloys, instrument design and geometry, surface treatments, rotational speed, torque, the root canal shape, sterilization cycles, and the number of clinical uses all influence the number of cycles to fracture (NCF) of NiTi rotary files(7, 8). In addition, the experimental test design with an artificial canal, whether static or dynamic, recorded to have an impact on the CF resistance of the endodontic rotary files(9, 10).

It is generally agreed that the dynamic motion of the rotary file is a good simulation to the clinical situation where the highest flexure point varies along the file length throughout the test similar to the stress encountered by a rotary file under clinical condition. Therefore, NiTi instruments lifespan can be extended under dynamic test mode. Consequently, the dynamic test was regarded to provide more clinically relevant information than the static one. On the other hand, the static test can give useful data about the effect of different design properties of the files or pre-treatment (surface or heat treatment) of the alloy on CF (11), which might be more interesting to develop and optimize a new endodontic files. Nevertheless, dynamic tests possess many shortcomings. For instance, relying on the used canal to bend the instrument, metallurgical properties of the endodontic instrument is altered by the tensional fatigue in addition to CF(12). Indeed, in dynamic test design, the CF instrument fractures and torsional fatigue cannot be clearly distinguished. Moreover, a standardization of the file axial movement with no lateral motion promoting torsional loads is challenging. A lateral movement of a rotary file during rotation could also result in another bending point located at the beginning of the root canal deforming dynamic test outcome (11).

Cyclic fatigue test is mainly performed in an artificial canal with known curvatures (length, angle and radius of curvature), filled with a lubricant to decrease the friction between the instrument and the artificial canal walls and to minimize the heat generation (13-15).Since the fatigue behaviour of NiTi rotary files has been greatly affected by the environmental conditions, CF testing has been proposed to be conducted in a similar environment close to the clinical condition such as NaOCl be used as a lubricant(16). Moreover, to some extent, the involvement of different lubricating agent during testing procedures may be attributed to the variation in the results (17, 18). Many studies used oil (13, 14), water (15, 19), glycerin (14, 20), or NaOCl(17).

One Curve (OC) (Micro-Mega, Besancon, France) is a more recent addition in NiTi instrument system for the root canal utilizing a single file. The manufacture of OC files is carried out by heat treatment using C-Wire technology. The OC files could be pre-bent to preserve the curvature and shape of the root canal, in addition to the control memory. Two different cross-section zones have been noticed in these files; the first part has a design with three different cutting edges, while the second (coronal) one presents a pattern with two cutting edges (21).

Testing of fatigue behaviour of rotary files has attracted the attention of many researchers and further studies are required to fully understand the fatigue failure under different test modes and environmental conditions. Therefore, the aim of this research was to analyze the effect of CF test designs on the lifespan of OC files. The null hypothesis asserts that the CF test modes and intracanal lubricants do not significantly influence the lifespan of OC endodontic rotary files.

2. Materials and Methods

2.1. File samples

Thirty-six OC heat-treated nickel-titanium (NiTi) rotary endodontic files (OC; Micro Mega, Besancon, France) with a tip size of 25 and a 0.06 tapering were collected and investigated under 20× magnification to make sure that they were defect-free. According to the modes of CF test and the intracanal lubricants, the files were divided into six groups with six samples in each (n = 6) as presented in Table 1.

Table 1.Experimental groups for CFR of endodontic files

Group Name	Test mode	Test environment
Group 1	Static	in air
Group 2	Static	in oil
Group 3	Static	in NaOCl
Group 4	Dynamic	in air
Group 5	Dynamic	in oil
Group 6	Dynamic	in NaOCl

2.2. Cyclic fatigue testing

Files were tested for CF resistance using an artificial canal. Inside a block of zirconia, the artificial canal was created with 6.06 mm radius, 0.6 mm apical diameter and 45 ° curvature angles. The curvature of the canal was specified within a range between 2.5 mm 5.5 mm from the canal tip(22). To permit a good observation of the instruments and to avoid instrument slipping out of the canal during testing a glass slab was used to cover the artificial canal. The experimental set-up for the CF tests is presented in Figure 2.

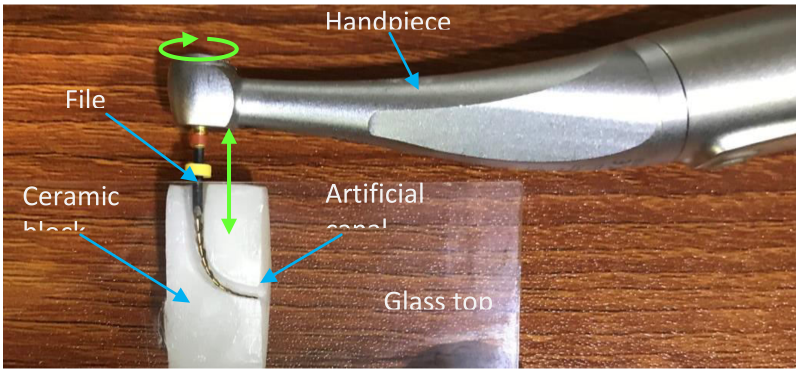

Figure 2. Experimental set-up for cyclic fatigue testing of rotary endodontic files

The files were tested in both static and dynamic modes where the artificial canal was filled with either artificial white oil (Iranoil, Tehran, Iran) or 1% NaOCl which prepared from a stock solution of 2% NaOCl (Chloraxid, Cerkamed Medical Company, Stalowa Wola, Poland).

In the static mode of the CF test, each file was positioned in a contra-angle endodontic handpiece (X-smart, Dentsply Maillefer, Ballaigues, Switzerland) at a speed of 350 rpm and at room temperature (25 ^{o}C). Following the manufacturer's recommendation, the OC files were rotated at a clockwise continuous rotation. The files rotated till the fracture. The time needed to fracture a file was measured by a 1/100 s chronometer. To calculate the NCF, the time required to fracture was multiplied by the number of rotations per minute. In the dynamic mode of test group, a similar protocol was used as in the static mode of test, except the back and forth axial movement of the rotated file inside the artificial canal. The axial movements' amplitude was 3 mm, with approximately 2 sec for every file displacement. The lengths of the fractured fragments of each file were measured with the aids of a digital caliper (Mitutoyo, Kawasaki, Japan).

2.3. Statistical analysis

Since, the data were normally distributed according to the Shapiro–Wilks test, One Way ANOVA and Bonferroni test were performed to define any statistically significant differences between the groups applying version 22.0 of SPSS software (IBM Corp., Armonk, US). All testing was performed at a confidence level of 95%, and $P \leq 0.05$.

3. Results

Table 2 and Figure 3 show the means and standard deviations of the NCF of tested groups. Statistical analyses expressed statistically significant differences between the tested groups. The group of dynamic tests with oil intracanal lubricant recorded the highest value (1351.39±7.06) of the NCF, followed by a group of a static model with oil (1193.89±7.96), the dynamic group with NaOCl (1093.82±39.08), and the static group with NaOCl (881.81±8.59). However, the testing of the file in air demonstrated the lowest fatigue resistances, where the static group without using an intracanal lubricant (560.00±8.25) was the worst. All the NCF results showed statistically significant difference between the groups.

The file fragment measurement results (Table 2 and Figure 4) showed that the groups of file tested in air recorded the longest fractured segments (3.35±0.04 and 3.62±0.03) followed by the group of dynamic+oil (2.85±0.03), and static+NaOCl group (2.70±0.03). However, group of dynamic + NaOCl and static +oil displayed the shortest segments with no significant differences. Highly statistically significant differences were reported between the groups (P = 0.000) except between the static +oil and dynamic+NaOCl groups. It should be noted that no correlation was found between the NCF and fragment length results for different groups.

Table 2: Mean (standard deviation) of the number of rotations to failure and length of fractured fragments.

Groups	NCF (SD)	Fragment length in mm (SD)
Static + air	560.00 (8.25)[a]	3.35 (0.04)[a]
Static + oil	1193.89 (7.96)[b]	2.58 (0.03)[b]
Static + NaOCl	881.81 (8.59)[c]	2.70 (0.03)[c]
Dynamic + air	636.81 (14.49)[d]	3.62 (0.03)[d]
Dynamic + oil	1351.39 (7.06)[e]	2.85 (0.03)[e]
Dynamic + NaOCl	1093.82 (39.08)[f]	2.55 (0.06)[b]

Note: Different superscript letters within a column highlight statistically significant difference between groups (P ≤ 0.05) and same letter in two groups does not indicate any significant difference (P ≥ 0.05)

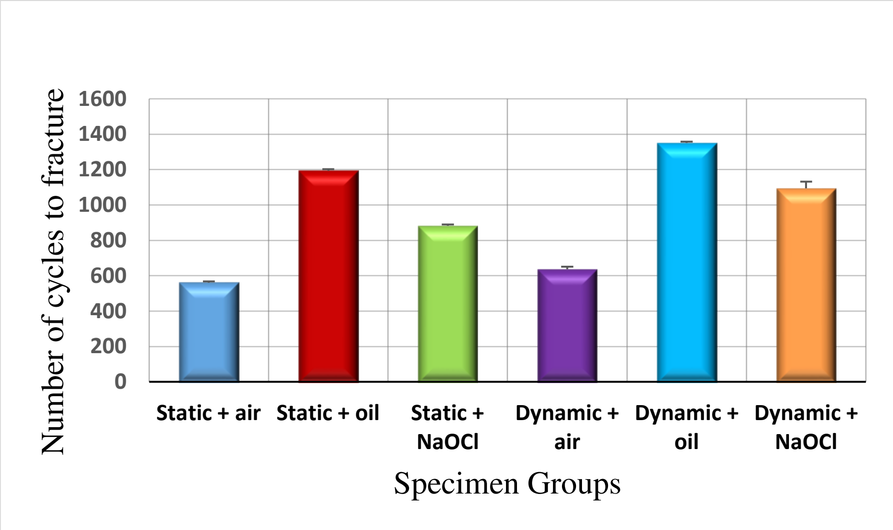

Figure 3.Number of cycles to fracture (NCF) in all tested groups of rotary files

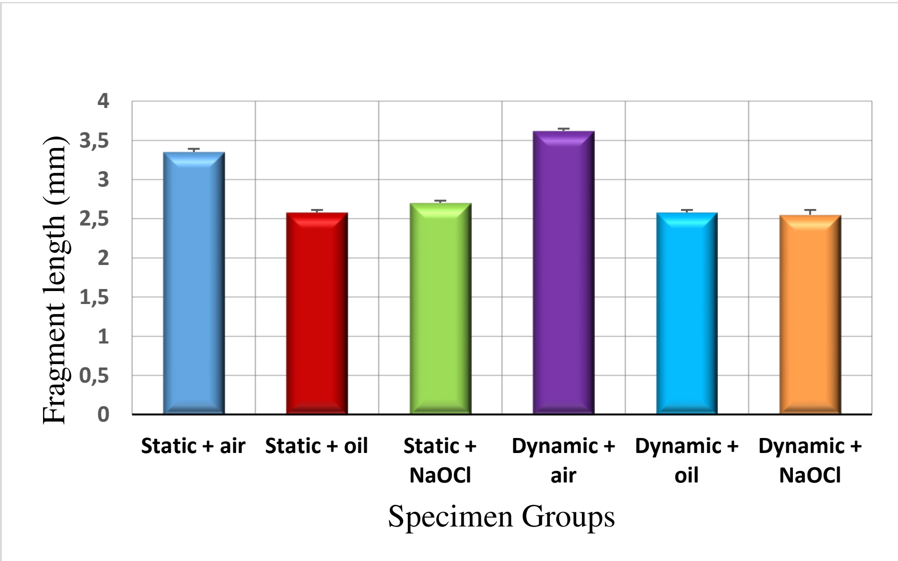

Figure 4. Fractured fragment lengths in all tested groups of rotary files

The test data on NCF and the length of fractured fragment for individual file are shown in Table 3 and Table 4 respectively.

Table 3. NCF data for all tested files from each specimen group

Groups	NCF					
	File 1	*File 2*	*File 3*	*File 4*	*File 5*	*File 6*
Group 1	571.67	560.00	548.33	560.00	565.83	554.17
Group 2	612.50	647.50	653.33	635.83	630.00	641.67
Group 3	1190.00	1207.50	1184.17	1195.83	1190.00	1195.83
Group 4	1341.67	1359.17	1347.50	1353.33	1347.50	1359.17
Group 5	886.67	875.00	869.17	892.50	880.83	886.67
Group 6	1073.33	1050.41	1125.83	1114.17	1055.83	1143.33

Table 4. Fragment length data in mm for all tested files from each specimen group

Groups	Fragment length (mm)					
	File 1	*File 2*	*File 3*	*File 4*	*File 5*	*File 6*
Group 1	3.30	3.41	3.35	3.35	3.39	3.32
Group 2	3.66	3.62	3.58	3.62	3.64	3.59
Group 3	2.61	2.55	2.58	2.54	2.57	2.59
Group 4	2.89	2.85	2.80	2.85	2.84	2.86
Group 5	2.75	2.66	2.68	2.71	2.72	2.70
Group 6	2.47	2.50	2.60	2.54	2.64	2.57

4. Discussion

In the endodontic literature, the CFR of NiTi rotary instruments has been an area of great interest. The fracture of NiTi rotary instruments is caused mainly by a combination and accumulation of stresses(23). During the fatigue test, the cyclic fatigue resistance is defined by the number of cycles that a file can endure. It is the numerical guide to measure the cyclic fatigue resistance. It is a cumulative measure as it is related to the intensity of tensile and compressive stresses (2, 6, 24, 25).Tobushi et al. (26)reported that the CF test is a reliable and simple approach to define the fatigue behaviour of NiTi instruments. In the current study, a single zirconia standardized artificial canal was used to ensure standardization of the canal dimensions (27), and to overcome and reduce the impact of other variables (6).

This research was aimed to assess whether CF resistance of OC files was varied according to the tests employed (static or dynamic), using oil or NaOCl as an intracanal lubricant. The findings reported that oil intracanal lubricant has a significant positive impact on the NCF and in relation to the mode of test, the dynamic one recorded higher number than the static test performed using both oil and NaOCl intracanal lubricants. According to the result of the current study, the mode of the CFR tests and the intracanal lubricants have a great influence on the lifespan of OC files, so the stated hypothesis was rejected.

In the present study, in comparison to the static mode, the dynamic mode of the CFR test resulted in a significant improvement in the OC lifespan. These findings agree with those reported by Li et al. (28), Ray et al. (29), and Hulsmann et al. (11) as they demonstrated that dynamic movement increased the lifespan of endodontic rotary instruments. In the static mode, the alternating tensile and compressive stresses are focused at the same zone of the endodontic instrument without any axial movement (28). The stresses are cumulative and promote microstructural alterations in the metallic type of the alloys used in the file. The current results indicated that the stress concentration at the same zone of the file shaft significantly minimized the NCF. In contrast, the tensile and compressive stresses are distributed along the tapered shaft of the instrument in the dynamic test, which can be attributed to the axial displacement or movement of the instrument inside the curved canal. Thus, the fatigue fracture resistance could be enhanced if the stress concentration at the same area of the instrument was avoided. The current results agreed with Li et al. (28) findings, where they indicated that this principle could be adapted for other types of files.

The present study confirmed the importance of applying an intracanal lubricant during the testing of the CFR of an endodontic file, avoiding the adverse effect of the friction between the files and canal walls, and the generated heat on the mechanical property of the NiTi files. The current result indicated a protective effect from the oil and 1.0% NaOCl as intracanal lubricants in the CFR test when compared to the tests in air. Although they used NaOCl at a higher concentration, the current result agreed with Pedulla et al. (30) as they reported that NaOCl (5.25% and 20 ^{o}C) improved the CFR of OC.

However, the current results were in disagreement with Cheung et al. (16) as they recorded that hypochlorite solution (5.25% at 37 ^{o}C) was a more damaging factor to fatigue life than air, deionized water, or silicone oil. The reasons for this disagreement could be due to the fact that, at a higher temperature, the corrosive effect of NaOCl became greater than the lubricant effect(31, 32). The adverse effect of the NaOCl also recorded by Elnaghy & Elsaka (17) as the fracture of the instruments in the air occurred after a higher number of cycles than that in sodium hypochlorite or saline. However, the disagreement might be attributed to different experimental settings, for example, the curvature angle of the artificial canal was 60º with continuous irrigation leading to a reduction in the solution volume and the exposure time. It has been demonstrated that NaOCl irrigant etches the NiTi instrument, and subsequently removing the surface nickel ions resulting in micro-holes (33). This corrosive activity of NaOCl has been recorded to be a point of stress build-up and this could help to propagate crack on the instrument. Therefore, the contact between files and NaOCl solution could cause a negative effect on the mechanical integrity of NiTi instruments (34, 35).

The average lengths of the fractured segments were affected by the CF test modes and the lubricants used. Although significant statistical differences were recorded between the groups, all the tested instruments fractured nearly at the starting point of the curved part of the artificial canal. The stress around this point of the instrument was apparently greater. Transformational design of OC cross-section (21) might modify the distribution of the maximum stress points (36). The difference in fragment lengths among the groups could be attributed to the effect of the test condition on the properties of the alloy, or an original defect in the files. Although significant statistical differences were distinguished between some of the groups, the fragment lengths did not show any clear relationship with the canal lubricants or the test modes.

5. Conclusion

Despite the limitations of this cyclic fatigue (CF) study, itis safe to conclude that using an intracanal lubricant during file testing is essential, and applying oil as an intracanal lubricant and dynamic test mode perform better than NaOCl lubricant and static test mode to improve the lifespan of One Curve (OC) rotary endodontic files in terms of number of cycles to fracture (NCF). However, the type of intracanal lubricants demonstrated a greater impact than the tests modes whether it was static or dynamic. The NCF of OC instruments significantly improved when the files were subjected to a dynamic CF test with oil, compared to the static mode and using NaOCl lubricant. According to these results, during rotary instrumentation of curved root canals, continuous pecking motions and oil intracanal lubricant are recommended. However, further research is required to define the impact of the frequency of the pecking motion and working time on the CF resistance of the endodontic rotary files.

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Conflicts of interest

There are no conflicts of interest.

References

.1 Arens FC, Hoen MM, Steiman HR, Dietz Jr GC. Evaluation of single-use rotary nickel-titanium instruments. Journal of Endodontics. 2003;29(10):664-6.

.2 Pruett JP, Clement DJ, Carnes Jr DL. Cyclic fatigue testing of nickel-titanium endodontic instruments . Journal of endodontics. 1997;23(2):77-85.

.3 Zelada G, Varela P, Martín B, Bahíllo JG, Magán F, Ahn S. The effect of rotational speed and the curvature of root canals on the breakage of rotary endodontic instruments. Journal of Endodontics. 2002;28(7):5-40 .2

.4 Rodrigues RC, Lopes HP, Elias CN, Amaral G, Vieira VT, De Martin AS. Influence of different manufacturing methods on the cyclic fatigue of rotary nickel-titanium endodontic instruments. Journal of endodontics. 2011;37(11):1553-7.

.5 Lopes HP, Britto IM, Elias CN, de Oliveira JCM, Neves MA, Moreira EJ, et al. Cyclic fatigue resistance of ProTaper Universal instruments when subjected to static and dynamic tests. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology. 2010;11.4-401:(3)0

.6 Yao JH, Schwartz SA, Beeson TJ. Cyclic fatigue of three types of rotary nickel-titanium files in a dynamic model. Journal of endodontics. 2006;32(1):55-7.

.7 Bhagabati N, Yadav S, Talwar S. An in vitro cyclic fatigue analysis of different endodontic nickel-titanium rotary instruments. Journal of endodontics. 2012;38(4):515-8.

.8 Lopes HP, Gambarra-Soares T, Elias CN, Siqueira Jr JF, Inojosa IF, Lopes WS, et al. Comparison of the mechanical properties of rotary instruments made of conventional nickel-titanium wire, M-wire, or nickel-titanium alloy in R-phase. Journal of endodontics. 2013;39(4):516-20.

.9 Thu M, Ebihara A, Maki K, Miki N, Okiji T. Cyclic Fatigue Resistance of Rotary and Reciprocating Nickel-Titanium Instruments Subjected to Static and Dynamic Tests. Journal of endodontics. 2020.

.10 Zubizarreta-Macho Á, Mena Álvarez J, Albaladejo Martínez A, Segura-Egea JJ, Caviedes Brucheli J, Agustín-Panadero R, et al. Influence of the Pecking Motion Frequency on the Cyclic Fatigue Resistance of Endodontic Rotary Files. Journal of Clinical Medicine. 2020;9(1):45.

.11 Hülsmann M, Donnermeyer D, Schäfer E. A critical appraisal of studies on cyclic fatigue resistance of engine-driven endodontic instruments. International Endodontic Journal. 20.45-1427:(10)52;19

.12 Dederich DN, Zakariasen KL. The effects of cyclical axial motion on rotary endodontic instrument fatigue. Oral surgery, oral medicine, oral pathology. 1986;61(2):192-6.

.13 Pedullà E, Benites A, La Rosa GM, Plotino G, Grande NM, Rapisarda E, et al. Cyclic fatigue resistance of heat-treated nickel-titanium instruments after immersion in sodium hypochlorite and/or sterilization. Journal of Endodontics. 2018;44(4):648-53.

.14 Plotino G, Grande NM, Testarelli L, Gambarini G, CastagnolaR, Rossetti A, et al. Cyclic fatigue of Reciproc and Reciproc Blue nickel-titanium reciprocating files at different environmental temperatures. Journal of endodontics. 2018;44(10):1549-52.

.15 Yılmaz K, Özyürek T, Uslu G. Comparision of Cyclic Fatigue Resistance of One Curve, Hyflex EDM, WaveOne Gold and Reciproc Blue Nickel-Titanium Rotary Files at Intra-canal Temperature. Cumhuriyet Dental Journal. 2019;22(1):42-7.

.16 Cheung GS, Shen Y, Darvell BW. Effect of environment on low-cycle fatigue of a nickel–titanium instrument. Journal of endodontics. 2007;33(12):1433-7.

.17 Elnaghy A, Elsaka S. Effect of sodium hypochlorite and saline on cyclic fatigue resistance of WaveOne Gold and Reciproc reciprocating instruments. International endodontic journal. 2017.8-991:(10)50;

.18 Uslu G, Özyürek T, Yılmaz K, Plotino G. Effect of dynamic immersion in sodium hypochlorite and EDTA solutions on cyclic fatigue resistance of WaveOne and WaveOne gold reciprocating nickel-titanium Files. Journal of endodontics. 2018;44.7-834:(5)

.19 Shen Y, Huang X, Wang Z, Wei X, Haapasalo M. Low environmental temperature influences the fatigue resistance of nickel-titanium files. Journal of endodontics. 2018;44(4):626-9.

.20 Lopes HP, Elias CN, Vieira MV, Vieira VT, de Souza LC, dos Santos AL. Influence of surface roughness on the fatigue life of nickel-titanium rotary endodontic instruments. Journal of endodontics. 2016;42(6):965-8.

.21 Mega M. Micro Mega (2020). One Curve brochure. Retrieved from: https://micro-mega.com/wp-content/uploads/2020/08/Brochure-One-Curve-EN-1.pdf. 2020.

.22 Sattar J. Abdul-Zahra Al Hmedat ZAJaSJA-N. Comparison of Cyclic Fatigue Among Protapergold, One Curve, Wave One® Gold and Vdw Blue Files. Biochem Cell Arch 2019;Vol. 19, (No. 1):1309-12.

.23 Plotino G ,Grande NM, Cordaro M, Testarelli L, Gambarini G. A review of cyclic fatigue testing of nickel-titanium rotary instruments. Journal of endodontics. 2009;35(11):1469-76.

.24 Lopes HP, Ferreira AA, Elias CN, Moreira EJ, de Oliveira JCM, Siqueira Jr JF. Influence of rotational speed on the cyclic fatigue of rotary nickel-titanium endodontic instruments. Journal of endodontics. 2009;35(7):1013-6.

.25 Lopes HP, Moreira EJL, Elias CN, de Almeida RA, Neves MS. Cyclic fatigue of ProTaper instruments. Journal of endodontics. 2007;33(1):55-7.

.26 Tobushi H, Shimeno Y, Hachisuka T, Tanaka K. Influence of strain rate on superelastic properties of TiNi shape memory alloy. Mechanics of Materials. 1998;30(2):141-50.

.27 Lopes HP, Elias CN, Vieira VT, Moreira EJ, MarquesRV, de Oliveira JCM, et al. Effects of electropolishing surface treatment on the cyclic fatigue resistance of BioRace nickel-titanium rotary instruments. Journal of endodontics. 2010;36(10):1653-7.

.28 Li U-M, Lee B-S, Shih C-T, Lan W-H, Lin C-P. Cyclicfatigue of endodontic nickel titanium rotary instruments: static and dynamic tests. Journal of endodontics. 2002;28(6):448-51.

.29 Ray JJ, Kirkpatrick TC, Rutledge RE. Cyclic fatigue of EndoSequence and K3 rotary files in a dynamic model. Journal of endodontics. 2007;33(12):1469-72.

.30 Pedullà E, Giusy Rita Maria La Rosa MSA, Gaetano Isola,, Generali TÖaL. Effects of Simultaneous Liquid or Gel SodiumHypochlorite Irrigation on the Cyclic Fatigue of Two
Single-File Nickel-Titanium Instruments. Applied Sciences. 2020;10(6666):10.

.31 Saeed DH, Rafea FA. Evaluation of the effect of temperature on cyclic fatigue resistance of three types of Nickel-Titanium rotary files with various alloy properties: An in vitro study. Erbil Dental Journal (EDJ). 2019;2(1):1.63-57

.32 Dosanjh A, Paurazas S, Askar M. The effect of temperature on cyclic fatigue of nickel-titanium rotary endodontic instruments. Journal of endodontics. 2017;43(5):823-6.

.33 Sarkar N, Redmond W, Schwaninger B, Goldberg A. The chloride corrosion behaviour of four orthodontic wires. Journal of oral rehabilitation. 1983;10(2):121-8.

.34 O'hoy P, Messer H, Palamara J. The effect of cleaning procedures on fracture properties and corrosion of NiTi files. International endodontic journal. 2003;36(11):72.32-4

.35 Oshida Y, Sachdeva RC, Miyazaku S. Microanalytical characterization and surface modification of TiNi orthodontic archwires. Bio-medical materials and engineering. 1992;2(2):51-69.

.36 Zhao D, Shen Y, Peng B, Haapasalo M. Effect of autoclave sterilization on the cyclic fatigue resistance of thermally treated Nickel–Titanium instruments. International Endodontic Journal. 2016;49(10):990-5.