Brazilian Dental Science
unesp
UNIVERSIDADE ESTADUAL PAULISTA
"JÚLIO DE MESQUITA FILHO"
Instituto de Ciência e Tecnologia
Campus de São José dos Campos

ORIGINAL ARTICLE
DOI: https://doi.org/10.4322/bds.2022.e3591

Evaluation of temperature effect on cyclic fatigue resistance of nickel-titanium instruments in a double-curved canal: a comparative study

Avaliação do efeito da temperatura na resistência a fadiga cíclica de instrumento níquel titânio em canal com dupla curvatura: estudo comparativo

Zainab Mohammed JUMAA[1], **Biland Mohammed Salim SHUKRI**[2]

1 - Mustansiriyah University, College of Dentistry. Baghdad, Iraq.
2 - Mustansiriyah University, College of Dentistry, Conservative Department. Baghdad, Iraq.

ABSTRACT

Objective: To investigate the effect of room and body temperatures on cyclic fatigue resistance of three endodontic nickel-titanium rotary files: Hyflex EDM (HEDM) (Coltene/Whaledent, Switzerland), WaveOne Gold (WOG) (Dentsply Maillefer, Switzer), and EdgeOne Fire (EOF) (EdgeEndo, Albuquerque, New Mexico, USA) in a double-curved canal. **Material and Methods:** In this study, Sixty NiTi rotary files were used. These files were divided into three groups (n = 20 for each group). Group A: HEDM (size 25, taper 0.08), group B: WOG (size 25, taper 0.07), and group C: EOF (size 25, taper 0.07). Each group was subdivided into two subgroups (n=10 for each subgroup). One of the subgroup was subjected to cyclic fatigue test at room temperature (20±1°C), while the other subgroup was subjected to cyclic fatigue test at body temperature (37±1°C). These files were tested by using a custom-made artificial canal with a double curvature (coronal curve: 60° curvature with 5 mm radius; apical curve: 70° curvature with 2 mm radius). All instruments were rotated according to the manufacturer instructions until the fracture occurred by using electric endodontic motor (Wave One, Dentsply Maillefer, Ballaigues, Switzerland). The number of cycles to fracture (NCF) and the fractured fragment length (FL) were recorded for each endodontic file. The data were gathered and statistically analyzed using shapiro-wilk test and two-way ANOVA test. The statistical significance was set at 0.05. **Results:** The NCF of WOG and EOF were significantly lower at body temperature as compared to room temperature ($p \leq 0.05$), whereas no difference was observed in NCF of HEDM at body and room temperatures ($p>0.05$). At 20±1°C, the results showed a non-significant difference between NCF of WOG and EOF ($p>0.05$), while the NCF of HEDM was significantly lower than the other groups ($p \leq 0.05$). At 37±1°C, the results showed a non-significant difference in NCF among the tested endodontic files ($p \leq 0.05$). There is non-significant difference in FL of each group at (20±1°C) and (37±1°C) ($p>0.05$). No statistical difference in FL among the tested files at room and body temperatures ($p>0.05$). **Conclusion:** The temperature has a significant effect on cyclic fatigue resistance of EOF and WOG, whereas no effect was observed on cyclic fatigue resistance of HEDM. WOG and EOF had a comparable NCF, while HEDM had a lower NCF than other groups at room temperature. At body temperature, all tested files have a comparable NCF. These results were attributed to the type of the alloy and heat treated that was used to manufacture these endodontic files. The cyclic fatigue test should be done at body temperature.

KEYWORDS

Body temperature; Cyclic fatigue; EdgeOne fire; Hyflex EDM; WaveOne Gold.

RESUMO

Objetivo: Investigar o efeito das temperaturas ambiente e corpórea na resistência a fadiga cíclica em três instrumentos endodônticos rotatório de níquel-titânio: Hyflex EDM (HEDM) (coltene/Whaledent, Switzerland), WaveOne Gold (WOG) Dentsply Maillefer, Switzer), e EdgeOne Fire (EOF) (EdgeEndo, Albuquerque, New Mexico, USA) em canais com dupla curvatura. **Material e Métodos**: Neste estudo foram utilizadas sessenta limas endodônticas rotatórias. Esses grupos foram divididos em três grupos (n=20). Grupo A: HEDM (tamanho 25, conicidade 0.08), grupo B: WOG (tamanho 25, conicidade 0.07), e grupo C: EOF (tamanho 25, conicidade 0.07). Cada grupo foi subdivididos em dois subgrupos (n=10). Um dos subgrupos foi submetido ao teste de fadiga cíclica em temperatura ambiente (20±1°C), enquanto o outro subgrupo foi submetido a ao teste de fadiga cíclica em temperatura corpórea (37±1°C). Essas limas foram testadas em um canal artificial feito sob medida com duas curvaturas (curva coronal: curvatura de 60º e com 5 mm de raio; curva apical: curvatura de 70º com 2mm de raio); Todos os instrumentos foram rotacionados de acordo com a instrução do fabricante até que a fratura ocorresse utilizando um motor endodôntico elétrico (Wave One, Dentsply Maillefer, Ballaigues, Switzerland). O número de ciclos até a fratura (NCF) e a comprimento do fragmento fraturado (FL) foram registrados para cada lima endodôntica. Os dados foram coletados e analisados pelo teste shopiro-wilk e ANOVA two-way. A significância estatística foi 0.05. **Resultados:** O NCF do WOG e do WOF foi significantemente menor na temperatura corpórea em comparação à temperatura ambiente (p≤0.05), enquanto não foi observada diferença entre NCF em HEDM em temperatura corpórea e temperatura ambiente (p>0.05). Em 20±1°C, os resultados mostraram diferença não significativa entre o NFC com WOG e EOF (p>0.05), enquanto o NCF com HEDM foi significante menor que os demais grupos (p≤0.05). A 37±1°C, os resultados mostraram diferença não significativa em NCF entre as limas endodônticas testadas (p≤0.05). Há diferença não significativa no FL de cada grupo (20±1°C) e (37±1°C) (p>0.05). Não houve diferença estatisticamente diferente no FL entre as limas testadas nas temperaturas ambiente e corporal (p>0,05). **Conclusão:** A temperatura tem efeito significativo na resistência a fadiga cíclica do EOF e WOG, enquanto não foi observado nenhum efeito na resistência a fadiga cíclica do HEDM. WOG e EOF tiveram um NCF comparável, enquanto HEDM teve um NCF menor do que os outros grupos em temperatura ambiente. À temperatura corporal, todas as limas testas apresentam semelhante NCF. Esses resultados foram atribuídos ao tipo de liga e ao tratamento térmico que foi utilizado na fabricação. O teste de fadiga cíclica deve ser feito à temperatura corporal.

PALAVRAS-CHAVES

EdgeOne fire; Fadiga cíclica; Hyflex EDM; Temperatura corpórea; WaveOne Gold.

INTRODUCTION

Changing the design, using different heat treatments and alloys, and altering the kinematics of NiTi rotary files were done by the manufacturers to improve the superelasticity and fatigue resistance of the nickel-titanium (NiTi) instruments [1,2]. In spite of advances in endodontic instruments, fracture of these instruments during treatment remains a problem for dentists [1]. This fracture usually occurs due to cyclic fatigue or torsional overload [3,4]. Fracture due to torsional fatigue occurs as a result of the file being stuck in the root canals while the hand piece continues to rotate. Cyclic fatigue occurs when the freely rotating file within the canal being exposed to frequent cycles of compression and tensile forces at the curved portion of the root canal [5]. Traditional radiography failed to reveal S-shaped root canal anatomy, so this make the treatment more complicated for clinicians [6]. HyFlexEDM (HEDM)(Coltene/Whaledent, Altstätten, Switzerland) is a single-file system with a continuous rotating motion. The heat treatment of controlled memory alloy is used to create this file system [7]. WaveOne Gold (WOG) (Dentsply Maillefer, Switzerland) is a single-file system that has a reciprocating motion with off center design and parallelogram cross section. A gold heat treatment method was used to produce this file. It is heated and then cooled slowly [8]. Edge One Fire (EOF) (EdgeEndo, Albuquerque, New Mexico, USA) is a single-file system that has the same cross section and reciprocating motion of the WOG and it is treated with a proprietary heat process called FireWire ™ [4]. Most cyclic fatigue studies of NiTi files were done at room temperature [9-11]. These don't perform the clinical conditions as NiTi rotary files that are used in the root canal which has a temperature similar to that of the body [7]. Some investigators have revealed that when the body temperature was raised, cyclic fatigue resistance was decreased drastically [12].

The aim of this work was to investigate the effect of room and body temperatures on the cyclic fatigue resistance of three endodontic nickel-titanium rotary files for HEDM, WOG, and EOF in a double-curved canal. The null hypotheses of this study were as follows:

- There would be a significant difference in fractured fragment length for each endodontic file system at two different temperatures and there would be a significant difference in fractured fragment length among endodontic files at room temperature and body temperature.

- There would be no significant difference in cyclic fatigue for each endodontic file system at room temperature and body temperature.
- There would be no significant differences in cyclic fatigue among endodontic file system at room temperature and body temperature.

MATERIAL AND METHOD

A total of 60 NiTi rotary files were used in this study. The sample calculation was based on previous study that was done by Klymus et al. [12]. These NiTi rotary files were divided into three groups (n=20 for each group), group A: HEDM (size25, taper 0.08), group B: WOG (size 25, taper 0.07), and group C: EOF (size 25, taper 0.07). These groups were tested in a double curvature canal. Each endodontic rotary file was examined under the Stereomicroscope (MEIJI Techno, Japan, model No. (HG175398)) x20 magnification to check if any manufacturing deformation may be found for exclusion before the testing procedure. Ten instruments of each endodontic file system were tested at room temperature (20±1°C) and the other ten endodontic files were tested at body temperature (37±1°C), simulating intracanal temperature. The artificial canal has two curves; the coronal curve with 60° angle of curvature and 5 mm radius which is located at 8 mm from the tip of the canal, while the apical curve has 70° angle of curvature with 2 mm radius which was located at 2mm from the tip of the canal [2,5,6]. The radius and angle of curvature were determined according to Pruett et al. [13]. A circle of 5mm diameter was milled at the end of the canal to reduce the torsional effect and to provide a space for a fractured piece [14]. The artificial canal (18 mm length) was covered by tempered glass to prevent the instrument from slipping out and to allow the observation of the instrument during operation. A circle was done in the tempered glass [15] which had the same size and place of the circle that milled at the end of the canal to allow the distal water to enter the artificial canal as shown in Figure 1.

The electric hand piece was mounted on a device to allow for precise and reproducible placement of each endodontic file inside the canal. Each file was placed into an artificial canal in a metal block, which was submerged in a Digital water bath (HH-W420, China) that was filled with distal water. The temperature of distal

(a) (b)

Figure 1 - a) Testing system for cyclic fatigue; b) Fracture of rotary endodontic file in an apical curve of artificial canal.

water was set to tested degree and wait for few second before the test was began. A thermometer was used for checking the temperature of distal water for more accuracy. All the endodontic files in each group were operated inside the artificial canal without pecking motion until the fracture occur when using a 6:1 reduction hand piece driven by motor device (Wave One, Dentsply Maillefer, Ballaigues). The speed for each group was adjusted according to the manufacturer instructions as follows: Group A: HEDM (speed 500 rpm, torque 2.5 N.cm), Group B and C: WOG and EOF files (speed 350 rpm, WaveOne ALL program which has a cutting motion of 150 degrees (counterclockwise) and a releasing motion of 30 degrees (clockwise)). The procedure was timed and the stop watch was stopped as soon as the fracture was detected visually and by video recording. The number of cycles to failure (NCF) for each instrument was calculated by multiplying the number of rotations per the seconds of rotation required to fracture [16]. The fractured fragment length (FL) of each instrument obtained by measuring it by using a digital vernier. The collected data were analyzed using SPSS (Statistical Packages for Social Sciences) version 21 (SPSS Inc., Chicago, IL). The data were analyzed by using Shapiro Wilk test and two-way ANOVA (Analysis of variance) for both NCF and FL. The statistical significance was set at 0.05.

RESULTS

The mean and standard deviations of NCF and FL for all groups are shown in Table I and Figure 2. The Shapiro Wilk test value for NCF and FL of three endodontic rotary files HEDM, WOG, and EOF at (20±1°C) and (37±1°C) were normally distributed ($P > 0.05$). Two way ANOVA test for NCF of HEDM exhibited non-significant difference between (20 ±1°C) and (37±1°C) ($p>0.05$), while there was a significant difference in NCF of WOG and EOF between both temperatures ($p\leq0.05$) as shown in Table II. At (20±1°C), there was a non-significant difference in NCF between WOG and EOF ($p>0.05$), while HEDM had significantly lower NCF values than other groups ($p\leq0.05$). At (37±1°C), there was a

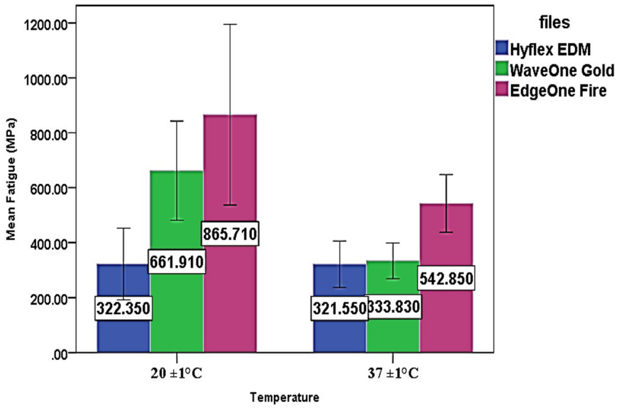

Figure 2 - Bar chart showing the means of NCF for each group at (20 ±1°C) and (37 ±1°C).

Table I - Mean and standard deviation of NCF and FL for each group at (20 ±1°C) and (37 ±1°C) for apical curved of artificial canal

Temp.	files	NCF		FL	
		Mean	SD	Mean	SD
20±1°C	Hyflex EDM	322.3500	182.00703	1.7150	.23918
	Waveone Gold	661.9100	252.35322	1.9180	.22225
	Edgeone Fire	865.7100	459.85874	1.8790	.32726
37±1°C	Hyflex EDM	321.5500	118.19039	1.7320	.21091
	Waveone Gold	333.8300	91.04528	1.9730	.21675
	Edgeone Fire	542.8500	146.77650	1.9690	.35120

Table II - Two way ANOVA test for NCF and FL for each group between (20 ±1°C) and (37 ±1°C)

File system	(I) temp.	(J) temp.	NCF		FL	
			Mean Difference (I-J)	Sig.	Mean Difference (I-J)	Sig.
Hyflex EDM	20	37	.800	.994	-.017	.887
Waveone Gold	20	37	328.080	.004*	-.055	.647
Edgeone Fire	20	37	322.860	.004*	-.090	.455

$p > 0.05$ non-significant, $^*p \leq 0.05$ significant.

non-significant difference in NCF among the file systems (p>0.05) as shown in Table III. There was no significant difference in FL among files groups at both temperatures as shown in Table II and There was no significant difference in FL between each group at room temperature and body temperature (P>0.05) as shown in Table III.

DISCUSSION

The resistance of NiTi endodontic files can be influenced by number of factors, including metallurgical design, manufacturing process, heat treatment of instrument, instrument size, cross-sectional design, helix angle, taper, core diameter, file kinematics, and the temperature to which the instrument is subjected [8].

The root canal anatomy of teeth cannot be determined from a proximal view on standard radiographs. The treatment of teeth with dilacerated (S-shaped) root canals can be challenging because of file breakage and losses of working length which are frequently reported as complications in such teeth [6].

Although the extracted human teeth might better reflect the clinical situations, they are not anatomically and morphologically standardized (curvature, diameter, and radius) in addition, a tooth can only be used once because of the shape of the root canal will change during instrumentation, making it impossible to standardize experimental conditions [17].

The dynamic model cannot replicate actual clinical conditions. It is more liable to procedural errors and is more difficult to keep the instruments in a precise trajectory [5]. For this reason a static model was used in this study. There are different methods for increasing the temperature of the environments, such as using a temperature-controlled oven or immersing the instruments in preheated solutions continuously during tests [18,19] which was used in this study.

The effect of temperature (room and body temperatures) on the cyclic fatigue resistance of the three endodontic files (HEDM, WOG, and EOF) was evaluated and the cyclic fatigue resistance was compared between them at room and body temperatures by using a metal block that was submerged in a distal water in a digital water bath. These instruments were chosen because each has a different manufacturing process.

The friction between the instruments and the artificial canal walls could lead to increase in the temperature due to the friction between the instruments and the artificial canal which increase the risk of crack formation and/or growth [12,20]. Cheung and Darvell [20] showed that the aqueous media did not affect the cyclic fatigue test. Additionally, Klymus et al. [12], affirmed that aqueous media simulate irrigating solutions more closely and avoid increasing the temperature [12]. So in this study, it was used water to decrease the friction.

According to the results of this study, all files fractured mainly in the apical curvature which might be attributed to the severity of the curvatures (the apical curvature have a radius of 2mm and the coronal curvature have a radius of 5mm). The results of previous cyclic fatigue studies on S-shaped root canals confirm this idea [5,6]. There was no significant difference in the mean length of the fracture piece of experimented files. The FL of each file occurred at the center of the curvature or just below this point. At this point, the stress had a greater effect on the endodontic rotary files [6], so the first null hypothesis was rejected.

Table III - Two way ANOVA for NCF and FL for each pair of groups at (20 ±1°C) and (37 ±1°C)

Temp.	(I) files	(J) files	NCF Mean Difference (I-J)	NCF Sig.	FL Mean Difference (I-J)	FL Sig.
20±1°C	Hyflex EDM	Waveone Gold	-339.560	.008	-.203	.285
		Edgeone Fire	-543.360	.000*	-.164	.527
	Waveone Gold	Edgeone Fire	-203.800	0.196	.039	1.000
37±1°C	Hyflex EDM	Waveone Gold	-12.280	1.000	-.241	.146
		Edgeone Fire	-221.300	.138	-.237	.157
	Waveone Gold	Edgeone Fire	-209.020	.177	.004	1.000

p > 0.05 non-significant, *p ≤ 0.05 significant.

Previous studies performed cyclic fatigue resistance test at room temperature. This temperature was lower than body temperature and should not be clinically relevant because the NiTi files are used inside the root which is surrounded by periodontium that have the same body temperature [2]. In a recent study, it was determined that the intracanal temperature during root canal therapy is 37+1°C [4]. Therefore, in the current study, all endodontic files were tested for cyclic fatigue resistance at intracanal temperature to mimic clinical conditions in addition to room temperature.

Dosanjh et al. [21], examined the effect of different temperatures on the cyclic fatigue resistance of NiTi rotary files and found that NCF values decreased as the temperature increased [21]. Vasconcelos et al. [1], evaluated the effect of two different temperatures (room and body temperatures) on the cyclic fatigue resistance of NiTi files. They reported that at body temperature, the cyclic fatigue resistance of tested files was significantly reduced as compared with room temperature. The main findings of the current study showed that the cyclic fatigue resistances of WOG and EOF at room temperature are more significant than at body temperature ($p \leq 0.05$). This is compatible with the aforementioned studies, while the result of previous study which was done by Ismail et al. [22], found that there was a non-significant difference in cyclic fatigue resistance of WOG at room and body temperatures which is different from the result of current study because of different test that was used.

According to the results of the present study, the HEDM showed a non-significant difference between the mean of NCF at room and body temperatures ($p > 0.05$), this result agree with the previous studies [18,23]. Also the current result agrees with a previous study done by Plotino et al. [24]. Plotino et al. observed that Protaper Gold had no significant difference in cyclic fatigue resistance at different temperatures. Shen et al. [25], evaluated cyclic fatigue resistance of six dissimilar endodontic files at different temperatures, and only one type (Vortex; Dentsply Sirona Endodontics) had significantly reduced cyclic fatigue resistance at 37°C compared to 22°C [25], while there were no significant differences in cyclic fatigue resistance of other endodontic tested files NiTi systems at 22°C and 37°C. So the second null hypothesis was partially rejected. The result of this study showed that the temperature at which the instruments are tested influenced on the results of cyclic fatigue resistance of NiTi files with a different behavior which depends on the heat treatment of the alloy and the type of alloy of the tested endodontic files [22,24].

At (20±1°C), there was non-significant difference in NCF between WOG and EOF. There were few previous studies compared the EOF with other instruments. In this study, the tested instruments (EOF and WOG) have the same cross section and reciprocating motion [4]. Despite of different alloy, Firewire instruments showed to be non-significant difference in NCF value when compared with identical instruments that made with Gold treatment at room and body temperatures. This result is not agree with the previous study [4] which showed that the EOF is more cyclic fatigue resistance than WOG, which was attributed to different test that was used.

HEDM displayed a lower value of NCF than other evaluated instruments at 20±1°C. The results of this study showed that the highest cyclic fatigue resistance was associated with files that have the reciprocation motion (EOF and WOG) followed by files that have a continuous rotation (HEDM). This indicated that the motion plays a major role in cyclic fatigue resistance. These findings might be attributed to the release of the reaction stresses that built up in the material by reversing the rotational direction [26]. Number of studies [22,27] reported that, regardless of the file type, reciprocation motion increased the cyclic fatigue resistance of files more than continuous rotation did. Karatas et al. [27], concluded that the fatigue life is associated with the number of times of opening and closing of the crack in an instrument. During reciprocation motion, the instrument needs to complete one rotation (360°) which require more time as compared to continuous rotation. Therefore, the number of times for opening and closing crack in a reciprocation motion is less when compared with a continuous rotation over the same time. This may explain the extended fatigue life of a reciprocation motion [27].

The instruments were used in this study had the same tip size (#25) with different tapers. At the first 3 mm from the tip, the HEDM has a taper of 0.08 mm/mm, whereas WOG and EOF have a taper of 0.07 mm/mm. Previous studies showed that instruments with lower taper have higher cyclic fatigue resistance [28]. This agrees with the results of the present study at room temperature.

To the author knowledge, there were no previous investigations that compared the cyclic fatigue resistance of Hyflex EDM, WaveOne Gold, and EdgeOne Fire at body temperature in S-shape canal. The results showed non-significant difference in NCF among the tested files (p≤0.05). This result depends on the heat treatment of the alloy and the type of alloy of tested files. The result is different from the previous investigations [23,29] which found that the cyclic fatigue of HEDM is more significant than WOG. This is due to different dimensions of artificial canal that was used. So the third hypothesis was partially rejected.

Although the results of the present study have important issue, they should be applied carefully in clinical practice because of other factors that may affect the cyclic fatigue resistance of the tested files, as using different irrigation solutions, usage force during instrumentation that may affect the properties of dissimilar types of NiTi instruments. Furthermore, in clinical practice there are other factors that may affect file separation like torsional load that is difficult to distinguish it from cyclic load clinically [14].

CONCLUSIONS

The main conclusions of this investigation can be summarized as follows:

1- The temperature has a significant effect on cyclic fatigue resistance of EOF and WOG, whereas no effect was observed on cyclic fatigue of HEDM. Cyclic fatigue test should be done at body temperature.

2- There was non-significant difference in NCF between WOG and EOF, while HEDM displayed a lower value of NCF than other evaluated instruments at room temperature.

3- The HEDM, WOG, and EOF have a comparable NCF at body temperature.

4- This results were attributed to type of alloy and heat treated that was used to manufacture these files.

Acknowledgements

The authors are grateful to Mustansiriyah University in Baghdad, Iraq (www.uomustasiryah.edu.iq) for its help in this work.

Author's Contributions

ZMJ, BMSS: Testing, writing, and reading.

Conflict of Interest

The authors have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Regulatory Statement

This study was done in artificial canal in a metal block and its not related to any human subjects.

Abbreviation

ANOVA: Analysis of variance

SPSS: Statistical packages for social sciences

REFERENCES

1. Vasconcelos RA, Murphy S, Carvalho CAT, Govindjee RG, Govindjee S, Peters OA. Evidence for reduced fatigue resistance of contemporary rotary instruments exposed to body temperature. J Endod. 2016;42(5):782-7. http://dx.doi.org/10.1016/j.joen.2016.01.025. PMid:26993574.

2. Özyürek T, Gündoğar M, Yılmaz K, Uslu G. Bending resistance and cyclic fatigue life of Reciproc Blue, WaveOne Gold, and Genius files in a double (S-shaped) curved canal. J Dent Res Dent Clin Dent Prospects. 2017;11(4):241-6. http://dx.doi.org/10.15171/joddd.2017.042. PMid:29354251.

3. Topçuoğlu HS, Topçuoğlu G, Kafdağ Ö, Balkaya H. Effect of two different temperatures on resistance to cyclic fatigue of one Curve, EdgeFile, HyFlex CM and ProTaper next files. Aust Endod J. 2020;46(1):68-72. http://dx.doi.org/10.1111/aej.12369. PMid:31410934.

4. Gambarini G, Galli M, Di Nardo D, Seracchiani M, Donfrancesco O, Testarelli L. Differences in cyclic fatigue lifespan between two different heat treated NiTi endodontic rotary instruments: WaveOne Gold vs EdgeOneFire. J Clin Exp Dent. 2019;11(7):e609-13. http://dx.doi.org/10.4317/jced.55839. PMid:31516658.

5. Uslu G, Gundogar M, Özyurek T, Plotino G. Cyclic fatigue resistance of reduced-taper nickel-titanium (NiTi) instruments in doubled-curved (S-shaped) canals at body temperature. J Dent Res Dent Clin Dent Prospects. 2020;14(2):111-5. http://dx.doi.org/10.34172/joddd.2020.024. PMid:32908652.

6. Al-Sudani D, Grande NM, Plotino G, Pompa G, Di Carlo S, Testarelli L, et al. Cyclic fatigue of nickel-titanium rotary instruments in a double (S-shaped) simulated curvature. J Endod.

2012;38(7):987-9. http://dx.doi.org/10.1016/j.joen.2012.03.025. PMid:22703666.

7. Gündoğar M, Özyürek T, Yılmaz K, Uslu G. Cyclic fatigue resistance of HyFlex EDM, Reciproc Blue, WaveOne Gold, and Twisted File Adaptive rotary files under different temperatures and ambient conditions. J Dent Res Dent Clin Dent Prospects. 2019;13(3):166-71. http://dx.doi.org/10.15171/joddd.2019.026. PMid:31857861.

8. Bueno CR, Cury MT, Vasques AM, Sivieri-Araújo G, Jacinto RC, Gomes-Filho JE, et al. Cyclic fatigue resistance of novel Genius and Edgefile nickel-titanium reciprocating instruments. Braz Oral Res. 2019;33:e028. http://dx.doi.org/10.1590/1807-3107bor-2019.vol33.0028. PMid:30994706.

9. Rashid SA, Al-Gharrawi HA. Cyclic fatigue of trunatomy nickel-titanium rotary instrument in single and double curvature canals: a comparative study. World J Dent. 2021;12(1):28-31. http://dx.doi.org/10.5005/jp-journals-10015-1793.

10. Uygun AD, Kol E, Topcu MK, Seckin F, Ersoy I, Tanriver M. Variations in cyclic fatigue resistance among ProTaper Gold, ProTaper Next and ProTaper Universal instruments at different levels. Int Endod J. 2016;49(5):494-9. http://dx.doi.org/10.1111/iej.12471. PMid:26011308.

11. Plotino G, Grande NM, Cotti E, Testarelli L, Gambarini G. Blue treatment enhances cyclic fatigue resistance of vortex nickel-titanium rotary files. J Endod. 2014;40(9):1451-3. http://dx.doi.org/10.1016/j.joen.2014.02.020. PMid:25146031.

12. Klymus ME, Alcalde MP, Vivan R, Só MV, Vasconselos BC, Duarte MA. Effect of temperature on the cyclic fatigue resistance of thermally treated reciprocating instruments. Clin Oral Investig. 2019;23(7):3047-52. http://dx.doi.org/10.1007/s00784-018-2718-1. PMid:30397733.

13. Pruett JP, Clement DJ, Carnes DL Jr. Cyclic fatigue testing of nickel-titanium endodontic instruments. J Endod. 1997;23(2):77-85. http://dx.doi.org/10.1016/S0099-2399(97)80250-6. PMid:9220735.

14. Yılmaz K, Uslu G, Özyürek T. In vitro comparison of the cyclic fatigue resistance of HyFlex EDM, One G, and ProGlider nickel titanium glide path instruments in single and double curvature canals. Restor Dent Endod. 2017;42(4):282-9. http://dx.doi.org/10.5395/rde.2017.42.4.282. PMid:29142876.

15. Grande NM, Plotino G, Silla E, Pedullà E, DeDeus G, Gambarini G, et al. Environmental temperature drastically affects flexural fatigue resistance of nickel-titanium rotary files. J Endod. 2017;43(7):1157-60. http://dx.doi.org/10.1016/j.joen.2017.01.040. PMid:28476464.

16. Lopes HP, Ferreira AA, Elias CN, Moreira EJ, Machado de Oliveira JC, Siqueira JF Jr. Influence of rotational speed on the cyclic fatigue of rotary nickel-titanium endodontic instruments. J Endod. 2009;35(7):1013-6. http://dx.doi.org/10.1016/j.joen.2009.04.003. PMid:19567325.

17. Plotino G, Grande NM, Cordaro M, Testarelli L, Gambarini G. A review of cyclic fatigue testing of nickel-titanium rotary instruments. J Endod. 2009;35(11):1469-76. http://dx.doi.org/10.1016/j.joen.2009.06.015. PMid:19840633.

18. Arias A, Macorra JC, Govindjee S, Peters OA. Correlation between temperature-dependent fatigue resistance and differential scanning calorimetry analysis for 2 contemporary rotary instruments. J Endod. 2018;44(4):630-4. http://dx.doi.org/10.1016/j.joen.2017.11.022. PMid:29398091.

19. Keles A, Ozyurek EU, Uyanik MO, Nagas E. Effect of temperature of sodium hypochlorite on cyclic fatigue resistance of heat-treated reciprocating files. J Endod. 2019;45(2):205-8. http://dx.doi.org/10.1016/j.joen.2018.11.003. PMid:30711179.

20. Cheung GSP, Darvell BW. Fatigue testing of a NiTi rotary instrument. Part 1: strain-life relationship. Int Endod J. 2007;40(8):612-8. http://dx.doi.org/10.1111/j.1365-2591.2007.01262.x. PMid:17532775.

21. Dosanjh A, Paurazas S, Askar M. The effect of temperature on cyclic fatigue of Nickel-titanium rotary endodontic instruments. J Endod. 2017;43(5):823-6. http://dx.doi.org/10.1016/j.joen.2016.12.026. PMid:28442122.

22. Ismail AG, Galal M, Nagy MM. Effect of different kinematics and operational temperature on cyclic fatigue resistance of rotary NiTi systems. Bull Natl Res Cent. 2020;44(1):1-5. http://dx.doi.org/10.1186/s42269-020-00370-4.

23. Oh S, Kum KY, Kim HJ, Moon SY, Kim HC, Chaniotis A, et al. Bending resistance and cyclic fatigue resistance of WaveOne Gold, Reciproc Blue, and HyFlex EDM instruments. J Dent Sci. 2020;15(4):472-8. http://dx.doi.org/10.1016/j.jds.2019.10.003. PMid:33505619.

24. Plotino G, Grande NM, Bellido MM, Testarelli L, Gambarini G. Influence of temperature on cyclic fatigue resistance of ProTaper Gold and ProTaper Universal rotary files. J Endod. 2017;43(2):200-2. http://dx.doi.org/10.1016/j.joen.2016.10.014. PMid:27989581.

25. Shen Y, Huang X, Wang Z, Wei X, Haapasalo M. Low environmental temperature influences the fatigue resistance of nickel-titanium files. J Endod. 2018;44(4):626-9. http://dx.doi.org/10.1016/j.joen.2017.11.004. PMid:29306534.

26. Gavini G, Caldeira CL, Akisue E, Candeiro GTM, Kawakami DA. Resistance to flexural fatigue of Reciproc R25 files under continuous rotation and reciprocating movement. J Endod. 2012;38(5):684-7. http://dx.doi.org/10.1016/j.joen.2011.12.033. PMid:22515903.

27. Karataş E, Arslan H, Büker M, Seçkin F, Çapar I. Effect of movement kinematics on the cyclic fatigue resistance of nickel–titanium instruments. Int Endod J. 2016;49(4):361-4. http://dx.doi.org/10.1111/iej.12453. PMid:25816834.

28. Faus-Llácer V, Kharrat NH, Ruiz-Sánchez C, Faus-Matoses I, Zubizarreta-Macho Á, Faus-Matoses V. The effect of taper and apical diameter on the cyclic fatigue resistance of rotary endodontic files using an experimental electronic device. Appl Sci (Basel). 2021;11(2):863. http://dx.doi.org/10.3390/app11020863.

29. Yilmaz 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 Dent J. 2019;22(1):42-7. http://dx.doi.org/10.7126/cumudj.477218.

Zainab Mohammed Jumaa
(Corresponding address)
Mustansiriyah University, College of Dentistry, Baghdad, Iraq.
Email: zainabyjy@gmail.com

Date submitted: 2022 July 23
Accept submission: 2022 Oct 10