EGYPTIAN DENTAL JOURNAL
www.eda-egypt.org
VOL. 68, 3971:3979, OCTOBER, 2022
PRINT ISSN 0070-9484 • ONLINE ISSN 2090-2360
CONSERVATIVE DENTISTRY AND ENDODONTICS
Submit Date : 26-06-2022 • Accept Date : 07-07-2022 • Available online: 01-10-2022 • DOI : 10.21608/edj.2022.146738.2168

CYCLIC FATIGUE RESISTANCE OF EDGEFILE X7, EDGE ONE, WAVEONE GOLD AND WAVEONE ROTARY FILES USING ARTIFICIAL CANALS WITH DIFFERENT ANGLES AND RADII OF CURVATURE

Fatma Mohamed Abu Naeem*, , Mohamed Nageh** *and* Dina A Morsy*

ABSTRACT

Aim: To assess and compare the cyclic fatigue resistance of EdgeFile X7, EdgeOne, WaveOne Gold and WaveOne rotary files using artificial canals with different angles and radii of curvature.

Materials and methods: One hundred and sixty NiTi files from four different systems (N= 40 each) were used; Group 1: WaveOne, Group 2: WaveOne Gold, Group 3: EdgeOne and Group 4: EdgeFile X7. The files were tested for cyclic fatigue resistance using a custom made static model with various angles and radii of curvature (angle 60° radius 2.5mm and radius 5mm and angle 90° radius 2.5mm and radius 5mm). The files were operated according to the manufacturers' instructions inside the artificial canals till fracture. A digital stopwatch was used to record the time till fracture (TTF) in seconds and the length of the fractured segment (FL) was recorded.

Results: The highest TTF values were found in the WaveOne Gold group followed by the EdgeOne group then the WaveOne group while the least was in the EdgeFile X7. There was no statistically significant difference between WaveOne Gold and EdgeOne at all angles and radii of curvature. There was a statistically significant difference between both the WaveOne Gold, EdgeOne and the EdgeFile X7. Angle 90° with 2.5mm radius showed the lowest cyclic fatigue resistance. WaveOne Gold and EdgeFile X7 showed lower FL compared to WaveOne.

Conclusion: WaveOne Gold and EdgeOne showed superior comparable cyclic fatigue resistance which was higher than that of WaveOne while EdgeFile X7 showed the least cyclic fatigue resistance.

KEYWORDS: WaveOne Gold, Edge files, Fire wire, Mwire, Cyclic fatigue.

* Department of Endodontics, Faculty of Dentistry, Cairo University, Cairo, Egypt
** Department of Endodontics, Faculty of Dentistry, Fayoum University

INTRODUCTION

Separation of endodontic files during clinical use is considered a major problem and is shown to be the most frequent procedural error that could occur during the chemo mechanical preparation [1,2]. The use of NiTi rotary files for root canal preparation has increased owing to their unquestionably favorable properties but unfortunately, they have the drawback of unpredicted fracture. Fatigue fracture happens due to repetitive tensile and compressive stresses at the point of maximum flexure of an instrument rotating in a curved canal and the instrument may not display any sign of fatigue or deformation prior to its use [3–6].

Recent NiTi instruments have been developed with enhanced fracture resistance features that include reciprocating kinematics instead of continuous rotation where reciprocating rotation was shown to increase the cyclic fatigue resistance of NiTi files, compared to continuous rotation[7–9]. The lower stress induced by reciprocating motion enables the endodontist to use a single NiTi instrument to prepare the entire root canal system[10]. The reciprocating motion is based on a counterclockwise (CCW) motion (cutting direction) and a clockwise (CW) motion (release of the instrument) [11]. Furthermore, modification of instruments' designs, its metallurgical properties and surface treatments greatly enhanced their resistance to fracture[12,13].

Edge One and EdgeFile X7 (EdgeEndo, Albuquerque, NM, USA) are two newly introduced files made from heat treated FireWire NiTi which is thought to have an improved cyclic fatigue resistance[14]. Edge One is a reciprocating single file with a parallelogram cross section while EdgeFile X7 is a rotation multiple file system with a parabolic cross section, and the manufacturer claims that both cross sections increase the cutting efficiency and strength of the file rendering it more resistant to fracture[15].

WaveOne and WaveOne Gold (Dentsply, Maillefer, Ballaigues, Switzerland) are single files reciprocating systems with different cross sections, geometry and different alloys. WaveOne is made of M Wire and has a modified convex triangular cross section in the apex with a convex triangular cross section in the middle and coronal sections, WaveOne Gold is manufactured with a gold heat treatment procedure with an off centered parallelogram cross section having two cutting edges. Gold heat treatment is executed manually by heating the file and then cooling slowly which generates Ti_3Ni_4 precipitates dispersed over the surface, in contrast to the premanufacturing heat treatment of M Wire technology. This new heat treatment improves the flexibility of the file and its cyclic fatigue resistance as well [16–1)8].

As the root canal curvature and its radius can affect the cyclic fatigue resistance of NiTi files which in turn possess a significant challenge to clinical endodontic practice[19], this study was conducted to assess and compare the cyclic fatigue resistance of EdgeOne, WaveOne Gold, WaveOne reciprocating file systems and EdgeFile X7rotation file system in different root canal curvatures with different radii of curvatures.

MATERIALS AND METHODS

Grouping

One hundred and sixty files of four different NiTi systems with different metallurgies and kinematics were used in this study and were divided into 4 main groups.

Group 1: WaveOne (Dentsply, Maillefer, Ballaigues, Switzerland) Primary size 25/0.07 made of Mwire in a reciprocating motion.

Group 2: WaveOne Gold (Dentsply, Maillefer, Ballaigues, Switzerland) Primary size (25/0.07) made of gold wire in a reciprocating motion.

Group 3: EdgeOne (EdgeEndo, Albuquerque,

NM, USA) size (25/ Variable taper) made of fire wire in a reciprocation motion

Group 4: EdgeFile X7 (EdgeEndo, Albuquerque, NM, USA) size 25/0.06 made of fire wire in a rotation motion

The main groups were further divided into subgroups according to the different angles of curvatures and radii of curvatures as follows:

Angle 60° with a 2.5mm radius, angle 60° with a 5mm radius.

Angle 90° with a 2.5mm radius and angle 90° a 5mm radius.

All the files were carefully inspected under a dental operating microscope (Seiler, BLVD, St. Louis, MO, USA) at 16 X magnification to detect any defects or deformities.

Cyclic fatigue apparatus

The cyclic fatigue test was performed using a custom-made apparatus that was specially designed for this experiment by using a modification of the apparatus described by Larsen *et al*. [20] and Capar *et al*.[21]. A stainless steel cyclic fatigue testing block with dimensions of 9.5 cm length x 4cm height and 0.5mm in thickness was fabricated. Four artificial canals were milled in this block (angle 90° radius 2.5mm, angle 90° radius 5mm, angle 60° radius 2.5mm and angle 60° radius 5mm) Figure (1). The depth of the simulated canals was 2mm. This block was fixed in a custom made cyclic fatigue testing apparatus to achieve a reproducible position for the handpiece and all the files throughout the test [22].

Cyclic fatigue test

All the files and the artificial canals were lubricated using a synthetic oil lubricant (Pana spray plus, NSK, Japan) to minimize the friction between the canal and files and to ensure the free rotation of files within the artificial canal. The top of the stainless steel block was covered with glass.

After the hand piece was mounted on the apparatus, each file; according to each group and subgroup, was precisely positioned in the block. Instruments were operated in an X smart plus endomotor (Dentsply Sirona, Ballaigues, Switzerland) according to the manufacturers' instructions and the length of the file was adjusted to 19 mm, where WaveOne was operated in the WaveOne Mode, WaveOne gold was operated in the WaveOne Gold Mode, EdgeOne was operated at a speed of 350 rpm and a torque of 3 N.cm in a reciprocating motion (150° counterclockwise (CCW) direction and 30° in a clockwise (CW) direction) and EdgeFile X7 was operated at a speed

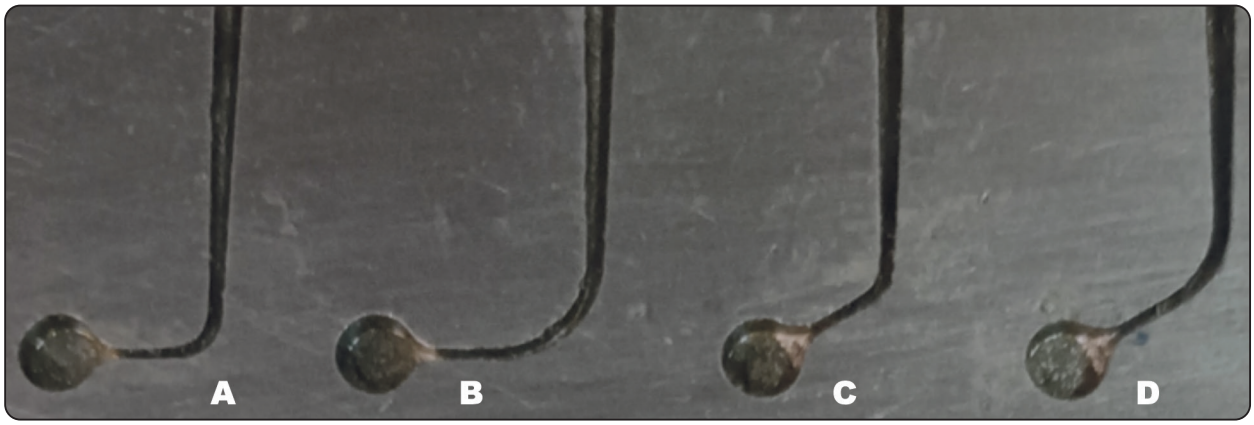

Fig. (1): Cyclic fatigue testing block; (a) angle 90° radius 2.5mm, (b) angle 90° radius 5mm, (c) angle 60° radius 2.5 mm, (d) angle 60° radius 5mm

of 350 rpm and a torque of 3 N.cm in a continuous rotation motion.

All the files were operated until fracture occurs and could be visually and audibly detected. The time from the start of the file motion till it fractures; time to failure (TTF), was recorded in seconds using a digital stopwatch which was started the moment the motor was turned on and was stopped at fracture detection.

The length of the fractured segment of each file (FL) was measured using an Endoblock ruler (Dentsply, Maillefer, Ballaigues, Switzerland).

Statistical analysis

Statistical analysis was performed with IBM SPSS Statistics for Windows, Version 26.0. Armonk, NY: IBM Corp. Data were presented as mean and standard deviation (SD). They were explored for normality using Kolmogorov-Smirnov and Shapiro-Wilk tests. Kruskal Wallis test was used to compare all tested groups followed by Mann Whitney U test for pair wise comparison. Mann Whitney test was used to compare different angles and radii of curvature in each group. The significance level was set at $P \leq 0.05$.

RESULTS

The means and standard deviations of the TTF values are shown in Table 1 and Figure 2. The highest TTF values were found in the WaveOne Gold group followed by the EdgeOne group then the WaveOne group while the least was in the EdgeFile X7. There was no statistically significant difference between WaveOne Gold and EdgeOne at all angles and radii of curvature. There was a statistically significant difference between both the WaveOne Gold, EdgeOne and the EdgeFile X7 where the EdgeFile X7 showed the lowest significant values. WaveOne group showed insignificant difference with all other groups.

For all the tested file systems, Angle 90° with a 2.5mm radius showed the lowest cyclic fatigue followed by Angle 90° with a 5mm radius. There was no statistically significant difference between angle 60° with a 2.5 mm radius and angle 60° with a 5mm radius.

The means and standard deviations of the lengths of the fractured segments (FL) are shown in Table 2 and Figure 3.

TABLE (1): Mean and SD of Time to failure for all the tested groups in seconds

		Angle 60				Angle 90				p-value
		2.5		5		2.5		5		
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Cyclic fatigue test	WaveOne	147.4^{abBC}	28.9	217.8^{abC}	32.1	63.7^{abA}	6.5	111.1^{abB}	15.9	<0.001*
	WaveOne Gold	176.5^{aBC}	26.1	277.6^{aC}	40.0	87.2^{aA}	27.8	139.1^{aB}	19.0	<0.001*
	EdgeOne	170.5^{aBC}	19.9	255.4^{aC}	38.0	78.7^{aA}	23.3	128.8^{aB}	12.5	<0.001*
	EdgeFile X7	111.0^{bBC}	9.4	165.8^{bBC}	33.8	48.0^{bA}	12.9	74.2^{bB}	12.7	<0.001*
p-value		<0.001*		<0.001*		<0.001*		<0.001*		

NS= non-significant, *= significant

Different lowercase letters within each column indicate significant difference. Different uppercase letters within each row indicates significant difference

TABLE (2): Mean and SD for the Lengths of the broken fragments (FL) for all the tested groups in mm

		Angle 60				Angle 90				p-value
		2.5		5		2.5		5		
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Length of the broken fragment	WaveOne	3.6^{aB}	0.6	3.6^{aB}	1.1	2.3^{aA}	0.8	3.2^{aAB}	0.9	0.01*
	WaveOne Gold	2.3^{aA}	0.9	2.6^{bA}	1.0	2.2^{aA}	0.5	3.0^{aA}	1.0	0.260 NS
	EdgeOne	3.1^{aAB}	0.8	3.7^{abB}	1.0	2.3^{aA}	0.5	3.5^{aB}	1.1	0.01*
	EdgeFile X7	3.6^{aB}	0.7	3.4^{bB}	1.0	1.9^{aA}	0.5	2.6^{aAB}	0.6	<0.001*
p-value		0.082 NS		0.009*		0.162 NS		0.298 NS		

NS= non-significant, *= significant

Different lowercase letters within each column indicate significant difference. Different uppercase letters within each row indicates significant difference

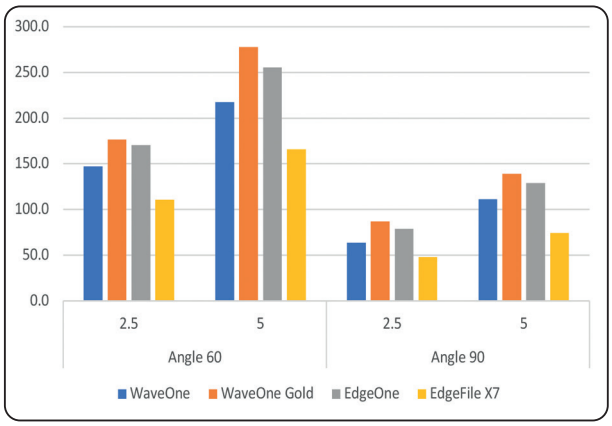

Fig (2): Bar chart showing the Mean and SD of the Time to failure (TTF) for all the tested groups in seconds

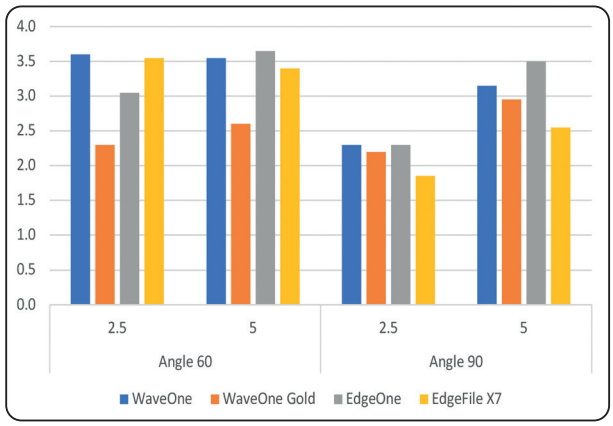

Fig. (3): Bar chart showing Mean and SD for the Lengths of the broken fragments (FL) for all the tested groups in mm.

At different angles and radii of curvature, there was no statistically significant difference among all tested file systems except with Angle 60° with a 5mm radius; in which WaveOne Gold and EdgeFile X7 showed lower fragment length compared to WaveOne.

For WaveOne Gold, insignificant difference was found between the different angles and radii of curvature (p=0.260). On the other hand, for WaveOne, EdgeOne and EdgeFile X7, angle 90° with a 2.5 mm radius showed the lowest fragment length compared to angle 60° with a 5mm radius and a 2.5mm radius.

DISCUSSION

The knowledge about the resistance of files to cyclic fatigue is very essential since it was shown that most of the files that fracture during clinical use, mainly fracture as a result of their cyclic fatigue, that's why manufacturers always try to improve the cyclic fatigue resistance of NiTi rotary files by altering the metallurgy, design, and kinematics of

the files[16,23–25]. Previous studies also reported that the file cyclic fatigue resistance is greatly affected by the radius and angle of the curvature of the root canal [26,27]. Therefore, the aim of this study was to assess and compare the cyclic fatigue resistance of EdgeOne, WaveOne Gold, WaveOne reciprocating file systems and EdgeFile X7rotation file system in different root canal curvatures with different radii of curvatures.

Fire wire (EdgeOne and EdgeFile X7), Gold wire technology (WaveOne Gold), M Wire (WaveOne) instruments were chosen to be tested in this study to reveal whether different manufacturing methods, alloys and kinematics would influence the fatigue resistance of the endodontic instruments produced with different alloys.

Stainless steel artificial canals have been used in the study rather than extracted teeth to standardize the test and to exclude all other possible confounders caused by other mechanisms of file separation away from cyclic fatigue[23,28]. The use of stainless steel material to manufacture the block and milling the canals inside it aimed at preventing the wear of the canals after repeated use thus preserving the same trajectory for all files. Furthermore, the depth of the artificial canals was milled to 2mm in order to accommodate the different sizes and tapers of all files allowing them to rotate freely inside the canal [29].

A glass top cover was used to cover the stainless steel testing block to allow visualization of the file while operating in the canal and the moment at which the instrument fractures, in addition, it also aided in maintaining the oil inside the canal for a longer period, preventing the file from deviating out of the canal space and preventing the loss of the broken fragments [20,21].

The length of the files was adjusted to 19mm using the file stoppers to standardize the instrument placement inside the canals for all files[20,28]

The results of this study showed that the cyclic fatigue values of all the reciprocating file systems; WaveOne Gold, WaveOne and EdgeOne, were greater than that of the rotational motion file system EdgeFileX7. These findings were in accordance with Castello-Escriva *et al*. 2012[30] , Kiefner *et al*. 2014[31] , Alcalde *et al*. 2018[32], Merima *et al*. 2022 [6]. and Bueno *et al*. 2020 [33] who showed that reciprocating motion reduces the cyclic fatigue resistance of endodontic files thus lowering the probability of instrument separation inside the root canal. However, the results were in disagreement with Gundogar *et al*.[16] and Oh *et al*. 2020 [3]. who both compared the cyclic fatigue resistance of WaveOne Gold, Reciproc and Hyflex EDM and concluded that the rotation motion HyFlex EDM showed the highest cyclic fatigue resistance which may be due to its electrical discharge machining process during manufacturing as well as being made of a CM-wire alloy.

In all tested files systems, angle 90° showed less cyclic fatigue resistance than angle 60°. In addition, a 2.5mm radius showed less cyclic fatigue resistance than a 5mm radius. The results were in accordance with Al Halawi *et al*. 2017[28] and Kotsi *et al*. 2011[34] who stated that the cyclic fatigue resistance increases with the decrease in the angle of curvature. The results were also in accordance with Font *et al*. 2012 [35] who stated that the decrease in the root canal radius of curvature significantly increased the likelihood of fracture. However, the results were in disagreement with Pedulla *et al*. 2020 [36] who found that the decrease in radius of curvature increases the cyclic fatigue resistance.

Regarding the two systems made of FireWire; EdgeOne reciprocating file and EdgeFile X7 rotation file, EdgeOne had more cyclic fatigue resistance than EdgeFileX7 which was statistically significant, this result was in accordance with Mathew *et al*. 2019[37] who tested the cyclic fatigue resistance of two

EdgeEndo fire wire files; one reciprocation motion file and one rotational motion file and showed that reciprocation motion files had better cyclic fatigue resistance than the rotational ones.

There was no statistically significant difference between WaveOne Gold and EdgeOne files regarding the cyclic fatigue resistance and both were superior to WaveOne file. The results were in accordance with Uslu *et al*. 2017[38] who investigated the cyclic fatigue resistance of WaveOne and WaveOne Gold under various conditions and concluded that WaveOne Gold had superior cyclic fatigue resistance compared to WaveOne. The results also agreed with Ozyurek 2016[39] who stated that the cyclic fatigue resistance of the WaveOne Gold Primary was higher than that of the WaveOne Primary and Reciproc R25 which may be due to its high Af value and 2-stage transformation behavior. These results disagreed with Jamleh *et al*. 2019[13]. who tested the cyclic fatigue resistance of a FireWire file and a Gold wire file and concluded that the one made of FireWire had a superior cyclic fatigue resistance compared to that made of Gold wire.

Regarding the length of the fractured instrument, angle 90° with a 2.5 mm radius showed the lowest fragment length, and there was no statistically significant difference among all groups except that of angle 60° with a 5 mm radius in the WaveOne Gold and EdgeFile X7 in comparison to WaveOne which could be due to the superior alloy of manufacturing[38]. The fractured length of each file occurred at the center of curvature or just below this point, which confirms that the instruments were positioned in a precise trajectory[16,39]

CONCLUSION

WaveOne Gold and EdgeOne showed a comparable cyclic fatigue resistance which was higher than that of WaveOne while EdgeFile X7 showed the least resistance to cyclic fatigue.

REFERENCES

1. Alfouzan K, Jamleh A. Fracture of nickel titanium rotary instrument during root canal treatment and re-treatment: a 5-year retrospective study. International Endodontic Journal. 2018;51(2):157–163.
2. Ungerechts C, Bårdsen A, Fristad I. Instrument fracture in root canals - where, why, when and what? A study from a student clinic. International Endodontic Journal. 2014;47(2):183–190.
3. Oh S, Kum KY, Kim HJ, Moon SY, Kim HC, Chaniotis A, Perinpanayagam H, Pedulla E, Chang S. Bending resistance and cyclic fatigue resistance of WaveOne Gold, Reciproc Blue, and HyFlex EDM instruments. Journal of Dental Sciences. 2020;15(4):472–478.
4. Shim KS, Oh S, Kum K, Kim YC, Jee KK, Chang SW. Mechanical and Metallurgical Properties of Various Nickel-Titanium Rotary Instruments. BioMed Research International. 2017;2017:4528601.
5. Sattapan B, Nervo GJ, Palamara JEA, Messer HH. Defects in Rotary Nickel-Titanium Files After Clinical Use. Journal of Endodontics. 2000;26(3):161-165.
6. Merima B, Ivona B, Dubravka M, Gianluca P, Ivica A. Surface roughness and cyclic fatigue resistance of reciprocating and novel rotary instruments after use in curved root canals. Australian Endodontic Journal. 2022 May 23; doi: 10.1111/aej.12627. Online ahead of print.
7. De-Deus G, Moreira EJL, Lopes HP, Elias CN. Extended cyclic fatigue life of F2 ProTaper instruments used in reciprocating movement. International Endodontic Journal. 2010;43(12):1063–1068.
8. Olcay K, Eyuboglu TF, Erkan E. Cyclic fatigue resistance of waveone gold, protaper next and 2shape nickel titanium rotary instruments using a reliable method for measuring temperature. Nigerian Journal of Clinical Practice. 2019; 22(10):1335–1340.
9. You SY, Bae KS, Baek SH, Kum KY, Shon WJ, Lee W. Lifespan of one nickel-titanium rotary file with reciprocating motion in curved root canals. Journal of Endodontics. 2010;36(12):1991–1994.
10. Ferreira F, Adeodato C, Barbosa I, Aboud L, Scelza P, Zaccaro Scelza M. Movement kinematics and cyclic fatigue of NiTi rotary instruments: a systematic review. International Endodontic Journal. 2017; 50:143–152.
11. Özyürek T, Uslu G, Yilmaz K. Influence of different

movement kinematics on cyclic fatigue resistance of nickel-titanium instruments designed for retreatment. Saudi Endodontic Journal. 2017;7(3):151.

12. Lopes HP, Gambarra-Soares T, Elias CN, Siqueira JF Jr, Inojosa IF, Lopes WS, Vieira VT. 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):516–520.
13. Jamleh A, Alghaihab A, Alfadley A, Alfawaz H, Alqedairi A, Alfouzan K. Cyclic Fatigue and Torsional Failure of EdgeTaper Platinum Endodontic Files at Simulated Body Temperature. Journal of Endodontics. 2019;45(5):611–614.
14. 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):823–826.
15. EdgeEndo Catalogue 2022.pdf.
16. Gündoğar M, Özyürek T. Cyclic Fatigue Resistance of OneShape, HyFlex EDM, WaveOne Gold, and Reciproc Blue Nickel-titanium Instruments. Journal of Endodontics. 2017;43(7):1192–1196.
17. Bueno CSP, Oliveira DP, Pelegrine RA, Fontana CE, Rocha DGP, Gutmann JL, Bueno CES. Fracture incidence of WaveOne Gold files: a prospective clinical study. International Endodontic Journal. 2020;53(9):1192–1198.
18. Elnaghy AM, Elsaka SE. Mechanical properties of ProTaper Gold nickel-titanium rotary instruments. International Endodontic Journal. 2016;49(11):1073–1078.
19. Ghattas MS, Hoen M. Comparison of resistance to cyclic fatigue of one novel reciprocating endodontic file system with two novel rotary endodontic file systems. Endodontic Practice US. 2015; 8:22–27.
20. Larsen CM, Watanabe I, Glickman GN, He J. Cyclic Fatigue Analysis of a New Generation of Nickel Titanium Rotary Instruments. Journal of Endodontics. 2009;35(3):401–403.
21. Capar ID, Ertas H, Arslan H. Comparison of cyclic fatigue resistance of novel nickel-titanium rotary instruments. Australian Endodontic Journal. 2015;41(1):24–28.
22. Plotino G, Grande NM, Cotti E, Testarelli L, Gambarini G. Blue treatment enhances cyclic fatigue resistance of vortex nickel-titanium rotary files. Journal of Endodontics. 2014;40(9):1451–1453.
23. Sedigh-Shams M, Atbaei M, Asar S, Ghahramani Y. Cyclic fatigue resistance: comparison of AF F-One and One Curve rotary instruments with Hyflex EDM OneFile in root canal therapy. Advances in Applied NanoBio-Technologies [Internet]. 2022(1):14–7. Available from: https://doi.org/10.47277/AANBT/3
24. Plotino G, Grande NM, Testarelli L, Gambarini G. Cyclic fatigue of Reciproc and WaveOne reciprocating instruments. International Endodontic Journal. 2012;45(7):614–618.
25. Castelló-Escrivá R, Alegre-Domingo T, Faus-Matoses V, Román-Richon S, Faus-Llácer VJ. In vitro comparison of cyclic fatigue resistance of ProTaper, WaveOne, and twisted files. Journal of Endodontics. 2012;38(11):1521–1524.
26. Grande NM, Plotino G, Pecci R, Bedini R, Malagnino VA, Somma F. Cyclic fatigue resistance and three-dimensional analysis of instruments from two nickel-titanium rotary systems. International Endodontic Journal. 2006;39(10):755–763.
27. Pruett JP, Clement DJ, Carnes DL. Cyclic Fatigue Testing of Nickel-Titanium Endodontic Instruments. Journal of endodontics. 1997;23(2):77-85.
28. Al Halawi M, Mehdi J, Jasim H. Evaluate the effect of canal curvature on Fracture Resistance and Cyclic Fatigue of Three NiTi Rotary Instruments (A comparative in vitro study). Journal of oral and dental research. 2017;4(2):184-198.
29. Fiad A, el Faramawy M, fahmy sarah. The effect of autoclave sterilization on Cyclic fatigue resistance of two Ni-Ti systems (an In-Vitro study). Egyptian Dental Journal. 2021;67(3):2743–2747.
30. Castelló-Escrivá R, Alegre-Domingo T, Faus-Matoses V, Román-Richon S, Faus-Llácer VJ. In vitro comparison of cyclic fatigue resistance of ProTaper, WaveOne, and twisted files. Journal of Endodontics. 2012;38(11):1521–1524.
31. Kiefner P, Ban M, De-Deus G. Is the reciprocating movement per se able to improve the cyclic fatigue resistance of instruments? International Endodontic Journal. 2014;47(5):430–436.
32. Alcalde MP, Duarte MAH, Bramante CM, de Vasconselos BC, Tanomaru-Filho M, Guerreiro-Tanomaru JM, Pinto JC, Só MVR, Vivan RR. Cyclic fatigue and torsional strength of three different thermally treated reciprocating

nickel-titanium instruments. Clinical Oral Investigations. 2018;22(4):1865–1871.

33. Bueno CSP, Oliveira DP, Pelegrine RA, Fontana CE, Rocha DGP, Gutmann JL, et al. Fracture incidence of WaveOne Gold files: a prospective clinical study. International Endodontic Journal. 2020;53(9):1192–1198.

34. Kosti E, Zinelis S, Molyvdas I, Lambrianidis T. Effect of root canal curvature on the failure incidence of ProFile rotary Ni-Ti endodontic instruments. International Endodontic Journal. 2011;44(10):917–925.

35. Font MG, Duran-Sindreu F, Castro SM, Bellido MM, Martínez RB, Cayón MR. Failure of protaper rotary Ni-Ti instruments used by undergraduate students. Journal of Clinical and Experimental Dentistry. 2012;4(4):199-203.

36. Pedullà E, la Rosa GRM, Virgillito C, Rapisarda E, Kim HC, Generali L. Cyclic Fatigue Resistance of Nickel-titanium Rotary Instruments according to the Angle of File Access and Radius of Root Canal. Journal of Endodontics. 2020;46(3):431–436.

37. Mathew PA, Nair RS, Angelo JMC, Mathai V, Vineet R v., Christopher SR. A comparative evaluation of cyclic fatigue resistance of FlexiCON (Edge Endo) files in rotary versus reciprocating motion at various curvatures - An in vitro study. Journal of Conservative Dentistry. 2019;22(6):554-558

38. 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(5):834–837.

39. Özyürek T. Cyclic Fatigue Resistance of Reciproc, WaveOne, and WaveOne Gold Nickel-Titanium Instruments. Journal of Endodontics. 2016;42(10):1536–1539.