

# Systematic Review

## **A critical appraisal of studies on the cyclic fatigue resistance of HyFlex EDM nickel-titanium instrument**

### **ABSTRACT**

**Aims:** to summarize the currently available evidence to point out the different outcomes of static versus dynamic tests and to assess whether cyclic fatigue tests provide useful data and information for clinical practice

**Study design:** Systematic Review.

**Place and Duration of Study:** From May 2015 to July 2021, a total of 21 studies on HyFlex EDM cyclic fatigue have been published in the Journal of Endodontics and the International Endodontic Journal and Odontology, and the Nigerian Journal of Clinical Practice and Journal of Dental Sciences restorative dentistry and endodontic and MDPI

**Methodology:** different studies comparing between Hyflex EDM and other rotary files as in: wave one gold, reciproc blue.

**Results:** REC showed that HYFLEX EDM has the highest cyclic fatigue resistance and conforming that sterilization has no influence in cyclic fatigue resistance.

**Conclusion:** Non-invasive independent predictors for screening esophageal varices may decrease medical as well as financial burden, hence improving the management of cirrhotic patients. These predictors, however, need further work to validate reliability.

### **1. INTRODUCTION**

Nickel-titanium (NiTi) rotary files became more widely used in endodontics for preparing root canals and with the use of NiTi rotary files, the complications that can be observed when using stainless steel files such as ledges, zips, perforations, and straightened root canals started to be seen less frequently.

In recent years, numerous engine-driven nickel-titanium (NiTi) systems have been introduced to the market (Haapasalo & Shen 2013). Topics of major interest in these

instruments include bending properties and flexibility, cutting efficacy and safety of use, and fracture resistance [1].

Despite the advantages related to the superplasticity, fracture of NiTi files (Serene et al. 1995) due to torsional overloading or flexural fatigue remains a concern in clinical practice (Iqbal et al. 2006). There are Possible strategies to increase the efficiency and safety of NiTi rotary files including an improvement in the manufacturing process, or the use of new alloys that provide superior mechanical proper-ties (Gambarini et al. 2011, Shen et al. 2013a) [2].

Cyclic fatigue resistance of Ni-Ti instruments improved by using different technologies, including heat treatment, electrolytic polishing, and electro-discharge machining<sup>[14]</sup> of electrical discharge machining (EDM) with controlled-memory feature and have greater resistance to cyclic fatigue fracture, micro-hardness, maximumtorque, and distortion angle. When compared to HyFlex CM (Coltene/Whaledent Inc.)<sup>[15-17]</sup>.

HyFlex EDM files are known as a new-generation single-file system made of a controlled memory alloy using electro-discharge machining technology. It was re- ported that the mechanical properties of HEDM files were significantly improved using this technology Thus, it's designed and marketed to shape root canals using a sin-gle-file technique in continuous rotation [3].

HyFlex EDM files have a constant 8% taper in the apical 4 mm; the taper de- creases to 4% toward the coronal region. Throughout the entire working part of the file, there are 3 different horizontal cross-sections: a quadratic cross-section in the apical region, a trapezoidal cross-section in the middle region, and an almost triangu-lar cross-section in the coronal region [4].

The HyFlex EDM is the first file system to feature the use of electrical discharg-ing machining (EDM) technology in contrast to the grinding method, which is conventionally used to produce NiTi files, using electric discharges, the file is shaped by melting and vaporization on the material using a 'non-contact production method (Pirani et al. 2015). According to a previous study, the use of EDM technology createsa crater-like appearance and increased its cyclic fatigue resistance (Pedulla et al. 2016) [5]. It has been tested that Autoclave sterilization generally did not significantlyincrease the cyclic fatigue and torsional fracture resistance of HyFlex EDM [6].

Cyclic fatigue is caused by the alternating tension-compression cycles to which they are subjected when flexed in the maximum curvature of the canal during rotation<sup>[7,8]</sup>. Tension and compression cycles at the point of highest flexure during instrument rotation in a curve result in cyclic fatigue fracture<sup>[9]</sup>.

To evaluate the cyclic fatigue resistance of the file, a static cyclic fatigue resistance test is performed without axial motion, where the instrument rotates at a designated length in the simulated canal until the instrument fractures<sup>[10]</sup>. The dynamic test incorporates axial movement and simulates the clinical situation<sup>[10-13]</sup>.

## **2. MATERIAL AND METHODS / EXPERIMENTAL DETAILS / METHODOLOGY**

### Literature research strategy:

There are a wide range between the cyclic fatigue results of the same instruments. The current review selected the Hyflex EDM instruments as a model and try to figure out the reliability of the static and dynamic cyclic fatigue test as a tool for instruments survival.

### Number of studies on cyclic fatigue

From May 2015 to July 2021, a total of 21 studies on HyFlex EDM cyclic fatigue have been published in the Journal of Endodontics and the International Endodontic Journal and Odontology, and the Nigerian Journal of Clinical Practice and Journal of Dental Sciences restorative dentistry and endodontic and MDPI. The number of such papers increased lately since 2017 Only 8 of 21 (38.095%) used dynamic study tests while the majority of them (85.714%) used static methods. (M. Hulsmann et al 2019)

### Variables in study designs <sup>(18-25)</sup>

Table 1 : Study design variability

No	Study Title	Authors	Journal Name	Year of Publication	Files used in comparison	Type of test (Static or dynamic)	Temperature during the test (Room temperature or simulated body temp.)	Results of the Hyflex EDM (Cyclic fatigue)
1	Cyclic fatigue resistance of HyFlex EDM, Reciproc Blue, WaveOne Gold, and Twisted File Adaptive rotary files under different temperatures and ambient conditions	Mustafa Gündoğar <sup>1</sup> , Taha Özyürek <sup>2</sup> , * Koray Yılmaz <sup>3</sup> and Gülşah Uslu <sup>4</sup>	Odontology	2018	HyFlex EDM, Reciproc Blue, WaveOne Gold, and Twisted File	Static	35°C	The HyFlex EDM file (3456.33 ± 633.37) file had the statistically highest fatigue resistance.
2	Effect of autoclave sterilization on cyclic fatigue and torsional fracture resistance of NiTi rotary instruments	Wooyoung Kim <sup>1</sup> , So-ram Oh <sup>2</sup> , Gil-Joo Ryu <sup>3</sup> , Tae-Hwan Kim <sup>1</sup> , Sung-Jae Kim <sup>1</sup> ,	Odontology	2019	ProTaper Universal (PTU), K3XF, HyFlex EDM (EDM), and TF adaptive (TFA).	Static		EDM CGr1 11,645.3 (1768.0)A, CGr2 11,935.9 (1634.9)A, CGr3 12,577.6 (2525.0)A
3	Torsional and Cyclic Fatigue Resistance of a New Nickel-Titanium Instrument Manufactured by Electrical Discharge Machining	Eugenio Pedullà <sup>1</sup> , Fabio Lo Savio <sup>2</sup> , Simona Boninelli <sup>3</sup> , Gianluca Plotino <sup>4</sup>	Journal of Endodontics, Jendodon	2015	Hyflex EDM OneFile (Coltene/Whaledent AG, Altstätten, Switzerland), Reciproc R25 (VDW, Munich, Germany), and WaveOne Primary (Dentsply Maillefer, Ballaigues, Switzerland)	Static		Hyflex EDM one file (NCF) mean: 973a, SD: 152, min:792, max:1186
4	Correlation between Temperature-dependent Fatigue Resistance and Differential Scanning Calorimetry Analysis for 2 Contemporary Rotary Instruments	Ana Arias, Jose C. Macorra, Sanjay Govindjee, Ove A. Peters	Journal of Endodontics	2017	Forty Hyflex EDM (H-EDM) files, 40 TRUShape (TS) files		Both	H-EDM behavior (room temperature mean life = 725.4 seconds; 95% CI, 658.8–798.8 and body temperature mean life = 717.9 seconds; 95% CI, 636.8–809.3).

5	Cyclic fatigue resistance of several nickel-titanium glide path rotary and reciprocating instruments at body temperature	K Yılmaz, G Uslu, M Gündoğar, T Özyürek, N M Grande, G Plotino	Journal of Endodontics	2018	One G, ProGlider, HyFlex EDM, and R-Pilot glide path NiTi files	Dynamic	Body temperature.	There was no difference between the HyFlex EDM and the ProGlider, HyFlex 388.21 ± 46.62b HY
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6	Cyclic Fatigue Resistance of OneShape, HyFlex EDM, WaveOne Gold, and Reciproc Blue Nickel-Titanium Instruments	Mustafa Gündoğar Ta ha Özyürek	Journal of Endodontics	2017	Reciproc Blue, HyFlex EDM, WaveOne Gold, One-Shape		Room temperature	The HyFlex EDM file (3456.33 ± 633.37) file had the statistically highest fatigue resistance
7	HyFlex EDM: superficial features, metallurgical analysis, and fatigue resistance of innovative electro-discharge machined NiTi rotary instrument	John Wiley & Sons Ltd	International Endodontic Journal	2015	HyFlex EDM prototypes		50 °C	HyFlex EDM 25.08 EDM (981±329) ,40.04 EDM (2013 ±425) , 50.03 EDM (1682 ± 241 )
8	Comparison of the Cyclic Fatigue Resistance of HyFlex EDM, Vortex Blue, ProTaper Gold, and OneCurve Nickel-Titanium Instruments	AD Uygun, M Ünal, S Falakaloğlu, Y Güven	Nigerian Journal of clinical practice	2020	HyFlex EDM, Vortex Blue, ProTaper Gold, and OneCurve Nickel-Titanium Instruments	Dynamic	35°C (±2)	HyFlex EDM number of cycles to fracture = (1710.42114.89), Fragment length = (6.7±049)
9	Cyclic Fatigue Resistance of Rotary and Reciprocating Nickel-Titanium Instruments Subjected to Static and Dynamic Tests	Myintthu ,Arata ebihara ,kei-ichiro maki ,nishijomiki ,Takashi okiji	Journal Of Endodontics	2020	Rotary and Reciprocating Nickel-Titanium Instruments	Both	between 20C and 40C	Static and dynamic cyclic fatigue resistance, median and interquartile range (IQR) of EDM, SCFR: median (723 ), IQR (621.08-792.33), DCFR: median : (2692.71), IQR : (1336.79-2949.06)
10	Cyclic fatigue resistance of R-Pilot, HyFlex EDM, and PathFile nickel-titanium glide path files in artificial canals with double (S-shaped) curvature	G. Uslu1, T. Oezyuerek1, K. Yilmaz2 & M. Guendoglar3	ENDODONTIC JOURNAL	2017	R-Pilot, HyFlex EDM, and PathFile NiTi glide path files		static	PathFile (1675.41 ± 201.55ax) (1062.03 ± 127.44ay) HyFlex EDM (2262.43 ± 271.44bx)(1706.72 ± 209.72by) R-Pilot (4894.82 ± 743.11cx) (3607.57 ± 519.06cy)  R-Pilot had the greatest cyclic fatigue resistance, followed by the HyFlex EDM and PathFile in both the apical and coronal curvatures
11	Evaluation of the Cyclic Fatigue and Torsional Resistance of Novel Nickel-Titanium Rotary Files with Various Alloy Properties	Mehmet Emin Kaval, DDS, PhD,* Ismail Davut Capar, DDS, PhD,† and Huşeyin Ertas, DDS, PhD†	Journal of Endodontics	2016	Hyflex EDM, ProTaper Gold (PTG), and ProTaper Universal (PTU)		23C	HyFlex EDM (3689a ± 1577) ProTaper Universal (350b ± 30) ProTaper Gold (5.9a ± 0.9) HyFlex EDM instruments exhibited the highest cyclic fatigue resistance and were followed by PTG and PTU groups

12	Evaluation of Cyclic Fatigue of Hyflex EDM, Twisted Files, and ProTaper Gold Manufactured with Different Processes: An In Vitro Study	Pooja D. Khandagale,1 Prashant P. Shetty,2 Saleem D. Makandar,3 Pradeep A. Bapna,2 Mohmed Isaqali Karo-bari,3,4 Anand Marya,5 Pietro Messina, and Giuseppe Alessandro Scardina 6	Journal of Endodontics	2021	Hyflex EDM, Twisted files, and ProTaper Gold	static and dynamic	Hyflex EDM (774.29) Twisted files (654.875) ProTaper Gold (375.575). A statistically significant difference was observed between the tested groups
13	Effect of Torsional and Fatigue Preloading on HyFlex EDM Files	Ya Shen, Charles Tra,, Ahmed Hieawy, Zhejun Wang,* and Markus Haapasalo,	j endod journal	2018	EDM and CM files were used	EDM files (51C–54C) than for CM files (32C–37C)	EDM instruments subjected to fatigue testing had a higher Nf compared to CM instruments. EDM ( 2490 306) results showed that EDM files had fatigue resistance superior to CM files, and the fatigue life of EDM instruments is longer than CM instruments. Even though a low amount of torsional preloading reduced the fatigue resistance of EDM instruments, the fatigue resistance of EDM is still higher than that of CM files without any preloading
14	Bending resistance and cyclic fatigue resistance of WaveOne Gold, Reciproc Blue, and HyFlex EDM instruments	Soram Oh ay , Kee-Yeon Kum by , Hyun-Jung Kim, Su-Young Moon c , Hyeon-Cheol Kim d , Antonis Chaniotis e, Hiran Perinpanayagam f , Eugenio Pedulla g, Seok Woo Chang	journal of Dental Sciences	2019	WaveOne Gold, Reciproc Blue, and HyFlex EDM instruments	static 22C	The Af of HyFlex EDM was found to be far above BT, which results in instruments that are in the martensitic state in clinical temperature. HyFlex EDM: RT >596.4 (102.7) BT > 599.6 (108.5) compared to WOG, RPB, and HDM systems. HyFlex EDM will exert superior flexibility and fatigue fracture resistance and might be better for the treatment of curved canals. The cyclic fatigue resistance of WOG and RPB decreased with the temperature increase. In contrast, the resistance of HDM didn't change.

### 3. RESULT AND DISCUSSION:

The introduction of rotary NiTi files in the field of endodontics has significantly changed the outcome of endodontic therapy. Rotary file systems have greatly enhanced the

level of precision and speed of the endodontic treatment. Apart from advantages, the rotary files also possess a few disadvantages. The file separation may take place inadvertently, which compromises the outcome of the endodontic rehabilitation and healing of the periradicular tissues [26].

Several factors contribute to the fracture of the rotary instrument. These include handling by the operator, usage, anatomy of the root canal, and design of NiTi rotary instruments. Because of these, various studies have been performed to investigate the reasons and physics of the instrument fracture [27]. The mechanism of rotary instrument separation was reported as a torsional failure and cyclic fatigue fracture [28]. Cyclic flexural fatigue occurs when an instrument rotates in a curved canal by repetitive compressive and tensile stresses, and torsional failure occurs when the instrument's tip is locked or jammed in the canal, but the shank of the file keeps rotating [29].

Although the resistance of files to CF has been improved with the development of new alloys [30-33], it is important to patients and still a concern for endodontists and general practitioners. Manufacturers in the field of endodontics continue to introduce new strategies to enhance the properties of rotary instruments.

The endodontic literature contains a plethora of studies on static and dynamic cyclic fatigue resistance tests performed on a large array of rotary or reciprocating nickel-titanium endodontic instruments. This review aimed to summarize the currently available evidence to point out the different outcomes of static versus dynamic tests and to assess whether cyclic fatigue tests provide useful data and information for clinical practice [34].

This focused review aimed to provide evidence-based answers to two main questions:

1. Are there different outcomes from static versus dynamic tests?
2. Do cyclic fatigue tests provide useful data and information for clinical practice?

These results suggest that both static and dynamic tests are currently poorly standardized. Numerous parameters have been shown to exert a marked impact on the results (Plotino et al. 2009) [35], with the environmental temperature representing the most relevant parameter

(Capar et al. 2014<sup>[36]</sup>, De Vasconcelos et al. 2016<sup>[37]</sup>, Shen et al. 2016<sup>[38]</sup>, Dosanjhet al. 2017<sup>[39]</sup>, Grande et al. 2017<sup>[40]</sup>, Alfawaz et al. 2018<sup>[41]</sup>, Yil-maz et al. 2018<sup>[42]</sup>).

Environmental temperature has a 500% impact on the lifetime of an instrument (Grande et al. 2017<sup>[40]</sup>). It can therefore be deduced that studies conducted under room temperature or under temperatures that do not correspond to the clinical situation any longer appear acceptable from a scientific point of view.

Furthermore, the available data strongly suggest that there is an urgent need to agree on either static or dynamic experimental set-ups. Evidence suggests that dynamic tests might have some advantages compared to static approaches, although maximal differences between highest and lowest published values for one instrument were considerably higher in dynamic than in static tests. Thus, it might be speculated that dynamic tests are more prone to procedural errors and are more technique-sensitive than static tests as it is difficult to keep the instruments in a precise trajectory (Li et al. 2002<sup>[43]</sup>, Plotino et al. 2010<sup>[44]</sup>, Pedulla et al. 2018a<sup>[45]</sup>).

UNDER PEER REVIEW

Once a consensus has been reached on the favored method, the next step should be to clearly define all relevant experimental parameters to limit the diversity of experimental designs and, as a result, distortion of the results. A clearly defined test design, preferably similar to an ISO specification, is a prerequisite for a reliable assessment of the corresponding studies (Plotino et al. 2009<sup>[35]</sup>). On the other hand, this review aims to answer if the cyclic fatigue provides information for clinical practice?

This question has no value since there is the vast majority of responses of the same instrument in different studies. All the studies that have been reviewed have limited information to be useful in clinician selection of instrument with no convincing evidence due to different study designs and results. Moreover, the majority of these studies have limitations in vitro, several variables such as taper, cross-sectional size, and manufacturing techniques affect the performance of files <sup>[46]</sup>.

different studies comparing between Hyflex EDM and other rotary files as in: wave one gold, reciproc blue and REC showed that HYFLEX EDM has the highest cyclic fatigue resistance and confirming that sterilization has no influence in cyclic fatigue resistance.

The clinician must use the data from the published study regarding the cyclic fatigue with a great caution.

## REFERENCES

- 1) M. Hulsmann<sup>1</sup>, D. Donnermeyer<sup>2</sup> & E. Schafer A critical appraisal of studies on cyclic fatigue resistance of engine-driven endodontic instruments, Endodontic journal, 2019, 1427-1445
- 2) . Pirne, et al. HyFlex EDM: superficial features, metallurgical analysis and fatigue resistance of innovative electro-discharge machined NiTi rotary instruments, Endodontic journal, 2016, 483-93

- 3) [HyFlexCMbrochure.Coltene/ WhaledentGmbH+Co.KG;2015](#)
- 4) K Yılmaz , G Uslu , M Gündoğar , T Özyürek , N M Grande , G Plotino. Cyclic fatigue resistances of several nickel-titanium glide path rotary and reciprocating instruments at body temperature. Endodontic journal 2018 ,924-930
- 5) Sattapan B, Nervo GJ, Palamara JE, Messer HH. Defects in rotary nickel-titanium files after clinical use. J Endod 2000;26:161–5.
- 6) Plotino G, Grande NM, Cordaro M, et al. A review of cyclic fatigue testing of nickel-titanium rotary instruments. J Endod 2009;35:1469–76.
- 7) Shen Y, Cheung GS-P, Peng B, et al. Defects in nickel-titanium instruments after clinical use: part 2—fractographic analysis of fractured surface in a cohort study. J Endod 2009;35:133–6.
- 8) Lopes HP, Elias CN, Vieira MV, et al. Fatigue life of Reciproc and Mtwo instruments subjected to static and dynamic tests. J Endod 2013;39:693–6.

- 9) Kelesx A, Eymirli A, Uyanık O, et al. Influence of static and dynamic cyclic fatigue tests on the lifespan of four reciprocating systems at different temperatures. *Int Endod J* 2019;52:880–6.
- 10) Haikel Y, Serfaty R, Bateman G, et al. Dynamic and cyclic fatigue of engine-driven rotary nickel-titanium endodontic instruments. *J Endod* 1999;25:434–40.
- 11) Yao JH, Schwartz SA, Beeson TJ. Cyclic fatigue of three types of rotary nickel-titanium files in a dynamic model. *J Endod* 2006;32:55–7.
- 12) Gundoglar M, Ozyurek T. Cyclic fatigue resistance of OneShape, HyFlex EDM, WaveOne gold, and Reciproc blue nickel-titanium instruments. *J Endod* 2017;43:1192–6.
- 13) 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;44:630-634
- 14) Goo HJ, Kwak SW, Ha JH, Pedulla E, Kim HC. Mechanical properties of various heat-treated nickel-titanium rotary instruments. *J Endod* 2017, 1872-1877
- 15) Iacono F, Pirani C, Generali L, et al. Structural analysis of HyFlex EDM instruments. *Int Endod J* 2017 Mar;50(3):303-313.
- 16) Iacono F, Pirani C, Generali L, et al. Structural analysis of HyFlex EDM instruments. *Int Endod J* 2017;50:303–13.
- 17) Gutmann J, Gao Y. Alteration in the inherent metallic and surface properties of nickel-titanium root canal instruments to enhance

performance, durability and safety: a focused review. *Int Endod J* 2012;45:113–28.

- 18) Attapan B, Nervo GJ, Palamara JE, Messer HH. Defects in rotary nickel-titanium files after clinical use. *J Endod*. 2000;26(3):161–5
- 19) Ferreira F, Adeodato C, Barbosa I, et al. Movement kinematics and cyclic fatigue of NiTi rotary instruments: a systematic review. *Int Endod J* 2016;50:143–152
- 20) Plotino G, Grande NM, Cotti E, et al. Blue treatment enhances cyclic fatigue resistance of vortex nickel-titanium rotary files. *J Endod* 2014;40:1451–3
- 21) Testarelli L, Plotino G, Al-Sudani D, Vincenzi V, Giansiracusa A, Grande NM, et al. Bending properties of a new nickel-titanium alloy with a lower percent by weight of nickel. *J Endod*. 2011;37:1293–5.
- 22) 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;40:1451–3.
- 23) Peters O, Gluskin A, Weiss R, Han J. An in vitro assessment of the physical properties of novel Hyflex nickel-titanium rotary instruments. *Int Endod J*. 2012;45:1027–34

- 24) De-Deus G, Silva EJNL, Vieira VTL, Belladonna FG, Elias CN, Plotino G, et al. Blue thermomechanical treatment optimizes fatigue resistance and flexibility of the reciproc files. *J Endod*. 2017, 462-466.
- 25) Gündoğar M, Özyürek T. Cyclic fatigue resistance of OneShape, HyFlex EDM, WaveOne Gold, and Reciproc Blue nickel-titanium instruments. *J Endod*. 2017;43:1192–1196.
- 26) Alapati S., Brantley W., Svec T., Powers J., Nusstein J., Daehn G. SEM observations of nickel-titanium rotary endodontic instruments that fractured during clinical use. *Journal of Endodontics*. 2005;31(1):40–43.
- 27) Cheung G. S. P., Darvell B. W. Low-cycle fatigue of rotary NiTi endodontic instruments in hypochlorite solution. *Dental Materials*. 2008;24(6):753–759.
- 28) Gary S. P., Cheung Instrument fracture: mechanisms, removal of fragments, and clinical outcomes. *Endodontic Topic*. 2007;16(1):1–26.
- 29) Cheryl Gary S. P., Cheung Y. Effect of environment on low-cycle fatigue of a nickel-titanium instrument. *Journal of Endodontics*. 2007;33(12):433–437.
- 30) Shen Y, Zhou H, Zheng Y, et al. Current challenges and concepts of the thermomechanical treatment of nickel-titanium instruments. *J Endod* 2013;39:163–72.

- 31) De-Deus G, Silva EJ, Vieira VT, et al. Blue thermomechanical treatment optimizes fatigue resistance and flexibility of the Reciproc files. *J Endod* 2017;43:462–466.
- 32) Plotino G, Grande NM, Cotti E, et al. Blue treatment enhances cyclic fatigue resistance of vortex nickel-titanium rotary files. *J Endod* 2014;40:1451–3.
- 33) Nguyen HH, Fong H, Paranjpe A, et al. Evaluation of the resistance to cyclic fatigue among ProTaper Next, ProTaper Universal, and Vortex Blue rotary instruments. *J Endod* 2014;40:1190–3.
- 34) M. Hülsmann, D. Donnermeyer, E. Schäfer. A critical appraisal of studies on cyclic fatigue resistance of engine-driven endodontic instruments. *International Endodontic Journal*. 2019.
- 35) Plotino G, Grande N, Cordaro M, Testarelli L, Gambarini G. A review of cyclic fatigue testing of nickel-titanium rotary instruments. *Journal of Endodontics* 35, 1469–76.
- 36) Capar ID, Ertas H, Arslan H (2014) Comparison of cyclic fatigue resistance of nickel-titanium coronal flaring instruments. *Journal of Endodontics* 40, 1182–5.
- 37) De Vasconcelos RA, Murphy S, Carvalho CA, Govindjee RG, Govindjee S, Peters OA (2016) Evidence for reduced fatigue resistance of contemporary rotary instruments exposed to body temperature. *Journal of Endodontics* 42, 1782–7.
- 38) Shen Y, Hieawy A, Huang X, Wang Z, Maezono H, Haapasalo M (2016) Fatigue resistance of a 3-dimensional conforming nickel-

titanium rotary instrument in double curvatures. *Journal of Endodontics* 42, 961–4.

- 39) Dosanjh A, Paurazas S, Askar M (2017) The effect of temperature on cyclic fatigue of nickel-titanium rotary endodontic instruments. *Journal of Endodontics* 43, 823–6.
- 40) Grande NM, Plotino G, Silla E, et al (2017) Environmental temperature drastically affect flexural fatigue resistance of nickel-titanium rotary files. *Journal of Endodontics* 43, 1157–60.
- 41) Alfawaz H, Alqedairi A, Alsharekh H, Amuzaini E, Alzahrani S, Jamleh A (2018) Effects of sodium hypochlorite concentration and temperature on the cyclic fatigue resistance of heat-treated nickel-titanium rotary instruments. *Journal of Endodontics* 44, 1563–6.
- 42) Yilmaz K, Uslu G, Gündoğar M, Özyürk N, Grande M, Plotino G (2018) Cyclic fatigue resistances of several nickel-titanium glide path rotary and reciprocating instruments at body temperature. *International Endodontic Journal* 51, 924–30.
- 43) Li UM, Lee BS, Shih CT, Lan WH, Lin CP (2002) Cyclic fatigue of endodontic nickel-titanium rotary instruments: static and dynamic tests. *Journal of Endodontics* 28, 448–51.
- 44) Plotino G, Grande N, Mazza C, Petrovic R, Testarelli L, Gambarini G (2010) Influence of size and taper of artificial canals on the trajectory of NiTi instruments in cyclic fatigue studies. *Oral Surgery Oral Medicine Oral Pathology Oral Radiology and Endodontology* , 2010 , 60–6.

- 45) Pedulla E, Corsentino G, Ambu F, et al , Influence of continuous rotation or reciprocation of Optimum Torque Reverse motion on cyclic fatigue resistance of nickel-titanium instruments. International Endodontic Journal 2018 .51, 522–8.
- 46) Gavini G, Caldeira CL, Akisue E, et al. Resistance to flexural fatigue of Reciproc R25 files under continuous rotation and reciprocating movement. J Endod 2012;38:684
- 47) Gianluca P , Nicola M , massimo C, luca T, Gianluca G , A Review of Cyclic Fatigue Testing of Nickel-Titanium Rotary Instruments , J endod , 2009, 1469-76.

M hulsmann , D donnermeyer , E Schafer , A critical appraisal of studies on cyclic fatigue resistance of engine-driven endodontic instruments, int endod j 2019, 142