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Factors Affecting the Cyclic Fatigue of Heat-Treated NiTi Rotary File: A Review

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Abstract

Clinicians face a major problem when a Nickel-Titanium (NiTi) rotary endodontic instruments fracture occurs inside the canal during treatment. It is time consuming for removal of these separated instruments, in addition to its technical difficulty. So for these reasons it is important to reduce the risk of file fracture. As a sequel, several attempts have been made to improve the mechanical features of NiTi rotary files, like changes in speed of operation, changing the geometric and dimensional characteristics, and several different metal treatments. The revolution of new heat-treated NiTi instruments opens a new era for basic, clinical and scientific research. This article concerns mostly with environmental and heat-treated factors, irrigation and type of rotation and their effects on heat-treated NiTi instruments found in most studies.

Introduction:

Different instruments used in root canal treatment (RCT) including instruments used for canal preparation and obturation like explorers, files and reamers, irrigation needles, Lentulo spirals, etc.[1]. Fracture of these instruments especially files and reamers may occur inside the canal during treatment. The cyclic fatigue fractures occur as a result of repetitive tension and compression stresses that the file is exposed to within the curved canals[1]. It is time consuming for removal of these separated instruments, in addition to its technical difficulty. So for these reasons it is important to reduce the risk of file fracture. As a sequel, several attempts have been made to improve the mechanical features of NiTi rotary files, like changes in speed of operation, changing the geometric and dimensional characteristics, such as tip sizing, taper, cross-section design, helical angle and pitch length design, operation speed and several different metal treatments[2,3]. In recent years, development in the processing and manufacturing of rotary NiTi have been attempted to reduce the

incidence of separated instruments [2,3]. This revolution of new heat-treated NiTi instruments opens a new era for basic, clinical, and scientific research. This article concerns mostly with environmental and heat-treated factors, irrigation, and type of rotation and their effects on heat-treated NiTi instruments found in most studies.

Literature Review

The literature review was organized into three sections (i) Environment and heat – treatment. (ii) Irrigants. (iii) Kinematics movements of instruments.

Effect of Environmental and Heat Treatment

Nickel-Titanium alloy has two heat-dependent crystal states (martensite and austenite)[4]. At temperatures higher than the transformation level, NiTi alloy has an austenite structure and is more rigid, whereas it is more flexible in low temperature with a martensite structure [4]. Martensite transforms into austenite, with shape memory properties when the NiTi alloy is heated over the intermediate temperature[5]. The newly developed heat-treated alloys present a higher transitional temperature that is come to or above the body temperature, when comparing with conventional NiTi alloy [4]. The life of cyclic fatigue not increased when NiTi alloy heat treated below 300ºC as found by **Yahata *et al*.,**[6] due to the remaining crystal lattice defect. Moreover the surface hardness of NiTi alloy decrease at 600ºC owing to recrystallization of NiTi alloy [7]. **Chi *et al*., in 2016**[8] conducted a study to assess the effect of two different heat treatments on the cyclic fatigue of ProTaper universal (PTU) F2 files (no treatment group, HT400ºC and HT600ºC groups). They found that the performance of PTU files in cyclic fatigue life was qualified through heat treatment. The cyclic fatigue life for files in the HT400ºC group was higher than file in control group. Moreover, files in the HTºC600 group showed extended cyclic fatigue life in comparing with the files in HT400ºC group and control group. Many studies concluded that to obtain a high percentage of the martensitic stage, intermediate temperature of martensitic transformation should be alter by heat technology. Preceding reports have indicated that flexibility of heat-treated NiTi instruments increased with extended cyclic fatigue life[9, 10, 11]. Many factors influence the heat treatment effect included: time, temperature, history of processing, and amount of prior cold work, which will develop different mechanical features for NiTi. Although different researchers have investigated the cyclic fatigue resistance of NiTi instruments at room temperature[12, 13, 14, 15, 16]. Other studies assessed the cyclic fatigue of NiTi alloy at body temperature to confirm significance results and resemble the flexural behavior at temperatures inside the root canal[17, 18, 19]. Authors have shown that body temperature capable of modifying the transformation temperatures of the NiTi, and greatly affect the flexural resistance of NiTi instruments [18, 19, 20]. Consequently the effect of environment and body temperatures was consider by **deVasconcelos *et al*.**,[20] two temperatures (20ºC and 37ºC) were taken into consideration when the fracture resistance of different rotary instruments compared: Hyflex control memory (HyFlex CM), TRShape, Vortex Blue (VB), and PTU, and correspond the results with transformation temperatures of martensitic. At ambient temperature, Hyflex CM file had a superior fracture resistance which is significant, followed by VB and TRUShape, whereas the lowest fracture resistance showed by PTU file. These results maintain the assurance that NiTi alloy is the more flexible and fatigue resistance when it is in more martensite phase[21, 22]. In point of fact, instruments manufactured with conventional NiTi wire instruments less flexible and fatigue resistant than M-Wire (Sportswire LLC, Langley, OK)[23,24]. The fatigue resistance for all instruments was decreased at body temperature, even with a different extent. For explanation the significant lowering in fatigue life at room temperature, one should consider the pertinent transformation temperatures. Furthermore, **Dosanjb *et al*.**, in 2017[17] compared the cyclic fatigue of instruments with dissimilarity in metallurgy at various

temperatures (3º,22º, 37º, and 60ºC).Three groups of NiTi instruments; EdgeFile (EF), VB, and ESX group were used. At 3ºC there was a decrease in number of cyclic fatigue (NCF) for EF group. The explanation of this decreasing may be related to the same mechanism of how traditional metals become more brittle just as they cool, causing them to fracture. Lowering the NCF related to the transition of NiTi alloy to an austenitic phase that caused by heating process. The NCF was doubled for Files in both the ESX and VB groups when they were placed in frozen water because they may have a more austenitic phase at room temperature in comparing with files in the EF group. By decreasing the temperature, they transition to a more martensitic phase. The difference in NCF for the ESX group from 37ºC to 60ºC was not significant. Their explanation that the files in the ESX group already being in mostly an austenitic phase at body temperature; therefore, further heating did not have an effect.

Dosanjb *et al*., study's supported by another study carried out by **Arias *et al***.,[25] who also found that rotary instruments with different post-machining heat treatment responded differently to changed ambient temperatures, and all instruments lasted significantly longer at room than at body temperature. The fracture resistance of different invention NiTi rotary single file, One Curve (OC), OneShape new generation (OSNG) and One shape (OS), was assessed by **Staffoli *et al***.,[26] in relation to environmental temperature and heat treatment. They found that when the temperature increased from 0 to 35ºC all files showed decrease in the fracture resistance significantly.

Moreover OC files with new features of thermal treatment showed the highest fatigue resistance in comparing with other groups at all the temperature, intension that mechanical properties and fracture resistance of NiTi instruments improved by heat-treatment of rotary NiTi files [11, 27, 28]. Statistical results from **Klymus** study proposed that instruments with Blue technology were more affected than instruments with Gold technology at body temperature[29]. The crystal lattice of Reciproc Blue (Rec Blue) 25.08 and X1 Blue file (X1 25.06) mostly changed suddenly at body temperature than that of WaveOne Gold (WOG) 25.07, and this could explain why the WOG 25.07 file showed reduction in the fracture resistance. The austenite finishing temperature of Gold (50.1–51.8 °C)[10] is higher than Blue technology (33.71–38 °C)[17]. At body temperature Rec Blue 25.08 and X1 25.06 given a lower percentage of martensitic phase than WOG 25.07, thereby decreasing the flexibility and the cyclic fatigue resistance. Their conclusions support the aforementioned studies in which the researchers showed a reduction in the time of the cyclic fatigue when exposed to body temperature[17,18].

Effect of irrigants

During root canal preparation NiTi files have contact with the irrigation solutions [30,3132,], that causes the deformation and corrosion of files and might lead to unexpected separation of file during instrumentation[30,31,32,]. Many types of irrigation solutions used in chemo-mechanical preparation, sodium hypochlorite NaOCl consider as a gold standard irrigant[30]. NaOCl with CIO− ions found in the structure were stated to have the effect on the increasing the corrosion. Many studies found that NaOCl and ethylene diamine tetraacetic acid (EDTA) solutions changed the physical properties of files in sites, where they are in contact with files, and the files fractured at those sites[32, 33, 34]. The antimicrobial properties and the tissue-dissolving capability of NaOCl could be enhanced by adding a surfactant; disturb the material; raising its concentration, volume, and/or temperature[35]. When single-file NiTi systems are recommended for root canal instrumentation of necrotic teeth, using preheated NaOCl could be beneficial because of its increased antimicrobial properties[35]. In spite of these advantages, its toxicity may be damaging to apical tissues when NaOCl drive out accidentally into the apical area and it is also highly destructive to metals[32]. Certain researchers have concluded that NaOCl affects the cyclic fatigue resistance of NiTi rotary files by way of corrosion[36,37,38].

Huang *et al*., introduced a different fatigue test model that mimic the clinical situation to estimate the corrosion effect of 5.25% NaOCl on NiTi rotary files under three different temperatures (22°C, 37°C, and 60°C). They found that the fatigue manner of NiTi instruments does not affect by NaOCl 5.25%, moreover no pitting or crevice corrosion was recognized on the fracture surface. The fracture resistance of NiTi files should be tested under particular temperature conditions. For determining the fracture risk at body temperature the austenite finish temperature of a file is essential [(39)].

In 2019 **Keles *et al*.**,[(40)] showed the adverse effect of NaOCl on the cyclic fatigue life of heat-treated files when the temperature of NaOCl increased. However, heat-treated files showed better cyclic fatigue resistance than conventional NiTi, even in high temperature[(40)]. Many studies used different temperatures and concentrations of NaOCl to see their effect on different types of NiTi instruments. **Alfawazet *et al*.**, in 2018[(41)] assessed the effect of temperature and the type of irrigants on the number of cycles to fracture of the ProTaper Gold (PTG) F2. They found that the fatigue resistance of PTG was decrease when the temperature increase from 23^{0}C in distilled water to 60^{o}C5 in 25% NaOCl. They concluded that NaOCl with increasing the surrounding temperature have adverse effect on the fatigue resistance. Other examined the effect of different type of irrigants. The cyclic fatigue resistance of WO, Reciproc, and PTU files was examined under the effects of 5.25% NaOCl and 17% EDTA solutions[(42)]. **Pedulla *et al*.**, found a decrease in the fracture resistance of all files actively exposed to EDTA for 3 minutes. Moreover they determined that NaOCl did not affect the cyclic fatigue resistance of the tested files. In 2016 **Elnaghy and Elsaka**[(31)] evaluated the effects of NaOCl and saline irrigants on the fracture resistance of WaveOne (WO) and Reciproc instruments. The authors determined the adverse effects of both NaOCl and saline solutions on the cyclic fatigue resistance of both files. Because of their finding, they stated that the irrigants caused deterioration and distortion on the surface of files, thus predisposing the files to possible accidental fractures.

Uslu *et al*., [(43)] **Topcuoglu *et al*.**[(13)] and **Ozyurek**[(44)] found that the cyclic fatigue resistance of WOG files was statistically higher than that of WO file, when WOG and WO files were compared with each other. These results established that the new heat metal treatment probably depict the main variable, which increases the fracture resistance of these files[(27)]. Accordingly to the data of their study, the submersion of WO and WOG into the NaOCl and EDTA solutions did not affect the cyclic fatigue resistance of the files. Their foundation are in agreement with the results of preceding study published that the cyclic fatigue resistance of conventional NiTi instruments which operate in rotation movement like Mtwo and Revo-S[(45)], and instruments which operate in reciprocating motion and made from M-Wire alloy like WO and Reciproc files[(46)], did not show any decreasing in cyclic fatigue resistance statistically when exposed to NaOCl for 1 to 5 minutes.

When NaOCl and EDTA used as mixing solution in final irrigation of root canals, a white color precipitate formed that reduces the antimicrobial characteristic and tissue dissolvability of NaOCl[(47)]. For this reason, hydroxyethylidene-bisphosphonate (HEBP) was recommended by **Zehnder *et al*.**, to be used with NaOCl as an alternative to EDTA as chelating [(33,48)]. When HEBP combined with NaOCl does not create any precipitate and does not affect the antimicrobial effectiveness of NaOCl solution, and tissue dissolving property [(33)]. Moreover the NaOCl/HEBP mixture reduced debris accumulation and smear layer formation.

To assess the effect of etidronate on the cyclic fatigue of heat-treated instruments **Erik *&Ozyurek*** in 2018[(49)] compared HEBP, NaOCl, and EDTA solutions and their mixtures on the cyclic fatigue resistance of Rec Blue, WOG and HyFlex Electrical Discharge Machining (HyFlex EDM) instruments that having various metallurgic properties at 37°C. According to the results of their study, the cyclic

fatigue resistance of tested files not affected by any type of irrigants when used alone. In accordance to their results, it was shown that the NaOCl irrigant had no effect on the fracture resistance of WOG and Rec Blue files[48]. While the cyclic fatigue resistances of HyFlex EDM, Rec Blue, and WOG files were reduced when NaOCl used in combination with HEBP at body temperature. This combination induces corrosion on the files, and decreases the cyclic fatigue resistance of tested files.

Effect of Kinematics Movements of file

The bulk of studies reviewed in this article addressed that reciprocating motion provided better resistance to cyclic fatigue than full rotation[12,50.51,52.53,54,55,56]. Different factors like Instrument design, rotational speed, the degree of curvature of the root canal, torque, alloy, and type of kinematics used, may affect the cyclic fatigue of rotary files. Many of rotary endodontic files initially produced to work in continuous rotation have been tested using different reciprocating motions, comparing their cyclic fatigue after use [51,57.58.59,60]. These studies used the same file system with different Kinematics to assess the effect of Kinematics motion only. So the influence of Kinematics could be evaluated without another variable.

Perez Higueras *et al*.,[61] and **De- Deus *et al*.**, [50, 12] reported that numerous continuous motion files improved cyclic fatigue resistance when moved with reciprocation movement; 144 clockwise (CW) and 72 counterclockwise (CCW). **da Frota *et al*.**, [62], **Degan *et al*.**, [63], **Elska & Elnaghy** [64] , and **El-Anwar *et al*.**,[65] used each of the files in motion in line with their program of the manufacturer. Most of the studies obtained better cyclic fatigue resistance with reciprocating motion compared with the full rotary files.

Moreover **Rubio *et al*.**,[66] stated that Reciprocating motion (Reciproc and WOG) improves the cyclic fatigue results compared to almost all the continuous motion systems studied (F360, iRace, Protaper Next (PTN), OS and Revo-S).

A significant difference was also found between different reciprocating motions with different angles of rotation[58]. Reconstruct the extent of reciprocation has a significant effect on the cyclic fatigue life of NiTi files[67]. **Gambarini *et al.,*** stated that the differences in the fracture resistance of different reciprocating angles might be inversely proportional to the angle of rotation [68]. **Capar& Arslan** in 2016[68] compared the lifespan of Reciproc instruments used with different motions whether in reciprocating motion 150°CCW-30° CW, 270° CCW-30°CW, 360° CCW-30° CW, or in continuous rotation utilizing a static testing set-up. The longest lifespan showed by all reciprocating motions compared to continuous rotation. **Karatas *et al*.**,[69] used a static motion device with different reciprocating movements (150° CW/30° CCW, 210° CW/30° CCW and 360° CW/30° CCW) and continuous rotation to analyzed the cyclic fatigue resistance of reciprocating instruments, OS and WO . All the reciprocating motions resulted in prolonged fatigue life, compared to continuous motion.

A short time ago Optimum Torque Reverse (OTR) kinematic has been developed to utilize the benefits of reciprocation and reduce its disadvantages[70]. During full rotation, the torque is automatically measured: the file moves in CW continues if the torque is less than the set value, but if the torque has reached the set value, the file moves reversely in CCW by 90° and then continues in the cutting direction CW for 180° till the torque becomes less than the set value. Thus, the reciprocation of OTR motion is incomplete reciprocation with CW rotational effect, so it can be used with instruments that cut in a CW direction like PTN, Revo S, Mtwo, Twisted File and EndoWave (these instruments are designed to cut in continuous CW rotation). As stated by manufacturer, the file fatigue as well as the risk of file fracture can be reduced with OTR [70].

Pedullà *et al*., in 2018[53] evaluated the resistance to cyclic fatigue of PTN, Revo-S, Mtwo, Twisted Files, and EndoWave. They were utilizing in continuous rotation or in reciprocation of OTR. According to inferential analysis all experimental files

significantly had higher cyclic fatigue in reciprocation of OTR motion than full rotation.

In 2019 **Pedulla *et al*.,**[71] conducted another study to assessed the influence of OTR on the cyclic fatigue resistance of heat-treated single file. HyFlex EDM, Reciproc R25 (Rec), primary WO, and primary WOG were used. Resistance to fracture was determined by registering time to fracture in artificial canal. Only Hyflex EDM and WOG showed higher fatigue resistance in reciprocation of OTR rotation compared to proper rotation. The reciprocating kinematics tested could explain the higher fracture resistance of HyFlex EDM in reciprocating OTR motion than in proper rotation[72,73]. However, cyclic fatigue of files operated with reciprocating kinematics was lower than the one used with the reciprocation of OTR motion, on the whole there was no reported difference in the cyclic fatigue of instruments operated with "RECIPROC ALL" and "WAVEONE ALL" movements,[54]. The explanation of this result may be the synergistic effect of the gold heat- treatment[74] and OTR reciprocating motion. Furthermore, the synergistic effect of CM heat treatment and EDM manufacturing process could explain the lower time to fracture (TTF) values of WOG than the ones of HyFlex EDM[75].

Conclusions:

- Cyclic fatigue resistance of new heat-treated NiTi rotary instrument reduced at body temperature.
- Post or pre, heat treatment of NiTi modifies the cyclic fatigue resistance with positive results.
- Irrigants negatively affected the cyclic fatigue resistance of heat-treated files and their adverse effect increase with increasing temperature.
- Movement kinematics is amongst the factors determining the resistance of rotary NiTi instruments to cyclic fracture. Moreover, the reciprocating movement promoted an extended cyclic fatigue life of the heat-treated NiTi instruments in comparison with conventional rotation.

References

1-McGuigan MB, Louca C, Duncan HF. Endodontic instrument fracture: causes and prevention. British Dental journal.214(7):341-8;2013.

2-Pereira ES, Peixoto IF, Viana AC, Oliveira, II, Gonzalez BM, Buono VT, et al. Physical and mechanical properties of a thermomechanically treated NiTi wire used in the manufacture of rotary endodontic instruments. International endodontic journal. 45(5):469-74;2012.

3-Ahn SY, Kim HC, Kim E. Kinematic Effects of Nickel-Titanium Instruments with Reciprocating or Continuous Rotation Motion: A Systematic Review of In Vitro Studies. Journal of endodontics. 42(7):1009-17;2016.

4-Shen Y, Zhou HM, Zheng YF, Campbell L, Peng B, Haapasalo M. Metallurgical characterization of controlled memory wire nickel-titanium rotary instruments. Journal of endodontics. 37(11):1566-71;2011.

5-Shen Y, Zhou HM, Zheng YF, Peng B, Haapasalo M. Current challenges and concepts of the thermomechanical treatment of nickel-titanium instruments. Journal of endodontics. 39(2):163-72;2013.

6-Yahata Y, Yoneyama T, Hayashi Y, Ebihara A, Doi H, Hanawa T, et al. Effect of heat treatment on transformation temperatures and bending properties of nickel-titanium endodontic instruments. International endodontic journal. 42(7):621-6;2009.

7-Capar ID, Ertas H, Arslan H. Comparison of cyclic fatigue resistance of novel nickel-titanium rotary instruments. Australian endodontic journal. 41(1):24-8;2015.

8-Chi CW, Lai EH, Liu CY, Lin CP, Shin CS. Influence of heat treatment on cyclic fatigue and cutting efficiency of ProTaper Universal F2 instruments. Journal of dental sciences. 12(1):21-6;2017.

9-Gao Y, Gutmann JL, Wilkinson K, Maxwell R, Ammon D. Evaluation of the impact of raw materials on the fatigue and mechanical properties of ProFile Vortex rotary instruments. Journal of endodontics. 38(3):398-401;2012.

10-Hieawy A, Haapasalo M, Zhou H, Wang ZJ, Shen Y. Phase Transformation Behavior and Resistance to Bending and Cyclic Fatigue of ProTaper Gold and ProTaper Universal Instruments. Journal of endodontics. 41(7):1134-8;2015.

11-Gundogar M, Ozyurek T. Cyclic Fatigue Resistance of OneShape, HyFlex EDM, WaveOne Gold, and Reciproc Blue Nickel-titanium Instruments. Journal of endodontics. 43(7):1192-6;2017.

12-De-Deus G, Silva EJ, Vieira VT, Belladonna FG, Elias CN, Plotino G, et al. Blue Thermomechanical Treatment Optimizes Fatigue Resistance and Flexibility of the Reciproc Files. Journal of endodontics. 43(3):462-6;2017.

13-Topcuoglu HS, Duzgun S, Akti A, Topcuoglu G. Laboratory comparison of cyclic fatigue resistance of WaveOne Gold, Reciproc and WaveOne files in canals with a double curvature. International endodontic journal. 50(7):713-7;2017.

14-Kaval ME, Capar ID, Ertas H. Evaluation of the Cyclic Fatigue and Torsional Resistance of Novel Nickel-Titanium Rotary Files with Various Alloy Properties. Journal of endodontics. 42(12):1840-3;2016.

15-Silva EJ, Rodrigues C, Vieira VT, Belladonna FG, De-Deus G, Lopes HP. Bending resistance and cyclic fatigue of a new heat-treated reciprocating instrument. Scanning. 38(6):837-41;2016.

16-Keskin C, Inan U, Demiral M, Keles A. Cyclic Fatigue Resistance of Reciproc Blue, Reciproc, and WaveOne Gold Reciprocating Instruments. Journal of endodontics. 43(8):1360-3;2017.

17-Dosanjh A, Paurazas S, Askar M. The Effect of Temperature on Cyclic Fatigue of Nickel-titanium Rotary Endodontic Instruments. Journal of endodontics. 43(5):823-6;2017.

18-Jamleh A, Yahata Y, Ebihara A, Atmeh AR, Bakhsh T, Suda H. Performance of NiTi endodontic instrument under different temperatures. Odontology. 104(3):324-8;2016.

19-de Hemptinne F, Slaus G, Vandendael M, Jacquet W, De Moor RJ, Bottenberg P. In Vivo Intracanal Temperature Evolution during Endodontic Treatment after the Injection of Room Temperature or Preheated Sodium Hypochlorite. Journal of endodontics. 41(7):1112-5;2015.

20-de Vasconcelos RA, Murphy S, Carvalho CA, Govindjee RG, Govindjee S, Peters OA. Evidence for Reduced Fatigue Resistance of Contemporary Rotary Instruments Exposed to Body Temperature. Journal of endodontics. 42(5):782-7;2016.

21-Alapati SB, Brantley WA, Iijima M, Schricker SR, Nusstein JM, Li UM, et al. Micro-XRD and temperature-modulated DSC investigation of nickel-titanium rotary endodontic instruments. Dental materials : official publication of the Academy of Dental Materials. 25(10):1221-9;2009.

22-Shen Y, Zhou H, Coil JM, Aljazaeri B, Buttar R, Wang Z, et al. ProFile Vortex and Vortex Blue Nickel-Titanium Rotary Instruments after Clinical Use. Journal of endodontics. 41(6):937-42;2015.

23-Pereira ES, Gomes RO, Leroy AM, Singh R, Peters OA, Bahia MG, et al. Mechanical behavior of M-Wire and conventional NiTi wire used to manufacture rotary endodontic instruments. Dental materials : official publication of the Academy of Dental Materials. 29(12):e318-24;2013.

24-Shen Y, Coil JM, Zhou H, Zheng Y, Haapasalo M. HyFlex nickel-titanium rotary instruments after clinical use: metallurgical properties. International endodontic journal. 46(8):720-9;2013.

25-Arias A, Hejlawy S, Murphy S, de la Macorra JC, Govindjee S, Peters OA. Variable impact by ambient temperature on fatigue resistance of heat-treated nickel titanium instruments. Clinical oral investigations. 23(3):1101-8;2019.

26-Staffoli S, Grande NM, Plotino G, Ozyurek T, Gundogar M, Fortunato L, et al. Influence of environmental temperature, heat-treatment and design on the cyclic fatigue resistance of three generations of a single-file nickel-titanium rotary instrument. Odontology. 107(3):301-7;2019.

27-Plotino G, Grande NM, Mercade Bellido M, Testarelli L, Gambarini G. Influence of Temperature on Cyclic Fatigue Resistance of ProTaper Gold and ProTaper Universal Rotary Files. Journal of endodontics. 43(2):200-2;2017.

28-Ozyurek T, Gundogar M, Uslu G, Yilmaz K, Staffoli S, Nm G, et al. Cyclic fatigue resistances of Hyflex EDM, WaveOne gold, Reciproc blue and 2shape NiTi rotary files in different artificial canals. Odontology. 106(4):408-13;2018.

29-Klymus ME, Alcalde MP, Vivan RR, So MVR, de Vasconselos BC, Duarte MAH. Effect of temperature on the cyclic fatigue resistance of thermally treated reciprocating instruments. Clinical oral investigations. 23(7):3047-52;2019.

30-Zehnder M. Root canal irrigants. Journal of endodontics. 32(5):389-98;2006.

31-Elnaghy AM, Elsaka SE. Effect of sodium hypochlorite and saline on cyclic fatigue resistance of WaveOne Gold and Reciproc reciprocating instruments. International endodontic journal. 50(10):991-8;2017.

32-Bonaccorso A, Tripi TR, Rondelli G, Condorelli GG, Cantatore G, Schafer E. Pitting corrosion resistance of nickel-titanium rotary instruments with different surface treatments in seventeen percent ethylenediaminetetraacetic Acid and sodium chloride solutions. Journal of endodontics. 34(2):208-11;2008.

33-Lottanti S, Gautschi H, Sener B, Zehnder M. Effects of ethylenediaminetetraacetic, etidronic and peracetic acid irrigation on human root dentine and the smear layer. International endodontic journal. 42(4):335-43;2009.

34-Shen Y, Qian W, Abtin H, Gao Y, Haapasalo M. Effect of environment on fatigue failure of controlled memory wire nickel-titanium rotary instruments. Journal of endodontics. 38(3):376-80;2012.

35-Stojicic S, Zivkovic S, Qian W, Zhang H, Haapasalo M. Tissue dissolution by sodium hypochlorite: effect of concentration, temperature, agitation, and surfactant. Journal of endodontics. 36(9):1558-62;2010.

36-Cavalleri G, Cantatore G, Costa A, Grillenzoni M, Comin Chiaramonti L, Gerosa R. The corrosive effects of sodium hypochlorite on nickel-titanium endodontic instruments: assessment by digital scanning microscope. Minerva stomatologica. 58(5):225-31;2009.

37-Fatma Y, Ozgur U. Evaluation of surface topography changes in three NiTi file systems using rotary and reciprocal motion: An atomic force microscopy study. Microscopy research and technique. 77(3):177-82;2014.

38-Cai JJ, Tang XN, Ge JY. Effect of irrigation on surface roughness and fatigue resistance of controlled memory wire nickel-titanium instruments. International endodontic journal. 50(7):718-24;2017.

39-Huang X, Shen Y, Wei X, Haapasalo M. Fatigue Resistance of Nickel-titanium Instruments Exposed to High-concentration Hypochlorite. Journal of endodontics. 43(11):1847-51;2017.

40-Keles A, Uzunoglu Ozyurek E, Uyanik MO, Nagas E. Effect of Temperature of Sodium Hypochlorite on Cyclic Fatigue Resistance of Heat-treated Reciprocating Files. Journal of endodontics. 45(2):205-8;2019.

41-Alfawaz H, Alqedairi A, Alsharekh H, Almuzaini E, Alzahrani S, Jamleh A. Effects of Sodium Hypochlorite Concentration and Temperature on the Cyclic Fatigue Resistance of Heat-treated Nickel-titanium Rotary Instruments. Journal of endodontics. 44(10):1563-6;2018.

42-Pedulla E, Franciosi G, Ounsi HF, Tricarico M, Rapisarda E, Grandini S. Cyclic fatigue resistance of nickel-titanium instruments after immersion in irrigant solutions with or without surfactants. Journal of endodontics. 40(8):1245-9;2014.

43-Uslu G, Ozyurek T, Yilmaz 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. 44(5):834-7;2018.

44-Ozyurek T. Cyclic Fatigue Resistance of Reciproc, WaveOne, and WaveOne Gold Nickel-Titanium Instruments. Journal of endodontics. 42(10):1536-9;2016.

45-Pedulla E, Grande NM, Plotino G, Pappalardo A, Rapisarda E. Cyclic fatigue resistance of three different nickel-titanium instruments after immersion in sodium hypochlorite. Journal of endodontics. 37(8):1139-42;2011.

46-Pedulla E, Grande NM, Plotino G, Palermo F, Gambarini G, Rapisarda E. Cyclic fatigue resistance of two reciprocating nickel-titanium instruments after immersion in sodium hypochlorite. International endodontic journal. 46(2):155-9;2013.

47-Grawehr M, Sener B, Waltimo T, Zehnder M. Interactions of ethylenediamine tetraacetic acid with sodium hypochlorite in aqueous solutions. International endodontic journal. 36(6):411-7;2003.

48-Tartari T, Guimaraes BM, Amoras LS, Duarte MA, Silva e Souza PA, Bramante CM. Etidronate causes minimal changes in the ability of sodium hypochlorite to dissolve organic matter. International endodontic journal. 48(4):399-404. 22;2015.

49-Erik CE, Ozyurek T. Effects of etidronate, NaOCl, EDTA irrigation solutions and their combinations on cyclic fatigue resistance of nickel-titanium single-file rotary and reciprocating instruments at body temperature. Odontology. 107(2):190-5;2019.

50-De-Deus G, Moreira EJ, Lopes HP, Elias CN. Extended cyclic fatigue life of F2 ProTaper instruments used in reciprocating movement. International endodontic journal. 43(12):1063-8;2010.

51-Gambarini G, Gergi R, Naaman A, Osta N, Al Sudani D. Cyclic fatigue analysis of twisted file rotary NiTi instruments used in reciprocating motion. International endodontic journal. 45(9):802-6;2012.

52-Nguyen HH, Fong H, Paranjpe A, Flake NM, Johnson JD, Peters OA. Evaluation of the resistance to cyclic fatigue among ProTaper Next, ProTaper Universal, and Vortex Blue rotary instruments. Journal of endodontics. 40(8):1190-3;2014.

53-Pedulla E, Corsentino G, Ambu E, Rovai F, Campedelli F, Rapisarda S, et al. Influence of continuous rotation or reciprocation of Optimum

Torque Reverse motion on cyclic fatigue resistance of nickel-titanium rotary instruments. International endodontic journal. 51(5):522-8;2018.

54-Pedulla E, Grande NM, Plotino G, Gambarini G, Rapisarda E. Influence of continuous or reciprocating motion on cyclic fatigue resistance of 4 different nickel-titanium rotary instruments. Journal of endodontics. 39(2):258-61;2013.

55-Rubini AG, Sannino G, Pongione G, Testarelli L, Al Sudani D, Jantarat J, et al. Influence of file motion on cyclic fatigue of new nickel titanium instruments. Annali di stomatologia. 4(1):149-51;2013.

56-Wan J, Rasimick BJ, Musikant BL, Deutsch AS. A comparison of cyclic fatigue resistance in reciprocating and rotary nickel-titanium instruments. Australian endodontic journal : the journal of the Australian Society of Endodontology Inc. 37(3):122-7;2011.

57-Gambarini G, Rubini AG, Al Sudani D, Gergi R, Culla A, De Angelis F, et al. Influence of different angles of reciprocation on the cyclic fatigue of nickel-titanium endodontic instruments. Journal of endodontics. 38(10):1408-11;2012.

58-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. 47(5):430-6;2014.

59-Kim HC, Kwak SW, Cheung GS, Ko DH, Chung SM, Lee W. Cyclic fatigue and torsional resistance of two new nickel-titanium instruments used in reciprocation motion: Reciproc versus WaveOne. Journal of endodontics. 38(4):541-4;2012.

60-Lee W, Hwang YJ, You SY, Kim HC. Effect of reciprocation usage of nickel-titanium rotary files on the cyclic fatigue resistance. Australian endodontic journal : the journal of the Australian Society of Endodontology Inc. 39(3):146-50;2013.

61-Perez-Higueras JJ, Arias A, de la Macorra JC. Cyclic fatigue resistance of K3, K3XF, and twisted file nickel-titanium files under continuous rotation or reciprocating motion. Journal of endodontics. 39(12):1585-8;2013.

62-da Frota MF, Espir CG, Berbert FL, Marques AA, Sponchiado-Junior EC, Tanomaru-Filho M, et al. Comparison of cyclic fatigue and torsional resistance in reciprocating single-file systems and continuous rotary instrumentation systems. Journal of oral science. 56(4):269-75;2014.

63-Dagna A, Poggio C, Beltrami R, Colombo M, Chiesa M, Bianchi S. Cyclic fatigue resistance of OneShape, Reciproc, and WaveOne: An in vitro comparative study. Journal of conservative dentistry : JCD. 17(3):250-4;2014

64-Elsaka SE, Elnaghy AM. Cyclic fatigue resistance of OneShape and WaveOne instruments using different angles of curvature. Dental materials journal. 34(3):358-63;2015.

65-El-Anwar MI, Yousief SA, Kataia EM, El-Wahab TM. Finite Element Study on Continuous Rotating versus Reciprocating Nickel-Titanium Instruments. Brazilian dental journal. 27(4):436-41;2016.

66-Rubio J, Zarzosa JI, Pallares A. A Comparative Study of Cyclic Fatigue of 10 Different Types of Endodontic Instruments: an in Vitro Study. Acta stomatologica Croatica. 53(1):28-36;2019.

67-Saber Sel D, Abu El Sadat SM. Effect of altering the reciprocation range on the fatigue life and the shaping ability of WaveOne nickel-titanium instruments. Journal of endodontics. 39(5):685-8;2013.

68-Capar ID, Arslan H. A review of instrumentation kinematics of engine-driven nickel-titanium instruments. International endodontic journal. 49(2):119-35;2016.

69-Karatas E, Arslan H, Buker M, Seckin F, Capar ID. Effect of movement kinematics on the cyclic fatigue resistance of nickel-titanium instruments. International endodontic journal. 49(4):361-4;2016.

70-Plotino G, Ahmed HM, Grande NM, Cohen S, Bukiet F. Current Assessment of Reciprocation in Endodontic Preparation: A Comprehensive Review-Part II: Properties and Effectiveness. Journal of endodontics. 41(12):1939-50;2015.

71-Pedulla E, Ambu E, Rovai F, Chang SW, Campedelli F, Corsentino G, et al. Influence of proper or reciprocating optimum torque reverse kinematics on cyclic fatigue of four single files. Journal of investigative and clinical dentistry. 10(3):e12409;2019.

72-Elnaghy AM, Elsaka SE. Torsion and bending properties of OneShape and WaveOne instruments. Journal of endodontics. 41(4):544-7;2015.

73-Gavini G, Caldeira CL, Akisue E, Candeiro GT, Kawakami DA. Resistance to flexural fatigue of Reciproc R25 files under continuous rotation and reciprocating movement. Journal of endodontics. 38(5):684-7;2012.

74-Ozyurek, T. Cyclic Fatigue Resistance of Reciproc, WaveOne, and WaveOne Gold Nickel-Titanium Instruments.J Endod. 42(10): 1536-9;2016.

75-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. 40(9):1451-3;2014.