Original Articles

Root Canal Angulation Change When Using Reciprocating Files in Different Temperatures

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Abstract

Heat-treated NiTi files express different properties at body temperature depending on the type of heat treatment. The aim of this study was to evaluate the reduction of root canal angulation using Blue, Gold and M wire NiTi file systems at different temperatures in simulated severely curved root canals. Eighty-eight resin models with 45° curved root canals were divided into eight groups based on temperature during instrumentation and file type: WaveOne Gold primary file (WOG), WaveOne primary file (WO), Reciproc Blue file (RPB), and Reciproc file (RP) at room temperature (25°C), with four additional groups at intracanal temperature (35°C). Resin models and handpieces were mounted on a customized fixed stand with restricted vertical handpiece movement in a temperature-controlled incubator. The sample preparations were conducted consistently in terms of cycle and amplitude by one operator. Curvature angulation of the canal was analyzed by using ImageJ according to Schneider's method. Mean differences in curvature degrees before and after instrumentation were compared within each group. The results showed that both temperature and file type affected the reduction in canal angulation ($p < 0.001$). WOG and RPB showed the lowest mean angulation reduction, followed by RP and WO ($p < 0.001$). There was a significant difference between 25°C and 35°C instrumentation in the WO and RP groups ($p < 0.001$), but not in the WOG or RPB groups ($P = 0.65, 0.17$). In severely curved canals, reduction of canal angulation after preparation was influenced by file type especially with M-wire (WO, RP) and temperature (35°C).

Keywords: Blue wire, Gold wire, M wire, Root canal angulation reduction, Temperature

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Introduction

A prognosis for endodontic treatment depends on successfully eliminating microorganisms from the affected root canals. Therefore, thoroughly preparing the root canal system would enhance the efficiency of irrigants and medicaments and optimal filling. Certain errors, such as ledges, transportation, zipping, and perforation, may occur during mechanical instrumentation, especially with stainless-steel files in a severely curved canal. Rotary nickel-titanium (NiTi) files, developed in 1988,[1] were designed to prevent these errors. Because of its flexibility, it could follow and conform to the original canal's shape and maintain the original foramen in its natural position.

Conventional NiTi alloys have been the raw material for the NiTi rotary files for several years. However, file separation due to cyclic fatigue failure sometimes occurs when the files are subjected to repeated bending and rotation within the curved canal. Improvement in metallurgy, heating, and cooling of the alloys significantly reduced cyclic fatigue failure and improved safety in curve canals. The first generation of heat-treated NiTi files is known as M-wire (Dentsply: Maillefer, Switzerland) and R-phase wire (SybronEndo: California, USA). In cooperation with the heat-treated files, the concepts of single-use and reciprocation motion were introduced as WaveOne (WO, Dentsply: Maillefer, Switzerland) and Reciproc (RP, VDW: Munich, Germany). They are more resistant to cyclic fatigue but still exhibit the same property as conventional NiTi alloy, which is the stress-induced martensitic property. This means that the deformed shape recovers to its original shape when the external force is removed.[2-5]

With a different heat-treating process, the degree of martensitic condition varies among each file system. The NiTi alloy of gold and blue wire as WaveOne Gold; WOG, (Dentsply: Maillefer, Switzerland) and Reciproc Blue; RPB, (SybronEndo: California, USA) are at a more martensitic phase at room temperature.[6] They can be deformed because of the reorientation of the martensitic crystalline structure, but they will recover their shape on heating above the transformation temperature, becoming more austenitic at higher temperatures.[5] Metallurgically, gold heat-treated files are more ductile, providing higher flexibility than conventional NiTi files and first-generation M wire files.[7]

Most of the previous cyclic fatigue and shaping ability studies of the NiTi files were performed at room temperature (20-25°C).[6,8,9] The results showed that the heat-treated file could maintain the working length, conform to the original canal anatomy, and have less canal transportation when compared to the conventional NiTi rotary files.[9-12] To simulate conditions closer to the natural environment within the root canal system, the temperature of approximately 35°C or 95°F was used in the *in vitro* cyclic fatigue experiments.[13,14] Results showed a reduction of cyclic fatigue of the heat-treated file, except for the Hyflex EDM file, at body temperature as compared to room temperature.[13]

The effect of temperature change might alter the file property. When flies have an austenitic state at body temperature, they become stiffer and have less fatigue resistance. This might be the cause of canal transportation or file separation in patients. However, how body temperature affects the ability of the heat-treated NiTi files to maintain the original root canal shape, especially in a severe curve canal, is still unknown. This study aimed to compare the change of root canal angulation before and after instrumentation with RP, WO, RPB, and WOG at the environment temperature of 25°C and 35°C in the resin model with a simulated 45° root canal.

Material and method

Resin models simulating 45°curved root canals (Nissin E-ENDR001 Series; Nissin Dental Products, Kyoto, Japan) were employed in this study. Prior to instrumentation, a glide path was confirmed using a K-file #15/.02 (Dentsply Sirona, Ballaigues, Switzerland). The resin models, with the glide path file inserted at the working length, were placed on a custom fixed stand and photographed at 8x magnification using a stereo-microscope (stereomicroscope system SZ 61, OLYMPUS corporation, Japan) to obtain pre-instrumentation images.

A total of 88 resin models were divided into eight experimental groups based on temperature and file type: WaveOne Gold primary file (WOG), WaveOne primary file (WO), Reciproc Blue file (RPB), and Reciproc file (RP) at room temperature (25°C), with four additional groups at intracanal temperature (35°C). All four file types were used as single-use instruments. The resin model, along with a 6:1 contra angle handpiece powered by a torque-control motor (X-smart plus; Dentsply Sirona, Ballaigues, Switzerland), was mounted on a custom fixed setting within a temperature-controlled incubator (Fig. 1). The incubator maintained a temperature of either 25°C or 35°C with 95% humidity, ensuring strict temperature control within a +/-1°C. Prior to preparation, verification was conducted using a thermocouple to recheck the temperature. The handpiece speed and torque were set according to the manufacturer's instructions. The WaveOne All program was configured for the WOG and WO groups, while the Reciproc All program was set for the RPB and RP groups. The mounted handpiece was moved up and down by operator, limited to the vertical direction only by custom fixed setting. Each rotary file was inserted into the root canal, and three pecking motions with a 3 mm amplitude were performed for three cycles, with the operator reaching the working length. The duration of one cycle was controlled not to exceed 5 seconds. After each cycle of instrumentation, the root canal was irrigated with 1 mL of distilled water that had been incubated in the same incubator at a consistent temperature. The temperature accuracy was confirmed using a thermocouple before applying it with a needle gauge 30 into the canal. Patency was ensured by employing a K-file #10/.02. The debris was cleaned from the cutting blade of the file using a moist, clean gauze.

After root canal preparation, the clean and dry resin models, with the rotary file inserted at the working length, were photographed under the stereomicroscope at 8x magnification using the same custom fixed stand as pre-instrumentation images. These images served as post-instrumentation images. The angulation of the canal curvature in the superimposed pre- and post-instrumentation images was analyzed using the ImageJ program (National Institutes of Health, Bethesda, MD) based on Schneider's technique. The difference in canal curvature angulation before and after instrumentation was compared among each group.

Data analysis was performed using IBM SPSS Statistics for Windows version 28.0 (IBM, Armonk, NY, USA). The Shapiro-Wilk test was used to assess the normal distribution of the data. The mean difference in root canal angulation between pre- and post-instrumentation images was compared among the groups using the Kruskal-Wallis test. The effect of file type and temperature on the difference in angulation was analyzed using a univariate test with Bonferroni correction. Additionally, comparisons of the difference in angulation for each temperature within the same file type were conducted using the Mann-Whitney U test. The significance level was set at 5% (.05).

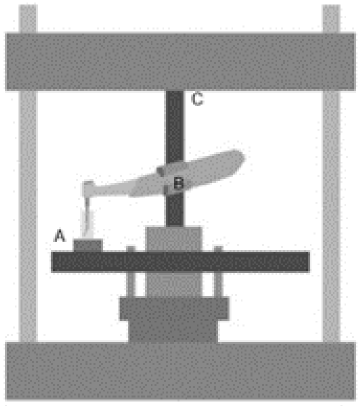

Figure 1 *Illustration of the customized device used for standardization of operator-related-variables. A; custom stand for fixed resin block, B; handpiece holder, C; vertical axis with a handle for operator to move handpiece upward and downward only*

Results

After root canal preparation at 35°C, the results showed that 5 out of 11 resin models in the RP group and 9 out of 11 resin models in the WO group exhibited transportation from the original canal (Fig. 2E and 2F). Transportation began at an average distance of 3.82±0.47 mm and 4.02±0.49 mm, shortened from the working length in the RP and WO groups, respectively. Conversely, in the RP and WO groups at 25°C, as well as in the WOG and RPB groups at both temperatures, canal preparation conformed to the root canal curvature.

Root canal preparation with each file system at both temperatures resulted in varying degrees of canal angulation reduction. The difference in curvature degrees between pre- and post-instrumentation was calculated and compared using the Kruskal-Wallis test (P = .05). The mean angulation reduction for each group is presented in Table 1. At both temperatures, the order of angulation reduction from lowest to highest was RPB, WOG, RP, and WO, respectively. The mean angulation reduction in the WO and RP groups was statistically higher than that in the WOG and RPB groups ($P < .05$), but there was no statistically significant difference ($P > .05$) between the WO and RP groups and the WOG and RPB groups.

Within groups of the same file type, only the WO and RP groups exhibited a statistically significant difference in root canal angulation reduction when comparing instrumentation at 35°C and 25°C (Mann-Whitney U test, $P < .001$) (Fig. 3). The results of the univariate analysis showed that the factors of file type and temperature during canal preparation significantly influenced the angulation change ($P < .001$), with the file type factor having a stronger effect on the degree of angulation reduction compared to the temperature factor.

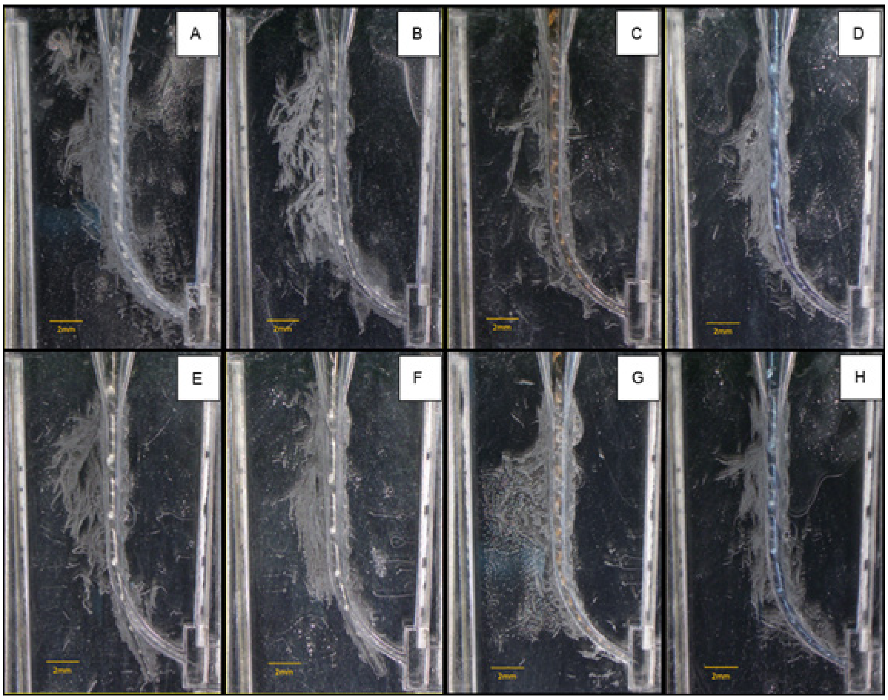

Figure 2 *The superimposed images pre-and post-instrumentation were obtained from imageJ program at 25°C A; Reciproc, B; WaveOne, C; WaveOne Gold and D; Reciproc Blue and 35°C E; Reciproc, F; WaveOne, G; WaveOne Gold and H; Reciproc Blue*

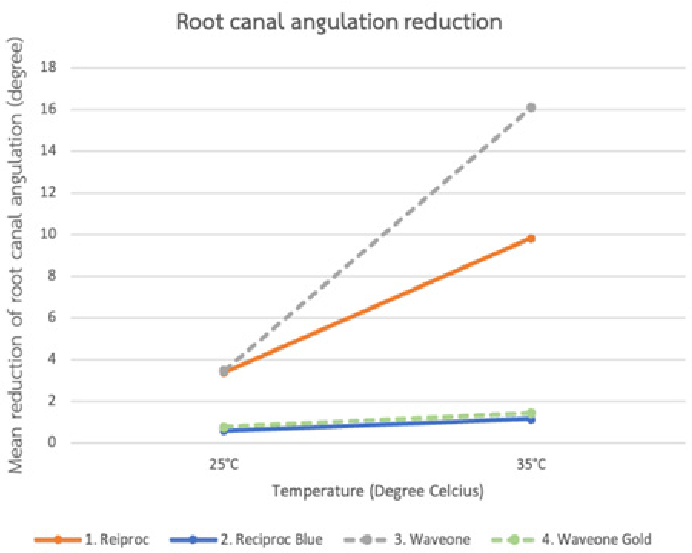

Figure 3 *The mean of root canal angulation (degree) produced by instrumentation with 4 different endodontic file types in different temperatures (25°C and 35°C) ((*); The mean difference was significantly different at different temperature)*

Table 1 *Root canal preparation with each file system at both temperatures resulted in varying degrees of reduction in root canal curvature*

Group	Reduction in root canal curvature angulation		*P*-value (Angulation change between 25°C and 35°C)
	Mean ± SD at 25°C	Mean ± SD at 35°C	
1. RP	3.383 ± 0.203 [a]	9.844 ± 2.223 [a]	<0.001*
2. RPB	0.571 ± 0.116 [b]	1.069 ± 1.029 [b]	0.652
3. WO	3.477 ± 0.258 [a]	16.108 ± 2.896 [a]	0.008*
4. WOG	0.766 ± 0.255 [b]	1.434 ± 0.346 [b]	0.171

The Mann-Whitney U test for the significance of the preparation temperature (25° or 35°C) on the mean reduction in root canal curvature angulation after using 4 different endodontic file systems (RP; Reciproc, RPB; Reciproc Blue, WO; WaveOne and WOG; WaveOne Gold). (*) = data was statistically significant different at different temperature (P-value < .001) The same letters show differences were not statistically significant (P > .05) in comparison with different groups in the same column

Discussion

This present study investigated the ability of four NiTi endodontic file systems in shaping severely curved canal resin models under different temperatures based on root canal angulation changes. Based on the results of this study, WOG and RPB showed significantly less canal angulation change compared to WO and RP at room temperature (25°C). The degree of angulation change ranged from 0.57-0.76 and 3.383-3.47 degrees fromRPB-WOG and RP-WO respectively. This finding contrasts with previous studies that showed no significant difference in the ability of WO, RP, WOG, and RPB to maintain the curved canal of extracted human molar teeth.[9,10] Previous studies reported only a 1.3 to 1.9 degree of angulation change after canal preparation, with WOG and RPB exhibiting the lowest values. The difference in the study's outcome was attributed to the use of severely curved resin models, which simulated an extreme situation to highlight the limitations of instrument properties in this study.

In accordance with prior research findings, it has been consistently observed that the intracanal temperature remains equivalent to the body temperature of 35°C.[15-17] Based on the aforementioned study, the simulated intracanal temperature in this study was set to 35°C to simulate the working temperature of the rotary file. At 35°C, the angulation reduction in the WO and RP groups (16.11 and 9.84 degrees, respectively) exhibited a statistically significant difference in root canal angulation reduction compared to the WO and RP groups at 25°C, as well as the WOG and RPB groups at both temperatures. The prevalence of canal transportation observed in the RP and WO groups at body temperature was 45.45% and 81.81%, respectively. Conversely, at 25°C, no observable canal transportation was noted in either the RP or WO groups. The severely curved root canal with an angulation of 45 degrees and the higher intracanal temperature during preparation in this study are considered to play an important role in canal transportation.

The point at which rotary file transportation commenced was observed to be 3.82±0.47 mm and 4.02±0.49 mm short of the working length in the RP and WO groups, respectively. The presence of canal curvature in this resin block, beginning 4 mm short of the working length, confirms that both WO and RP exhibited transportation from the curvature's initiation point when utilized in severely curved root canals at 35°C. This scenario may significantly impede the thorough debridement of the root canal system, should it arise in actual clinical practice.[18]

This study demonstrated the effect of temperature on the ability of NiTi files to maintain severely curved root canals during instrumentation. Previous studies have also shown that increased temperatures can affect the properties of the rotary file. The increased temperature to 35°C can affect the cyclic fatigue resistance in all file systems, such as RP, RPB, WO, and WOG, but at different levels. Therefore, the properties of M-wire are more affected by temperature than gold and blue wire.[6,13,14,22,23] The

NiTi alloy of WOG and RPB has undergone multiple heat-treating processes and is characterized by a more martensitic phase at room temperature. The gold and blue heat-treated files can be deformed due to the reorientation of the martensitic crystalline structure but can recover their shape upon heating above the transformation temperature.[5] However, at body temperature, the phase composition of WOG is a mixed state of martensite and R-phase.[13] Metallurgically, gold heat-treated files are more ductile and provide higher flexibility than conventional NiTi files and the first generation of M-wire files.[7] On the other hand, WO and RP are manufactured from M-wire NiTi, which contains an austenite microstructural phase with fewer amounts of martensite and without R-phase at body temperature.[2,19,20] The austenite start (As) to finish (Af) temperature of M-Wire has been found to be around 5 to 50 °C, respectively.[3,21] Therefore, M-wire still exhibits a shape memory effect and can restore its shape at either room or body temperature.

The different cross-sections and tapers of the rotary files may also play a role in maintaining canal curvature during root canal preparation. The WO file has a convex triangular cross-sectional design, while WOG has a cross-section with a parallelogram structure and two cutting edges.[24] WOG has the smallest core area compared to WO and RPB.[6] Instruments with larger tapers, especially in the apical portion like WO, tend to cause more transportation due to decreased flexibility, while those with lesser taper like WOG show less transportation.[9,25] However, with reciprocal motion, reciprocating rotary NiTi files are associated with a decreased incidence of file fracture,[26] increased fatigue lifespan, and preservation of the original canal anatomy.[27] The results of the RP and RPB groups at 35°C may reflect the effect of different materials, even if they have the same design, convex S-shape cross-section, diameter, taper, and kinematics. The thermal treatment of RPB was associated with a finer structure, smaller grains, increased fracture resistance, and reduced hardness and lower elastic modulus compared to RP.[4]

A simulated severely curved resin model may not fully reflect the clinical conditions under which endodontic instruments operate due to differences in hardness between resin and human teeth.[28] However, resin models provide standardized samples because they are produced with the same diameter, taper, curvature, and material. The credibility of resin blocks as an ideal experimental model for analyzing endodontic preparation techniques has been validated.[29,30] In this study, the focus was on the different mechanical properties of each instrument system at different temperatures, so other confounding factors needed to be eliminated. Previous studies have shown that the more severe the curvature, the more root canal deviation or shortening of working length occurs.[29,31,32] The elastic memory of the file provides a restoring force that straightens it when it has been deformed by the curvature. This restoring force leads to canal transportation and prevents the instrument from remaining perfectly centered within the canal.[33] The thermal treatment of files may improve their flexibility, increasing resistance during the preparation of curved canals.[34]

Hence, in severely curved root canals, consideration should be given to the utilization of conventional or austenitic files, as they pose a risk of inducing straightening or transportation of the root canal in clinical contexts. Therefore, further studies should investigate alternative materials for resin models that closely mimic the mechanical properties of human teeth or explore patient-specific 3D-printed root canal models, aiming to provide a more accurate representation of clinical conditions while maintaining standardization. Additionally, the comparison of endodontic instrument performance in resin models to their performance in actual clinical settings requires further study to ensure validity.

Conclusion

The reduction in root canal angulation after instrumentation was influenced by file type and temperature. WaveOne and Reciproc created a significant reduction in root canal angulation, especially at 35°C, while WaveOne

Gold and Reciproc Blue can maintain the original canal for both temperatures.

Conflict of interest : None disclosed.

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Reference

1. Walia H, Brantley WA, Gerstein H. An initial investigation of the bending and torsional properties of nitinol root canal files. ***J Endod*** 1988;14(7):346-51.

2. Ye J, Gao Y. Metallurgical characterization of M-Wire nickel-titanium shape memory alloy used for endodontic rotary instruments during low-cycle fatigue. ***J Endod*** 2012;38(1):105-07.

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

4. Generali L, Puddu P, Borghi A, Brancolini S, Lusvarghi L, Bolelli G, *et al.* Mechanical properties and metallurgical features of new and ex vivo used Reciproc Blue and Reciproc. ***Int Endod J*** 2020; 53(2):250-64.

5. Shen Y, Zhou HM, Zheng YF, Peng B, Haapasalo M. Current Challenges and Concepts of the Thermomechanical Treatment of Nickel-Titanium Instruments. ***J Endod*** 2013;39(2):163-72.

6. Hou XM, Yang YJ, Qian J. Phase transformation behaviors and mechanical properties of NiTi endodontic files after gold heat treatment and blue heat treatment. ***J Oral Sci*** 2020;63(1):8-13.

7. Özyürek T. Cyclic Fatigue Resistance of Reciproc, WaveOne, and WaveOne Gold Nickel Titanium Instruments. ***J Endod*** 2016;42(10):1536-39.

8. Pedullà E, Lo Savio F, Boninelli S, Plotino G, Grande NM, La Rosa G, *et al.* Torsional and Cyclic Fatigue Resistance of a New Nickel-Titanium Instrument Manufactured by Electrical Discharge Machining. ***J Endod*** 2016;42(1):156-9.

9. Bürklein S, Flüch S, Schäfer E. Shaping ability of reciprocating single-file systems in severely curved canals: WaveOne and Reciproc versus WaveOne Gold and Reciproc blue. ***Odontology*** 2019;107(1):96-102.

10. Saber SE, Nagy MM, Schäfer E. Comparative evaluation of the shaping ability of WaveOne, Reciproc and OneShape single-file systems in severely curved root canals of extracted teeth. ***Int Endod J*** 2015;48(1):109-14.

11. Zhou HM, Shen Y, Zheng W, Li L, Zheng YF, Haapasalo M. Mechanical properties of controlled memory and superelastic nickel-titanium wires used in the manufacture of rotary endodontic instruments. ***J Endod*** 2012;38(11):1535-40.

12. Kuhn G, Jordan L. Fatigue and mechanical properties of nickel-titanium endodontic instruments. ***J Endod*** 2002;28(10):716-20.

13. Oh S, Kum KY, Kim HJ, Moon SY, Kim HC, Chaniotis A, *et al.* Bending resistance and cyclic fatigue resistance of WaveOne Gold, Reciproc Blue, and HyFlex EDM instruments. ***J Dent Sci*** 2020;15(4):472-78.

14. Plotino G, Grande NM, Testarelli L, Gambarini G, Castagnola R, Rossetti A, *et al.* Cyclic Fatigue of Reciproc and Reciproc Blue Nickel-titanium Reciprocating Files at Different Environmental Temperatures. ***J Endod*** 2018;44(10):1549-52.

15. 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. ***J Endod*** 2015;41(7):1112-15.

16. Cameron JA. The effect of ultrasonic endodontics on the temperature of the root canal wall. ***J Endod*** 1988;14(11):554-59.

17. Cunningham WT, Balekjian AY. Effect of temperature on collagen-dissolving ability of sodium hypochlorite endodontic irrigant. ***Oral Surg Oral Med Oral Pathol*** 1980;49(2):175-7.

18. Wu MK, Fan B, Wesselink PR. Leakage along apical root fillings in curved root canals. Part I: effects of apical transportation on seal of root fillings. ***J Endod*** 2000;26(4):210-6.

19. 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. ***Int Endod J*** 2012;45(5):469-74.

20. Alapati SB, Brantley WA, Iijima M, Clark WA, Kovarik L, Buie C, *et al.* Metallurgical characterization of a new nickel-titanium wire for rotary endodontic instruments. ***J Endod*** 2009;35(11):1589-93.

21. Generali L, Puddu P, Borghi A, Brancolini S, Lusvarghi L, Bolelli G, *et al.* Mechanical properties and metallurgical features of new and ex vivo used Reciproc Blue and Reciproc. ***Int Endod J*** 2020;53(2):250-64.

22. Hou XM, Yang YJ, Qian J. Phase transformation behaviors and mechanical properties of NiTi endodontic files after gold heat treatment and blue heat treatment. ***J Oral Sci*** 2020;63(1):8-13.

23. Scott R, Arias A, Macorra JC, Govindjee S, Peters OA. Resistance to cyclic fatigue of reciprocating instruments determined at body temperature and phase transformation analysis. ***Aust Endod J*** 2019;45(3):400-6.

24. Webber J. Shaping canals with confidence: WaveOne GOLD single-file reciprocating system. ***Int Dent*** 2016;6(3):6-17.
25. Saleh AM, Gilani PV, Tavanafar S, Schäfer E: Shaping ability of 4 different single-file systems in simulated S-shaped canals. ***J Endod*** 2015;41(4):548-52.
26. Plotino G, Ahmed HMA, Grande NM, Cohen S, Bukiet F. Current Assessment of Reciprocation in Endodontic Preparation: A Comprehensive Review - Part II: Properties and Effectiveness. ***J Endod*** 2015;41(12): 1939-50.
27. Goldberg M, Dahan S, MacHtou P. Centering ability and influence of experience when using waveone single-file technique in simulated canals. ***Int J Dent*** 2012;2012:206321.
28. FS W. Endodontic therapy. 6th ed. st.louis, missouri: mosby; 2004, 189-92.
29. Weine FS, Kelly RF, Lio PJ. The effect of preparation procedures on original canal shape and on apical foramen shape. ***J Endod*** 1975;1(8):255-62.
30. Dummer PM, Alodeh MH, al-Omari MA. A method for the construction of simulated root canals in clear resin blocks. ***Int Endod J*** 1991;24(2):63-6.
31. Berutti E, Chiandussi G, Paolino DS, Scotti N, Cantatore G, Castellucci A, *et al.* Effect of Canal Length and Curvature on Working Length Alteration with WaveOne Reciprocating Files. ***J Endod*** 2011;37(12):1687-90.
32. Tien M, Tjoa H, Zhou M, Abbott PV. Comparative Study of Four Endodontic File Systems to Assess Changes in Working Length during Root Canal Instrumentation and the Effect of Canal Curvature on Working Length Change. ***J Endod*** 2020;46(1):110-15.
33. García M, Duran-Sindreu F, Mercadé M, Bueno R, Roig M. A comparison of apical transportation between profile and RaCe rotary instruments. ***J Endod*** 2012;38(7):990-2.
34. Prados-Privado M, Rojo R, Ivorra C, Prados-Frutos JC. Finite element analysis comparing WaveOne, WaveOne Gold, Reciproc and Reciproc Blue responses with bending and torsion tests. ***J Mech Behav of Biomed Mater*** 2019;90:165-72.