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Surface profile of different heat-treated nickel-titanium files before and after root canal preparation

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The aim of this study was to evaluate surface wear, presence of microcracks and surface irregularities of WaveOne (WO) and WaveOne Gold (WOG) instruments before and after multiple uses. Eight Primary instruments of the WO and WOG systems were evaluated, each one was used to prepare six mesial canals of extracted human mandibular molars. The surface of the instruments was evaluated before use (T0), after instrumentation of three (T1) and six (T2) root canals. Surface wear was analyzed using a three-dimensional optical profiler and the presence of microcracks and surface irregularities were evaluated using a tabletop scanning electron microscopy. The Friedman test was used to assess surface wear and Kruskal-Wallis test to evaluate the presence of microcracks and surface irregularities, with a 5% significance level. There was a significant increase in wear in both groups at T2, compared to T0 (p=0.0003). The surface wear after instrumentation of six canals (T2-T0) was statistically greater in the WOG group, than in the WO group (p=0.02), where the presence of microcracks was significantly greater and increased after multiple uses (p<0.05). The presence of surface irregularities in the cutting blade before and after use was statistically greater in the WOG group than WO group (p<0.05). Wear of the cutting blade, microcracks and surface irregularities were observed on the surface topography of all the instruments after multiple uses. These surface changes may affect the cutting efficiency of WOG files and increase the risk of fracture of WO files.

Key Words: Endodontics, nickel-titanium, optical profiler, waveone, waveone gold.

Introduction

For over three decades, nickel-titanium (NiTi) alloys have been used to manufacture endodontic files. To improve the mechanical properties of these instruments, especially resistance to cyclic fatigue, thermal processing has been used in their manufacture process. These treatments change the transition temperatures of the crystalline phases, as well as the percentage of each phase, austenite and martensite, in the NiTi alloy. This change influences the mechanical and functional properties, the clinical performance and the increase in the useful life of endodontic instruments (1,2).

During endodontic use, mechanical friction between the file and the root canal walls may lead to changes in the surface topography of endodontic instruments (2-4). Heat treatments can reduce the surface hardness of these instruments, which may affect their resistance to surface wear and damage caused by use (1,5). In addition, the method of alloy preparation can influence the thickness of the titanium oxide layer formed on the NiTi alloy surface, which prevents the NiTi of the internal layer from undergoing wear and corrosion (2). These surface changes of endodontic instruments can affect their cutting efficiency and increase the risk of unexpected fractures (6). There is still a gap in the literature if different heat treatments used in the manufacture process can influence the resistance of NiTi files to alterations in surface topography after multiple uses.

The WaveOne system (WO; Dentsply Sirona Endodontics, Ballaigues, Switzerland), introduced by Dentsply Sirona Endodontics in 2011, is manufactured using M-Wire, a heat-treated NiTi alloy. In 2016, the same manufacturer introduced the WaveOne Gold system (WOG; Dentsply Sirona Endodontics, Ballaigues, Switzerland). These instruments are manufactured using Gold-Wire, a heat-treated NiTi alloy that, according to the manufacturer, gives the file high flexibility, resistance to cyclic fatigue and excellent cutting efficiency. The gold heating processes results in an increased amount of martensite in the crystalline structure of the Gold-Wire compared to the M-Wire alloy, reducing its surface microhardness (5,7). Previous studies have shown that intact and used WOG instruments have rougher surfaces than new and used WO and M-Wire instruments (3,4,8).

According to Hou et al. (1), the phase transformation behaviors of WOG and the relationships with their mechanical properties have remained unclear, such as the impact of the multiple uses on alterations in surface topography of these files. This knowledge can provide more information regarding their properties, performance and limitation (4). However, no study in the literature has evaluated, using a nanoscale methodology, the surface profiles of new and used heat-treated files after multiple uses in extracted human teeth.

Therefore, the aim of this study was to evaluate surface wear, presence of microcracks and surface irregularities of WaveOne (WO) and WaveOne Gold (WOG) instruments before and after multiple uses, with OP and scanning electron microscopy (SEM). The null hypothesis was that, although the two different NiTi instruments received different heat treatments, there would be no significant differences between their surface wear and between the presence of microcracks and irregularities in their cutting blade surface before and after multiple uses in human teeth.

Material and methods

This study was approved by ethics committee of the University of São Paulo, Faculty of Dentistry (protocol number 01345118.5.0000.0075). To calculate the sample size, a pilot test was performed previously. By adopting a significance level of 95% and power of test of 85% using Biostat 5.0 software (Mamirauá Institute for Sustainable Development, Belém, Brazil), the study reached the minimum sample size of 8 instrument of each system. Therefore, a sample of 8 endodontic instruments per group was used.

Ninety-six mesial root canals of forty-eight extracted human mandibular molars were selected. To determine the root canal curvature according to the Schneider's method (9), digital mesiodistal and buccolingual radiographs were taken using the parallel technique. The Image J software (University of Madison, Madison, USA) was used to assess the curvature of the mesial root canals. Only teeth with root canal curvature angle range between 20° and 40° degrees, intact pulp chamber, fully developed apex, and two independent mesial canals (Vertucci type IV) were included in the study. Selected teeth were sterilized by autoclaving (Gnatus, Barretos, Brazil), cleaned with periodontal curettes (Golgran, São Paulo, Brazil), and then stored in distilled water at 37º C. The crowns were removed using a diamond disk (Fava, São Paulo, Brazil) to standardize the measure of the mesial roots to 16 mm.

The working length (WL) was determined by inserting a size 10 K-file (VDW, Munich, Germany) into the canal until its tip was visible at the apical foramen. This length was measured and 1 mm was subtracted. A glide path was established using a size 15-K file (VDW, Munich, Germany) to the WL, standardizing the initial diameter. Teeth in which files with a larger diameter reached the WL passively were replaced.

Of the 48 teeth included in the study, 32 had a mesial canal curvature between 30º and 40º, and 16, between 20º and 29º. Mesiobuccal canals were assigned to the WO group and mesiolingual canals, to the WOG group.

Root canal instrumentation

Eight WO Primary (25/0.08) and 8 WOG Primary (25/0.07) files were selected for this study. Each file was used to prepare six mesial canals of extracted human mandibular molars. The WO files were used in the mesiobuccal canals, and the WOG files, in the mesiolingual canals of the same mesial root. A hand held condensation silicone device (Coltene - Whaledent, Allstetten, Switzerland) was used to fix and stabilize each sample during the root canal instrumentation. All the root canal preparations were performed by a single operator using the X-Smart Plus endodontic motor (Dentsply Sirona Endodontics, Ballaigues, Switzerland) according to the manufacturer's instructions. Irrigation was accomplished with 2.5% sodium hypochlorite (NaOCl), using 15 mL for each root canal preparation.

The instrumentation protocol in the two groups was: after initial irrigation with 2.5% NaOCl, the instrument was inserted in three pecking motions towards the apex. Then, the canals were irrigated with 2.5% NaOCl and recapitulated a size 15 K-file to the WL. Reciprocating files were cleaned using gauze and inserted into the root canal. The same process was repeated until WL was reached. After the complete root canal instrumentation, the endodontic file was using sterilized gauze and distilled water, to remove dentinal debris.

Surface assessment and quantitative analysis

The file's surfaces were evaluated at three time points: T0 – intact files; T1 – after instrumentation of three mesial canals and sterilization by autoclaving; T2 – after instrumentation of three other three mesial canals and sterilization. Of the three canals prepared at each time point, one had a curvature between 20° and 29°, and two, between 30° and 40°. After the instrumentation of three mesial canals and before the process of sterilization, the endodontic files were cleaned using sterilized gauze and distilled water, to remove dentinal debris.

The ZeGage™ Zemetric optical profiler (Zygo, Middlefield, Connecticut) was used to measure the height of the cutting blade at a 3-mm distance from the tip of each instrument (n=8). The dimensions of the scanned areas were 880 × 400 μm^2. A condensation silicone (Perfil; Coltene, Rio de Janeiro, Brazil) stub was performed to ensure a standard position. At the first acquisition, the X, Y and Z axis values were determined using a ZeGage Profiler and the ZeMaps 1.11 software (Zygo, Middlefield, Connecticut). These values were repeated in the other acquisitions. Images were analyzed using the same software, which measures cutting blade height from an adjacent flute. The Rpv (peak-to-valley height) value was used to measure cutting blade height. According to the manufacturer, Rpv value is the height difference between the lowest and highest points of the surface.

Images of the four apical millimeters of each file (n=8) were acquired using a HITACHI TM3000 tabletop SEM (Hitachi, Tokyo, Japan) at a 250X magnification to evaluate microcracks and surface irregularities at T0, T1 and T2. Three blinded and previously calibrated observers scored the images independently (Table 1). Initially ten random images were used for calibration and discussion among observers, and to ensure inter-rater reliability, the Cohen kappa value was calculated. The evaluation occurred in a same room with the light off and on the same computer (Samsung NP270E5K – Seoul, South Korea) and disagreements were resolved using the predominant score.

Table 1. Scores for evaluating SEM images.

Score	Microcracks	Surface irregularities
1	No microcracks in cutting blade	Continuous and regular cutting blade
2	1 to 3 microcracks in cutting blade	Irregular and no more than 50% of file surface analyzed without continuous cutting blade
3	4 or more microcracks in cutting blade	Irregular and more than 50% of file surface analyzed without continuous cutting blade

Statistical analysis

The data were analysed using the Shapiro-Wilk test to verify the assumption of normality. The height of cutting blade of the instruments in their respective groups at T0, T1 and T2 was analyzed using Friedman and Dunn post hoc tests ($p < 0.05$). Mann-Whitney test was used to compare WO and WOG groups, evaluating the wear of cutting blade after the T1 – T0, T2 – T0, and T2 – T1 time periods. Kruskal-Wallis test was used to analyze the scores obtained by examination of SEM images. The Biostat 5.0 software (Mamirauá Institute for Sustainable Development, Belém, Brazil) was used for the statistical analysis and the level of significance was set at 5%.

RESULTS

Presence of microcracks on cutting blade surface

The Cohen kappa value was 0.80. In the WO group, at T1 and T2, the presence of microcracks was significantly greater in the second, third and fourth apical millimeters than in the first millimeter ($p<0.05$). A statistically significant difference was found in the presence of microcracks between T0-T1 and T0-T2 in WO files ($p<0.05$).

There were no statistically significant differences between the four millimeters of WOG files analyzed at T1 and T2 ($p>0.05$). Besides that, the number of uses did not influence the presence of microcracks in WOG files.

The presence of microcracks was statistically greater in WO group than WOG group at T1 and T2 ($p<0.05$) (Figure 1).

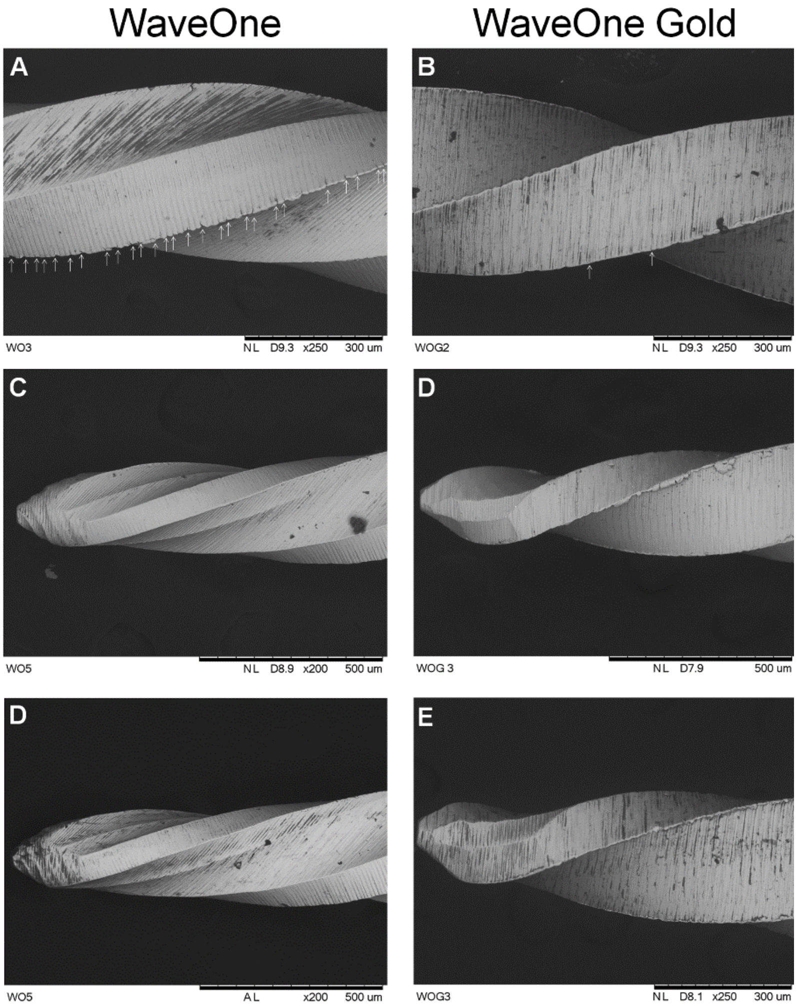

Figure 1. SEM images. In A and B, presence of microcracks in T2. The white arrows indicate the microcracks. (A) WO Primary file, score 3. (B) WOG Primary file, score 1; In C and D, presence of surface irregularities in the first millimeter of the instruments, in T0. (C) WO Primary file, score 1. (D) WOG Primary file, score 3; In E and F, presence of surface irregularities in the first millimeter of the same file of C and D, in T2. (E) WO Primary file, score 1. (F) WOG Primary file, score 1.

Presence of irregularities on cutting blade surface

No significant difference was found in WO and WOG files regarding cutting blade irregularities in the four millimeters evaluated and at the three study time points ($p>0.05$). The presence of surface irregularities was greater in the first millimeter of WOG files than of WO files at the three study time points ($p<0.05$) (Figure 1). No statistically significant differences were found between WO and WOG files in the second and third millimeters at the three study time points ($p>0.05$). In the fourth millimeter, however, the presence of cutting blade irregularities in intact WO files was statistically greater than in WOG files at the same time point ($p<0.05$) (Figure 1). No significant difference was found in the fourth millimeter between WO and WOG files at T1 and T2 ($p>0.05$).

Cutting blade wear

Cutting blade height was significantly different between T0 and T2 for the WO and WOG ($p<0.05$) (Table 2). In both groups, cutting blade height was not significantly different between T0 and T1 or T1 and T2 ($p>0.05$).

Table 2. Mean (µm ± standard deviation) cutting blade height (µm) of WO and WOG files at the three study time points.

Endodontic system	T0	T1	T2	P-value
WO	94.21 ± 10.57^{ac}	91.95 ± 9.25^{ab}	88.47 ± 11.10^{bd}	0.0003
WOG	63.98 ± 23.46^{ac}	59.48 ± 22.60^{ab}	53.36 ± 21.24^{bd}	0.0003

Different lower-case letters indicate statistically significant differences.

The cutting blade wear was significantly greater after the instrumentation of six mesial mandibular canals (T2-T0) in the WOG group than WO group, but there were no significant differences at T1-T0 and T2-T1 between the two groups (Table 3).

Table 3. Median (µm ± standard deviation) and percentage (%) wear of the cutting blades of WO and WOG files at the three study time points.

Study time point	WO		WOG		P-value
	Median	%	Median	%	
T1-T0	2.26 ± 1.58[a]	2.4%	4.50 ± 2.86[b]	7.03%	0.05
T2-T1	3.47 ± 2.28[a]	3.78%	6.11 ± 4.09[a]	6.09%	0.24
T2-T0	5.73 ± 2.30[a]	10.28%	10.61 ± 4.58[b]	16.89%	0.027

Different lower-case letters indicate statistically significant differences.

Discussion

The results of this study indicate that there are differences in wear, in presence of microcracks and surface irregularities of cutting blades between WO and WOG Primary files, and that the number of uses affects its surface topography. Therefore, the null hypothesis was rejected.

Cutting blade wear was found in both systems after multiple uses, and it was statistically significant after the instrumentation of six root canals. Cutting blade wear and the presence of surface irregularities were significantly greater in WOG files than in WO files. In contrast, the presence of microcracks was greater in WO files, and this increased with use. These changes to the cutting blade could adversely affect the cutting efficiency of the files (6).

The use of SEM images for the evaluation of topographic changes on the surface of endodontic files is a well-documented method to measure morphological features accurately (2,10-14). This method also ensures that the same specimen can be evaluated at different time points. Intact files showed an irregular topography, with manufacturing defects, particularly perpendicular to the file axis. These defects may compromise the physical and mechanical properties of endodontic files and make them more susceptible to fracture (12-14).

The machining process of endodontic instruments is difficult because the burs used during manufacture become dull and blunt and rapidly lead to irregularities on the wire surface (11,13). These irregularities on surface of intact endodontic instruments may contribute to their deterioration or can lead to larger defects, compromising their useful life (15). According to Hanan et al. (15) the improvement of surface finishing of these instruments could reduce deterioration in multiple uses. Heat treatments applied before machining may facilitate manufacturing, because they reduce the hardness of the wire surface (5,10). In the present study, the presence of cutting blade irregularities was statistically greater in new WOG files than in new WO files, and this finding is in agreement with a previous study (3,4). M-Wire technology is based on heat treatment before machining, while Gold-wire technology is performed by heating and then slowly cooling the file after machining (7,10). In addition to the differences in polishing and finishing processes and the timing of the application of the thermomechanical treatment may explain the difference in the presence of cutting blade irregularities found in the present study (3,4).

The presence of microcracks after use was significantly greater in WO files than in WOG files. Moreover, the multiple uses affected the presence of microcracks in the WO group. These findings are in agreement with other studies, which found a high incidence of microcracks on the surface of WO files and an increase after use, when comparing to WOG (1,4,10). This may be assigned to reversible martensitic transformation, a process that has excellent energy absorption characteristics, leads to less damage per use and explains the better results found for WOG files (16). Crystals in the martensitic phase make the alloy ductile, which increases both its deformation capacity and its cyclic fatigue resistance, whereas NiTi in the austenitic phase is strong, hard and more resistant to deformation (7,16). A previous study showed that the fatigue resistances of martensitic NiTi wires is higher than for superelastic NiTi alloys, increasing the useful life of endodontic instruments (1), and the constant reuse of instruments manufactured in M-Wire leads to surface wear and deformation (2,4). The change in the thermal history of the alloy can produce an instrument with different characteristics for endodontic use, modifying their clinical performance (17).

Optical profilometry (OP), the non-destructive method chosen for the evaluation of cutting blade wear after the instrumentation of mesial canals of extracted human mandibular molars, provides a three-dimensional evaluation of endodontic file surfaces. Previous studies have compared endodontic instruments before and after use in simulated root canals made in clear resin blocks using OP (18-20). The results of studies that use resin blocks cannot be extrapolated to clinical practice because its mechanical properties differ from human dentin. Moreover, the heat generated from instrumentation may soften the resin, which may decrease the attrition between file surfaces and the simulated root canal walls (21).

Cutting blade wear was found in both systems after multiple uses, and it was statistically significant after the instrumentation of six root canals. Surface wear was significantly greater in WOG files than in WO files. Previous studies showed, using OP, that after the instrumentation of four root canals, WOG files exhibited a higher level of surface deformation than WO files (4) and M-Wire instruments (3). The present study showed a difference in surface wear between WO and WOG only after preparation of six root canals. The gold heating processes results in an increased amount of martensite in the NiTi alloy crystalline structure and at body temperature, WOG has martensite structures, which reduces its microhardness (1,5,7).

The manufacturer of both systems recommends the single use of these files because of possible damage to their structure, which is cumulative, and the difficulty in ensuring adequate sterilization (22). However, these files are often reused, particularly because of their high cost. In addition, these reciprocating files may be used safely, in relation of their resistance to cyclic fatigue fracture, in the instrumentation of three posterior teeth (10,23).

The irrigating solution used during instrumentations was 2.5% NaOCl. Studies have already demonstrated that NaOCl affects the surface of endodontic files (3,24). In contrast to the conditions of previous studies that used OP (4,18-20), the samples of the present study were kept at 37° C. NaOCl injected into root canals at room temperature rapidly reaches body temperature (25). Therefore, the files in the present study were used at a temperature similar to the found in clinical conditions during laboratory trials. Moreover, files have different phase transition temperatures, which affect their mechanical properties during use.

The cleaning process of endodontic instrument, before the sterilization, was made with sterilized gauze and distilled water, similar to previous studies (18-21). No thermochemical cleaning process was used after endodontic use to avoid any damage to the surface of the instrument. As in other studies (3,4,12,18-20), the apical region of the instrument was used to evaluate the surface because this area is the part of the instrument that most suffers solicitations, which could be related to the high apical force applied during the pecking motion used for root canal instrumentation (12). However, a previous study showed that the surface defects were most associated with the middle third, which was the section that most suffered solicitations in Reciproc instruments after preparation of simulated root canals (6).

One of the disadvantages of using human teeth is the fact that variations of canal curvature and diameter may affect the way that mechanical loads are applied on the endodontic instruments (17). The present study chose mesiobuccal and mesiolingual canals of extracted human mandibular molars to test both systems because of their anatomic similarities (13). Besides that, the root canal curvature, the measure of the mesial roots and the initial apical diameter were standardized, similar a previous studies, in order to avoid anatomical variations that may influence the results obtained in the present study (3,4).

The present study is the first one that compared, using a nanoscale methodology, the surface profiles of WO and WOG before and after multiple uses. Despite the limitations of the present study, which used only two reciprocating endodontic systems in human teeth, the findings suggest that the anatomical condition may interfere with the choice of heat-treated endodontic instrument. After multiple uses, the Gold-wire instruments proved to be more resistant to the formation of microcracks, however, there was an increase in wear and surface irregularities, which can lead to a decrease in cleaning efficiency and a longer cleaning time. In contrast, the multiples uses suggested an increase the risk of fractures for superelastic instruments, while even after the instrumentation of only three canals, however, without a significant wear of the cutting blade. Future *in vitro* studies investigating the impact of these surface changes on the root canal preparation and on surface chemistry of NiTi files are needed, such as clinical studies to assess the impact of these surface changes on the success of endodontic treatment.

Wear of the cutting blade, microcracks and surface irregularities were found on the surface topography of all the instruments after multiple uses. WO Primary files were more resistant to cutting blade wear and presented a greater amount of microcracks than WOG Primary files after multiple uses. However, more surface topography alterations were identified in the WaveOne Gold instruments.

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Resumo

O objetivo deste estudo foi avaliar o desgaste de superfície, a presença de microtrincas e irregularidades superficiais dos instrumentos WaveOne (WO) e WaveOne Gold (WOG) antes e após múltiplos usos. Oito instrumentos Primary dos sistemas WO e WOG foram avaliados, cada um utilizado no preparo de seis canais mesiais de molares inferiores humanos extraídos. A superfície dos instrumentos foi avaliada antes do uso (T0), após a instrumentação de três (T1) e seis (T2) canais radiculares. O desgaste de superfície foi analisado utilizando um perfilômetro ótico tridimensional e a presença de microtrincas e irregularidades superficiais foram avaliadas usando um microscópio eletrônico de varredura de bancada. O teste de Friedman foi usado para avaliar o desgaste de superfície e o teste de Kruskal-Wallis para avaliar a presença de microtrincas e irregularidades superficiais, com nível de significância de 5%. Houve um aumento significativo no desgaste em ambos os grupos em T2, comparado a T0 (p=0.0003). O desgaste de superfície após a instrumentação de seis canais (T2-T0) foi estatisticamente maior no grupo WOG que no grupo WO (p=0.02), onde a presença de microtrincas foi estatisticamente maior e aumentou após os múltiplos usos (p<0.05). A presença de irregularidades na superfície da lamina de corte antes e após o uso aumento significativamente no grupo WOG comparado ao grupo WO (p<0.05). Desgaste da lâmina de corte, microtrincas e irregularidades superficiais foram observadas na topografia de superfície de todos os instrumentos após os múltiplos usos. Essas alterações na superfície podem afetar a eficiência de corte dos instrumentos WOG e amentar o risco de fratura dos instrumentos WO.

References

1. 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;63:8-13.

2. Bastos MMB, Hanan ARA, Bastos AMB, Marques AAF, Garcia L, Sponchiado ECJ. Topographic and Chemical Analysis of Reciprocating and Rotary Instruments Surface after Continuous Use. Braz Dent J 2017;28:461-6.

3. Zafar MS. Impact of Endodontic Instrumentation on Surface Roughness of Various Nickel-Titanium Rotary Files. Eur J Dent 2020.

4. AlRahabi AMK, Atta RM. Surface nanoscale profile of WaveOne, WaveOne Gold, Reciproc, and Reciproc blue, before and after root canal preparation. Odontology 2019;107:500-6.

5. 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. J Endod 2017;43:462-6.

6. Spicciarelli V, Corsentino G, Ounsi HF, Ferrari M, Grandini S. Shaping effectiveness and surface topography of reciprocating files after multiple simulated uses. J Oral Sci 2019;61:45-52.

7. Gavini G, Santos MD, Caldeira CL, Machado MEL, Freire LG, Iglecias EF, et al. Nickel-titanium instruments in endodontics: a concise review of the state of the art. Braz Oral Res 2018;32:e67.

8. Ozyurek T, Yilmaz K, Uslu G, Plotino G. The effect of root canal preparation on the surface roughness of WaveOne and WaveOne Gold files: atomic force microscopy study. Restor Dent Endod 2018;43:e10.

9. Schneider SW. A comparison of canal preparations in straight and curved root canals. Oral Surg Oral Med Oral Pathol 1971;32:271-5.

10. Fangli T, Maki K, Kimura S, Nishijo M, Tokita D, Ebihara A, et al. Assessment of mechanical properties of WaveOne Gold Primary reciprocating instruments. Dent Mater J 2019;38:490-5.

11. Marending M, Lutz F, Barbakow F. Scanning electron microscope appearances of Lightspeed instruments used clinically: a pilot study. Int Endod J 1998;31:57-62.

12. Pirani C, Paolucci A, Ruggeri O, Bossu M, Polimeni A, Gatto MR, et al. Wear and metallographic analysis of WaveOne and reciproc NiTi instruments before and after three uses in root canals. Scanning 2014;36:517-25.

13. Qaed NA, Mourshed BD, Al-Shamiri HM, Alaizari N, Alhamdah SS. The Effect of surface topographical changes of two different surface treatments rotary instrument. J Clin Exp Dent 2018;10:e49-e53.

14. Troian CH, So MV, Figueiredo JA, Oliveira EP. Deformation and fracture of RaCe and K3 endodontic instruments according to the number of uses. Int Endod J 2006;39:616-25.

15. Hanan ARA, Meireles DA, Sponchiado Júnior EC, Hanan S, Kuga MC, Bonetti Filho I. Surface Characteristics of Reciprocating Instruments Before and After Use - A SEM Analysis. Braz Dent J 2015;26:121-7.

16. 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;37:1566-71.

17. Miccoli G, Gaimari G, Seracchiani M, Morese A, Khrenova T, Di Nardo D. In vitro resistance to fracture of two nickel-titanium rotary instruments made with different thermal treatments. Ann Stomatol (Roma) 2017;8:53-8.

18. Barbosa I, Ferreira F, Scelza P, Neff J, Russano D, Montagnana M, et al. Defect propagation in NiTi rotary instruments: a noncontact optical profilometry analysis. Int Endod J 2018;51:1271-8.

19. Ferreira F, Barbosa I, Scelza P, Russano D, Neff J, Montagnana M, et al. A new method for the assessment of the surface topography of NiTi rotary instruments. Int Endod J 2017;50:902-9.

20. Ferreira FG, Barbosa IB, Scelza P, Montagnana MB, Russano D, Neff J, et al. Noncontact three-dimensional evaluation of surface alterations and wear in NiTi endodontic instruments. Braz Oral Res 2017;31:e74.

21. Gu Y, Kum YK, Perinpanayagam H, Kim C, Kum DJ, Lim SK, et al. Various heat-treated nickeletitanium rotary instruments evaluated in S-shaped simulated resin canals. Journal of Dental Sciences 2017;12:14-20.

22. Kim JW, Ha JH, Cheung GS, Versluis A, Kwak SW, Kim HC. Safety of the factory preset rotation angle of reciprocating instruments. J Endod 2014;40:1671-5.

23. Bueno CSP, Oliveira DP, Pelegrine RA, Fontana CE, Rocha DGP, Bueno C. Fracture Incidence of WaveOne and Reciproc Files during Root Canal Preparation of up to 3 Posterior Teeth: A Prospective Clinical Study. J Endod 2017;43:705-8.

24. Cai JJ, Tang XN, Ge JY. Effect of irrigation on surface roughness and fatigue resistance of controlled memory wire nickel-titanium instruments. Int Endod J 2017;50:718-24.

25. 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;41:1112-5.

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