Mechanical properties of reciprocating thermally treated NiTi endodontic instruments

Propriedades mecânicas de instrumentos endodônticos de NiTi reciprocantes tratados termicamente

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ABSTRACT
The aim of this study was to evaluate the flexibility, buckling resistance, dynamic cyclic fatigue resistance and roughness pattern of Reciproc R25 M-Wire (R25M), Reciproc Blue R25 (R25B) and WaveOne Gold Primary (WOGP) NiTi reciprocating instruments. Thirty-three R25M, 30 R25B e 30 WOGP, all with 25mm in length, were tested. The flexibility was determined by 45° bending tests according to the standard ANSI/ADA number 101 specification. To determine the buckling resistance an increasing axial load was applied to the instruments until the file underwent an elastic displacement of 1mm. A customized machine was used to perform the dynamic cyclic fatigue test measuring the time to fracture in a metallic stainless steel canal measuring 1.4 mm of diameter, 19 mm of total length, an angle of 86 degrees and 6 mm of curvature radius. The roughness was obtained using a profilometer. Results were analyzed using one-way ANOVA and Student-Newman-Keuls post-hoc test. Analysis were performed with the significance level (α) of 5%. The instruments presented the following order of flexibility: R25B > WOGP > R25M ($P < 0.05$); buckling resistance: R25M > R25B > WOGP ($P < 0.05$); and cyclic fatigue resistance: R25B > R25M > WOGP ($P < 0.05$). No differences were observed regarding the roughness pattern ($P > 0.05$). The R25B file presented superior flexibility and performance under fatigue tests. The R25M have higher buckling resistance. Instruments demonstrated similar characteristics of surface.

Keywords: reciprocating NiTi files, roughness, buckling resistance, cyclic fatigue, flexibility.

RESUMO
O objetivo deste estudo foi avaliar a flexibilidade, resistência à flambagem, resistência à fadiga cíclica dinâmica e padrão de rugosidade dos instrumentos alternativos Reciproc R25 M-Wire (R25M), Reciproc Blue R25 (R25B) e WaveOne Gold Primary (WOGP) NiTi. Foram testados trinta e três R25M, 30 R25B e 30 WOGP, todos com 25 mm de comprimento. A flexibilidade foi determinada por testes de flexão de 45 ° de acordo com a norma ANSI / ADA número 101 especificação. Para determinar a resistência à flambagem, uma carga axial crescente foi aplicada aos instrumentos até que a lima sofresse um deslocamento elástico de 1 mm. A máquina customizada foi utilizada para realizar o ensaio de fadiga cíclica dinâmica medindo o tempo de fratura em um canal metálico de aço inoxidável medindo 1,4 mm de diâmetro, 19 mm de comprimento total, ângulo de 86 graus e 6 mm de raio de curvatura. A rugosidade foi obtida em perfilômetro. Os resultados foram analisados usando ANOVA de uma via e teste post-hoc de Student-Newman-Keuls. As análises foram realizadas com nível de significância (α) de 5%. Os instrumentos apresentaram a seguinte ordem de flexibilidade: R25B> WOGP> R25M (P

<0,05); resistência à flambagem: R25M> R25B> WOGP (P <0,05); e resistência à fadiga cíclica: R25B> R25M> WOGP (P <0,05). Não foram observadas diferenças em relação ao padrão de rugosidade (P> 0,05). A lima R25B apresentou flexibilidade e desempenho superiores em testes de fadiga. O R25M tem maior resistência à flambagem. Os instrumentos demonstraram características de superfície semelhantes.

Palavras-chave: arquivos NiTi recíprocos, rugosidade, resistência à flambagem, fadiga cíclica, flexibilidade.

1 INTRODUCTION

Despite the numerous advantages of NiTi endodontic instruments, these instruments present risk of fracture specially during its use in cases with challenging anatomy such as curved and/or atresic root canals. Once the separation occurs, the removal of the fragment is critical or impossible, worsening the prognosis of the treatment. To overcome this problem, different designs and NiTi alloys have been proposed aiming to increase flexibility, fatigue resistance, canal centering ability and cutting efficiency (Thompson, 2000; Shen et al., 2011; Silva et al., 2018). In addition to these modifications, changes in the activation kinematics, such as reciprocating motion has been shown to extend the life span and resistance to fatigue of NiTi instruments when compared to continuous rotary motion (Silva et al., 2018).

The Reciproc Blue (VDW, Munich, Germany) and the WaveOne Gold (Dentsply Sirona, Ballaigues, Switzerland) represent a new generation of thermally-treated NiTi reciprocating endodontic files. The NiTi alloy thermal treatment consists in repeated cycles of heating and cooling, under specifics temperatures and times, which promote modifications in the crystal structure (Plotino et al., 2014; De-Deus et al., 2017). Each manufacturer has its own proprietary thermal-treatment. According to them, this technology is able to improve the flexibility and the fatigue life making the use of these instruments safer. The Reciproc Blue system present similar design to the previous Reciproc M-Wire (VDW), but its blue wire treatment promotes improvements in the mechanical properties (De-Deus et al., 2017). The WaveOne Gold system suffered drastic modifications in relation to its precursor (WaveOne M-Wire system), the design has been completely overhauled and the gold wire treatment was applied. The cross-section in parallelogram shape and the eccentric axis of rotation are two new elements of the design of these instruments (Gündogăr & Özyürek, 2017).

The instrument flexibility can be understood as its ability to bend when submitted to a perpendicular load in relation to it axis, this property is fundamental to prepare curved region without undesirable wear (Lopes et al., 2012). Endodontic instruments with improved flexibility might reduce trans-operatory accidents such as canal transportation[8] and also improve instrument cyclic fatigue resistance (Shen et al., 2011; Silva et al., 2018; Plotino et al., 2014; De-Deus et al., 2017; Gündogăr & Özyürek, 2017; Rodrigues et al., 2019). The buckling resistance is defined as the elastic lateral deformation of an endodontic instrument when subjected to a compressive load applied in the longitudinal direction of the file axis (Lopes et al., 2012). Instruments with low buckling resistance may not be able to proceed beyond constrictions or anatomic obstructions during the exploration of narrow canals (Lopes et al., 2012). Although previous studies evaluated several mechanical properties of thermal-treated NiTi reciprocating instruments (Silva et al., 2018; Plotino et al., 2014; De-Deus et al., 2017; Gündogăr & Özyürek, 2017; Zupanc et al., 2018), little is known regarding their flexibility and buckling resistance. Therefore, the present study was designed to test the flexibility, buckling resistance, dynamic cyclic fatigue and roughness pattern of Reciproc M-Wire, Reciproc Blue and WaveOne Gold instruments. The null hypotheses tested were as follows:

1. There are no differences in the flexibility of the instruments;
2. There are no differences in the buckling resistance of the instruments;
3. There are no differences in the cyclic fatigue fracture resistance of the instruments;
4. There are no differences in the roughness pattern of the instruments.

2 MATERIAL AND METHODS

2.1 INSTRUMENTS CHARACTERISTICS AND DIVISION OF GROUPS

Ninety-nine NiTi endodontics instruments were used: 33 Reciproc R25 M-Wire 25/0.08 (R25M), 33 Reciproc Blue R25 25/0.08 (R25B) and 33 WaveOne Gold Primary 25/0.07 (WOGP). All instruments presented 25 mm in length. For standardization and reliability of the experiment, the tested instruments were previously examined for defects or deformities under a stereomicroscope. No defects were observed in any of the tested instruments.

2.2 BENDING RESISTANCE TEST

The bending resistance test was performed in 10 randomly selected instruments of each system by using a universal testing machine (DL 200 MF; Emic, Paraná, Brazil) according to the ISO 3630-1 specification (ISO 3630-1) and previously published studies

(De-Deus et al., 2017; Lopes et al., 2012; Rodrigues et al., 2011; Lopes et al., 2007). A 20N load cell was attached to the head of the machine to perform the test. The speed applied was 15 mm/min by means of a flexible stainless steel wire with one end fastened to the testing machine head and the other end attached 3 mm from the instrument tip. This test was conducted until the tip of each specimen underwent an elastic displacement of 45°. The force values were acquired in the 45° position, and the maximum load to bend each file was recorded.

2.3 BUCKLING RESISTANCE TEST

In this test, the load was applied in the axial direction of each instrument using a universal test machine (Emic DL 200-MF) and the maximum buckling load (elastic lateral deformation) was recorded as performed in previously published studies (Lopes et al., 2012; Lopes et al., 2012; Lopes et al., 2014). The 20N loading cell was selected. The mounting rod of the instrument was attached to the head of the universal testing machine by a chuck and the tip of the instrument was compressed under in an aluminum plate with a rough surface. A speed of 15 mm/min was applied in the axial direction until a lateral elastic (compressive) displacement of 1mm occurred.

2.4 DYNAMIC CYCLIC FATIGUE TEST

The cyclic fatigue test was performed using an artificial stainless steel canal measuring 1.4 mm in diameter and 19 mm in length. The tube had a curved segment with 9 mm in length, radius of 6 mm and an angle of 86 degrees between the two straight segments that measure 7 mm and 3 mm respectively (De-Deus et al., 2017; Rodrigues et al., 2011; Lopes et al., 2012; Lopes et al., 2007). The canal was lubricated with glycerin to reduce friction, minimizing the heat by friction.

The instrument/contra-angle set were subjected to a movement with 3 mm of vertical amplitude, with a 1-cycle speed every each 2 seconds. The 6:1 contra-angle (Sirona Dental Systems, Bensheim, Germany) was coupled to the VDW Silver engine (VDW, Munich, Germany). All instruments were activated in " RECIPROC ALL " mode, as recommended by the manufacturers. After the tests the time was recorded at the moment the fracture was detected visibly and/or audibly and submitted to the statistical tests.

2.5 SEM ANALYSIS

The surface facture and the helical shank of the fractured instruments were observed in a scanning electron microscope (SEM, JSM 5800; JEOL, Tokyo, Japan) to determine the type of fracture and to determine if there was any important plastic deformation on the conical helical shaft. The magnification used was X500, and the micrographs were obtained with a spot size of 5 and voltage of 13.5 kV.

2.6 ROUGHNESS TEST

The roughness of the files was quantified using the New View 7100 Profilometer (Zygo Co, Middlefield, CT). The test was realized in 3 instruments of each group. The roughness was measured along the instruments in 10 points, generating a total of 30 points per group. The profilometer provided three-dimensional analyzes of the surfaces and measured peaks and valleys with a vertical resolution of 0.1 µm. The area determined for the test was at the valley of helical shaft canal. The diameter was established by a mask of 0.2 mm, and the measurement area was the same for all instruments. The measured roughness (Ra), average roughness, was submitted to posterior statistical analysis.

2.7 STATISTICAL ANALYSIS

The preliminary data analysis revealed the normality of the groups using the Shapiro-Wilk test. Then, the groups were submitted to the analysis of variance (ANOVA), complemented by the post-hoc test of Student-Newman-Keuls. All tests were performed with the significance level (α) of 5%.

3 RESULTS

The means and standard deviations of the values of the bending resistance, buckling resistance, dynamic cyclic fatigue time and surface roughness pattern are shown in the Table 1.

The ascending orders of the studied properties are: flexibility - R25B > WOGP > R25M ($P < 0.05$); buckling resistance - R25M > R25B > WOGP ($P < 0.05$); and fatigue life - R25B > R25M > WOGP ($P < 0.05$). The SEM images revealed that the fracture surface of all groups tested showed ductile morphological characteristics (**Figure 1**).

There was no statistically significant difference regarding the roughness of the tested instruments ($P > 0.05$). The 3D images of the files displayed similar patterns (Figure 2).

4 DISCUSSION

The first results of the present study demonstrated that the R25B files were significantly more flexible than WOGP and R25M. Therefore, the first null hypothesis was rejected. These results corroborate with those found in previous studies that have confirmed that blue-alloy instruments are more flexible than M-Wire and gold-alloy ones (De-Deus et al., 2017; Keskin et al., 2017). Although R25B and R25M files have the same tip diameter, taper and geometry ("S" shape cross-section); they differ in the NiTi alloy. The blue wire thermal treatment made the R25B more flexible (De-Deus et al., 2017). In addition, the R25B instruments presented greater flexibility than the WOGP. R25B have a greater taper than WOGP; however, R25B is manufactured with blue wire treatment that presents greater flexibility than gold wire treatment (Keskin et al., 2017; Alcade et al., 2017; Plotino et al., 2018), and also has a smaller cross-section area than WOGP, that results in a more flexible nucleus (**Figure 1**). Taken together, these properties explain the superior flexibility of R25B instruments when compared to WOGP. Despite the larger cross-sectional area of WOGP (parallelogram shape), this instruments presented greater flexibility in relation to the R25M. The gold wire thermal treatment, which presents greater flexibility in relation to M-Wire, explain this difference (Alcade et al., 2017; Plotino et al., 2018).

Clinically, the resistance to buckling is a fundamental condition for root canal exploration because it is related to the ability of the instrument to advance through the canal in the apical direction. The second results of the present study demonstrated that R25M have a higher buckling resistance, while WOGP have the lower one. Therefore, the second null hypothesis was also rejected. These results corroborate with studies that show that the instruments manufactured in the M-Wire alloy present higher resistance than martensitic NiTi instruments (De-Deus et al., 2017; Keskin et al., 2017; Lopes et al., 2013a). As more rigid the instrument is at his long axis, greater is its ability to negotiate and advance in the apical direction of the root canal (Lopes et al., 2012; Belladonna et al., 2018). Instruments with low resistance to buckling, such as WOGP and R25B, may undergo deformations, making their progression difficult. Instruments with low resistance to buckling may make it difficult to treat calcified canals and retreatments. On the other hand, the more flexible the instrument, the greater its ability to keep the preparation centralized and to work on the curved part of the canal (Lopes et al., 2013a; Belladonna et al., 2018; Jamleh et al., 2018; De-Deus et al., 2019; Lopes et al., 2016a; Ozyurek et al., 2016).

The bending resistance tests and buckling evaluate the flexibility of the tested instruments, but in different directions. In the bending resistance, the force is applied transversely to the long axis of the instrument positioned 45º in relation to the ground plane, this configuration does not correspond to the clinical reality, but allows to compare the flexibility of the different instruments studied. In buckling resistance test the force is applied to the long axis, and the maximum force is measured. This represents the resistance that the instrument would resist before arching in the condition of the use, being more representative of clinical reality. In both tests the geometry (taper and diameter) and the metallic alloy (M-wire, blue and gold treatments) influenced directly the results (De-Deus et al., 2017; Plotino et al., 2012; Topçuağlu et al., 2017). The R25 instrument presented higher resistance in both tests due to its M-wire alloy and its greater taper .08. Comparing the R25B and WOGP, the first presented greater flexibility and resistance to buckling, becoming the most interesting option among the martensitic NiTi instruments studied (Lopes et al., 2014; Keskin et al., 2017; Plotino et al., 2018).

Despite the limitations of *in vitro* studies, the dynamic cyclic fatigue model was adopted to a better approach of the clinical scenario (Ozyurek, 2016; Topçuağlu et al., 2017; Pedulla et al., 2018; Keles et al., 2019; Yao et al., 2006; Lopes et al., 2013b). The third results of the present study demonstrated that R25B has the better cyclic fatigue resistance and the WOGP has the worse one. Therefore, the third null hypothesis was rejected. This result corroborates with several previously published studies (De-Deus et al., 2017; Keskin et al., 2017; Plotino et al., 2018; Topçuağlu et al., 2017; Lopes et al., 2013a; De-Deus et al., 2014). The improved behavior of R25B under fatigue when compared to its precursor R25M is in accordance with their flexibility and is directly related to its NiTi wire. This is in agreement with the findings of other authors (De-Deus et al., 2017; Keskin et al., 2017). Regarding the WOGP instruments, the difference in its cross-section influenced the result: its larger area in parallelogram shape contributed to reduce its resistance to fatigue. another critical point that may have influenced in the fatigue test is that the instruments are designed differently, one of the unique features of WOGP is that they are asymmetric and have a decentralized axis of rotation, which does not occur in the R25M and R25B (Gündogăr & Özyürek, 2017; Keskin et al., 2017). The SEM analysis revealed that all instruments had a fracture surface with ductile type characteristics, regardless of the thermal treatment (M-wire, gold or blue wire).

The fourth results of the present study demonstrated no difference in the surface roughness of the different tested instruments (P>0.05). Therefore, the fourth null hypothesis was accepted. Previous studies demonstrated that the surface finish has influence on the fatigue life of the instruments (Lopes et al., 2010; Lopes et al., 2016b); however, in the present study this variable did not have impact on the fatigue tests. The differences in the fatigue can be attributed to the geometry and the NiTi alloy flexibility (caused by the heat treatment).

5 CONCLUSIONS

It can be concluded that the R25B file presented superior flexibility and performance under fatigue tests. The R25M have higher buckling resistance. Instruments demonstrated similar characteristics of surface finish.

REFERENCES

ALCALDE, M.P.; TANOMARU-FILHO, M.; BRAMANTE, C.M.; DUARTE, M.A.H.; GUERREIRO-TONUMARU, J.M.; CAMILO-PINTO, J.; et al. Cyclic and Torsional Fatigue Resistance of Reciprocating Single Files Manufactured by Different Nickel-titanium Alloys. J Endod, V. 43, n. 7, p. 1186-91, 2017. https://doi.org/10.1016/j.joen.2017.03.008

BELLADONNA, F.G.; CARVALHO, M.S.; CAVALCANTE, D.M.; FERNANDES, J.T.; MACIEL, A.C.C.; OLIVEIRA, H.E.; et al. Micro–computed Tomography Shaping Ability Assessment of the New Blue Thermal Treated Reciproc Instrument. J Endod, V. 44, n. 7, p. 1146-50, 2018. https://doi.org/10.1016/j.joen.2018.03.008

DE-DEUS, G.; VIEIRA, V.T.L.; SILVA, E.J.N.; LOPES, H.; ELIAS, C.N.; MOREIRA, E.J. Bending Resistance and Dynamic and Static Cyclic Fatigue Life of Reciproc and WaveOne Large Instruments. J Endod, V. 40, n. 4, p. 575-9, 2014. https://doi.org/10.1016/j.joen.2013.10.013

DE-DEUS, G.; SILVA, E.J.N.L.; VIEIRA, V.T.L.; BELLADONA, F.G.; ELIAS, C.N.; PLOTINO, G.; et al. Blue Thermomechanical Treatment Optimizes Fatigue Resistance and Flexibility of the Reciproc Files. J Endod, V. 43, n. 3, p. 462-6, 2017. https://doi.org/10.1016/j.joen.2016.10.039

DE-DEUS, G.; MILLA, L.C.; BELLADONNA, F.G.; CAVALCANTE, D.M.; SIMÕES-CARVALHO, M; SOUZA, E.M.; et al. Performance of Reciproc Blue R25 Instruments in Shaping the Canal Space without Glide Path. J Endod, V. 45, n. 2. p. 194-8, 2019. https://doi.org/10.1016/j.joen.2018.10.011

GÜNDOGĂR, M.; ÖZYÜREK, T. Cyclic Fatigue Resistance of OneShape, HyFlex EDM, WaveOne Gold, and Reciproc Blue Nickel-titanium Instruments. J Endod, V. 43, n. 7, p. 1192-6, 2017. https://doi.org/10.1016/j.joen.2017.03.009

ISO 3630-1 (2008) Dentistry – Root canal instruments – Part 1: General requirements and test methods.

JAMLEH, A.; ALFADLEY, A.; ALFOUZAN, K. Vertical Force Induced with WaveOne and WaveOne Gold Systems during Canal Shaping. J Endod, V. 44, n. 9, p. 1412-5, 2018. https://doi.org/10.1016/j.joen.2018.05.010

KELES, A.; EYMIRLI, A.; UYANIK, O.; NAGAS, E. Influence of static and dynamic cyclic fatigue tests on the lifespan of four reciprocating systems at different temperatures. Int Endod J, V. 52, n. 6, p. 1-7, 2019. https://doi.org/10.1111/iej.13073

KESKIN, C.; INAN, U.; DEMIRAL, M.; KELIŞ, A. Cyclic Fatigue Resistance of Reciproc Blue, Reciproc, and WaveOne Gold Reciprocating Instruments. J Endod, V. 43, n. 8, p. 1360-63, 2017. https://doi.org/10.1016/j.joen.2017.03.036

LOPES, H. P.; MOREIRA, E.J.L.; ELIAS, C.N; ALMEIDA, R.A.; NEVES, M.S. Cyclic fatigue of Protaper instruments. J Endod, V. 33, n. 1, p. 55-7, 2007. https://doi.org/10.1016/j.joen.2006.09.003

LOPES, H.P.; ELIAS, C.N; VIEIRA, V.T.L; MOREIRA, E.J.L.; MARQUES, R.V.L.; OLIVEIRA, J.C.; et al. Effects of electropolishing surface treatment on the cyclic fatigue resistance of BioRace nickel-titanium rotary instruments. J Endod, V.36, n. 10, p. 1653-7, 2010. https://doi.org/10.1016/j.joen.2010.06.026

LOPES, H.P.; ELIAS, C.N.; MANGELLI, M.; LOPES, W.S.P.; AMARAL, G.; SOUZA, L.C.; et al. Buckling resistance of pathfinding endodontic instruments. J Endod, V. 38, n. 3, p. 402–4, 2012. https://doi.org/10.1016/j.joen.2011.10.029

LOPES, H.P.; GAMBARRA-SOARES, T.; ELIAS, C.N.; SIQUEIRA Jr, J.F.; INOJOSA, I.F.J.; LOPES, W.S.P.; VIEIRA, V.T.L. Comparison of the mechanical properties of Rotary instruments made of conventional nickel-titanium wire, M-wire, or nickel-titanium alloy in R-phase. J Endod, V. 39, n. 4, p. 516-20, 2013a. https://doi.org/10.1016/j.joen.2012.12.006

LOPES, H.P.; ELIAS, C.N.; VIEIRA, M.V.B; SIQUEIRA, J.F.; MANGELLI, M.; LOPES, W.S.P.; et al. Fatigue life of Reciproc and Mtwo instruments subjected to static and dynamic tests. J Endod, V. 39, n. 5, p. 693-6, 2013b. https://doi.org/10.1016/j.joen.2012.11.048

LOPES, W.S.P.; LOPES, H.P.; ELIAS, C.N.; VIEIRA, M.V.B.; MANGELLI, M.; CUNHA, R.S. Resistance to bending and buckling of WaveOne and Reciproc instruments. ENDO (Lond Engl), V. 8, n. 2, p. 153–6, 2014.

LOPES, H.P.; LOPES, W.S.P.; VIEIRA, V.T.L.; ELIAS, C.N.; CUNHA, R.S. Evaluation of the Flexibility, Cyclic Fatigue, and Torsional Resistance of Rotary Endodontic Files Made of Different Nickel-Titanium Alloys. Int J Dentstry Oral Sci, V.S8, p. 1-5, 2016a. https://doi.org/10.19070/2377-8075-SI08001

LOPES, H.P.; ELIAS, C.N.; VIEIRA, M.V.B.; VIEIRA, V.T.L.; SOUZA, L.C.; SANTOS, A.L. Influence of Surface Roughness on the Fatigue Life of Nickel-Titanium Rotary Endodontic Instruments. J Endod, V. 42, n. 6, p. 965-968, 2016b. https://doi.org/10.1016/j.joen.2016.03.001

OZYUREK T. Cyclic Fatigue Resistance of Reciproc, WaveOne, and WaveOne Gold Nickel-Titanium Instruments. J Endod, V. 42, n. 10, p. 1536–9, 2016. https://doi.org/10.1016/j.joen.2016.06.019

PEDULLA, E.; LA ROSA, G.R.M.; BONINELLI, S.; RINALDI, G.; RAPISARDA, E.; KIM, H. Influence of Different Angles of File Access on Cyclic Fatigue Resistance of Reciproc and Reciproc Blue Instruments. J Endod, V. 44, n. 12, p. 1849-55, 2018. https://doi.org/10.1016/j.joen.2018.08.012

PLOTINO, G.; COSTANZO, A.; GRANDE, N.M.; PETROVICK, R.; TESTARELI, L.; GAMBARINI, G. Experimental evaluation on the influence of autoclave sterilization on the cyclic fatigue of new nickel-titanium rotary instruments. J Endod, V.38, n.2, p. 222-5, 2012. https://doi.org/10.1016/j.joen.2011.10.017

PLOTINO, G.; GRANDE, N.M.; COTTI, E.; TESTARELLI, L.; GAMBARINI, G. Blue treatment enhances cyclic fatigue resistance of vortex nickel-titanium rotary files. J

Endod, V. 40, n. 9, p. 1451–3, 2014. https://doi.org/10.1016/j.joen.2014.02.020

PLOTINO, G.; GRANDE, N.M.; TESTARELLI, L.; GAMBARINI, G.; CASTAGNOLA, R.; ROSSETI A, et al. Cyclic Fatigue of Reciproc and Reciproc Blue Nickel-titanium Reciprocating Files at Different Environmental Temperatures. J Endod, V. 44, n. 10, p. 1549-52, 2018. https://doi.org/10.1016/j.joen.2018.06.006

RODRIGUES, R.C.V.; LOPES, H.P.; ELIAS, C.N.; AMARAL, G.; VIEIRA, V.T.L.; MARTIN, A.S. Influence of different manufacturing methods on the fatigue of rotary nickel-titanium endodontic instruments. J Endod, V. 37, n. 11, p. 1553-56, 2011. https://doi.org/10.1016/j.joen.2011.08.011

SHEN, Y.; ZHOU, H.M.; CAMPBELL, L.; PENG, B.; HAAPASALO, M. Metallurgical characterization of controlled memory wire nickel-titanium rotary instruments. J Endod, V. 37, n. 11, p. 1566-71, 2011. https://doi.org/10.1016/j.joen.2011.08.005

SILVA, E.J.N.L.; HECKSHER, F.; ANTUNES, H.S.; DE-DEUS, G.; ELIAS, C.N.; VIEIRA, V.T.L. Torsional Fatigue Resistance of Blue-treated Reciprocating Instruments. J Endod, V. 44, n. 6, p. 1038-41, 2018. https://doi.org/10.1016/j.joen.2018.03.005

THOMPSON, S.A. An overview of nickel-titanium alloy used in dentistry. Int Endod J, V. 33, n. 4, p. 297-310, 2000. https://doi.org/10.1046/j.1365-2591.2000.00339.x

TOPÇUAĞLU, H.S.; DÜZGÜN, S.; AKIT, A.; TOPÇUAĞLU, G. Laboratory comparison of cyclic fatigue resistance of WaveOne Gold, Reciproc and WaveOne files in canals with a double curvature. Int Endod J, V. 50, n. 7, p. 713-7, 2017. https://doi.org/10.1111/iej.12674

YAO, J.H.; SCHWARTZ, S.A.; BEESON, T.J. Cyclic fatigue of three types of rotary nickel-titanium files in a dynamic model J Endod, V.32, n. 1, p. 55-7, 2006. https://doi.org/10.1016/j.joen.2005.10.013

ZUPANC, J.; VAHDAT-PAJOUH, N.; SCHAFER, E. New thermomechanically treated NiTi alloys – a review. Int Endod J, V. 51, n.10, p. 1088-1103, 2018. https://doi.org/10.1111/iej.12924

TABLE

Table 1**.** Means and standard deviation to flexibility (gf), buckling resistance (gf), time to failure (s) and roughness (Ra) of the tested instruments.

Instruments	**Flexibility(gf)**	**Buckling (gf)**	**Cyclic Fatigue (s)**	**Roughness (Ra)**
R25M	418.3 ± 16.3^A	445.9 ± 8.5^A	$219.2 \pm 22{,}3^A$	1.22 ± 0.18^A
R25B	283.9 ± 16.2^B	366 ± 10.8^B	$404.6 \pm 27{,}3^B$	1.24 ± 0.17^A
WOGP	354.4 ± 16.1^C	235.5 ± 8.4^C	161.4 ± 12.1^C	1.39 ± 0.24^A

Different superscript letters represent statistical differences between groups ($P < 0.05$).

FIGURES AND LEGENDS

Figure 1. Fracture surface of instruments showing morphology characteristics of ductile type. Reciproc M-wire (A and B), Reciproc Blue (C and D) and Wave one Gold (E and F). The left micrograps were obtained with a magnification of 200X, it was possible to visualize the instruments cross-section on them. The right ones with 1000X displays the microvoids characteristics of ductile fracture.

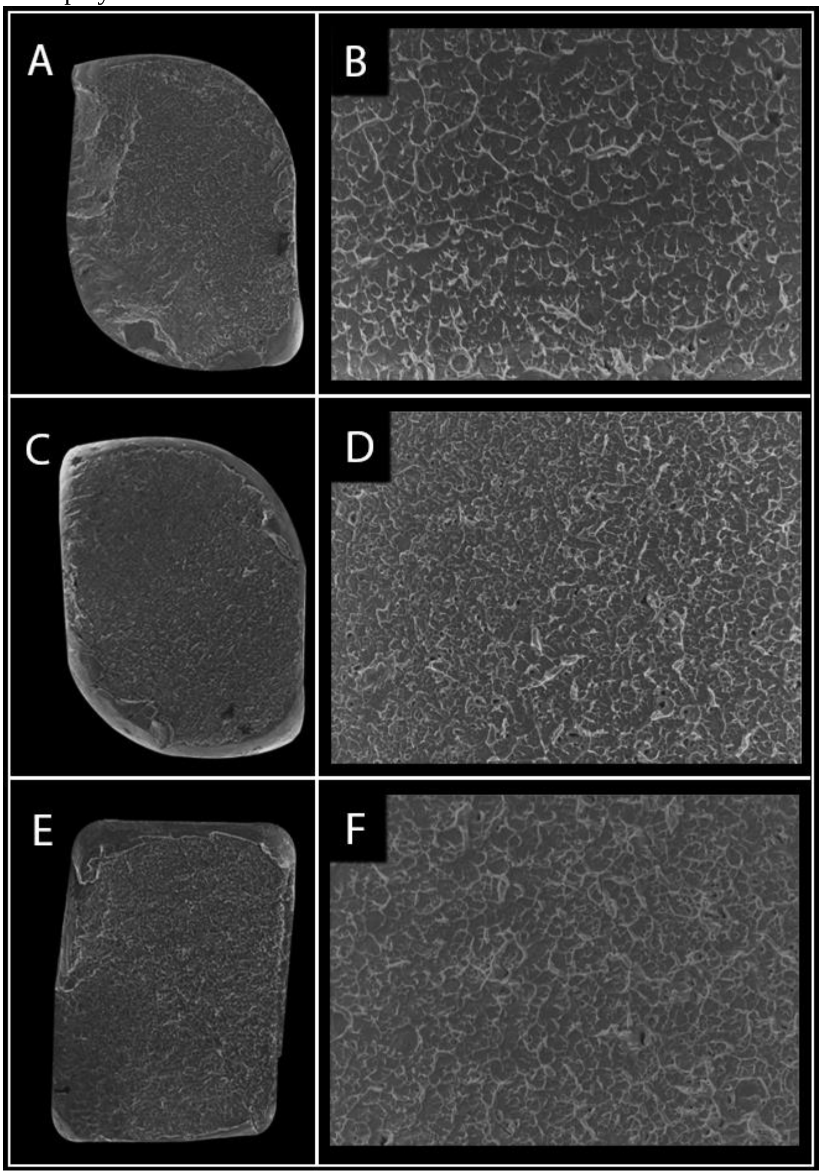

Figure 2. 3D Instrument surface morphology reconstructed by interferometry. (A) Reciproc M-wire, (B) Reciproc Blue and (C) Wave One Gold instrument.