Cyclic and Torsional Fatigue Resistance of a New Rotary File on a Rotary and Reciprocating Motion.

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Abstract

Introduction: This study aimed to evaluate the cyclic and torsional fatigue resistance of a new nickel-titanium (Flat File 25.04) instrument on continuous and reciprocating motion. **Methods:** Sixty instruments of the ProDesign Logic2 25.03 and 25.05 (Easy Equipamentos Odontológicos, Belo Horizonte, Brazil), and MK Flat File 25.04 (n=20) (MK Life, Porto Alegre, Brazil) were used. For the cyclic fatigue test, an artificial stainless steel simulated canal with an angle of 60° and a radius of curvature of 5mm located 5mm from its tip was used. Torque and angle of rotation at failure of instruments on torsional fatigue test was based on the ISO 3630-1 protocol, in which the 3mm tip of each instrument was fixed and connected to an electric motor and a load cell. The fractured surface of each fragment was examined by scanning electron microscopy. Data were analyzed using 1-way analysis of variance and Tukey's test with a significance level of 5%. **Results:** Flat File 25.04 had lower cyclic fatigue in both kinematics than the Logic instruments ($P < .05$). Reciprocating motion improved the cyclic fatigue of the tested instruments ($P < .05$). Flat File 25.04 had similar torque to Logic2 25.05 ($P < .05$), and both were superior to Logic2 25.03 ($P < .05$). The angular deflection values were different for the three tested instruments ($P < .05$), in the decreasing order: Logic2 25.03, 25.05, and Flat File 25.04. **Conclusion:** Flat File presented acceptable resistance to cyclic and torsional fatigue resistance. Reciprocating motion improved the cyclic fatigue resistance of the instruments and can be considered when using programmable motors.

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Running Title: New rotary file on different kinematics

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Keywords: Endodontics. Cyclic fatigue. Torsional resistance. NiTi instruments.

Research Highlights: Scanning eletron microscopy evaluation of different endodontic rotary file and fatigue resistance tests.

Graphical Abstract

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Introduction: This study aimed to evaluate the cyclic and torsional fatigue resistance of a new nickel-titanium (Flat File 25.04) instrument on continuous and reciprocating motion. **Methods:**Sixty instruments of the ProDesign Logic2 25.03 and 25.05 (Easy Equipamentos Odontológicos, Belo Horizonte, Brazil), and MK Flat File 25.04 (n=20) (MK Life, Porto Alegre, Brazil) were used. For the cyclic fatigue test, an artificial stainless steel simulated canal with an angle of 60° and a radius of curvature of 5mm located 5mm from its tip was used. Torque and angle of rotation at failure of instruments on torsional fatigue test was based on the ISO 3630-1 protocol, in which the 3mm tip of each instrument was fixed and connected to an electric motor and a load cell. The fractured surface of each fragment was examined by scanning electron microscopy. Data were analyzed using 1-way analysis of variance and Tukey's test with a significance level of 5%.**Results:** Flat File 25.04 had lower cyclic fatigue in both kinematics than the Logic instruments ($P < .05$). Reciprocating motion improved the cyclic fatigue of the tested instruments ($P < .05$). Flat File 25.04 had similar torque to Logic2 25.05 ($P < .05$), and both were superior to Logic2 25.03 ($P < .05$). The angular deflection values were different for the three tested instruments ($P < .05$), in the decreasing order: Logic2 25.03, 25.05, and Flat File 25.04. **Conclusion:** Flat File presented acceptable resistance to cyclic and torsional fatigue resistance. Reciprocating motion improved the cyclic fatigue resistance of the instruments and can be considered when using programmable motors.

Keywords: Endodontics. Cyclic fatigue. Torsional resistance. NiTi instruments.

INTRODUCTION

Conventional nickel-titanium (NiTi) alloy instruments present super elasticity and memory control characteristics, predominantly in the austenite phase. However, when induced by temperature drops or mechanical stress application, they change to martensite, acquiring more flexibility [1,2].

However, these instruments are subject to failure, for example, torsional or cyclic fatigue [3]. Thus, technologies that prioritize variations in kinematics, cross-sectional design, and surface treatments have been proposed to improve their mechanical properties and, consequently, their clinical performance and safety of use [4-8].

Recently, a new NiTi instrument was created with the trade name of Flat File (MK Life, Porto Alegre, Brazil). This instrument has a Gold heat treatment and is available in a sequence of three instruments: 20.04, 25.04, and 35.04. It has an innovative design, with a flat side, without cutting blades, to allow more space for the irrigating solution, escape for debris, and less pushing effect of the instrument inside the root canal.

NiTi endodontic instruments are constantly subjected to tension and compression forces during root canal preparation, especially in accentuated curvatures. In addition, due to the simplification of the preparation technique, often, when only one instrument is used, there is a possibility that the tip of these instruments is in close contact with the root canal walls and, therefore, subject to torsional fractures [6].

Due to this, mechanical tests of cylic and torsional fatigue should be performed, and the results compared with existing instruments before their clinical use. Therefore, the objective of this study was to compare a new NiTi instrument (Flat File) with another instrument with similar dimensions (ProDesign Logic2) regarding its mechanical properties of torsional and cyclic fatigue on the continuous and reciprocating motion [7,8].

MATERIALS AND METHODS

Sample size determination was performed using G*Power 3.1 for Windows (Heinrich Heine, University of Dusseldorf) and the Wilcoxon-Mann-Whitney test from the "t" test group. An alpha-type error of 0.05, a beta-type power of 0.95, and an N2/N1 ratio of 1 were also adopted [8].

For the tests, a total of 60 NiTi instruments were selected: ProDesign Logic2 25.03 (n=20) and 25.05 (n=20) (Easy Equipamentos Odontologicos, Belo Horizonte, Brazil) and MK Flat File 25.04 (n=20) (MK Life, Porto Alegre, Brazil). All instruments were inspected for possible defects or deformations under a microscope (Alliance, Sao Paulo, Brazil) at 16x magnification. Flat File instruments are sold in a sterile blister, with no need for sterilization prior to testing. ProDesign Logic2 instruments have been subjected to a sterilization process according to the manufacturer's standards to simulate a precondition of clinical use.

Cyclic fatigue test

All instruments used were analyzed, and resistance to cyclic fatigue (ten for each group of instrument [n=5 for continuous mode and n=5 for reciprocating mode]) was tested at controlled room temperature (37o +- 1oC) [12,13]. The instruments were connected to a VDW Silver engine (VDW GmbH, Munich, Germany), which was connected to the cyclic fatigue device. The predefined programs were selected according to the manufacturers for the continuous motion. ProDesign Logic2 25.03 and 25.05 instruments were used in continuous motion at 950 rpm with 2 N/cm and 4N/cm of torque, respectively. Flat File instruments were used in continuous motion at 500 rpm with 2 N/cm of torque. When the reciprocating motion was tested, the instruments were coupled to an Eighteeth E-connect Pro motor (Eighteeth, Changzhou City, China) connected to the cyclic fatigue device. The ProDesign Logic 25.03, 25.05, and Flat File 25.04 were used in reciprocating motion at 350rpm with an angle of rotation of 150o forward and 30o reverse.

The instruments were positioned in a device simulating an artificial canal made of stainless steel, with a curvature of 60o and a radius of curvature of 5 mm located 5 mm from the instrument's tip. The device has an outer arch with a 1 mm deep groove that served as a guide for the instruments' path, keeping them in the curvature and allowing them to rotate freely during the tests. This device allowed a precise and reproducible position of the curvature that was established for all instruments used.

A digital stopwatch recorded the time to fracture, and a digital camera captured data to ensure fracture time accuracy in seconds.

Torsional fatigue test

For the torsional tests, a specific machine (Analogica, Belo Horizonte, Brazil) was used that measured the torque and controlled the rotation angle through the connection to a computer, collecting all the data. The tests performed was based on the ISO 3630-1 (1992)

Torque was measured through the force exerted on a small load cell attached to a lever arm on the long axis of torsion. Ten instruments from each system were used for this step. Before testing, the instrument's handles were removed at the point where they were attached to the torsion shaft. The 3 mm ends of the instruments were attached to a chuck connected to an electric motor. The electric motor was operated clockwise at a speed of 2 rpm.

Scanning Electron Microscopic Evaluation

The fractured surfaces of 5 instruments of each file, randomly selected after cyclic and torsional fatigue tests, were examined by scanning electron microscopy JSM-6060 (Jeol Brasil Ltda, Mirandopolis, Sao Paulo) to look for the topographic features of the fractured instruments. Before scanning electron microscopic (SEM) evaluation, instruments were ultrasonically cleaned to remove debris. The photomicrographs were taken at 200X magnification. Furthermore, additional photomicrographs were taken at 1000X magnification in the center of the fractured surface of the instruments submitted to torsional testing.

RESULTS

The mean and standard deviation values of the cyclic (seconds) and torsional (maximum torque), and angular deflection (rotation angle) fatigue tests are shown in Table 1.

Regarding the cyclic fatigue in continuous motion, Flat File 25.04 instruments showed the lowest cyclic fatigue resistance than the Logic 25.03 and 25.05 instruments ($P < .05$). In addition, Logic 25.03 presented the highest cyclic fatigue resistance ($P < .05$). In reciprocating motion, all instruments had higher cyclic fatigue resistance than when activated in continuous motion ($P< .05$). The Flat File 25.04 showed the lowest values of cyclic fatigue resistance when compared to Logic 25.03 and Logic 25.05 ($P< .05$). Logic 25.03 presented higher cyclic fatigue resistance values than Logic 25.05 ($P< .05$)

The torsional test showed that the Flat 25.04 instruments presented similar torque to the Logic 25.05 instrument ($P > .05$). The Logic 25.03 instrument presented the lowest torque values ($P < .05$). Regarding the angular deflection, all the instruments had significantly different values, according to the following decreasing order: Logic 25.03, 25.05, and Flat File 25.04 ($P<.05$)

SEM evaluation

Scanning electron microscopy of the fracture surface showed similar and typical torsional and cyclic fatigue features for all instruments tested. After the torsional test, the instruments showed concentric abrasion marks and tear-shaped marks at the center of rotation (Fig. 1A–C and a–c). In the cyclic fatigue test, all the files presented fractured surfaces with microcracks, with morphologic characteristics of a ductile fracture (Fig. 2A–C and a-c).

DISCUSSION

Several factors may have been responsible for the results obtained in this study. The instruments performance in mechanical tests are also influenced by the type of NiTi alloy used and the heat treatment used. Flat File files are featured with gold heat treatment that has an austenite finish temperature approximately at 50oC [9] , while Logic files are featured with a controlled memory alloy (CM wire) that has an austenite finish temperature around 55oC [10,11]. So, when the cyclic fatigue test is performed with a controlled temperature (37oC) simulating a body temperature [12,13] ,CM Wire instruments present more martensite phase during the test than gold heat treatment. This austenitic finishing temperatures influence properties during root canal preparation at body temperature [14]. So far, with a crystalline structure predominantly martensite that allows the control of the shape memory of the instrument, being extremely flexible and more resistant to cyclic fatigue, for example, when compared to "Gold" instruments [2] .These aspects justify the higher fatigue cyclic values presented by Logic instruments compared with Flat File.

Core mass and cross-sectional design also can influence the results of mechanical tests. A smaller metal volume is associated with more excellent cyclic fatigue resistance [15]. This fact could be explained when calculating the bending section modulus, the ratio of moment of inertia, and the distance from the neutral axis in the instrument center to the instrument surface and geometrical shape [14]. In short, flat cross-section designs such as S-Shape are associated with an increased cyclic fatigue resistance [15, 16]. Also, bigger cross-sections are associated with a stiffer instrument, with great flexural strength and torsional resistance [17]. Logic instruments have a double helix cross-section, while Flat File instruments have a modified S-section. However, the reduction of the metallic mass of Flat File instruments to generate only one side with active spirals can negatively influence the cyclic fatigue values compared to Logic instruments. Besides, the manufacturing process (surface treatment) of Flat File instruments to provide a flat surface may also influence their structural characteristics, generating irregularities in this portion [18]. Possible microcracks can lead to instrument fractures under clinical or laboratory stress, especially in curvatures when the alloy is subjected to tension and compression [19].

Higher cyclic fatigue values on both kinematics (continuous and reciprocating) for the Logic 25.03 compared to the Logic 25.05 can be justified by the taper of the instruments. Instruments with the same heat treatment and structural characteristics but high taper will present lower resistance to cyclic fatigue than those instruments with low taper [20]. The static cyclic fatigue test was performed as described in previous studies [8,21]. In this model, the instruments are mounted in a stabilized handpiece that provides a free rotation in an artificial canal under specific conditions until the instruments fracture [22]. This condition leads the NiTi instruments to the maximum stress, mainly because they remain in a static position inside the simulated canal, generating areas of stress concentration (tension and compression) of the alloy in a specific region of the instrument. This method reduces some biases and induces less localized mechanical stress, increasing the time and number of cycles to fatigue [17,23].

Cyclic fatigue occurs through the formation of microcracks in surface irregularities that extend through the instrument during cycles until the fracture occurs [24]. Studies showed that reciprocating motion increases resistance to cyclic fatigue compared to continuous motion [25-27]. During reciprocating motion, the instrument disengages from the canal walls at the moment of higher tension, delaying the formation of microcracks on the surface of the endodontic instrument [28]. The use of rotary instruments in conventional reciprocating motion (150o reverse, 30o forward) had not been encouraged because their spirals were designed to cut in a clockwise direction. However, with the development of programable motors that allow modifications of the angle and direction of rotation, reciprocating kinematics also can be employed for rotary instruments (150o forward, 30o reverse) [29]. These programmable endodontic motors allow reciprocating motion to both sides (i.g. clockwise or counterclockwise)[29].

After the torsional resistance test, the Flat File 24.04 and Logic 25.05 showed higher values than the Logic 25.03 instrument ($P < .05$). This finding could be explained because it may be associated with its greater taper than the 0.3 instruments, which results in more torsional resistance than instruments with smaller tapers [14,17]. Higher values of torsional resistance are associated with instruments with greater mass, either as a function of their cross-section, tip diameter, or taper [30]. Also, torsional stiffness could be increased by files with reduced pitch and increased cross-sectional areas. For example, rectangular cross-sections had superior torsional stiffness compared to triangular cross-sections [31]. Specific cross-sectional configurations are more prone to failure by torsional overload than others by the principle of mechanics when an instrument with a small core diameter is more susceptible to failure by torsional overload [4]. The investigation of this property is essential to estimate the torque value necessary for the instrument to fracture inside the simulated canal contributing to the possibility of working with these instruments at a torque value lower than that necessary to cause a fracture.

Scanning electron microscopic analysis showed a typical fractographic appearance of cyclic fatigue and torsional fracture, presenting similar images among the three analyzed instruments. The fragments showed crack initiation areas on the cyclic fatigue test image, with numerous dimples on the fractured surface. After the torsional test, the instruments demonstrated the typical features of shear failure, including concentric tear marks and fibrous microscopic dimples at the center of rotation [21,32,33].

Finally, angular deflection makes it possible to identify how much the instrument can deform when attached to the root canal prior to its fracture by torsion. The angular deflection values obtained in this study differed for all instruments ($P < .05$). Flat File showed the lowest angular deflection values. This result can be attributed to its gold heat treatment since the CM treatment present in Logic files, provides greater flexibility and ductility [2,5]. In addition, Flat File instruments have a modified S section that is more irregular than the double helix section of Logic instruments. Asymmetrical cross-sections such as Flat File instruments generate worse stress distribution when used, making instruments of this type more susceptible to fracture [30].

CONCLUSIONS

Geometric characteristics, Ni-Ti alloy, heat treatment and manufacturing process influence the mechanical properties of the Ni-Ti instruments. Flat File 25.04 instrument presented a good resistance to cyclic fatigue, torsional loads, and angular deflection. Reciprocating motion improved the cyclic fatigue resistance of Flat File instrument and can be considered when using programmable endodontic motors.

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REFERENCES

1. Miyai K, Ebihara A, Hayashi Y, Doi H, Suda H, Yoneyama T. Influence of phase transformation on the torsional and bending properties of nickel-titanium rotary endodontic instruments. Int Endod J. 2006;39:119–26.
2. Zupanc J, Vahdat-Pajouh N, Schafer E. New thermomechanically treated NiTi alloys – a review. Int Endod J. 2018;51:1088–103
3. Martin B, Zelada G, Varela P, Bahillo JG, Magan F, Ahn S, et al. Factors influencing the fracture of nickel-titanium rotary instruments. Int Endod J. 2003;36:262–6.
4. Zhang EW, Cheung GSP, Zheng YF. Influence of cross-sectional design and dimension on mechanical behavior of nickel-titanium instruments under torsion and bending: A numerical analysis. J Endod [Internet]. 2010;36:1394–8.
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;39:163-72.
6. Ahamed SBB, Vanajassun PP, Rajkumar K, Mahalaxmi S. Comparative Evaluation of Stress Distribution in Experimentally Designed Nickel-titanium Rotary Files with Varying Cross Sections : J Endod [Internet]. 2018;44:654–8.
7. Tokita D, Ebihara A, Miyara K, Okiji T. Dynamic Torsional and Cyclic Fracture behavior of ProFile Rotary Instruments at Continuous or Reciprocating Rotation as Visualized with High-speed Digital Video Imaging. J Endod [Internet]. 2017;43:1337–42.
8. Alcalde MP, Duarte MAH, Bramante CM, de Vasconselos BC, Tanomaru-Filho M, Guerreiro-Tanomaru JM, et al. Cyclic fatigue and torsional strength of three different thermally treated reciprocating nickel-titanium instruments. Clin Oral Investig [Internet]. 2018;22:1865–71.
9. 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. J Endod. 2015;41:1134-8.
10. Shen Y. et al. (2011a). Fatigue testing of controlled memory wire nickel-titanium rotary instruments. Journal of Endodontics, 37, pp. 997-1001.
11. Shen Y. et al. (2013b). HyFlex nickel–titanium rotary instruments after clinical use: metallurgical properties. International Endodontic Journal, 46, pp. 720-9.
12. 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. Clin Oral Investig. 2019;23:3047-3052
13. Weissheimer T, Heck L, Calefi PHS, Alcalde MP, da Rosa RA, Vivan RR, Duarte MAH, So MVR. Evaluation of the mechanical properties of different nickel-titanium retreatment instruments. Aust Endod J. 2021;47:265-272.
14. Burklein S, Zupanc L, Donnermeyer D, Tegtmeyer K, Schafer E. Effect of Core Mass and Alloy on Cyclic Fatigue Resistance of Different Nickel-Titanium Endodontic Instruments in Matching Artificial Canals. Materials (Basel). 2021;14:5734.
15. Di Nardo D., Gambarini G., Seracchiani M., Mazzoni A., Zanza A., Giudice A.D., D'Angelo M., Testarelli L. Influence of different cross-section on cyclic fatigue resistance of two nickel–titanium rotary instruments with same heat treatment: An in vitro study. Saudi Endod. J. 2020;10:221–225
16. Gambarini G, Galli M, Di Nardo D, Seracchiani M, Donfrancesco O, Testarelli L. Differences in cyclic fatigue lifespan between two different heat treated NiTi endodontic rotary instruments: WaveOne Gold vs EdgeOne Fire. J Clin Exp Dent. 2019;11:e609-e613.
17. De-Deus G, Leal Vieira VT, Nogueira da Silva EJ, Lopes H, Elias CN, Moreira EJ. Bending resistance

and dynamic and static cyclic fatigue life of Reciproc and WaveOne large instruments. J Endod. 2014;40:575-9.

18. Lopes HP, Elias CN, Vieira VT, Moreira EJ, Marques RV, de Oliveira JC, Debelian G, Siqueira JF, Jr. Effects of electropolishing surface treatment on the cyclic fatigue resistance of BioRace nickeltitanium rotary instruments. J Endod. 2010;36:1653-7.
19. Campbell L, Shen Y, Zhou HM, Haapasalo M. Effect of fatigue on torsional failure of nickel-titanium controlled memory instruments. J Endod. 2014;40:562-5.
20. Ha JH, Park SS. Influence of glide path on the screw-in effect and torque of nickel-titanium rotary files in simulated resin root canals. Restor Dent Endod. 2012;37:215-9.
21. Alcalde MP, Tanomaru-Filho M, Bramante CM, Duarte MAH, Guerreiro Tanomaru JM, Camilo-Pinto J, So MVR, Vivan RC. Cyclic and torsional fatigue resistance of reciprocating single files manufactured by different Nickel-titanium alloys. J Endod 2017; 43:1186–1191.
22. Alcalde M, Duarte MAH, Amoroso Silva PA, Souza Calefi PH, Silva E, Duque J, Vivan R. Mechanical Properties of ProTaper Gold, EdgeTaper Platinum, Flex Gold and Pro-T Rotary Systems. Eur Endod J. 2020;5:205-211
23. Pedulla E, Lizio A, Scibilia M, Grande NM, Plotino G, Boninelli S, et al. Cyclic fatigue resistance of two nickel-titanium rotary instruments in interrupted rotation. *Int Endod J.* 2017;50:194–201
24. Christ HJ. Fundamental mechanisms of fatigue and fracture. Stud Health Technol Inform 2008;133:56–67.
25. Varela-Patino P, Ibanez-Parraga A, Rivas-Mundina B, Cantatore G, Otero XL, Martin-Biedma B. Alternating versus continuous rotation: a comparative study of the effect on instrument life. J Endod. 2010;36:157-9.
26. Gavini, G., Caldeira, C. L., Akisue, E., Candeiro, G. T. de M., & Kawakami, D. A. S. (2012). Resistance to Flexural Fatigue of Reciproc R25 Files under Continuous Rotation and Reciprocating Movement. Journal of Endodontics 2012; 38, 684–687.
27. Silva EJNL, Hecksher F, Antunes HDS, De-Deus G, Elias CN, Vieira VTL. Torsional Fatigue Resistance of Blue-treated Reciprocating Instruments. J Endod. 2018;44:1038-1041.
28. De-Deus G, Moreira EJ, Lopes HP, Elias CN. Extended cyclic fatigue life of F2 ProTaper instruments used in reciprocating movement. Int Endod J. 2010;43:1063-8.
29. Capar ID, Arslan H. A review of instrumentation kinematics of engine-driven nickel–titanium instruments. International Endodontic Journal, 2016; 49, 119–135.
30. Xu X, Eng M, Zheng Y, Eng D. Comparative study of torsional and bending properties for six models of nickel-titanium root canal instruments with different cross-sections. J Endod 2006; 32: 372–5.
31. Baek SH, Lee CJ, Versluis A, Kim BM, Lee W, Kim HC. Comparison of torsional stiffness of nickel-titanium rotary files with different geometric characteristics. J Endod. 2011;37:1283-6
32. Kim HC, Kwak SW, Cheung GS, et al. Cyclic fatigue and torsional resistance of two new nickel-titanium instruments used in reciprocation motion: Reciproc versus WaveOne. J Endod 2012;38:541–4.
33. Pedulla E, Lo Savio F, Boninelli S, et al. Torsional and cyclic fatigue resistance of a new nickel-titanium instrument manufactured by electrical discharge machining. J Endod 2016;42:156–9.

TABLES

	Cyclic Fatigue(seconds) Rotary	Cyclic Fatigue (seconds) Reciprocating	Torque(Ncm)	Angle(º)
Instruments	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Flat 25.04	194.89 ± 5.81 Cb	337.76 ± 15.12 Ca	1.15 ± 0.11 A	407.59 ± 6.18 C
Logic 25.03	298.60 ± 27.07 Ab	654.13 ± 47.75 Aa	0.43 ± 0.06 B	862.43 ± 103.45 A
Logic 25.05	237.30 ± 42.99 Bb	575.42 ± 64.07 Ba	1.11 ± 0.08 A	672.30 ± 129.93 B

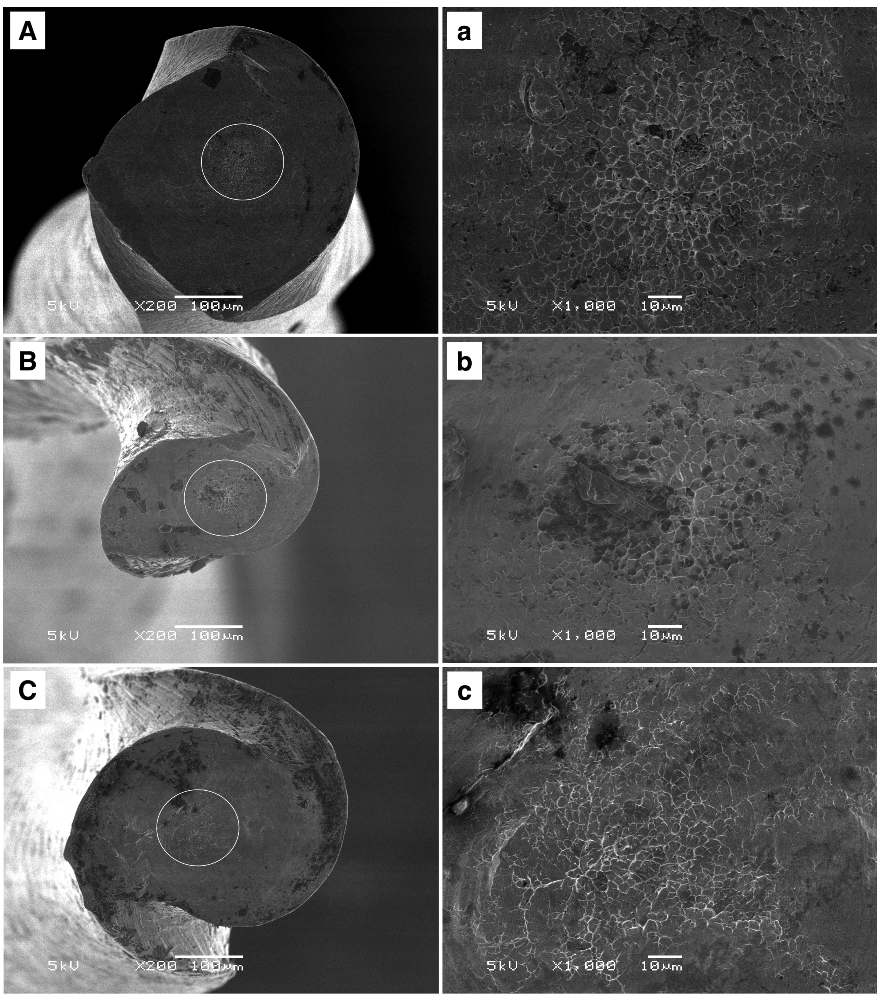
Table 1 – Mean Cyclic Fatigue (Time in seconds), Torque (Ncm), and Angle of Rotation (º) of the Instruments tested.

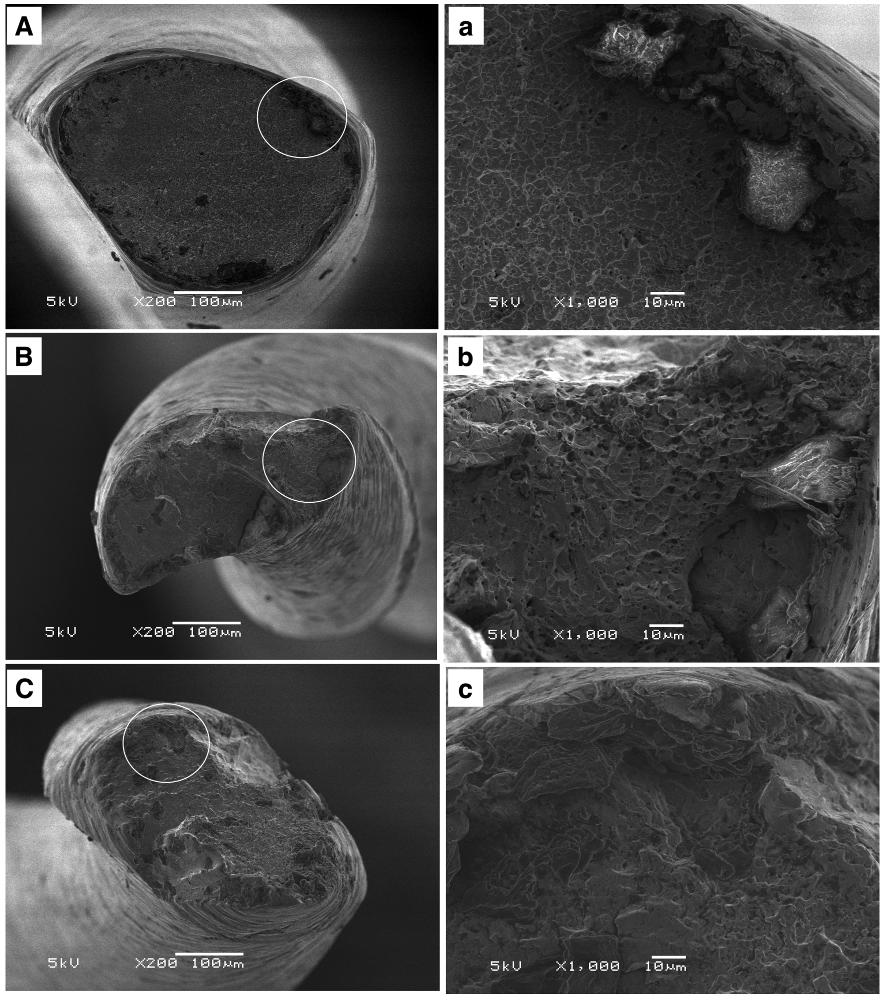
Different upper letters on columns indicate statiscal differences among groups after ANOVA one-way and post-hoc of Tukey ($P < 0{,}05$).

FIGURES

Figure 1 - Scanning electron microscopy images of the fractured surfaces of separate fragments after torsional testing (first row: A, a = Flat File 25.04; second row: B, b = ProDesign Logic2 25.03; bottom row: C, c = Prodesign Logic2 25.05). The left column shows images with the circular boxes indicating concentric abrasion marks at $\times$ 200 magnification; the right column shows concentric abrasion marks at $\times$ 1000 magnification; and the skewed dimples near the center of rotation are typical features of torsional failure.

Figure 2 - Scanning electron microscopy images of the fractured surfaces of separated fragments of cyclic fatigue testing (first row: A, a = Flat File 25.04; second row: B, b = ProDesign Logic2 25.03; bottom row: C, c = Prodesign Logic2 25.05). The crack origins are identified by circular boxes. The images show numerous dimples spread on the fractured surfaces, which constitute a typical feature of ductile fracture.




A
5kV X200 100µm
a
5kV X1,000 10µm
B
5kV X200 100µm
b
5kV X1,000 10µm
C
5kV X200 100µm
c
5kV X1,000 10µm