Research, Society and Development, v. 11, n. 6, e47511629570, 2022
(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v11i6.29570

Fatigue strength of Bassi Logic™ and Hyflex EDM endodontic instruments in an artificial canal with an extreme curvature

Resistência à fadiga dos instrumentos Bassi LogicTM e Hyflex EDM em canal artificial de curvatura extrema

Resistencia a la fadiga de dos instrumentos Bassi LogicTM e Hyflex EDM en canales artificiales de curvatura extrema

Received: 04/24/2022 | Reviewed: 05/01/2022 | Accept: 05/02/2022 | Published: 05/04/2022

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Abstract
The objective of this study was to perform a comparative analysis of the fatigue strength of NiTi instruments in an *in vitro* model (artificial canal). Ten Hyflex EDM instruments (tip: 10; taper: .05) (Coltene/Whaledent, Altstätten, Switzerland) and ten Bassi Logic™ instruments (tip: 15; taper: .05) (Bassi Endo, Belo Horizonte, Brazil) were used. For the static bending fatigue strength test, we used a stainless-steel artificial canal with a 5-mm curvature radius, 90º curvature, and inner diameter of 1.5 mm. The instruments were run in the artificial canal until the occurrence of fracture. The time was recorded and the number of cycles was calculated. The length of the fragments was measured and three samples from each group were analyzed using scanning electron micrscopy for the characterization of metal fatigue. The data were compared using the nonparametric Man-Whitney test (samples with non-normal distribution), with the significance level set at 5% ($p<0.05$). Bassi Logic™ instruments tolerated a greater number of cycles compared to the Hyflex EDM ($p < 0.05$). Significant differences in fragment size were also found between groups ($p < 0.05$). Mean fragment size was larger among the Hyflex EDM instruments compared to the Bassi Logic™ instruments.The Bassi Logic™ 15.05 exhibited greater fatigue strength in artificial canals with an accentuated curvature compared to Hyflex EDM 10.05.
Keywords: Dental instruments; Endodontics; Rotation.

Resumo
O objetivo do trabalho foi avaliar comparativamente a resistência à fadiga por flexão de instrumentos de NiTi através de modelo in vitro (canal artificial). Dez instrumentos Hyflex EDM (Coltene/Whaledent, Altstätten, Suíça), ponta 10 taper .05 e 10 instrumentos Bassi LogicTM (Bassi Endo, Belo Horizonte, Brasil), ponta 15, taper .05 foram incluídos nesse trabalho. Para o teste estático de resistência à fadiga por flexão, utilizou-se um canal artificial de aço inoxidável com um raio de curvatura de 5 mm, um ângulo de curvatura de 90º e um diâmetro interno de 1,5 mm. Os instrumentos

foram girados nos canais artificiais até a ocorrência da fratura, tempo de fratura foi registrado e foi calculado o número de ciclos até a fratura. Foram medidos os comprimentos dos fragmentos rompidos e 3 amostras de cada grupo foram avaliadas em microscopia eletrônica de varredura para caracterização da fadiga metálica. Os dados foram avaliados pelo teste Não Paramétrico de MannWhitney (para amostras sem distribuição normal). O nível de significância estabelecido foi p<0,05. Os instrumentos os Bassi LogicTM 15.05 apresentaram uma maior resistência à fadiga em canais artificiais com curvatura acentuada, quando comparados com instrumentos Hyflex EDM 10.05.
Palavras-chave: Endodontia; Instrumentos odontológicos; Rotação.

Resumen

El objetivo de este trabajo fue evaluar comparativamente la resistencia a la fatiga por flexión de instrumentos de NiTi a través de un modelo in vitro (canal artificial). En este trabajo se incluyeron diez instrumentos Hyflex EDM (Coltene/Whaledent, Altstätten, Suiza), punta 10, conicidad .05 y 10 instrumentos Bassi LogicTM (Bassi Endo, Belo Horizonte, Brasil), punta 15, conicidad .05. Para el ensayo de resistencia a la fatiga por flexión estática se utilizó un canal artificial de acero inoxidable con un radio de curvatura de 5 mm, un ángulo de curvatura de 90º y un diámetro interno de 1,5 mm. Los instrumentos se rotaron en los canales artificiales hasta que se produjo la fractura, se registró el tiempo hasta la fractura y se calculó el número de ciclos hasta la fractura. Se midieron las longitudes de los fragmentos rotos y se evaluaron 3 muestras de cada grupo en microscopía electrónica de barrido para caracterizar la fatiga metálica. Los datos fueron evaluados por la prueba no paramétrica de Mann-Whitney (para muestras sin distribución normal). El nivel de significación establecido fue p<0,05. Los instrumentos Bassi LogicTM 15.05 mostraron una mayor resistencia a la fatiga en canales artificiales con curvatura acentuada, en comparación con los instrumentos Hyflex EDM 10.05.
Palabras clave: Endodoncia; Instrumentos dentales; Rotación.

1. Introduction

The introduction of the nickel-titanium (NiTi) alloy in endodontics has led to the production of more flexible instruments with greater fatigue strength in comparison to stainless-steel instruments (Walia et al., 1988), which has enabled the root canal treatment with the use of mechanized tools. However, the unexpected fracture of NiTi instruments is a worrisome factor (Yared 2004; Gambarini 200). In clinical practice, the fracture of such instruments occurs in two different ways: torsional fracture or bending fatigue (Yared 2004; Capar et at., 2015). A torsional fracture occurs when the tip of the instrument is blocked in the canal as the shaft continues to rotate (Alcalde et al., 2018). Bending fatigue occurs due to the accumulation of tension and compression cycles located at a point along the instrument, leading to considerable stress that causes the emergence and propagation of microcracks that lead to a fracture (Plotino et al., 2009; Bueno et al., 2019). Despite all the technology employed in the manufacturing of dental instruments, such as thermal and surface treatments to optimize the mechanical properties, and the use of glide path instruments to minimize the tension applied to shaping instruments (Peters et al., 2017), fracture due to fatigue is the most prevalent type of failure (Wei et al., 2007). This increased prevalence occurs because, despite the flexibility of such instruments, it is not possible to standardize tooth anatomy. Thus, accentuated and dual curvatures remain an obstacle to endodontic success (Schäfer et al., 2002).

Changes in the design of the instruments, manufacturing process, and the thermomechanical treatment of NiTi alloy have been developed to enhance clinical performance and provide greater safety during use (Peters et al., 2017; Gavini et al., 2018). Bassi Logic^{TM} files (Bassi Endo, Belo Horizonte, Brazil) are endodontic instruments with tips ranging from #15 to #50 and constant tapers that have a different cross-sectional design, depending on the taper. The manufacturing process is based on CM-wire thermal treatment, which has a greater arrangement of martensite crystal structure, known for its ordered monocyclic shape and for providing greater flexibility compared to the austenite crystal structure. Due the large amount of this martensite structure, these instruments have little or no shape memory, making them more flexible and fatigue resistant (de Menezes et al., 2017; Alcade et al., 2017). HyFlex EDM files (Coltene/Whaledent, Altstatten, Switzerland) are produced by the electrical discharge machining (EDM) of conventional NiTi wires through thermal erosion, which partially melts and evaporates the wire by discharges of electrical sparks; these were the first endodontic instruments manufactured with EDM (Pirani et al., 2016;

Gündoğar & Özyürek, 2017).

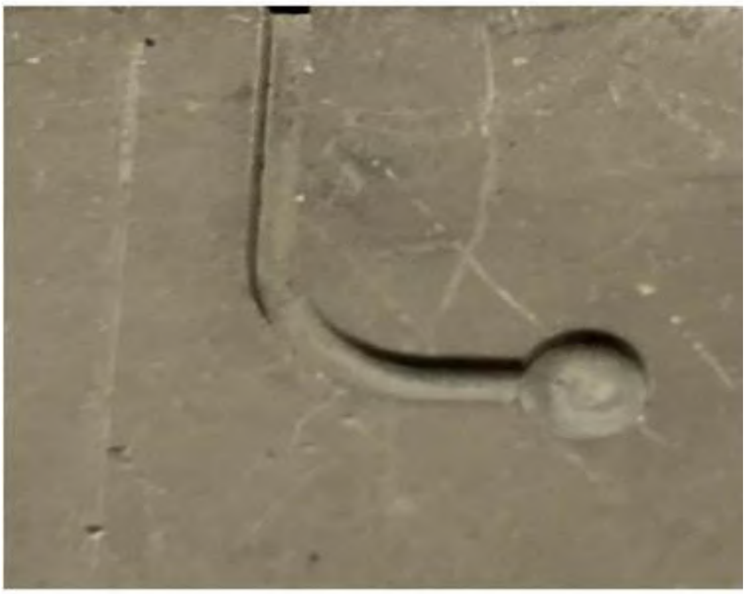
To date, no studies in the literature have compared the cyclic fatigue strength of the Bassi Logic™ and HyFlex EDM systems. Therefore, the aim of the present study was to perform a comparative analysis of the bending fatigue strength of these two NiTi instruments using an *in vitro* model (artificial canal). The null hypothesis was that there would be no significant difference in fatigue strength between the two instruments.

2. Methodology

The fatigue strength of different Ni-Ti endodontic instruments was tested. For such, we used ten Hyflex EDM instruments (tip: 10; taper: .05) (Coltene/Whaledent, Altstätten, Switzerland) and ten Bassi Logic™ instruments (tip: 15; taper: .05) (Bassi Endo, Belo Horizonte, Brazil).

For the static bending fatigue test, an artificial canal was designed and fabricated in a 3D printer with the following dimensions: 1.5 mm in width, 2.0 mm in slot depth, 19.0 mm n total length, 90° curvature, and 5 mm of curvature radius (Figure 1). The working length was standardized at 19 mm for all instruments. A special oil (WD-40 Company, Milton Keynes, England) was used to reduce the friction of the file upon contact with the walls of the artificial canal. All instruments were run following the manufacturer's recommendations: Bassi Logic™ with continuous rotation of 350 rpm and 1.5 N of torque; HyFlex EDM run at 500 rpm and 1.8 N of torque. The Easy SI motor was used with a 16:1 counter-angle. The instruments were run in the artificial canals until the occurrence of fracture, which was determined visually and by sound. The time to fracture was recorded in seconds using three difference chronometers. The times displayed on the chronometers were summed and divided by three using a computer program to obtain the mean. The number of cycles until fracture (NCF) was also calculated. The fractured instruments were cleaned with isopropyl alcohol prior to scanning electron microscopy (SEM). The lengths of the broken fragments were measured and three samples from each group were submitted to SEM with magnification 200 and 500 times for the characterization of the fracture.

Figure 1: Artificial canal used for bending fatigue test.



Source: Authors.

As the data exhibited non-normal distribution, the nonparametric Mann-Whitney test was used for the comparisons.

The level of significance was set to 5% ($p < 0.05$).

3. Results

In this study, 20 Ni-Ti files [10 in Group A (Hyflex EDM) and 10 in Group B (Logic™)] were submitted to exhaustive rotation until failure due to fracture of the instrument. Time to fracture, number of rotation cycles to fracture, and size of the fragments were determined.

The mean and standard deviation values for the number of cycles until fracture and the fragment sizes are displayed in Table 1. The Bassi Logic™ instruments tolerated a greater number of cycles compared to the Hyflex EDM ($p < 0.05$). The number of cycles per instrument are shown in **Figure 2.** Significant differences in fragment size were also found between groups ($p < 0.05$). Mean fragment size was larger among the Hyflex EDM instruments compared to the Bassi Logic™ instruments.

Table 1. Descriptive statistics of groups and comparative test

Descriptive Statistics	Fragment size (mm) A	Fragment size (mm) B	Number of cycles A	Number of cycles B
Minimum	5.0	6.0	279.2	1155.0
Mean	6.2	7.0	380.0	1413.1
Standard deviation	0.6	0.8	48.1	175.2
Median	6.0	7.0	395.8	1437.9
1st Q – 3rd Q	6.0 – 6.6	6.4 – 7.1	350.0 – 418.8	1238.9 -1518.9
Maximum	7.0	9.0	433.3	1677.0
Mann-Whitney (p-value)	0.0312 **SIG**		0.0002 **SIG**	

Source: Authors.

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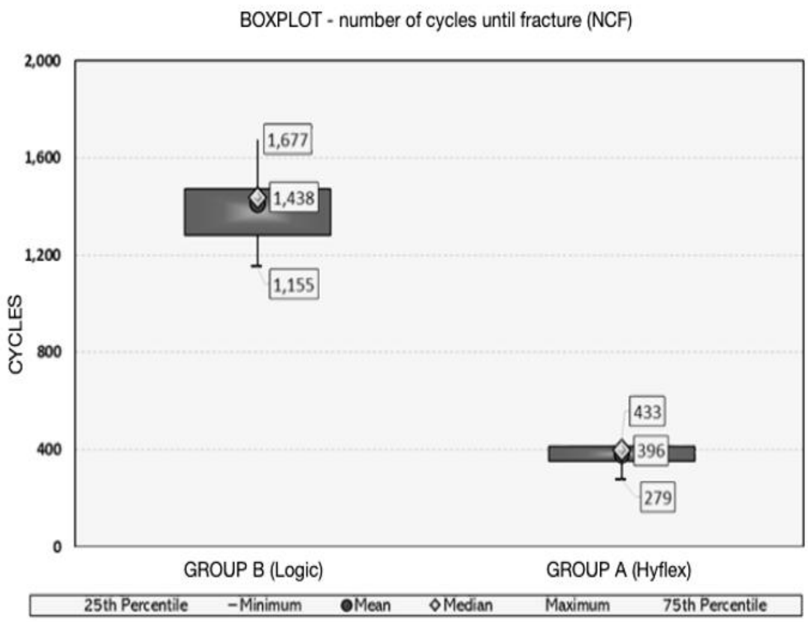
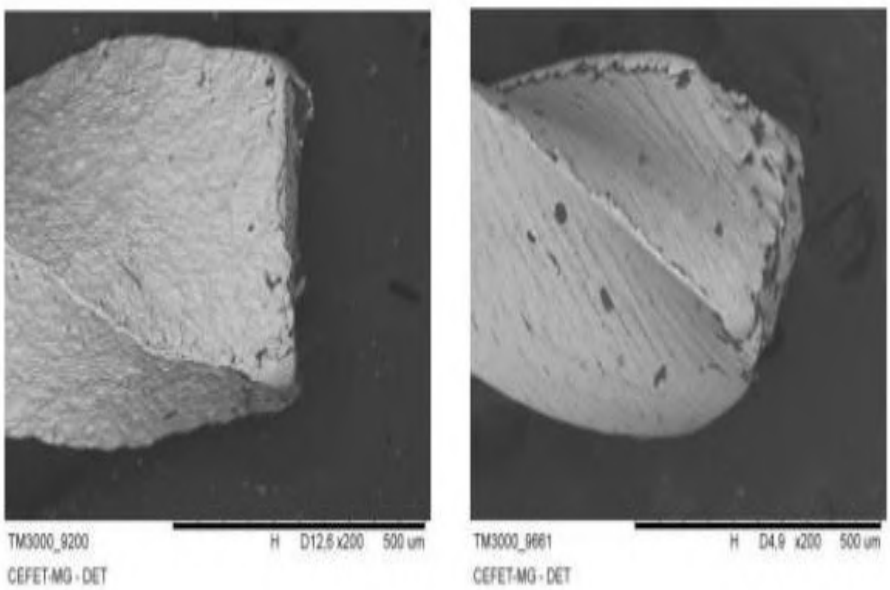
Figure 2: Boxplot of number of cycles tolerated in Groups A and B.



Source: Authors.

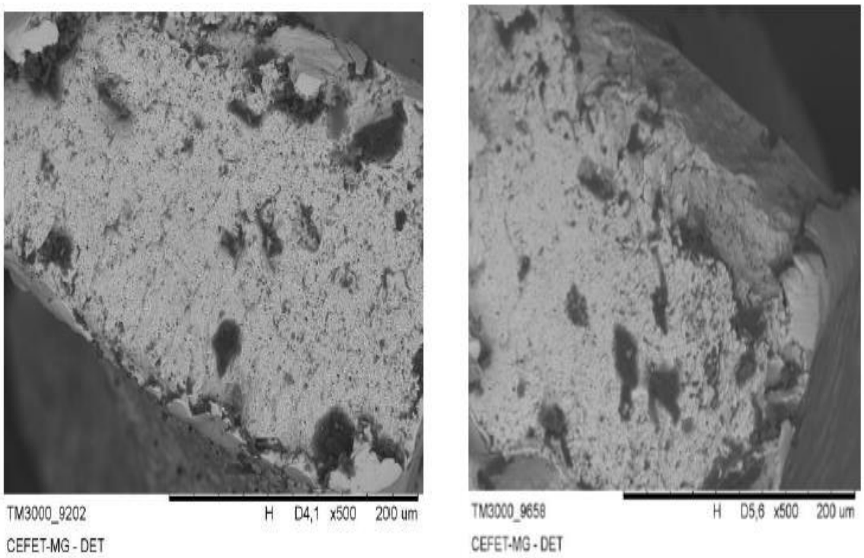
The instruments were submitted to SEM for the investigation of the characteristics of the instruments and the confirmation that fracture occurred due to fatigue, with no signs of torsional fracture (Figures 3 and 4).

Figure 3: Scanning electron microscopy images (side view) of Groups A (Hyflex) and B (Logic) showing absence of plastic deformation in region of break, discarding possibility of torsional fracture.



Source: Authors.

Figure 4: Images of rectangular cross-sections of Groups A (Hyflex) and B (Logic) showing microcracks, indicating ductile fracture. The characteristics of NiTi alloy are compatible with this type of fracture, generating the development of cracks at the edges of microcavities and causing the continuous, gradual rupture of the material.



Source: Authors.

4. Discussion

The results of this test revealed that, under the same circumstances, the Bassi Logic™ 15.05 instrument tolerates a significantly greater number of cycles until fracture compared to the Hyflex EDM 10.05 instrument. Therefore, the null hypothesis was rejected.

Studies have demonstrated the high bending fatigue strength of Hyflex EDM compared to other renowned instruments on the market. Gündogar and Özyürek demonstrated greater flexibility and fatigue strength of the Hyflex EDM compared to the OneShape, Wave One Gold, and Reciproc Blue instruments (Gündoğa & Özyürek, 2017). Pedullà et al. reported the better performance of the Hyflex EDM compared to Vortex Blue, Protaper Gold, and OneCurve (Pedullà et al., 201; Uygun et al., 2020). Kaval et al. compared the Hyflex EDM to the Protaper Gold and Universal instruments (Kaval et al., 2016). The instruments were compared under the same test conditions in all these studies.

Prodesign Logic instruments recently had their name changed to Bassi Logic™, but the instruments are the same. Studies have also reported the high bending fatigue strength of these instruments compared to other renowned products found on the market. Menezes et al. demonstrated that the Prodesign Logic and Prodesign R instruments tolerated a greater number of cycles in an accentuated curvature until fracture compared to Wave One Gold (de Menezes et al., 2017). Cardoso et al. compared the Prodesign Logic, XP-endo shaper, and iRace instruments and found greater fatigue strength for XP-endo shaper, followed by Prodesign Logic (Cardoso et al., 2019). Silva et al. compared the fatigue strength of the reciprocating Prodesign R, which, according to the manufacturer, has the same alloy as Bassi Logic™, to the Reciproc Blue and WaveOne Gold instruments in severe curvatures and found that the Prodesign R tolerated a greater number of cycles (Silva et al., 2018). Alcalde et al. compared Prodesign R, Reciproc, and Unicone and also found the that Prodesign R had the greatest fatigue strength (Alcalde et al., 2017).

No previous studies have compared the cyclic fatigue strength of the Bassi Logic™ and HyFlex EDM systems. The literature reports that both products have greater fatigue strength compared to other instruments on the market. The present investigation is the first study to compare the two instruments. When using the speed and torque recommended by the manufacturers, the Bassi Logic™ 15.05 tolerated more continuous rotations in an extremely curved canal compared to Hyflex EDM 10.05.

There is no standardization for bending fatigue tests, but the most widely used method is the running of the instruments in an artificial canal, which is generally metallic (Plotino et al., 2009; Ferreira et al., 2017). The need to assess the fatigue strength of instruments is based on the fact that this is the most frequent type of fracture during endodontic treatment (Cheung et al., 2005; Wei et al., 2007; Fernández-Pazos et al., 2018). In the present study, we examined the fractured instruments using scanning electron microscopy, which confirmed that the instruments were fractured due to the fatigue of the metal (Figures 3 and 4), as no plastic defects were found along the axes of the instruments.

Tooth anatomy is a constant challenge in endodontics. Teeth with accentuated curves are less common, but it is important to have extremely flexible instruments with adequate bending fatigue strength for such cases (Schäfer et al., 2002). The degree of curvature of the root canal directly influences the number of cycles an instrument can tolerate and instruments tolerate a smaller number of cycles around their long axis in more accentuated curves (Zelada et aç., 2002; Kosti et al., 201; Lopes et al., 2013). In the present study, the instruments were fatigued in an accentuated curve to determine their performance in an extreme situation.

The use of an accentuated curvature was due to that that both instruments have little metallic mass. The amount of mass of an instrument is inversely proportional to its bending fatigue strength. Instruments with smaller tips/tapers have a smaller amount of metal compared to those with larger tips/tapers, resulting in more flexible instruments with greater bending fatigue strength (Whipple et al., 2009; Plotino et al., 2014). The accentuated curvature, difference in the alloy used, and differences in the amount of metallic mass in the instruments at the point of greatest stress are related to the difference in the size of the fragments after fracture. In the present study, the fragments were larger when the Hyflex EDM instrument was used ($p < 0.05$).

Another difference between the instruments evaluated is the treatment of the alloy. While the Bassi Logic™ has the CM-wire alloy, the surface of the Hyflex EDM instrument is treated by electrical discharges. Different thermomechanical treatments of NiTi have been employed and each specific treatment exerts a direct influence on mechanical behavior. Thus, small changes in the treatment can lead to a different performance (Peters et al., 2017; Gavini et al., 2018; Zupanc et al., 2018).

The velocity stipulated by the manufacturers of the products tested in the present study also differs. While 350 rpm is recommended for the Bassi Logic™, 500 rpm is recommended for the Hyflex EDM. Velocity is a factor that exerts an influence on the bending fatigue strength of endodontic instruments. Higher speeds lead to the faster propagation of microcracks on the surface of the instrument and a shorter time until fatigue (Lopes et al., 2009; Gao et al., 2010; Pedullaà et al., 2014). Velocity was not standardized in the present study, as the instruments were used following the manufacturers' recommendations.

There are also differences in the design of the instrument. Products launched on the market generally have singularities and few instruments have a similar design. The Bassi Logic™ 15.05 instrument has a quadrangular cross-section (Pinheiro et al., 2018), whereas the Hyflex EDM 10.05 instrument has three cross-sectional shapes along its access: a more quadrangular shape in the apical third evolving to a trapezoidal shape in the coronal third (Pirani et al., 2016; İnana t al., 2019). Although cross-sectional differences exert an influence on mechanical performance (Basheer et al., 2018), the two instruments tested in the present study had a similar shape in the third where the fractures occurred (**Figure 4**). Therefore, this aspect was not considered a factor related to performance.

Despite the differences in the geometry of the two products compared herein, the Bassi Logic™ has a greater metallic mass than the Hyflex EDM due to the superior tip of the instrument. In contrast, the speed used on the test was slower. These are properties that may have affected the results. However, the Bassi Logic^{TM} tolerated threefold as many cycles in an accentuated curvature until fracture compared to the Hyflex EDM, demonstrating that it is more resistance to fracture in canals with an accentuated curvature.

Further studies are needed to compare the other instruments of the systems described above as well as compare them to other instruments on the market.

5. Conclusion

Based on the results of the present study, the Bassi Logic^{TM} 15.05 instrument has greater fatigue strength in an artificial canal with an accentuated curvature compared to the Hyflex EDM 10.05 instrument when both are used following the recommendations of the manufacturers.

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