ORIGINAL ARTICLE/ARTICOLO ORIGINALE

Evaluation of the cyclic fatigue resistance of rotary pathfinding instruments made of nickel-titanium (NiTi) alloys with different heat treatments

KEYWORDS
Endodontics, Nickel-titanium instruments, Cyclic fatigue, Pathfinding files, Heat treatment.

PAROLE CHIAVE
Endodonzia, strumenti al nichel-titanio, fatica ciclica, file per il percorso di scivolamento, trattamento termico.

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Valutazione della resistenza alla fatica ciclica di strumenti rotanti per il percorso di scivolamento realizzati con diversi trattamenti termici delle leghe di nichel-titanio (NiTi).

Abstract

Aim: *The aim of this study was to compare the cyclic fatigue resistance of rotary pathfinding instruments made of nickel-titanium (NiTi) alloys submitted to different heat treatments.*
Materials and Methods: *Eighty NiTi endodontic files were divided into four study groups, as follows: Scout Race 15.02 (FKG Deintaire SA), Pathfile 19.02 (Dentsply Maillefer, Ballaigues, Switzerland), Proglider 16.02 (Dentsply Maillefer, Ballaigues, Switzerland), and Hyflex GPS 20.02 (Coltène Whaledent, Allstätten, Switzerland). The instruments were subjected to cyclic fatigue testing using simulated canals with a 6mm radius and 30° or 45° curvature angles. The data obtained were organized in an Excel spreadsheet and analyzed statistically using BioEstat 5.3 software (Marimauá Institute, Manaus, Brazil). The non-parametric Kruskal-Wallis test was used in the analysis. The Mann-Whitney U-test was used for multiple comparisons, at a significance level of 5%.*
Results: *The Hyflex instrument was superior to all the other instruments (p<0.05), and Pathfile had a superior fatigue time (p<0.05) compared with Scout Race and Proglider, for both of the curvature angles analyzed. No significant difference was observed between Scout Race and Proglider.*
Conclusions: *Cyclic fatigue resistance of the HyFlex GPF instrument was the highest among those tested, and the curvature radius had a significant effect on fatigue resistance. A significant decrease in the cyclic fatigue time was observed, with an increase in the flexion (curvature angle), irrespective of the instrument analyzed.*

Obiettivi: *Lo scopo di questo studio era di confrontare la resistenza alla fatica ciclica degli strumenti rotanti per il percorso di scivolamento realizzati con leghe di nichel-titanio (NiTi) sottoposte a diversi trattamenti termici.*
Materiali e metodi: *Ottanta strumenti in NiTi sono stati divisi in quattro gruppi di studio, come segue: Scout Race 15.02 (FKG Deintaire SA), Pathfile 19.02 (Dentsply Maillefer, Ballaigues, Svizzera), Proglider 16.02 (Dentsply Maillefer, Ballaigues, Svizzera), e Hyflex GPS 20.02 (Coltène Whaledent, Allstätten, Svizzera). Gli strumenti sono stati sottoposti a prove di fatica ciclica utilizzando canali simulati con un raggio di 6 mm e angoli di curvatura di 30° o 45°. I dati ottenuti sono stati organizzati in un foglio di calcolo Excel e analizzati statisticamente utilizzando il software BioEstat 5.3 (Istituto Marimauá, Manaus, Brasile). Nell'analisi è stato utilizzato il test non parametrico Kruskal-Wallis. Il test U Mann-Whitney è stato utilizzato per confronti multipli, con un livello di significatività del 5%.*
Risultati: *Lo strumento Hyflex è risultato superiore a tutti gli altri strumenti (p<0,05) mentre il Pathfile aveva un tempo di fatica superiore (p<0,05) rispetto a Scout Race e Proglider, per entrambi gli angoli di curvatura analizzati. Nessuna differenza significativa è stata osservata tra Scout Race e Proglider.*
Conclusioni: *La resistenza alla fatica ciclica dello strumento HyFlex GPF era la più alta tra quelle testate ed il raggio di curvatura influenzava in maniera significativa la resistenza alla fatica. È stata osservata una diminuzione significativa del tempo di fatica ciclica, con un aumento della flessione (angolo di curvatura), indipendentemente dallo strumento analizzato.*

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Introduction

Exploration of the root canals conducted immediately after gaining access to the pulp chamber is essential to allow larger caliber files to reach the working length without any deviation or impediment (1, 2). Thus, a number of files with different nickel-titanium (NiTi) alloys have become available for pathfinding during root canal treatment.

The files are coupled to an engine and driven with continuous rotation kinematics, and they have greater flexibility and resistance to cyclic fatigue, thus enabling improved root canal preparation (3). However, it should be noted that NiTi files are still subject to a considerable risk of fracturing within the root canal, despite having higher quality and efficiency than those made of steel (4).

The separation of NiTi rotary files occurs in two ways: by torsion or cyclic fatigue (5). Torsional fracture occurs when the tip of the file engages the canal and the remainder continues to rotate freely within it (6). Cyclic fatigue fracture occurs when the file rotates freely within the canal in tensile-compressive cycles, until it reaches its point of maximal flexion.

This happens during a complete cycle of the instrument. In the first half cycle, one portion is submitted to tensile and the other to compressive stress, the reverse occurring during the final half cycle. This repeated effect, caused by the curvature of root canals, increases rotational fatigue, and represents the main factor leading to instrument separation (7).

Pathfile (Dentisply Maillefer, Ballaigues, Switzerland) and Scout Race (FKG Dentaire, La Chaux-de-fonds, Switzerland) instruments are manufactured with a conventional NiTi alloy, and are used for exploration of root canals. They have four cutting edges, a square cross-section and a taper of 0.02 mm (8).

Recent technology has been producing pathfinding files with different types of NiTi alloys, aiming at increasing resistance to cyclic fatigue. One of these files is the Proglider (Denstsply Maillefer), an instrument manufactured with a NiTi alloy called M-Wire. This pathfinding system consists of only one file and, unlike the other abovementioned files, has a progressive taper varying from 2% to 8% up to its final diameter (9).

Another instrument manufactured following the latest discovery in NiTi alloy heat treatments was the Hyflex GPF file (Coltène-Whaledent, Allstätten, Switzerland). Its structure is made of a NiTi CM-Wire alloy with controlled memory, making it extremely flexible and more resistant to cyclic fatigue fracture. This file also has a quadrangular cross-section, similar to that of Pathfile and Scout Race (8).

Thus, the aim of this study was to compare the cyclic fatigue resistance of pathfinding rotatory files made of nickel-titanium alloys subjected to different heat treatments. The null hypothesis is that there would be no difference between the fracture times observed in the different study groups.

Materials and Methods

Eighty NiTi endodontic files were used to conduct this experiment. The following file types were used: Scout Race 15.02 (FKG Deintaire SA), Pathfile 19.02 (Dentsply Maillefer, Ballaigues, Switzerland), Proglider 16.02 (Dentsply Maillefer, Ballaigues, Switzerland), and Hyflex GPS 20.02 (Coltène Whaledent, Allstätten, Switzerland).

Two stainless steel devices were fabricated in an angled tube format and used to simulate a root canal, to test the resistance of the instruments to cyclic fatigue fracture. The file to be tested was set to rotate freely within the devices, under constant pressure (Figure 1).

The tubes were made of stainless steel and had an internal diameter of 1.04 mm, total length of 20 mm and curvature radius of 6 mm. The curved portion of the device measured 9.4 mm, and the straight portion, 10.6 mm. One tube had an angle of 30° and the other an angle of 45° relative to the concave surface of the tube curvature. The tubes and the contra-angle were secured in two bench mini-vises to avoid variations in position and angulation during the tests.

Figure 1
Stainless steel devices fabricated in an angled tube format and used to simulate a root canal.

A single holder was created to fit the two mini-vises, with a height difference of 30 mm. This way the mini-vises were always coupled in the same position. The mini-vise used to hold the devices was fixed to a workbench. The other mini-vise was mobile to facilitate handling during insertion and removal of the files at each test; nevertheless, it had a preset, precise fitting guide fixed to the bench (Figure 2).

Figure 2
Support created with the two mini-vises for the experiment.

The instruments were driven by an endodontic motor (VDW Silver, VDW, Munich, Germany) coupled to a 6:1 contra-angle (Sirona Dental Systems GmbH, Bensheim, Germany). The files in each group were tested in clockwise continuous rotation, with the settings of speed and torque recommended by their respective manufacturers. Chlorhexidine gel (Maquira SA, PR, Brazil) was used as a lubricant to reduce the friction between the endodontic instrument and the metal. All the files were activated until their fracture was observed visually. The time elapsed between activation and fracture of each instrument was recorded with a 1/100 s chronometer and tabulated by a single evaluator.

The data were organized in an MS Excel spreadsheet and analyzed statistically using BioEstat 5.3 software (Marimauá Institute, Manaus, Brazil). The non-parametric Kruskal-Wallis test was used, owing to significant differences among the group variances. The Mann-Whitney U-test was used for multiple comparisons, at a significance level of 5%.

The fragments were measured with a digital caliper to assess whether a pattern occurred in the length of the fractured fragment in each group.

Results

The resistance values of the Hyflex file were the highest among all groups, both at 30º and 45º ($p<0.05$) (Table 1).

The fatigue time of the Pathfile instrument was statistically longer than that of the Proglider and Scout Race instruments, for the two angles tested ($p<0.05$). At the 45º angulation, the Pathfile still had a fatigue time longer than that of the Scout Race ($p=0.0425$) and Proglider ($p=0.0046$) instruments. There was no statistically significant difference between the Scout Race and Proglider instruments for either angle ($p>0.05$). The results showed that an increase in flexion (angulation) promoted a significant decrease in cyclic fatigue time, irrespective of the group analyzed ($p<0.05$). Thus, the following ranking was observed for cyclic fatigue resistance, irrespective of the angulation analyzed: Hyflex>Pathfile>Proglider=Scout Race. The fragment length assessment revealed no statistical difference between the study groups (Table 2).

Table 1

Mean cyclic fatigue times (in seconds) for the different instruments used, at the angles of 30° and 45°

Angle\Group	Hyflex	Pathfile	Scout Race	Proglider
30°	9949[a]	2850[b]	841[c]	1010[c]
45°	1247[a]	381[b]	130[c]	147[c]

Different letters represent results with statistically significant differences

Table 2

Mean length (in millimeters) of the instrument fragments measured after cyclic fatigue testing

Files	Angle	Mean (mm)
Hyflex GPF	30°	9.7
Pathfile	30°	9.6
Proglider	30°	9
Scout Race	30°	9.6
Hyflex	45°	10
Pathfile	45°	9.4
Proglider	45°	9.2
Scout Race	45°	9

Discussion

The technological advancement of NiTi files led to the creation of new designs and systems that rendered instrumentation faster and more effective, enabling the original anatomy of root canals to be preserved, and leading to fewer iatrogenic errors during endodontic treatment (10). Despite all the flexibility and elasticity offered by NiTi instruments during endodontic treatment in curved canals, the fracture of these instruments within the root canal remains a distinct possibility (11).

Hence, new manufacturing methods using heat treatments (M-Wire and CM-Wire) have emerged for NiTi files, as well as modified cutting blades and electrochemical polishing, providing even greater elasticity and resistance to prevent cyclic fatigue fracture. Our results showed that the fatigue time at 45º was significantly shorter than at 30º, irrespective of the instrument group analyzed ($p<0.05$). The cyclic fatigue of an instrument is directly related to its degree of curvature; therefore, the higher the degree of curvature, the lower its resistance to cyclic fatigue (12, 13). Martin et al. (2003) (14), obtained a greater number of cyclical fatigue fractures in canals that had more pronounced curvatures. This result corroborates the results of the present study.

The Hyflex GPF file was superior to the others, irrespective of the flexion analyzed. Despite the paucity of information on the performance of this file in relation to cyclic fatigue in terms of time (s), its greater resistance compared with the other files can be attributed to its heat treatment (CM-Wire), which enabled the instrument to adapt to the canal curvature and diminished the areas of tension and compression (15). In another study on static cyclic fatigue, the Hyflex 25.08 file achieved a greater number of cycles compared to the other files, and this result was also related to the properties of the CM-Wire alloy (16).

Uslu G et al. (2018) (17) tested cyclic fatigue in S-shaped artificial canal with R-pilot (VDW, Munich, Germany), Hyflex EDM and Pathfile. R-Pilot had the greatest cyclic fatigue resistance followed by HyFlex EDM and PathFile in both apical and coronal curvature. R-pilot has a reciprocating motion different from the other files that have a rotational movement, according to the author was the main reason to have obtained a better performance than the other files.

In the present study, the cyclical fatigue time of the Pathfile instrument was significantly longer than that of the Scout Race and Proglider instruments, for the two curvature variations tested. The fact that the Proglider file presented lower resistance performance when compared with the Hyflex GPF and Pathfile files can be accounted for the fact that the greater the diameter of the file in the area of tension and compression, the lower its resistance to cyclic fatigue (18, 19, 20).

Capar et al. (2015) (8), and Enalghy et al. (2014) (9), conducted a cyclic fatigue test comparing the Proglider and Pathfile instruments with an angle of 90º and a radius of 5 mm. The results of both studies indicate that the Proglider file reached a greater number of cycles until failure (NCF), diverging from our study. The authors associated

this result to the fact that the Proglider file uses the M-Wire heat treatment during manufacturing to produce an alloy with greater flexibility and greater resistance to cyclic fatigue as compared with the Pathfile instrument, produced with conventional NiTi.

Tpçuoglu et al. (2018) (21) after evaluation of the Cyclic fatigue resistence of ProGlider, PathFile and ScoutRaCe instruments in an artificial S-shaped canal, the ProGlider files were found to have greater cyclic fatigue resistence than the PathFile and ScoutRaCe in the apical curvature. However, there was no significant difference between these files in the coronal curvature, diverging from our study. Serefoglu et al. (2018) (22) performed a cyclic fatigue study comparing the R-Pilot (VDW, Munich, Germany), Wave One Gold Glider (Dentsply, Maillefer) and the Proglider file in a metal device with 90º angle and 3 mm radius. The Proglider showed statistically the lowest performance compared to the other files. The R-Pilot file has a smaller diameter than the Proglider, so the authors indicated that this was one of the relevant factors. The Wave One Gold Glider presented a better result that it was for presented a gold thermal treatment, making the file more flexible and with that it presents a greater resistance to cyclic fatigue in relation to the file Proglider that has M-Wire treatment.

The performance of the Scout Race file was inferior to that of the Hyflex GPF and Pathfile instruments. One of the factors involved in this result may have been the speed variation in rotations per minute (RPM). The Scout Race file runs at 800 RPM, whereas the Hyflex GPF and Pathfile instruments run at 300 RPM.

Analyzing the influence of rotations per minute during cyclic fatigue testing, Lopes et al. (2009) (5), showed that the higher the number of RPM, the lower the resistance to cyclic fatigue.

The length of the fragment of all fractured files was similar in all groups and angulations tested. This can be explained by the fact that the cyclic fatigue process involves the instrument rotating freely within the root canal, and then undergoing tensile and compressive stress at the point of curvature, leading to metal fatigue (23). Other authors state that the cyclical fatigue fracture occurs because it undergoes contraction and flexion as it moves through the point of curvature (24, 25). Thus, since all files were standardized at 22 mm with a rubber stop, they all fractured at the point of tension of the curvature of the devices used during the tests. The NiTi rotary pathfinding files included in this study vary widely in terms of alloy type, taper, diameter, and recommended torque and RPM settings; this may have influenced the results of the tests performed to evaluate cyclic fatigue (26).

Within the limitations of this study, the CM-Wire NiTi alloy showed greater resistance to cyclic fatigue than NiTi M-Wire and conventional instruments. To avoid fractures of the instruments it is necessary to understand the physical properties and the changes that occur during the different types of heat treatment associated with their different types of cross-section, so that the ideal instrument can be chosen according to the varied clinical situations present in the dentist routine.

Conclusions

The results of this study showed that the Hyflex GPF file presented a significantly higher resistance to cyclic fatigue compared with the other files analyzed, irrespective of the degree of curvature. The observed ranking of cyclic fatigue resistance was Hyflex>Pathfile>Proglider=Scout Race. The files tested with 30º angulation presented greater resistance to cyclic fatigue compared with those tested with 45º angulation. The length of the fractured fragment was similar in all groups and for both angles analyzed.

Clinical Relevance

The present study demonstrated clinical relevance for testing the resistance to cyclic fatigue of pathfinding instruments and thus making the root canal exploration with rotary instruments safer.

Conflict of Interest

The authors declare not to have any conflict of interest.

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