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Fatigue Resistance of New and Used Nickel-Titanium Rotary Instruments: a Comparative Study

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Abstract

Objectives. Aim of the present study was twofold. First, to evaluate *in vitro*, the performance of two different NiTi rotary instruments in one molar case; then, to evaluate their resistance to cyclic fatigue, compared to new ones.

Materials and Methods. 25 ProTaper Next (PTN) nickel-titanium (NiTi) instruments (Maillefer-Dentsply, Baillagues, CH) for each of the following two sizes: X1 (17.04) and X2 (25.06) were randomly divided into two groups. The first group (n = 10) immediately underwent to a cyclic fatigue test. The second group (n = 15) was initially used to prepare 15 extracted molar teeth and then subjected to a cyclic fatigue test. Same was done for 25 Horizen (HZ) instruments (Kerr Endodontics, Orange, Ca) for each of the following two sizes: 20.04 and 25.06. Instruments were rotated in curved artificial canal until fracture occurred and times to fracture were recorded. All data were collected and statistically analyzed using a variance test (confidence interval CI = 95%).

Results. HZ reached working length more rapidly than PTN, and with less deformations. For the fatigue tests, all the new instruments were significantly more resistant than the used ones. The HZ instruments were significantly more resistant in all sizes than PTN, both when new and used instruments were tested.

Conclusions. Since in previous studies ProTaper Next demonstrated a better resistance to cyclic fatigue than most of nickel-titanium instruments, Horizen's performance put them in a high rank amongst the most resistant nickel-titanium rotary instruments. ***Clin Ter 2018; 169(3):e96-101. doi: 10.7417/CT.2018.2061***

Key words. *cyclic fatigue, endodontic rotary instruments, nickel-titanium, root canal therapy*

Introduction

The introduction of nickel-titanium (NiTi) alloy in the manufacturing of endodontic instruments represented a significant improvement: easier and faster shaping procedures allowed operators to reduce operative time and minimizing iatrogenic errors (1, 2). Owing to the superior mechanical properties of the NiTi alloy, it was possible to use endodontic instruments of greater tapers in continuous rotation, to increase the effectiveness and rapidity of the cutting, and to achieve more predictable tapered shapes (3, 4). However, several studies reported a significant risk of intracanal separation of NiTi rotary instruments (5-7).

Although multiple factors contribute to instruments' separation, cyclic fatigue has been proven to be one of the leading causes (8, 9). Fatigue failure usually begins with microcracks that arises from irregularities on the instrument's surface. During each loading cycle, microcracks deepen until the complete separation of the instrument (10, 11). All new NiTi rotary instruments are affected by some irregularities and inner defects as a consequence of the manufacturing process and the distribution of these defects influences their resistance to fracture (12, 13). In recent years, manufacturers tried to find different solutions to produce instruments which are more resistant to flexural and torsional stress. These improvements were mainly related to changes in design, heat treatments of the alloys and the use of reciprocating mechanical motions (9, 10). Protaper Next (Maillefer-Dentsply, Baillagues, CH) (PTN) are NiTi rotary instruments made from M-wire alloy, are characterized by an off-centered rectangular cross section that is claimed to give a snake-like swaggering movement as it advances into the root canal, which should reduce instrumentation's stress. Many studies proved excellent clinical and *in vitro* performance of the PTN instruments, and recommended clinical use of simplified techniques with a limited number of instruments (14-16). PTN is a sequence of 5 instruments, but according to Van der Vyver and Scianamblo (2013) (17), in many cases, shaping can be achieved by only using the first two instruments: X1 (17.04) and X2 (25.06). Other authors recommend to create a glide path prior to canal preparation, as described by the manufacturer's guidelines (14).

Horizen (Kerr Endodontics, Orange, USA) NiTi rotary instruments (HZ) have been recently developed, but not commercialized yet. HZ instruments undergo to a proprietary, customized heat treatment, which is different from size to size. The goal is maximizing resistance in the smaller sizes and flexibility in the bigger ones. Unfortunately, the specific heat treatments provided are not disclosed by the

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manufacturer. HZ have a triangular cross-section, variable pitch design and non uniform taper, which is constant only in the first 5 mm (Fig. 1).

The aim of this study was to evaluate *in vitro*, the performance of two different NiTi rotary instruments in one molar case, according to the following parameters: capability to reach full working length without instrument's failure or deformation. Then, by performing cyclic fatigue tests on new and used instruments, to evaluate their resistance to cyclic fatigue and how much is weakened an instrument after a molar case.

Material and methods

25 ProTaper Next (PTN) NiTi instruments for each of the following two sizes: X1 (17.04) and X2 (25.06), were randomly divided into two groups. The first group (n = 10) immediately underwent to a cyclic fatigue test (group PTN1 = new instruments). The second group (n = 15) was initially used to prepare 15 extracted inferior molar teeth with a single-use (one molar) technique and then the used instruments that did not show any sign of deformation/fracture were subjected to a cyclic fatigue test (Group PTN2 = used instruments). All instruments have been previously inspected using an optical stereomicroscope at x20 magnification for morphological analysis and for any signs of visible deformation. If defective instruments were found, they were discarded, and not subjected to the clinical or fatigue tests. Same was done for the 25 Horizen (HZ) instruments for each of the following two sizes: 20.04 and 25.06. The HZ instruments were randomly divided in two groups to be subjected to the cyclic fatigue testing: HZ1 = new instruments (n = 10) and HZ2 (n = 15) to be used in extracted molar, as previously explained

Fig. 1. Horizen 20.06 instrument's design

for the PTN Groups. The used instruments that did not show any sign of deformation/fracture were subjected to a cyclic fatigue test (Group HZ2). Extracted human mandibular first and second molars were collected. The reasons for extraction were not related to this study. The age and gender of patients were unknown. The selected teeth were cleaned to remove any organic tissue and then they were autoclaved in PBS at 121 °C for 20 min. Teeth presenting root fractures, immature apex, previous endodontic treatment, posts or metallic crowns were not included. In addition, teeth presenting calcifications, or initial apical diameter greater than a #20 K-file were excluded. A total of 30 molar teeth were included in the study. To ensure the anatomical standardization of the sample, teeth were scanned by means of digital x rays to determine the angles and radii of curvatures (primary and secondary) of each canal. Molars were divided in two groups, with similar anatomy and assigned to each different instrumentation technique (n = 15). Crowns were slightly flattened to warrant a reproducible working length (WL). The coronal opening and straight access to the canal orifice was obtained using high speed diamond burs. Canals were irrigated with 2 mL of 5% sodium hypochlorite (NaOCl) and checked for patency with a #8 K-file introduced up to the apical foramen, under x10 magnification (Kaps Microscope, Germany). The length of this file was recorded and subtracted 0.5mm to determine the WL. All the experimental procedures were performed by 2 general practitioners, using new instruments for each tooth. The irrigation was executed with 5% NaOCl delivered with a 30-G needle attached to a syringe inserted 3 mm from the WL. The glide path and/or coronal flaring and the shaping procedures were performed using an Aseptico Pro Endodontic Motor (Aseptico, Woodinwille, Wa), following the manufacturer's instructions, in terms of motion, rpm (300) and torque settings (2,5 N). Each instrument was used in only one molar case (3 - 4 canals). Following manufacturers' guidelines (www.dentsply.com), for the PTN group a glide-path was achieved before PTN instrumentation by using Pathfiles P1 and P2 (Dentsply-Maillefer, Baillagues, CH) instruments, while for the HZ Group an orifice opener size 25.08 was used. Any problems encountered during instrumentation, i.e. instruments' distortions, breakage or failure to negotiate full working length were recorded. After shaping procedures were completed, radiographs were taken to visualize iatrogenic errors, if occurred (Fig. 2 and 3). Pre- and post-instrumentation optical inspection of instruments using x5 magnification (Orascoptic Loops) was performed to check any signs of deformation or fracture before and after usage. Data were recorded and analyzed. Deformed instruments after clinical use were also analyzed under Kaps Operative microscope (x20) to visualize entity and location of deformations. Broken or deformed instruments were immediately discarded and not subjected to the cyclic fatigue test. A scanning electron microscope (SEM) was used to examine the fractured surfaces of the fragments (Fig. 4-5).

The cyclic fatigue testing device used in the present study has been used for studies on cyclic fatigue resistance previously (18-20). The device consists of a mainframe to which is connected the electric handpiece and a stainless-steel block containing the artificial canals. The electric handpiece was mounted on a mobile device to allow precise and reproducible placement of each instrument inside

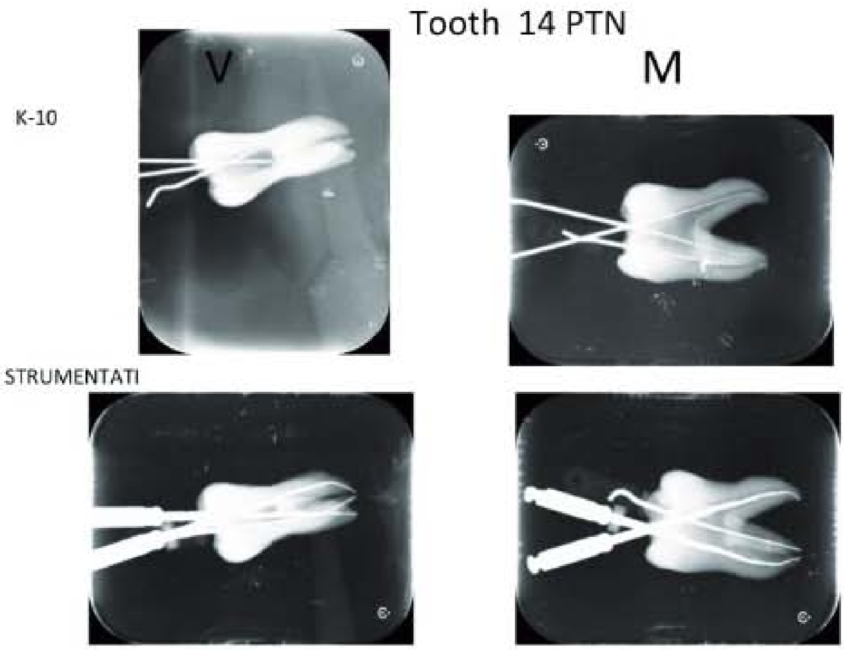

Fig. 2. Pre- and postoperative radiographs of a molar treated with PT instruments.

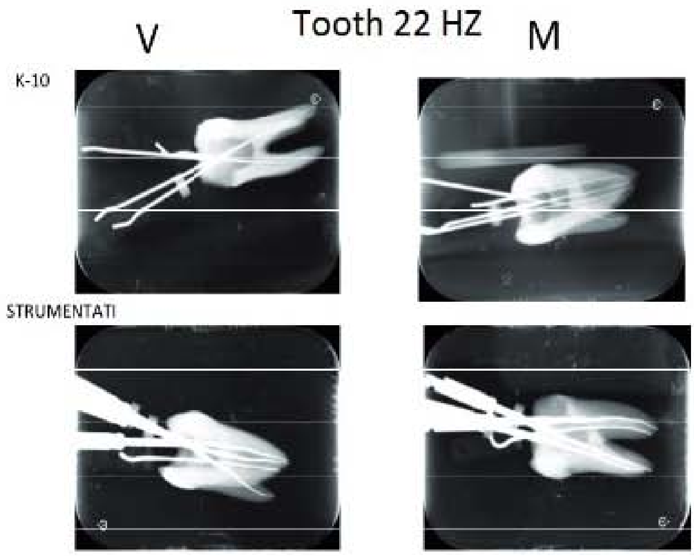

Fig. 3. Pre- and postoperative radiographs of a molar traded with Horizen instruments.

the artificial canal to the same depth (12 mm). The same simulated root canal with a 60 degree angle of curvature and 5 mm radius of curvature was used for all the tested instruments (Fig. 6). All instruments were inserted at the same length and then rotated at 300 rpm with maximum torque until fracture occurred. For each instrument, the time to fracture (TTF) was visually assessed and recorded with a 1/100 sec chronometer. NCF (number of cycles to fracture) were also calculated.

The arithmetic means and standard deviations were calculated for the time to fracture and total number of cycles to failure. One-way analysis of variance was used to compare the mean cyclic failure amongst the groups. Post hoc Tukey's test was performed to compare the difference of the means between the groups at a significance level of $P < 0.05$. Data was statistically analysed using the SPSS 17.0 software (SPSS Incorporated, Chicago, IL, USA).

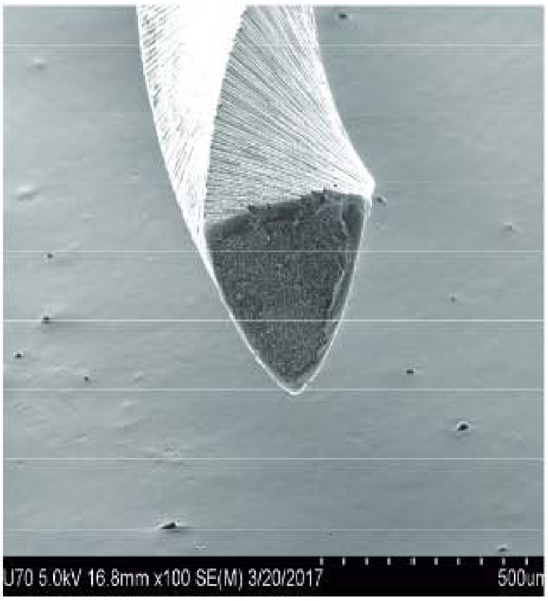

Fig. 4. Fractured image at SEM of a HZ instrument

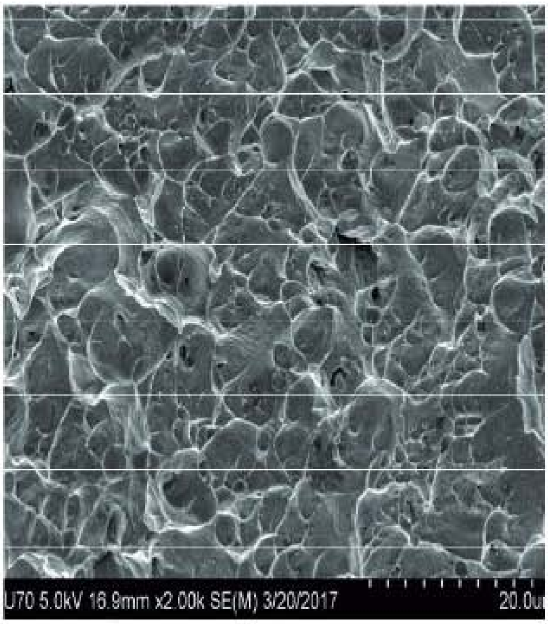

Fig. 5. Fractured image at SEM of a HZ instruments

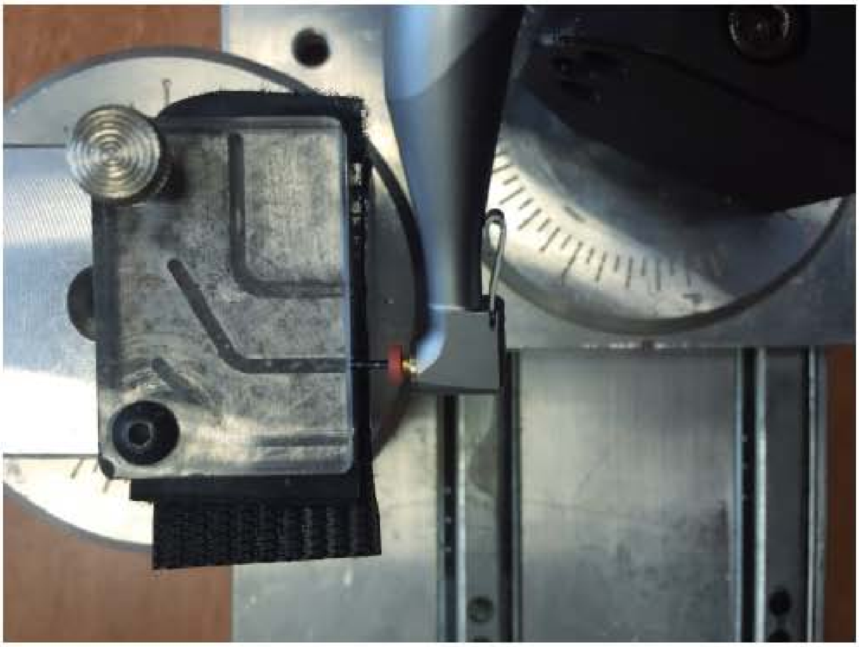

Fig. 6. The testing device for cyclic fatigue.

Results

For the PTN group all instruments reached full working length, with the exception of four instruments. Two X1 and one X2 showed deformations of the flutes and were consequently discarded while one X2 separated during intracanal use. For the HZ group all instruments reached full working length, with the exception of two instruments: one 20.04 showed deformations of the flutes and consequently was discarded, while one 20.04 separated during intracanal use. As consequence, cyclic fatigue test of used instruments was performed in 10 instruments of each size, randomly selected among those who did not exhibit any sign of deformation/ fracturing after clinical use.

Results from the cyclic fatigue tests are shown in tables 1 and 2. For both techniques statistical analysis found significant differences (P < 0.05) amongst the groups. All the new instruments were significantly more resistant than the used ones. The HZ instruments were significantly more resistant than PTN both when new and used instruments were tested. The weakening of HZ after use was lower than the weakening shown by PTN in both tested sizes. The reduction of resistance to fatigue of used instruments was 45% for X1, 46% per X2, 33% for 20.04 and 35% for 25.06.

Discussion

Several strategies have been incorporated in the manufacturing process to improve resistance and reduce the incidence of separation of NiTi instruments. These methods include (a) advanced surface treatment or electropolishing that finishes the surface and prevents microcracks' propagation, (b) varying the taper within one file and modifying the cross-section, thus reducing the contact area of the instrument with the canal's walls, (c) changing tip and/or flute design, i.e using a variable pitch design to reduce torsional stress, (d) heat treatment or thermal processing that optimizes the microstructure of NiTi alloys (9-10). In recent years, the advancement in the instrument's design and manufacturing processes allowed the production of a new generation of NiTi instruments, with better flexibility and greater resistance to intracanal fracture. The tested instruments were designed to fulfill these goals. Many authors have previously positively evaluated mechanical and clinical performance of PTN instruments (21, 22), but no data is currently available for HZ, because they have not been commercialized yet. Since in previous studies PTN demonstrated a better resistance to cyclic fatigue than the majority of current competitors, the significantly better results shown by HZ put these new instruments in a high rank amongst the most resistant NITI rotary instruments. In the present study, the overall incidence of instruments' deformations and breakage was lower for HZ than PTN. The results of the cyclic fatigue tests on new instruments can explain these findings. In both sizes, new HZ instruments showed a better resistance to fatigue *in vitro*. Moreover, results showed that HZ were less weakened after the instrumentation of the extracted molar. Since anatomy was very similar between the two groups, HZ instruments showed a better resistance to intracanal stress and/or were able to accumulating less metal stress during instrumentation. Such a lower accumulation may be related to many factors: a lower operative torque, an improved cutting efficiency and debris removal capability, thus generating less friction (23). In the tested operative sequences, the first instruments were slightly different in dimensions, while the second ones were same, thus providing a better comparison between the different techniques. All canals were prepared up to same size 25 and .06 taper, in order to have similar amount of enlargement and consequently similar instrumentation stress. The concept of larger apical sizes has been advocated to improve bacterial reduction. However, maintaining smaller sizes (> 20, < 40) is considered to be desirable for the preservation of radicular dentin in the majority of cases (24). HZ allowed a slightly more predictable negotiation of canals. For the PTN group, all instruments reached full working length, with the exception of four instruments. For the HZ group all instruments reached full working length, with the exception of two instruments.

In the present study, NiTi glidepath instruments were used before PNT X1 and X2, as suggested by previous researchers. It was reported that creating a glide path revealed better performance with fewer canal aberrations when compared with PTN only (25). For the HZ technique, an orifice opener (HZ 25.08) was used before using the tested instruments (20.04 and 25.06), as recommended by the manufacturer.

The new Horizen instruments showed better resistance to fatigue both in new and used instruments when compared to Protaper Next. These results supported the safe clinical use of the new Horizen instruments also with a sequence limited to 2 - 3 instruments only.

Table 1. Results of cyclic fatigue tests

Cyclic Fatigue Resistance in seconds		
Group	**Conditions**	**Mean (SD)**
PTN X1	new	42.1 (7.59)
PTN X1	used	23.2 (9.06)
PTN X2	new	25.8 (6.51)
PTN X2	used	14.1 (5.19)
HZ 20.04	new	63.4 (6.23)
HZ 20.04	used	42.3 (7.01)
HZ 25.06	new	30.6 (6.31)
HZ 25.06	used	19.8 (5.58)

PTN = ProTaper Next; HZ = Horizen; SD = standard deviations.

Table 2. Statistical significance of the cyclic fatigue tests

Statistical significance amongst groups	
Comparison between instruments	Significance
New PTN X1 vs used PTN X1	0,0001
New PTN X2 vs used PTN X2	0,0012
New PTN X1 vs new PTN X2	0,0008
Used PTN X1 vs used PTN X2	0,0247
New HZ 20.04 vs used HZ 13.06	0,0006
New HZ 25.06 vs used HZ 25.06	0,0005
New HZ 20.04 vs new HZ 25.06	0,0006
Used HZ 13.06 vs used HZ 25.06	0,0003
New PTN X1 vs new HZ 20.04	0,0001
New PTN X2 vs new HZ 25.06	0,0341
Used PTN X1 vs used HZ 20.04	0,0002
Used PTN X2 vs used HZ 25.06	0,0013

PTN = ProTaper Next; HZ = Horizen.

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