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A New Device to Test the Bending Resistance of Mechanical Endodontic Instruments

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Abstract: The aims of the present study were to propose a new machine for testing the bending behavior of an instrument at multiple specific points along the cutting surface and to compare the influence of proprietary heat treatment on the bending ability of EdgeTaper (ET), Protaper Universal (PTU), EdgeTaper Platinum (ETP), and Protaper Gold (PTG). A total of 320 instruments were examined in the present study: 80 ET, 80 PTU, 80 ETP, and 80 PTG. The bending ability of all instruments was tested at a 45° angle and on three different portions of the instrument at 3, 6, and 9 mm from the tip using a customized device. Statistical analysis showed significant differences among each single instrument of the series and between ET and PTU as well as ETP and PTG. The bending behavior of a nickel–titanium rotary instrument is its ability to bend without any plastic deformation. This feature, according to the results of the present study, is variable along the cutting surface; therefore, it should be evaluated. Due to the present testing device, it would be possible to obtain reliable and trustworthy information about an instrument's bending ability.

Keywords: flexibility; nickel–titanium; bending ability

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1. Introduction

Endodontics have greatly changed in the last years thanks to technological developments and the introduction of nickel–titanium rotary (NTR) instruments. Such improvements have sharply reduced operative times and allowed us to overcome anatomical complexities [1]. Today, NTR instruments come in several shapes to take advantage of the different characteristics of the instruments. Although NTR instruments reduce working time, unexpected separation during instrumentation occurs more often than in stainless steel (SS) files [2]. The two main patterns of fracture investigated in the literature are flexural and torsional failure [3–6]. These are determined by clinical complexities, for example, severe curvatures and narrow canals. Therefore, various geometric, dimensional, and alloy modifications have been developed to avoid fractures. Different cross-sections have been designed to reduce blade engagement with the canal walls, variable taper was introduced to allow a selective dentin cut, and heat treatments were developed to modify the mechanical properties of nickel–titanium [7,8]. It is well known that the nickel–titanium alloy exists in two different temperature-dependent structures, austenitic and martensitic, each with its particular features of resistance, flexibility, and elasticity [9]. The austenite phase is a more rigid and aggressive structure, whereas martensite can be easily deformed and is more flexible and ductile. Moreover, the present literature commonly agrees on the influence of the alloy on bending ability, which is the ability of the instrument to bend without any plastic deformation. This allows the file to overcome severe curvatures and to reduce the risk of fracture due to flexural stresses [10]. Therefore, the use of heat treatment during manufacturing processes has made it possible to decide whether the alloy of the NTR instrument would be austenitic or martensitic at clinical temperatures [11]. In addition to this, various brands have proposed different geometric designs to enhance the mechanical features of the instruments and to make NTR instruments able to shape to the most challenging curvatures.

The recent literature, especially since the spread of cone beam computed tomography (CBCT), includes a vast variety of articles that have studied root canal curvatures in different ways, considering the angle and the height of curvature, using two vertices to determine curvature, and showing a higher percentage of curvature, mainly due to 3D evaluation [12–15]. This change in knowledge of the root canal anatomy led to a change in the method of evaluating NTR instruments. Several cyclic fatigue studies have been published, with new devices able to reproduce real anatomical curvatures in vitro [16]. Furthermore, thanks to new devices, it has been possible to evaluate the influence of the pulp chamber opening on the mechanical resistance of NTR files. Despite these improvements being a milestone in cyclic fatigue evaluation, the study of the bending ability of NTR instruments is still obsolete. The most common evaluation device is the bending test assessed by ISO 3630-1, which involves clamping 3 mm of the tip of each instrument in a chuck and applying an angular deflection of 45° [17]. Starting with the abovementioned premises, a new device has been developed and tested in the present study to test bending ability for other parts of rotary files.

Protaper Universal (PTU; Dentsply Sirona, Ballaigues, Switzerland), Protaper Gold (PTG; Dentsply Sirona, Ballaigues, Switzerland), EdgeTaper (ET; Albuquerque, NM, USA), and EdgeTaper Platinum (ETP; Albuquerque, NM, USA) are similar instruments which share a cross-sectional design, tip, and taper dimension and differ only in the heat treatment of the alloy. Previously published studies have already evaluated the torsional resistance and the cyclic fatigue resistance of these instruments but no published studies have yet evaluated the bending ability of the abovementioned rotary files.

Therefore, the aim of the present study was twofold: to propose a new device to test the bending behavior of an instrument at multiple specific points along the cutting surface and to compare the influence of proprietary heat treatments on the bending ability of ET, PTU, ETP, and PTG.

2. Materials and Methods

A total of 320 instruments were examined in the present study: 80 ET, 80 PTU, 80 ETP, and 80 PTG. Each of the abovementioned sequences consists of 4 instruments with the same tip and taper dimensions: S1 (18.02v), S2 (20.04v), F1 (20.07v), and F2 (25.06v). In the present study, 20 S1, 20 S2, 20 F1, and 20 F2 instruments for each brand were used.

All instruments, before undergoing the bending tests were inspected using a 20× stereomicroscope (Zeiss, Oberkochen, Germany) to detect macroscopic defects, such as microcracks. No instruments were discarded for this reason.

The device used for the present test was a customized one that consisted of a main platform made of a stainless steel (SS) alloy. On this platform was mounted a load cell linked to a digital display, a mobile device that allowed the repeatable position of the file on the load cell, and an analog protractor. The mobile device made it possible to measure the bending resistance at different portions of the instrument, whereas the analog protractor allowed the measurement of different bending angles (Figure 1).

In the present study, each test was performed by the same experienced operator to avoid differences in skill. All instruments were tested at a 45° angle and at three different positions of the instrument: 3, 6, and 9 mm from the tip of the instrument (Figure 2).

All measurements, shown on the display attached to the load cell, were recorded on a spreadsheet and statistically analyzed using the Mann–Whitney U-test.

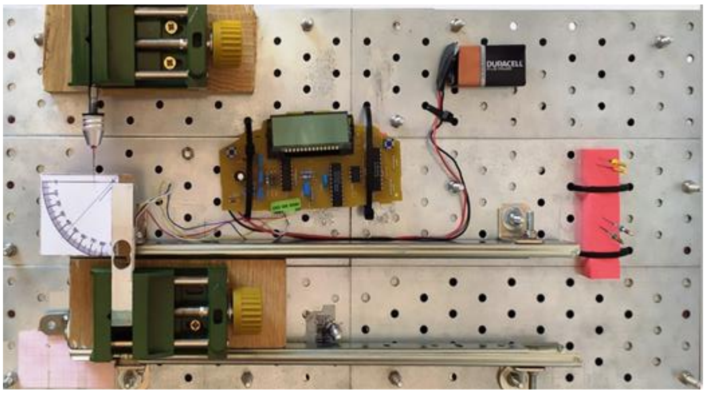

Figure 1. Mobile bending resistance device: overview.

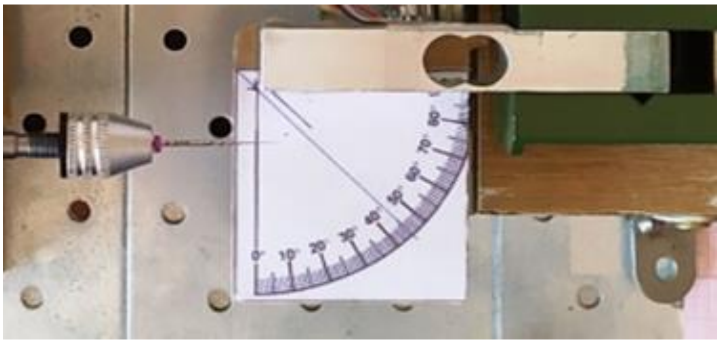

Figure 2. Mobile device with protractor for calculation of the bending angle.

3. Results

The results of the present study are shown in Table 1 for the instruments with a traditional NiTi alloy, ET, and PTU; Table 2 shows the results for the heat-treated instruments, ETP, and PTG.

Table 1. Traditional alloy bending resistance test: PTU and ET mean values (g).

	PTU				ET			
	S1	**S2**	**F1**	**F2**	**S1**	**S2**	**F1**	**F2**
3 mm	101.33 ± 3.80	151.33 ± 5.79	226.17 ± 6.84	256.33 ± 5.24	125.00 ± 5.7	228.83 ± 7.3	317.50 ± 4.0	329.17 ± 3.9
6 mm	249.00 ± 10.28	381.50 ± 7.15	432.50 ± 9.98	434.17 ± 8,35	528.67 ± 8.0	554.33 ± 9.1	556.17 ± 5.8	566.33 ± 7.8
9 mm	764.33 ± 24.48	764.33 ± 15.94	820.33 ± 13.30	825.67 ± 21.92	1048.00 ± 23.3	980.00 ± 4.1	967.17 ± 12.1	974.67 ± 12.8

Table 2. Heat-treated alloy bending resistance test: PTG and ETP mean values (g).

	PTG				ETP			
	S1	**S2**	**F1**	**F2**	**S1**	**S2**	**F1**	**F2**
3 mm	54,33 ± 2.94	103.67 ± 2.40	116.17 ± 2.33	154.50 ± 6.21	42.83 ± 2.56	86.33 ± 3.50	113.67 ± 3.52	116.83 ± 5.49
6 mm	230.00 ± 9.16	294.00 ± 9.20	269.00 ± 9.12	281.67 ± 5.39	209.17 ± 4.60	233.00 ± 5.46	218.33 ± 4.24	205.67 ± 4.55
9 mm	556.67 ± 7.77	558.00 ± 11.49	562.17 ± 8.56	564.33 ± 8.85	472.00 ± 8.77	445.33 ± 4.98	443.00 ± 7.06	457.00 ± 3.05

Statistical analysis showed significant differences among:

- Each instrument alone (S1, S2, F1, F2) at each specific point (3, 6, and 9 mm);
- Each instrument of the series (S1, S2, F1, F2) comparing ET with PTU;
- Each instrument of the series (S1, S2, F1, F2) comparing ETP with PTG.

The means and standard deviations were calculated and the data analyzed using the Mann–Whitney U-test for bending resistance comparisons at 3, 6, and 9 mm for each PTU and

ET instrument and for each PTG and ETP instrument and for 3, 6, and 9 mm bending resistance in the same instrument. Significance was set to the 95% confidence level.

4. Discussion

Since one of the two reasons of instrument failure is flexural behavior, bending ability has been demonstrated to be one of the main features of NTR instruments. For this reason, the flexural ability of a rotary instrument has been thoroughly investigated using different methods of evaluation [4,17].

Protaper Universal (PTU; Dentsply Sirona, Ballaigues, Switzerland) is a sequence of six instruments with a triangular convex cross-section that does not undergo any thermal treatment. A second version of these files, the Protaper Gold (PTG), was produced using the same sequence and the same cross-section but it was improved with a proprietary thermal treatment, the Gold Wire (Dentsply Sirona, Ballaigues, Switzerland). This proprietary thermal treatment has been widely evaluated in the literature and is well known to have enhanced features such as bending and flexural behavior.

EdgeEndo (Albuquerque, NM, USA) released several types of instrument with different designs and shapes to the marketplace. EdgeTaper (ET) is a system similar to PTU, sharing the cross-sectional design and sequence and no heat-treated alloy. Moreover, EdgeEndo modified EdgeTaper with a proprietary thermal treatment to improve its bending behavior and cyclic fatigue resistance, creating the EdgeTaper Platinum (ETP).

From the results of the present study, it is possible to witness different bending behaviors both among the different instruments and along the same instrument, focusing on three precise points: 3, 6, and 9 mm from the tip. In Table 1, the bending resistance of a single instrument increases along its cutting surface (3, 6, and 9 mm). The bending behavior of an NTR instrument is mainly influenced by features as its core and cross-section diameter: the smaller the core diameter or the cross-sectional design, the higher the flexibility [18]. The statistical difference between these two brands might be justified by the different NiTi alloys used to manufacture the different instruments. The information given by the results cited above could be underestimated because it is logical to think that the bigger the core of the file, the greater the stiffness of the instrument. However, such information, assessed by this new testing machine, could drive clinicians' choice of instrument used in daily practice, considering the anatomical complexities of the case regarding root canal curvatures.

Table 2 shows the comparison between ETP and PTG. These two files are quite similar since they share most features, such as cross-sectional design and tip and taper dimension, except for the heat treatment. Each brand has its own proprietary thermal treatment, Gold and Platinum Wire [19]. From the results of the present study, both proprietary thermal treatments enhance the flexibility of the file and this is in accordance with most current literature [20]. The most relevant result is the significant difference between ETP and PTG. The present study shows that ETP's bending resistance is higher than that of PTG at all the tested portions and for every instrument of the sequence. These findings confirm and complete the results of previously published articles on cyclic fatigue resistance comparisons of these two files. This increased flexibility should depend on the Platinum Wire treatment, the only difference between the two instruments.

Thanks to this new device, it is possible to witness the progressively higher flexural resistance of NTR instruments from the apical part of the instrument toward the coronal part. Since the current prevalent test for bending evaluation is the bending test assessed by ISO 3630-1, the new testing device proposed by the present article could be a viable solution to overcome the limitation of the former bending test. The innovation relies on evaluating bending at three different points, which would provide a more representative description of the bending ability of an NTR instrument. The ISO 3630-1 test was first developed to analyze the bending ability of SS manual instruments. Throughout the years, this test has also been used to analyze the bending ability of NTR instruments, without considering the structural differences between the two instruments. Moreover, the development of the ISO test was dependent on the lack of anatomical knowledge. Nowadays, with the spread of CBCT evaluation, the apical part of the root is not the only curved one. It is possible to see several curvatures at different portions of the root canal system [12–15]. Therefore, the bending properties of the coronal part of the instrument, despite it not being subjected to the same amount of stress as the apical one [21], should be investigated as well.

The concept of minimally invasive dentistry has led to clinicians approaching root canal treatment in a conservative way in terms of root canal shaping and the access cavity. According to Plotino et al. [22], the more conservative the access cavity, the more difficult and angulated the access to the canal. A traditional access cavity removes the amount of dentin necessary to access the orifices of the canals directly. On the contrary, a conservative one exploits the flexural features of the heat-treated rotary instruments to enter the canal in a tilted way. Therefore, the comparison between a traditional access cavity and a conservative one is not only conducted in terms of the percentage of dentin spared but also of the slope of insertion of the instrument. It is not possible anymore to rely on a test such as ISO 3630-1 due to anatomical reasons, metallurgic reasons, and different clinical approaches. For these reasons, evaluations of the bending ability of an instrument should consider the whole instrument. The present testing machine provides the correct amount of information to do so.

Thanks to this new testing machine, it may be possible to precisely investigate the bending behavior of the whole rotary instrument, providing more reliable and realistic information about the flexibility of the instrument.

5. Conclusions

Since modern endodontics is moving toward a more tailor-made clinical practice, scientific research should follow this trend. Therefore, the present testing machine should be considered as a useful device to better describe the bending ability of NTR instruments rather than the ISO 3630-1 test due to the abovementioned findings.

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