

Mechanical properties of new endodontic instruments: a comparative approach with different in vitro tests

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Abstract

The goal of the present study to tested and compared a new file system (“Diamond”, Edge Endo, Albuquerque, NM) with a well-known and investigated one (Protaper Gold,Dentsply Maillefer, Baillegues,Switzerland) using three of the most widely used testing methods for NiTi rotary instruments : stiffness, torsional and cyclic fatigue tests. For each size and test, ten instruments were analyzed for each of the two brands and then the data were collected. Mean values and the standard deviations of all tests were then statistically analyzed using 1-way ANOVA followed by the post hoc Tukey test with significance set to a 95% confidence level. Results from the present study showed that the new “Diamond” instruments are more flexible than Protaper in size 25 (F2). On the contrary Protaper size 25 is more resistant to torsional stress when measuring torque at failure. All the other sizes show no statistically significant difference it the previously mentioned tests. On the contrary, statistically significant differences can be noted in all sized when evaluation torsional resistance using the deflection angle and cyclic fatigue, with “Diamond” instruments providing the best Results. Therefore, data of the present study suggest the clinical use of the new “Diamond “ instruments for easy, safe and predictable root canal shaping procedures

Keywords: Nickel-titanium, heat treatments, mechanical properties

Introduction

The clinical performance and mechanical properties of the nickel-titanium (NiTi) instruments are mainly related to three factors (1-5). The first one is the design, the second one is the manufacturing process including alloys and heat treatments, and the third is motion and clinical handling. The instruments’ design for many years has been the main characteristic determining performance and properties of the nickel-titanium rotary files and also due to the differences in design the endodontic instruments have been called with different names.

The design can be different in the cross section, in the number and type of cutting part, in the flute number, width and depth, in the tip: As a consequence it has a great impact on the way the NiTi instruments progress towards the apex, cut the dentine and remove the debris, and on the torsional and flexural stresses applied on the instrument and the resistance to them (6-8) . For more than 20 years design has been the major (and only) feature to determine the properties of the NiTi instruments, but in the last

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decade the manufacturing process has gained a much higher impact and relevance. This is related to the fact that the nickel-titanium alloy is very sensitive to heat and during the grinding process a lot of heat is generated, which can significantly damage the crystal structure of the alloy and its integrity. As a matter of fact it makes the alloy more rigid and more at risk of fracture by easier crack propagation due to superficial and internal defects. By partially restoring the crystal structure, the heat treatments can improve a lot the instruments' flexibility and also the resistance to cyclic fatigue (9-12).

This is the reason why heat treatment has become so popular nowadays and we can distinguish the nickel-titanium instruments in two different categories : the traditional super elastic mainly austenitic at room temperature nickel-titanium instruments and the new heat-treated mainly martensitic pre-bendable ones. It must be also underlined that the heat treatments are not disclosed by manufacturers and they can be significantly different between brands, but also amongst instruments from the same brand, because a current tendency is also to have different heat-treatments within the same instruments or withing different files inside a sequence.

The last factor that influences the performance of the instruments is the motion and the clinical handling because dentists can apply different motions which may result in a much easier progression of the file, more cutting efficiency but also more risk of screwing in and more risk of intracanal breakage. Instruments cab be used with a motion or a combination of motions, aiming at improving efficacy and safety of the procedure (13-16).

Another current tendency is manufacturers trying to develop instruments that are slightly less invasive, than traditional ones aiming at improving long-term outcomes by minimizing weaking of tooth structure and unnecessary flaring of the root canal system. Moreover, manufacturers are also developing more user-friendly instruments, which are designed to be more flexible more efficient in cutting in an attempt to make progression easier and faster for dentists, while keeping safety as a key factor, too.

All the above-mentioned improvements could be obtained by choosing one direction in the manufacturing or another, but also by combining innovations both in the design and innovation on the heat treatment. Therefore a proper analysis of the effect of design or manufacturing on each mechanical property is beneficial to ensure such a combined improvement.

Mechanical testing of the nickel-titanium rotary instrument has become very popular in the last decades because it's a quite simple and a relatively easy way to analyze mechanical properties of the file and to define which is the effect of a single specific change in the design or in the heat treatment on the mechanical properties of the file. Literature review (3) show that they are well established methodologies and also the cyclic fatigue test (which is not defined by ISO standard) has been used for more than 20 years by now and has become a sort of golden standard, even if many factors (canal design and dimensions, temperature, etc.) can influence the final Results (17-19) . It must be underlined

that Results from these mechanical tests cannot be totally translated into the clinical practice because the performance of an instrument inside the root canals also depends on many other factors including the anatomy, dental hardness, the canal dimensions (20). Moreover the outcome of the endodontic treatment is also related to a proper diagnosis, evaluation of anatomic complexities, correct debridement and obturation of the root canal systems (20-25). However better mechanical properties of rotary instruments can lead to less iatrogenic errors while shaping and better quality of the above-mentioned procedures.

In the present study we evaluated a new file system (here called "Diamond") developed by Edge Endo (Albuquerque, New Mexico), which combines a unique variable design, variable dimensions and carriable heat treatments inside the sequence to improve simplicity, performance and safety of the procedure. The new system is tested and compared with a well-known and investigated root canal instrument (Protaper Gold, Dentsply Maillefer, Baillegues, Switzerland) using three of the most widely used testing methods for NiTi rotary instruments.

Materials and methods

The mechanical properties of the new "Diamond " files were evaluated and compared with Protaper Gold, even if the instruments are slightly different in design, dimensions, sequence and heat treatment. For each brand we used three instruments which are probably the most used ones clinically, since not all dentists utilize Orifice Openers or make an apical finishing in size 30 or bigger . Therefore the following instruments were tested : S2, F1 and F2 for the Protaper Gold, and Shaper, F1 and F2 for the Diamond. S1 and Slider were not tested because, even if similar in design only one of them (S1) is heat treated.

All the instruments were tested according to two ISO standard methods of testing (stiffness test and torsion test) plus with a cyclic fatigue test (20). Each test was performed by the same expert operator to avoid error due to different operators' skill. For each size and test, 10 instruments were analyzed for each of the two brands and then the data were collected . Mean values and the standard deviations of all tests were then statistically analyzed using 1-way ANOVA followed by the post hoc Tukey test with significance set to a 95% confidence level.

For the flexibility test (Figure 1) the instrument was bent at 45 degree under constant load and the amount of force that was needed to get the 45° angle deformation was recorded and evaluated. The test strictly followed ISO standard 3630-1 and therefore it is a stiffness test: the smaller the value, the more flexible is the instrument.

The torsional test was conducted according to ISO standard 3630-1 by blocking the instrument at three millimeters of the tip and rotating it with a 2rpm speed (Figure 2). Maximum torque at failure (MAF) was evaluated and recorded for each instrument. For the torsional test, the higher the value, the higher is the resistance- Moreover the deflection angles (DA) were

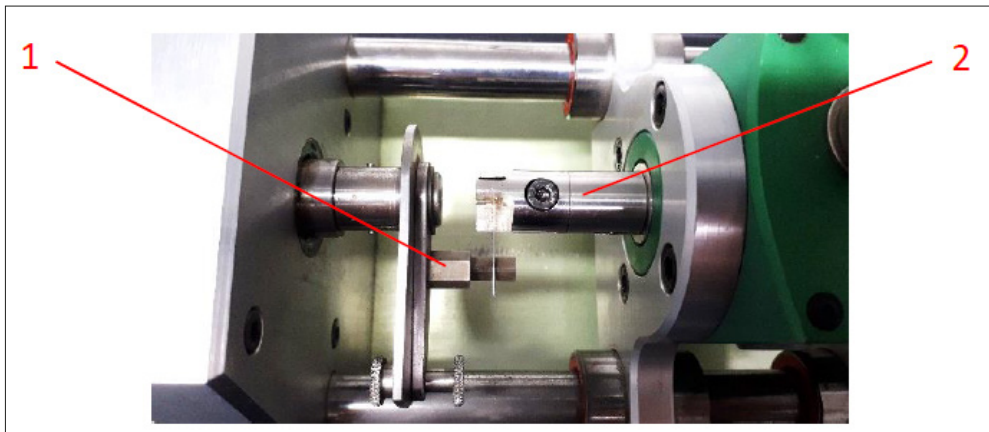


Figure 1. Apparatus for ISO bending (stiffness) test

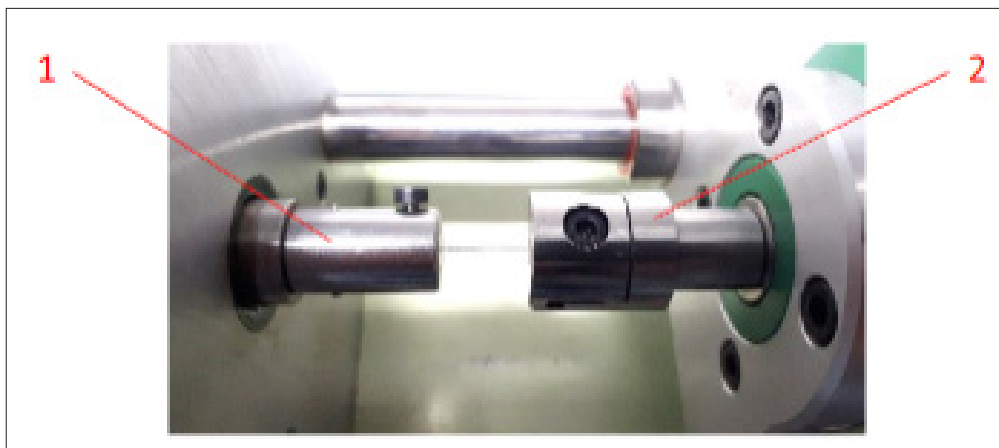


Figure 2. Apparatus for ISO torsional test (MAF and AD)

also recorded. During the same test it is also possible to measure how much rotation a blocked instrument can still do before breakage. The bigger the angle, the more resistant to torsional stress is the instrument. For the cyclic fatigue test, which does not follow ISO standards, a device that was used in many previous test was used. All instruments were rotated at at body temperature, inside an artificial canal with a 75 ° degree curve with 5 mm radius. Each instrument was rotated

inside the canal until a visible and/or audible sign of fracture was detected. Speed was different because recommendations from manufacturers are different: 500 rpm for Diamond and 300 rpm for Protaper. Therefore time to fracture was measured using a digital chronometer with a sensitivity of 0.01 seconds. and then cycles to fracture was calculated. Comparing cycles to fracture is independent from the speed and this allows a proper comparison.

Table 1. Mean Values and Significant difference amongst the tested instrument

	Name	Size	Fatigue (cycles)	Stiffness (Ncm)	Torsion (Ncm)	Torsion (°)
Diamond	Shaper	20/.04v	1338 *	0,115	0,524	616*
Diamond	F1	20/.07v	1647*	0,283	0,874	585*
Diamond	F2	25/.07v	1145*	0,394 *	1,146	629*
Protaper	S2	20/.04v	543	0,132	0,634	339
Protaper	F1	20/.07v	804	0,286	0,964	369
Protaper	F2	25/.08v	591	0,794	1,592*	389

Results

Results are shown in Table 1, which shows mean values for all test and significant differences when present (*).

More precisely, for the Cyclic fatigue test the Results (Cycles to fracture) were the following ones: Diamond Shaper (Mean 1338 SD 156) vs Protaper S1 (Mean 543 SD 70) showed a statistically significant difference ($P = 0,009$). Diamond F1 (Mean 1647 SD 157) vs Protaper F1 (Mean 804 SD 95) showed a statistically significant difference ($P = 0,018$). Diamond F2 (Mean 1145 SD 98) vs Protaper F2 (Mean 591 SD 35) showed a statistically significant difference ($P = 0,021$).

For the stiffness test the Results (Ncm) were the following ones: Diamond Shaper (Mean 0,115 SD 0,19) vs Protaper S1 (Mean 0,132 SD 0,22) showed no statistically significant difference ($P = 1,94$). Diamond F1 (Mean 0,283 SD 0,109) vs Protaper F1 (Mean 0,286 SD 0,5) showed no statistically significant difference ($P = 3,24$). Diamond F2 (Mean 0,394 SD 0,49) vs Protaper F2 (Mean 0,794 SD 0,7) showed a statistically significant difference ($P = 0,033$).

For the torsional resistance measured by MAF (Ncm) the Results were the following ones: Diamond Shaper (Mean 0,524 SD 0,01) vs Protaper S1 (Mean 0,634 SD 0,023) showed no statistically significant difference ($P = 1,12$). Diamond F1 (Mean 0,874 SD 0,04) vs Protaper F1 (Mean 0,964 SD 0,109) showed no statistically significant difference ($P = 1,79$). Diamond F2 (Mean 1,146 SD 0,08) vs Protaper F2 (Mean 1,592 SD 0,101) showed a statistically significant difference ($P = 0,017$). For the torsional resistance measured by DA (degrees) the Results were the following ones: Diamond Shaper (Mean 616° SD 27,5) vs Protaper S1 (Mean 339° SD 21,3) showed a statistically significant difference ($P = 0,003$). Diamond F1 (Mean 585° SD 34,1) vs Protaper F1 (Mean 369° SD 24,4) showed a statistically significant difference ($P = 0,022$). Diamond F2 (Mean 629° SD 41,1) vs Protaper F2 (Mean 389° SD 31,1) showed a statistically significant difference ($P = 0,015$).



Figure 3. Apparatus for cyclic fatigue test

Discussion

This study was conducted in vitro and all the testing machines have been evaluated in previous studies (20). There is a robust agreement that at the moment these are the more commonly used or standard tests for the nickel-titanium rotary instruments. However, it must be underlined that according to current literature (3), one single test is not enough to evaluate and compare instruments, because improvements in one properties may Results in some decrease of other properties. Therefore when evaluating and comparing new instruments, it is highly recommended to make a series of different tests and see how the instruments perform in all these tests. Some changes in the heat treatment and the design may be more in favor of a specific characteristic of the instrument versus the other, but in any case innovations should not have a negative impact on other properties, or if this happens it should be evaluate and explicated inside the article in recent years a comprehensive evaluation of many mechanical properties is now highly recommended when testing and comparing rotary instruments with different design and heat treatments. Utilizing all above mentioned tests can offer us a well-established means of investigation to evaluate in vitro mechanical properties, even if the dimensions, the cross-section design and also the heat treatment are not exactly the same between the tested instruments.

Results from the present study showed that the new "Diamond" instruments are more flexible than Protaper in size 25 (F2). Actually in the other sizes flexibility is similar and the better performance of size 25 (F2) is probably related to a slightly smaller taper. Such a significant difference in size 25 is an advantage in clinical practice because a more flexible instrument will be able to finalize preparation in curved canals more easily and rapidly, with less risk of the autogenic errors. It must be noted, however that in clinical practice the risk of ledges or canal blockages in also strongly relate to tip design, which is a feature not evaluated in the current research.

The importance of a more flexible NiTi instruments has emerged during years, because a major drawback of Niti rotary techniques was determined by the relative stiffness of the NiTi alloy. The traditional super-elastic nickel-titanium alloy was seven eight times more flexible than stainless steel, but such a huge improvement versus the stainless steel manual instrumentation was not always true in clinical practice. More precisely, since dentists were using nickel-titanium instruments with bigger tapers and dimensions, these rotary instruments were much more rigid than the small stainless steel files. The majority of the finishing NiTi instruments were more rigid than a number 10 15 and even 20 stainless steel file, thus resulting in difficulties of the NiTi instruments in safely and efficiently treating complex curvatures. With the introduction of heat treatment in the manufacturing of NiTi production, we have now instruments that are two three times more flexible when comparing to traditional super-elastic NiTi instruments. Such an improvement in the flexibility it is a major advantage because it will help clinicians in

treating more cases, more complex curvature and also in achieving these goals with an easier way. Moreover flexibility is also directly related to cyclic fatigue resistance, which is a measurement of the strength of the file which is rotating inside a curvature. Therefore in the great majority research the more flexible instruments were found to be more resistant also with cyclic fatigue. This feature is a big clinical advantage because the instrument will be able to negotiate a more complex curvature but with an increased resistance to breakage, which will reduce risks inside this complex curvature. In the present study the new “Diamond” instruments, despite similar flexibility in sizes S2 (Glider) and F1 were found significantly more resistant and flexible than Protaper Gold in all the compared sizes.

Such a significant and robust improvement (approximately two times better) can be related to the differences in the heat treatments.

When evaluating the torsional resistance using ISO standard test, it must be underlined that the test was developed for manual files and therefore it is very challenging. As a consequence the difference are often less evident and sometimes we cannot find statistically significant differences between heat treated instruments, because the test is very challenging and test the instrument in a very dramatic situation, by blocking it at 3 mm from the tip. When you block the instrument close to the tip and you keep it rotating even if at low speed, the instrument will very easily break. But this is not a common usage of the instruments, actually it is the opposite, since dentists must avoid in clinical practice to have instruments' tip blocked inside a root canal. If this happens it is a mistake which may result in an intracanal breakage.

The ISO torsional test actually measure to different parameters: the MAF (maximum torque at failure, which records the torque needed to break the file when tip is blocked) and the DA (deflection angles, which measures the number of degrees an instrument can still rotate without before breakage when tip is blocked). Results of the present study show a similar behavior in the MAF with no statistically significant differences between the tested instruments in sizes S2 and F1. On the opposite MAF was higher for Protaper F2 probably related to slightly bigger taper and mass compared to Diamond F2. For such size differences in dimensions were significantly affecting both flexibility and torsional strength. However the influence of different heat treatment can be demonstrated, as previously demonstrated by Cyclic fatigue test, by measuring DA. In all sizes DA was significantly bigger for the Diamond instrument, showing the positive effect of the heat treatment on the alloy. This improvement (nearly double values for each size) could also be clinically relevant because it allows the instrument to have a greater plastic deformation and slight more time before breakage after tip is blocked. These features could help clinicians to reduce the risk of failure due to torsional stress.

Protaper gold instruments were selected because it has been commercialized for many years and evaluated and compared in many studies worldwide

with positive Results. By comparing versus Protaper the new “Diamond” instruments showed very promising mechanical properties with some significant improvements. The new “Diamond” instruments are manufactured with a unique design of cross-section and flutes, aiming at improving cutting ability and debris removal. The files also have their own proprietary heat treatment that makes them flexible and more resistant to fatigue. These features should allow them to instrument the root canals in a faster and less invasive way compared with traditional techniques. Obviously some other testing in terms of cutting efficiency and in terms of clinical performance in vivo are needed to prove these statements, but the above-mentioned improvements in the mechanical properties shown by these comparative tests can suggest the clinical use of these new instrument for easy, safe and predictable root canal shaping procedures.

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