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Developing of a new device for static and dynamic tests of Ni-Ti instruments for root canal treatment

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Abstract

The present work aims to design and carry out a torque device able to perform static and dynamic tests of Ni-Ti instruments for root canal treatment. The realization of this device was carried out by the design and optimization performed on the single components and on the system globally.

The device is mainly composed by a step-step motor operating on a lever with equal arms. The first one drives a chuck transmitting the torque to the base of the root canal instrument, while the second one is connected on one side to a pulley, connected to a second chuck that allows the locking of the free end of the root canal instrument.

In order to verify the device efficiency, three series of different types of root canal instruments were tested. On these, the authors have designed and carried out an experimental campaign, consisting of static and dynamic tests: the first ones to measure the rotation and the torsional UTS, the second ones to measure the fatigue strength.

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Keywords: Ni-Ti instruments; Torquemeter

1. Introduction

During recent years, there has been a progressive tendency towards the use of nickel-titanium (Ni-Ti) rotary instruments for the preparation of the root canal (Thompson (2000), Kuhn and Jordan (2002)). At the same time, there was the appearance on the market of a large number of different Ni-Ti systems (Serene et al. (1995), Camps and Pertot (1995)). The manufacture of flexible instruments of varying characteristics (taper, shape, material, etc.) for using with low speed motors, air or electric, has provided the opportunity to the expert clinician to achieve predictable shapes of the channel with the highest increased speed and efficiency. In recent years, the use of rotary instruments in Ni-Ti

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metal alloy has established itself in endodontics as the greatest innovation in the instrumentation of the root canal system (Ruddle (2000), Alapati et al. (2009)). The success of this technique compared to methods that included the use of traditional hand tools is mainly due to the alloy mechanical properties superior to those offered by steel, but also to the innovations made by manufacturing process as part of the design of the instruments. In particular, as regards size and taper. The advantages that the introduction of Ni-Ti alloys resulted in endodontics can be summed up in three basic points: speeding up of operating procedures, streamlining operational procedures, predictability and effectiveness of treatment. Despite these advantages, unfortunately, the properties of Ni-Ti do not allow maintaining an ideal flexibility in the larger taper and sizes yet, especially if applied to particularly complex curvatures (Walia et al. (1988), Yum et al. (2011)). Currently, however, in order to achieve greater flexibility and fatigue resistance in the instruments of bigger size, it seeks to improve the characteristics of the alloy by increasing the mechanical characteristics.

However, despite the excellent results in terms of greater flexibility, cutting capacity and less risk of fracture during root canal preparation, these tools can fail for bending-torsion within their limit of elasticity Peters et al. (2003), Ninan and Berzins (2013)). The fracture of the instruments in Ni-Ti during rotation occurs with two different mechanisms: torsion fracture and fracture for alternating cyclic bending (Parashos and Messer (2006), Pedullà et al. (2015)). The former can be influenced by the macroscopic instrument shape. The flexural fractures are mainly due to defects in the surface of the instrument and can be due to cyclic fatigue (Yared et al. (2000), Al-Sudani et al. (2012), Parashos et al. (2004)).

2. Aim of the paper

For proper use, it is necessary to establish the performances in the use of rotary Ni-Ti instruments in clinical practice, expressed as safety on static fracture risk of such instruments. The behavior of the tools has to be investigated both in the static field, as well as, then, focusing on the fatigue resistance at very low number of cycles.

With this aim, a research program was carried out, in order to verify and to compare the performances of different instruments for root canal treatment (Pedullà et al. (2015b, 2015c), Berutti et al. (2014)). The program involves the static and dynamic response, either in terms of torsion or in terms of bending and fatigue. For this purpose, it was designed and created a torque-meter providing, by means of a custom-made strain gage load cell, the value of the resistant torque during the rotation of the quasi-static root canal instrument (Sattapan (2000)) based on ISO 3630-1 standards (2008). The present work aims to design and carry out a torque device able to perform static and dynamic tests of Ni-Ti instruments for root canal. The realization of this device was carried out by the design and optimization performed on the single components as well as on the system globally. This type of torque-meter may be used not only to test Ni-Ti instruments, but also for conducting torsion test on small cylindrical rods (with diameter of some mm), ensuring the accuracy and reproducibility of the measurements.

In order to verify the device efficiency, three series of different types of root canal instruments were tested (Pedullà (2015a)). On these, the authors have designed and carried out an experimental campaign, consisting of static and dynamic tests: the first ones to measure the resistance to torsion, the second ones to measure the fatigue strength at very low number of cycles. The dynamic tests consist in applying a defined number of cycles at different percentage of the breaking torque to the root canal instruments. The goal is to optimize the operation of the machine even for this type of tests. The quality of the measurements obtained assures a good linearity and a total absence of slippage.

3. General description of the testing machine

The principle for testing the torsion strength of root canal instruments is to measure the torque and angular deformation of each file during a test (Bonfanti et al. (2005)). To measure the torsion on the root canal instruments a torque-meter has been designed and realized which, based on ISO 3630-1 standards, provides the real-time measurement of the torque exerted on the various types of files by a servo-controlled motor. This choice was dictated by the guidelines of ISO (Fig. 1), which provide the use of a low-speed motor (2 rpm) and the connection of the root canal instrument between two chucks. One of these with jaws hardened steel (where to insert the handle of the root canal instrument) and the other at first made of brass (where is fixed the tip of the tool to a length of 3 to 5 mm).

The torque-meter is essentially based on the operating principle of the precision balance (Fig. 2). In fact, it consists of a lever with equal arms that allows carrying out the indirect comparison between the torque produced on the endodontic instrument by the stepper motor and the resisting torque measured by a strain gage load cell. Once the root canal instrument set on the chuck of the stepper motor, this, rotating at an angular speed of 2 rpm, generates a torque rotating a second chuck. On the axis of the latter, it is keyed a pulley connecting an inextensible steel cable that drag the right arm of the lever. The strain gage load cell provides the value of the force F_2 that, due to the design characteristics of the lever, will be equal and opposite of F_1. Then, it is possible obtain the value of the torque as the product of the force multiplied by the pulley radius R. This couple is the one that brings the tool to break.

Then, it was created a system transferring the static mechanical power supplied by the motor to the endodontic tool and transforming it into a resistant torque. This device, represented in CAD 3D in Fig. 3, is composed mainly of a step motor and by a yoke at equal arms. The first controls a chuck that transmits the torque to the root canal instrument, while the second is connected on one side to a pulley, the other side is rigidly attached to a custom-made load cell, in turn connected to the base. The pulley is connected, via a shaft, to a second chuck which allows the locking the free end of the root canal reamer. Ultimately, the root canal instrument is clamped between the two chucks: the first, integral with the drive shaft, transmits the torque; the other, connected by the torque transducer to the strain gage load cell, returns the resistant torque (Fig. 4).

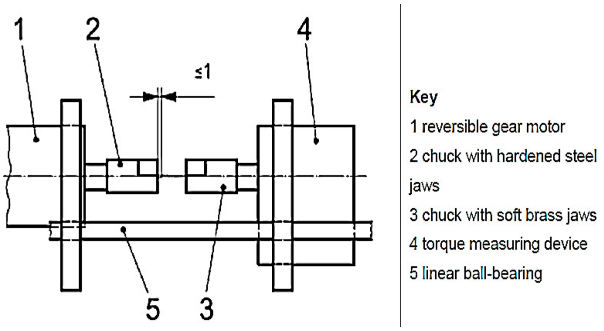

Fig. 1. ISO 3630-1 standards for the torque-meter.

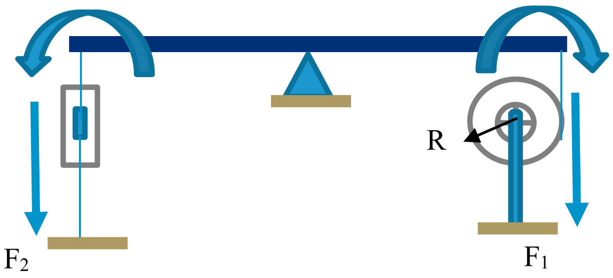

Fig. 2. Loading scheme.

The standard model to achieve the torque-meter is shown in the figure and consists of the following parts:

- low speed reversible gear motor, capable of rotating the test specimens at 2 rpm;
- torque measuring device, fixed on two linear ball bearings mounted on the shaft of the device;
- first chuck, used to fix the specimens to 5 mm from the tip and coaxial with the axis of the torque;
- second chuck, used to lock the handle of the specimen;
- separate amplifier, to monitor engine operations;
- digital display, for recording the torque and angular deformation;
- digital encoder, to measure the angular rotation and verify the frequency.

The stepper motor operating the root canal instrument was controlled in speed and position by means of a Java subroutine. The stepper motor selected is the model 103-H7123-5040 (flange 56 mm, 0.85 Nm) and the programmable electronic board choice is the 1063-Phidget Stepper Bipolar1-Motor by Phidgets. The Phidget Stepper board controls position, speed and acceleration of the bipolar stepping motor. Java was used as a programming language of Phidget board, while NetBeans IDE 8.0 as execution compiler.

In order to be able to remove between their chucks in the mounting phase of the endodontic instrument and bring them in the working phase, the motor shaft has been replaced by two coaxial shafts. The interior is keyed to the motor shaft, the outer slides on the first and is tightened with a locking screw once the desired position is reached. The gripping of the instrument to 3÷5 mm from the tip is ensured by a reference needle, consisting of a plate integral with the base and a double flat groove formed on the shaft outer diametrically opposite generatrices. These latter covering the dual function of the reference point for clamping to 5 mm and a flat key of the attachment section to tighten the chuck motor side (Fig. 5).

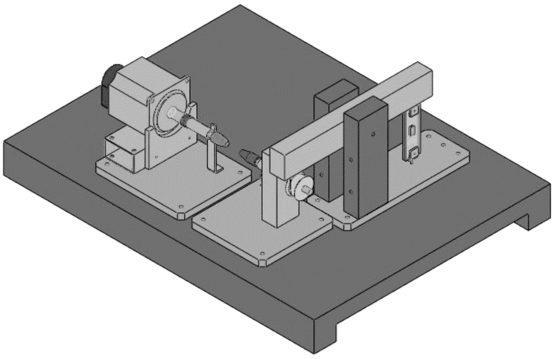

Fig. 3. CAD representation of the torque-meter.

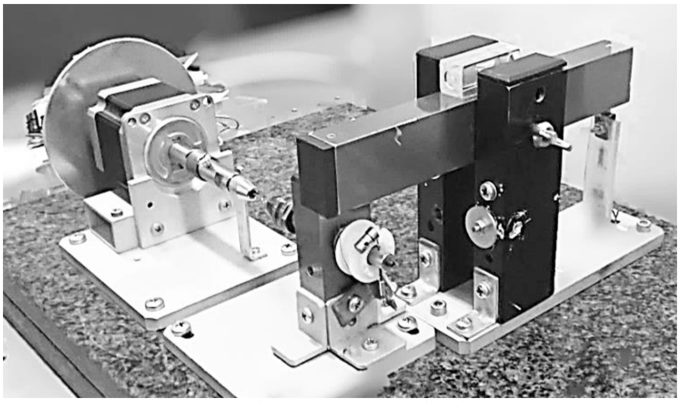

Fig. 4. The torque-meter realized.

In a first release, the two chucks did not exhibit a perfect alignment due to the first wooden platform not perfectly flat. Then, firstly, the solid shaft to the engine has been adjusted, minimizing or eliminating altogether the starting eccentricity. Moreover, the various components are mounted respectively on three flat aluminum bases (verified in the abutment plane), in turn fixed on a granite platform (Fig. 4). To complete the system to make coaxial the shafts, it was also installed a return spring between the axes in order to facilitate the detachment of the circuit at the time of the break of the instrument under test (Fig. 6).

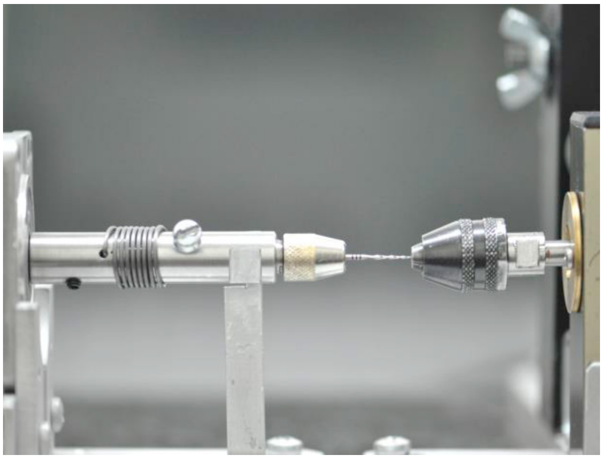

Fig. 5. Ni-Ti instrument clamped between the chucks.

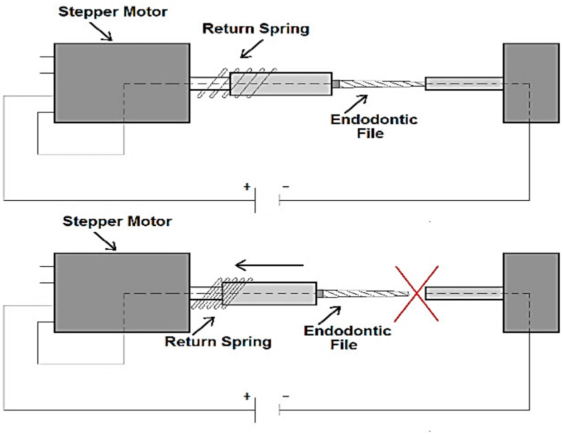

Fig. 6. Scheme of the system to facilitate the detachment of the circuit.

Some problem derived by the use of a brass chuck, as imposed by ISO 3630-1. The basic problem consists in the fact that the brass chuck did not guarantee a gripping such as to totally lock the tool Ni-Ti. The slips that were put in evidence during the tests, due to the increased hardness of Ni-Ti than brass, accelerated wear of the chuck, thus creating a chain reaction increasing the slips themselves. Thus, although in contrast to the standard, it was opted for the use of a hardened steel mandrel (Proxy) allowing a better gripping and avoiding slips. Since this chuck, similar in structure to that of brass, would again required the loosening of the tightening of the tower, it has been made movable the shaft integral with to the engine, replacing it with two coaxial shafts, as previously described. Thus, it is then possible to remove the chucks between them during assembly and bring them in the working position.

The pulley, directly mounted, did not allow the machine to perform the fatigue tests that, in dental practice, take place by swinging the crankshaft between the zero and an angle equal to a fixed percentage of the angle of failure (25%, 50 % and 75%). In fact, during the discharging phase, the steel wire connecting the pulley with the end of the rocker arm remained slack. Then, in the next loading phase, part or the whole accomplished rotation was used to put back the wire under tension. Thus, a bearing/freewheel is inserted between the shaft and the hub of the pulley, thus achieving an anti-return device in which the engine drives, rotating clockwise, while it automatically detaches turning counterclockwise. In this way, a ratchet system allows rotation only in one direction and, in the return phase, the pulley remains locked at that point, while the shaft is free to return to the starting position. Then, the wire always remains in tension and the loading and unloading stages are virtually linear.

An incremental rotary encoder HEDS-5500#A06, quadrature output, maximum rotation 30000 rpm was used to measure the rotation. The strain gage custom-made cell was made by placing a strain gage between two silicone strips of 1 mm thickness. After many attempts, using strips of various materials (neoprene, polypropylene), in fact, the material that gave the best compromise in terms of mechanical resistance, high elasticity and recovery was the silicone. In practice, the strain gage has been trapped between two silicone stripes, thus making the whole structure of the strain cell more performant. Only in this way, as shown by the graph of Fig.7, you can notice the good linearity in the process of loading and unloading. The two ends of the strain cell were fixed on one side to the rocker arm and the other to the base. It was necessary to carry out careful initial calibration to define the response curve of the instrument as a function of the applied loads (μm/m/N). The strain gage unit used is a National Instruments SCXI-1600. The software that enables the management and control of the strain gage unit was developed entirely in LabView. The calibration was performed by applying known loads to the strain gage load cell gradually increasing for a time necessary to obtain a stable response and thereafter discharging it gradually to avoid the viscoelastic phenomena. The detected values were then fitted, obtaining the polynomial curve of the second order reported in Fig.8. Let put in evidence, however, the almost linear behavior of the curve.

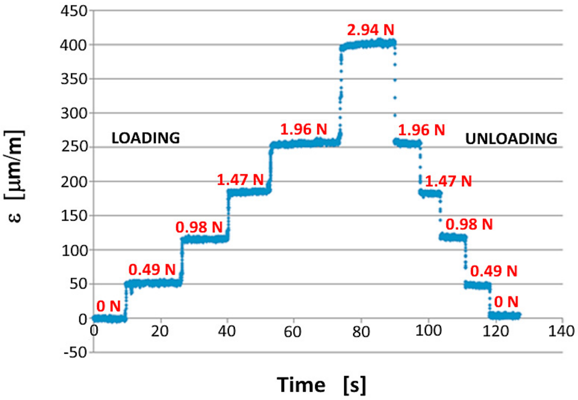

Fig. 7. Sequence of loading and unloading to calibrate the load cell.

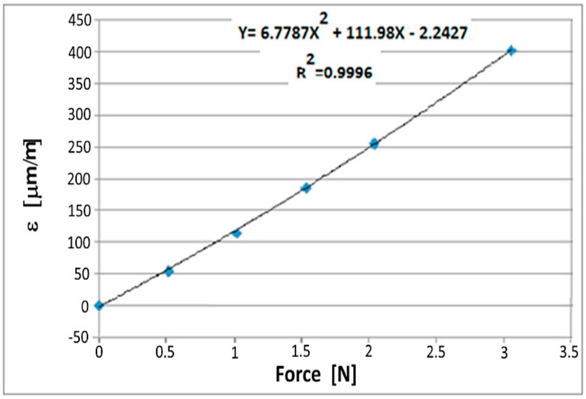

Fig. 8. Load cell calibration curve.

In order to associate a rotation angle to the torque necessary to generate the breakage of the root canal instrument, the motor shaft has been equipped with an encoder, mounted on the base, giving a redundant measure of the frequency, confirming that assigned to the stepper motor by software. For this purpose it has been considered a system capable of interrupting the power supply to the exact moment of the break. At first, this system was based on an electric circuit obtained by connecting a motor power supply pole between the two chucks, obtaining that the tip itself serve as a conductor. As long as the tip remains intact, the connection is secured and the shaft rotates; as soon as rupture occurs, in theory you should terminate the connection and block the encoder. In practice, however, the two chucks being fixed at the same distance, even rupture occurred, the electrical connection continued to be ensured by an electric arc produced between the lengths of the root canal instrument. Thus, it was developed a device that, by means of a return spring, bring the two sliding shafts in the rest position as soon as the break occurs, totally interrupting the electric contact (Fig. 6).

4. Experimental analysis

The tests were carried out on some Ni-Ti instruments the new generation, innovative in endodontics, to establish limits and safety in their use in clinical practice, translated as risk of fracture within the tooth cavity. The instruments on which we have worked are of three different types of the same size: Protaper-next, MTwo and HyFlex (Fig. 9). Of these, an experimental procedure was designed, consisting of static and dynamic tests: the first to measure the rotation and the torsional UTS, the latter to measure the fatigue strength.

As we said previously, having to perform both static and dynamic tests, the software to control the testing procedure has been set in a different way, depending on the type of test performed. Some parameters have remained unchanged for both tests, while others were modified.

4.1. Static tests

The static tests were performed by setting the number of steps of the stepping motor at a relatively high value (about 12,800 step) with respect to the previous point of failure calculated as average for each type. With this function, the stepper motor should fulfill four complete revolutions but, as soon as the specimen arrives at break, the shaft rotation stops and with it also the measure of the encoder, integral to it, by the mechanism above described. From the analyzed data, the time vs. torque graphs for the three types tested were obtained (Fig. 10). The various instruments show large differences either in terms of stiffness or in terms of maximum rotation. It is possible to observe that, as soon as the breaking point was reached, the connection between the two chucks is decoupled via the sliding shaft and the return spring and the torque resets. In this way, in addition to achieving a well-defined corresponding angle value, it is possible clearly identify the breaking point and also, the system can freely return to the starting position by downloading all the stress in the loading phase and coming back to an null torque.

Finally, the result of the tests carried out on endodontic instruments are also in good agreement with the values found in the technical literature, confirming the reliability of the device.

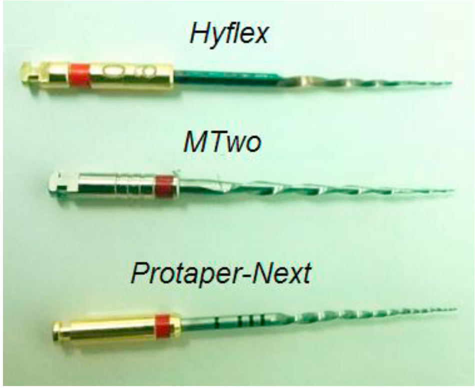

Fig. 9. Ni-Ti instruments tested.

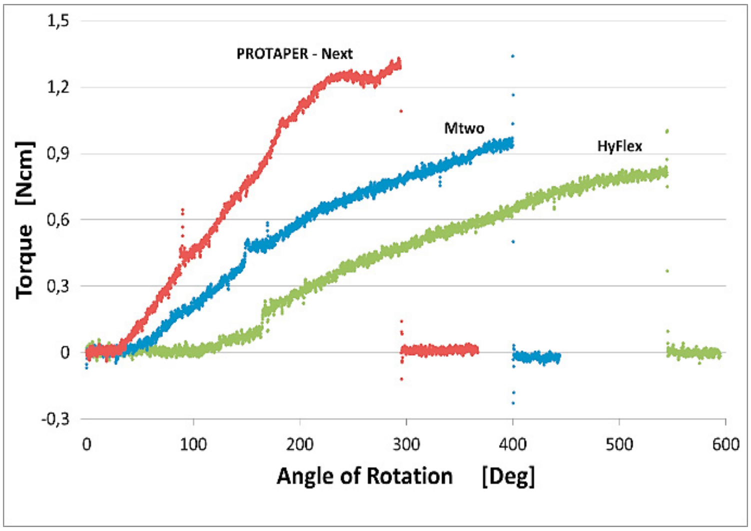

Fig. 10. Torque vs. rotation response of the Ni-Ti instruments.

4.2. Dynamic tests

The dynamic tests were carried out by running the oscillations between the initial position, corresponding to 0 degrees, and a position, always expressed in degrees, corresponding to a percentage of the breaking torque of each type of specimen. The adopted procedure provide 20 or 40 cycles to 25%, 50% and 75% of the breaking torque, respectively. The goal is to optimize the operation of the machine even for this type of tests. Considering that the device is able to perform tests mainly under rotation control, the first tests, carried out for torque at the 25%, 50% and 75% of the maximum rotation, do not allows to maintain the torque at the desired value, being non linear the behavior of the curves torque-rotation.

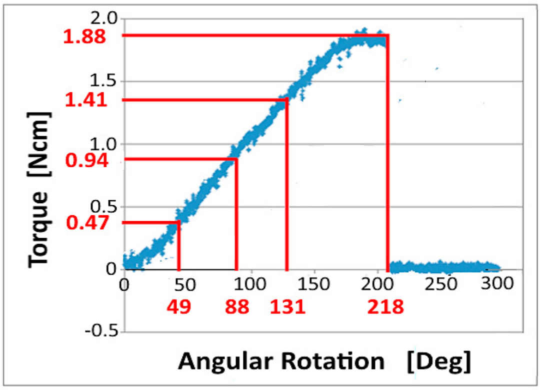

Fig. 11. Correspondence between levels of torque and rotation for the dynamic tests.

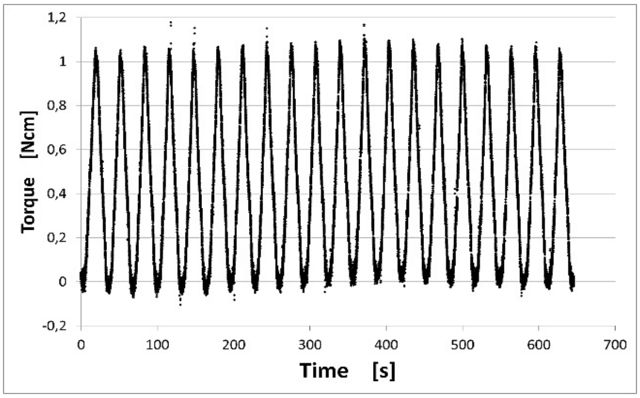

Fig. 12. Applied dynamic torque for a 20 cycles test.

Then, it was necessary to create a correspondence between the percentage of torque and the angular rotation for each instrument and to apply, for the previous 20 or 40 cycles, this rotation to the instruments. As an example, the evaluation of the rotation and the applied torque are shown in Fig.11. Fig. 12 shows an example of applied dynamic torque vs. time for a 20 cycles test.

Finally, the hysteresis areas were estimated by the cyclic measures, processed by Matlab by correlating the torque and the rotation on the basis of the time synchronization, at different number of cycles for the different instruments. After few cycles, the hysteresis area stabilize its shape. The hysteretic behavior is well defined grace to the large number of points detected per cycle (of the order of 100 point per cycle).

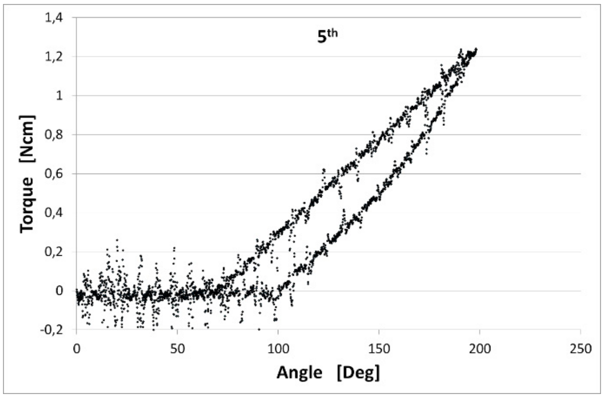

Fig. 13. Hysteresis behavior at 5th cycle.

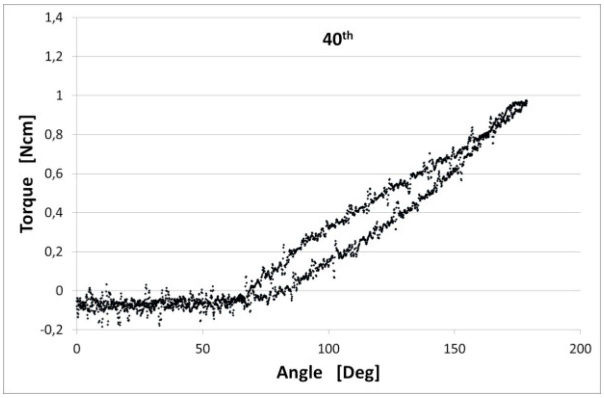

Fig. 14. Hysteresis behavior at 40th cycle.

As an example, the hysteresis at the beginning of the test (5th cycle, Fig. 13) and at the end (40th cycle, Fig. 14) are shown.

5. Conclusions

The present study is part of a larger research program performed in co-operation between research groups of Engineering and Medicine departments on the behavior of Ni-Ti instruments for root canal treatment. In order to perform a testing campaign on Ni-Ti instruments in different loading and environmental conditions, based on ISO 3630-1 standards, a dedicated torque-meter was designed and realized.

The performances to torque of the instruments depend on the shape, the material composition and the working process and have to be investigated both in static and dynamic conditions. Then, the device was designed to carry out either static or dynamic (Very Low Cycle Fatigue) tests.

The realization of this torque-meter was possible thanks to a careful optimization performed as well as on the individual components and on a global device. Particularly, the choice of the material and of the geometry with which it was realized the strain gage load cell (suitable for the measurement of a low-torque amount without providing an excessive torque), the torque transmission system and the mounting of the instrument on the chucks.

It was also designed and made a transmission system to coaxial axes, allowing easy installation of root canal instruments on the chucks, and able to stop the engine in the exact instant of failure, so as to obtain the corresponding torsion angle.

A preliminary campaign of tests was performed on three different type of Ni-Ti instruments, carried out either under torque static loading or applying a very low number of cyclic torque, 20 or 40 cycles as previous by the standard. On the basis of the data collected, it was also possible to define the hysteretic behavior of the different Ni-Ti instrument, following the response with a large number of couples torque-rotation for each cycle.

The good performances of the device have been highlighted by both the result of the tests performed on the root canal instruments, which are in good agreement with the values found in the technical literature, as well as for the quality of the graphics obtained, which have a good linearity and a total absence of slippage.

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