Flexibility and resistance to cyclic fatigue of endodontic instruments made with different nickel-titanium alloys: a comparative test

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Summary
Aim. **A new manufacturing method aiming at to producing more flexible and resistant NiTi endodontic instruments has been recently developed (Hyflex, produced with CM wire). The purpose of the study was to determine whether this new manufacturing method produces NiTi instruments (Hyflex) of superior flexibility and/or superior resistance to cyclic fatigue, when compared with instruments produced by a traditional manufacturing process or thermally treated NiTi alloy (M-wire).**
Materials and methods. **Twelve .06 size 25 Hyflex instruments (Coltene, Allstatten, Switzerland), and twelve 06.25 Vortex instruments (Dentsply-Tulsa, OK, USA) and twelve 06.25 Endosequence instruments (Brasseler, Savannah, GA, USA) were initially evaluated for stiffness on bending, followed by a cyclic fatigue test. For the stiffness test test procedures strictly followed ISO 3630-1, and bending moment was measured when the instrument attained a 45 degrees bend. The cyclic fatigue test was performed in a customized artificial stainless steel canal (60° degree curvature with 5 mm radius). Instruments were rotated at 300 rpm until fracture. All data obtained were recorded and statistically analyzed using an ANOVA test.**
Results. **Statistical analysis of data showed that bending moments were significantly greater ($P < .05$) for Vortex and EndoSequence instruments (mean values 59.06 g/cm and 48,98 g/cm respectively), compared to the Hyflex instruments (mean value 35.60 g/cm). For the cyclic fatigue test Hyflex and Vortex were significantly more resistant than EndoSequence instruments ($P < .05$).**
Conclusions. **Results of the present study demonstrate the ability of the new CM-wire manufacturing process to produce NiTi rotary instruments more flexible and more resistant to cyclic fatigue than instruments produced by a traditional manufacturing process or a thermally treated NiTi alloy (M-wire).**

Key words: cyclic fatigue test, NiTi alloy, rotary instruments, resistance of endodontic instruments.

Introduction

It is well known that during root canal preparation, endodontic instruments are subjected to different forces, including flexion, torsion, traction and apical pressure. Thus, they should have properties capable of preventing mechanical failure and also minimizing the possibility of undesirable alterations in canal anatomy. Loss of flexibility may result in ledges, transportations and perforations. This is why nickel-titanium (NiTi), a very unique alloy with specific properties very suitable for the endodontic use, has become popular in the last decades. The super-elastic property of the alloy can be described briefly. The stress value remains fairly constant up to a certain point of instrument deformation. At the same time, when the deformation rebounds, the stress value remains fairly constant. These characteristics are very useful in clinical practice, allowing an increased elastic deformation and, consequently, increasing flexibility of the endodontic instruments. The process of manufacturing of endodontic instruments from nickel-titanium was investigated initially by Walia et al.(1), who demonstrated that NiTi instruments have a greater degree of elastic flexibility in bending and torsion, as well as superior resistance to torsional fracture, when compared with stainless-steel instruments manufactured with the same process. The mechanical properties of endodontic instruments, like flexibility and resistance to fracture, are affected by several factors, such as dimensions, tip size and conicity, design, chemical composition of the metallic alloy and thermo-mechanical processes applied during manufacturing (2-4). To date, despite the fact that NiTi alloys demonstrate improved elasticity, which significantly reduces the restoring force, and reduces the amount of transportation that occurs during canal preparation, this elasticity is limited by the size and taper of instrument used (5,6). Therefore the fabrication of instruments of greater taper resulted in a significant increase of the stiffness of rotary instruments, and increased risk of fatigue failure (7). This is not an ideal characteristic for an instrument which is going to reach full working length in a curved canal, resulting in an increased risk of canal transportation in the portion of the canal after the start of the curvature, and in an increased risk of intracanal failure.
An ideal solution to increase instruments' performance is to use an improved nickel-titanium alloy with superior flexibility and resistance to fracture. Recently, new manufac-

turing processes (which are patented and not disclosed by manufacturers) involving heat treatment of the alloy have been developed in order to improve mechanical properties of the alloy for the endodontic use. The M-wire technology developed by Tulsa Dental was one of the first thermally treated NiTi alloy used for the endodontic use. A new manufacturing method aiming at to producing more flexible and resistant NiTi endodontic instruments has been recently developed by Coltene (CM wire). On these basis, the aim of the present study was to evaluate the bending properties and the cyclic fatigue resistance of NiTi rotary instruments produced with thermally treated alloys and compare them with those of commercially available NiTi instruments manufactured with traditional methods.

Materials and methods

Twelve instruments of each following NiTi rotary instrumentation technique were selected for the study:

a) EndoSequence 0625 (Brasseler, Savannah, GA, USA);
b) Hyflex 0625 (Coltene, Allstatten,Switzerland);
c) Vortex 0625 (Denstply-Tulsa, Tulsa, OK, USA).

The NiTi rotary instruments were selected based on a similar cross-sectional design and according to three different manufacturing processes: traditional grinding of NiTi (EndoSequence), M-wire (Vortex) and CM wire (Hyflex) technologies.
Before the tests, all instruments were examined under a measuring microscope at D3 and D16 to ensure uniformity of dimensions (according to the tolerance indicated by ISO 3630-1), and under a stereo microscope (magnification x20) to ensure uniformity of cutting flutes and defect free surfaces. All defective instruments were eliminated from the study, and substituted by other new instruments from the same manufacturer. Bending moment was measured when the instrument attained a 45° bend. Experimental procedures strictly followed testing methodology described in ISO 3630-1 (8), using a computerized device. After the stiffness test the same instruments were subjected to a cyclic fatigue test. The cyclic fatigue testing device used in the present study has been used in many previous studies on cyclic fatigue resistance performed by the authors (9-14). The device consists of a mainframe to which a mobile plastic support for the electric hand-piece is connected and a stainless steel block containing the artificial canals. The electric hand-piece was mounted on a mobile device to allow the precise and reproducible placement of each instrument inside the artificial canal. This placement ensured three-dimensional alignment and the positioning of the instruments to the same depth. The artificial canal was manufactured by reproducing an instrument's size and taper, thus providing the instrument with a suitable trajectory that respects the parameters of the curvature chosen. A simulated root canal with a 60° angle of curvature and 5-mm radius of curvature was constructed for instrument type. The center of the curvature was 5 mm from the tip of the instrument, and the curved segment of the canal was approximately 5 mm in length. All of the instruments were rotated at 300 rpm using a VDW motor (Munich, Germany) until fracture occurred. For each instrument, the time in seconds was recorded by the same operator with a chronometer to an accuracy of 0.1 s. After positioning the instrument in the canal and as soon as rotation started, timing was initiated. Timing stopped when instrument breakage was observed. Number of cycles at failure (NCF) was calculated for each instrument, by multiplying time to failure (in seconds) by 5 (which is 5 rotation x second = 300 rpm). For both tests all data were recorded and subjected to statistical evaluation ($p<.05$) using ANOVA test.

Results

For the bending test mean values and standard deviation for each group of instruments are shown in Table 1. The higher the value, the more rigid the instruments. Table 2 shows a statistical comparison of results: Hyflex were found to be the most flexible instruments, showing a significant difference ($P < .05$) in comparison with the other instruments. Vortex were not found to be significantly more flexible than EndoSequence instruments).
For the cyclic fatigue test mean values and standard deviation for each group of instruments are shown in Table 3. The higher the value, the more resistant the instruments. Table 4 shows a statistical comparison of results: Hyflex were found to be the most resistant instruments, showing a significant difference ($P <.05$) in comparison with EndoSequence and Vortex instruments.

Discussion

In the last years many new endodontic instruments, alloys and manufacturing processes have been commercialized in an attempt to improve performance and safety of root canal instrumentation. When new root canal instruments with innovative manufacturing process which differs markedly from conventional ones are produced, several characteristics need to be investigated and tested to allow an efficient and safe clinical usage. On these basis, the aim of the present study was to determine whether a new manufacturing method (CM wire) produces NiTi instruments of superior flexibility and fatigue resistance, when compared with instruments produced by a traditional or a thermally treated NiTi alloy (M-wire).
Results from the present study showed that Hyflex were the most flexibile instruments, with a significant improvement ($P <.05$) in flexibility ranging over the other tested commercially available instruments produced with the M-wire or the traditional grinding process (Tabs. 1-2). De-

	Mean values	Standard deviation
Hyflex 0625	19,46	(SD 2,7)
Vortex 0625	67,58	(SD 4,2)
EndoSequence 0625	62,11	(SD 5,7)

Table 1. Bending test: mean value and standard deviation for group of instruments.

Hyflex vs Vortex	Significant difference (P<.05).
Hyflex vs EndoSequence	Significant difference (P<.05).
Vortex vs EndoSequence	No significant difference (P>.05).

Table 2. Statistical comparison of results: Hyflex were found the most flexible in comparison with the other instruments.

spite the fact that flexibility is influenced by instruments design, such a great improvement is mainly related to the new manufacturing process (CM wire), which seems to play a major role in increasing flexibility of the Hyflex instrument. No significant difference were noted between Vortex and EndoSequence. Even if some articles report an increased flexibility of CM-wire vs traditional NiTi, data from the present study does not support those findings. Since the tested instruments were similar but not identical in cross-sectional design, it can be stated that the theoretical increase of flexibility of m-wire is not enough to overcome a slight increase of stiffness due to a different cross-sectional design.
In the present test M-wire technology did not produced a significant improvement in the cyclic fatigue testing over the traditional grinding method, while a statistically significant difference was noted with CM wire (Tabs. 3-4). Such differences may be due to the different alloys but also due to different instrument design. In fact, while cross-sectional design among the three tested instrument is similar, flute design is different. It is well know that flexural fatigue is highly influenced by the flute design, and therefore the complex design of Endosequence instrument could result in more stress concentration points and, as a consequence, less resistance to cyclic fatigue.

	Mean values	Standard deviation
Hyflex 06 25	424,4	(SD 63,2)
Vortex 06 25	287,8	(SD 52,8)
EndoSequence 06 25	280,2	(SD 37,6)

Table 3. Cyclic fatigue test: mean values and standard deviation for each group of instruments.

Hyflex vs Vortex	Significant difference (P<.05).
Hyflex vs EndoSequence	Significant difference (P<.05).
Vortex vs EndoSequence	No significant difference (P>.05).

Table 4. Statistical comparison of the test results: Hyflex were the most flexible resistant instruments.

These improvements in the manufacturing process shown by the CM wire technology can very useful in clinical practice. Nickel-titanium possess an unique flexibility that can usually withstand the rapid, repeated distortions of rotation in curved canals (10), but, unfortunately, flexibility is limited by the size and taper of instrument used. Therefore, a tip 25/06 taper NiTi rotary instrument is usually more rigid than small stainless steel K-files, i.e. size 15 or 20. Several changes in cross-sectional and flute design have been introduced in the last years in order to increase flexibility of greater tapered instruments which are intended to be used in apical portion of curved root canals, but no clinically significant improvement was achieved (2). Therefore a significant improvement in the flexibility of the alloy should be highly beneficial, providing NiTi instruments of greater taper with a superior ability to negotiate curved canals, to reduce the tendency of iatrogenic errors and to allow dimensionally adequate apical preparations of curved canals while maintaining the original path (21-23). Moreover, endodontic files that show an increased flexibility are also perceived to be more resistant to cyclic fatigue. A possible explanation is that when the instrument is rotated inside a curved canal and is subjected to tensile and compressive stress, a more flexible instruments could accommodate this stress in a better way, thus increasing fatigue resistance. In the present study such correlation between flexibility and fatigue resistance was found to be valid for the all the tested instruments.

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