Fatigue Resistance of Engine-driven Rotary Nickel-Titanium Instruments Produced by New Manufacturing Methods

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Abstract

The aim of the present study was to investigate whether cyclic fatigue resistance is increased for nickel-titanium instruments manufactured by using new processes. This was evaluated by comparing instruments produced by using the twisted method (TF; SybronEndo, Orange, CA) and those using the M-wire alloy (GTX; Dentsply Tulsa-Dental Specialties, Tulsa, OK) with instruments produced by a traditional NiTi grinding process (K3, SybronEndo). Tests were performed with a specific cyclic fatigue device that evaluated cycles to failure of rotary instruments inside curved artificial canals. Results indicated that size 06-25 TF instruments showed a significant increase ($p < 0.05$) in the mean number of cycles to failure when compared with size 06-25 K3 files. Size 06-20 K3 instruments showed no significant increase ($p > 0.05$) in the mean number of cycles to failure when compared with size 06-20 GT series X instruments. The new manufacturing process produced nickel-titanium rotary files (TF) significantly more resistant to fatigue than instruments produced with the traditional NiTi grinding process. Instruments produced with M-wire (GTX) were not found to be more resistant to fatigue than instruments produced with the traditional NiTi grinding process. *(J Endod 2008;34:1003–1005)*

Key Words

Cyclic fatigue, endodontic instruments, manufacturing process, nickel-titanium

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In 1988, Walia et al. (1) reported on the improved properties of a nickel-titanium (NiTi) alloy called nitinol for the manufacturing of endodontic instruments. Endodontic treatment has since benefited from the development of NiTi engine-driven rotary instruments because their increased taper allows for simpler and more efficient root canal preparations (2). As a result, there are now many engine-driven rotary systems available commercially that use NiTi instruments of varying designs and dimensions to facilitate cleaning and shaping procedures (3, 4).

Despite these improvements, instrument separation is still a major concern when using NiTi rotary files (5–7). Cyclic fatigue failure is reported to occur unexpectedly without any sign of previous permanent deformation (8, 9). This occurs because of the alternating tension/compression cycles that instruments are subjected to when flexed in the region of maximum curvature of the canal (10–12). Many variables such as the operational speed (13), the effects of the irrigant's action (14), the metal surface treatments (15), and the metallurgic characterization of the NiTi alloys (16) that could possibly influence the fatigue resistance of NiTi rotary files have been investigated, but there have been no scientific methods developed to date that evaluate the functional lifespan of NiTi rotary instruments. Furthermore, there have been no testing protocols approved by the International Standard Organization to establish minimum standards for an instrument's cyclic fatigue resistance.

Possible strategies to increase instrument resistance to cyclic fatigue include an improvement in the manufacturing process or the use of new alloys that provide superior mechanical properties. Recently, new manufacturing processes for NiTi endodontic instruments have been developed by manufacturers attempting to overcome these limitations. In 2007, a new NiTi alloy termed the M-Wire (Dentsply Tulsa-Dental Specialties, Tulsa, OK) was developed, and it is currently used for the manufacture of GT series X instruments (Dentsply Tulsa-Dental Specialties). The manufacturer states that a proprietary new thermal process is used to produce an alloy that provides instruments with greater flexibility and increased resistance to cyclic fatigue compared with files constructed from traditional NiTi alloy (17).

More recently, a completely different manufacturing process has been developed by SybronEndo (Orange, CA) to create a new NiTi rotary file for root canal preparation called the Twisted File (TF). It uses twisting of a ground blank in combination with heat treatment to reportedly enhance superelasticity and increase cyclic fatigue resistance (18). More precisely, TF instruments are created by taking a raw NiTi wire in the austenite crystalline structure and transforming it into a different phase of crystalline structure (R-phase) by a process of heating and cooling. In the R-phase, NiTi cannot be ground, but it can be twisted. Once twisted, the file is heated and cooled again to maintain its new shape and convert it back into the austenite crystalline structure, which is superelastic once stressed. Because ground instruments are not inherently resistant to fracture because grinding across the crystalline structure creates microfracture points along the length of the instruments, the new process aims at respecting the grain structure for maximum strength.

There have been no studies published to date on the mechanical properties of these new NiTi rotary instruments. The aim of the present study was to investigate whether cyclic fatigue resistance is increased for NiTi instruments manufactured using these new processes. This was evaluated by comparing instruments produced by using the twisted method (TF) and those using the M-wire alloy (GTX) with instruments produced by a traditional NiTi grinding process (K3, SybronEndo).

Materials and Methods

Two groups of NiTi endodontic instruments consisting of identical instrument sizes (constant .06 taper and 0.20 tip diameter or constant .06 taper and 0.25 tip diameter) were tested: (1) group A compared K3 size 25 and .06 taper (SybronEndo) with TF size 25 and .06 taper (SybronEndo) and (2) group B compared K3 size 20 and .06 taper (SybronEndo) with GT series X, size 20, and .06 taper (Dentsply Tulsa-Dental Specialties).

Ten instruments from each system were tested for cyclic fatigue resistance, resulting in a total of 40 instruments. All instruments had been previously inspected by using an optical stereomicroscope with 20× magnification for morphologic analysis and for any signs of visible deformation. All defective instruments were discarded.

The cyclic fatigue testing device used in the present study has been used for studies on cyclic fatigue resistance previously performed by the authors (19, 20). The device consists of a mainframe to which a mobile plastic support is connected for 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 the artificial canal (Fig. 1). This ensured three-dimensional alignment and 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 each instrument. 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. The instruments were rotated at a constant speed of 300 rpm by using a 16:1 reduction handpiece (W & H Dentalwerk, Burmoos, Austria) powered by a torque-controlled electric motor (X-Smart; Dentsply Maillefer, Ballaigues, Switzerland). To reduce the friction of the file as it contacted the artificial canal walls, a special high-flow synthetic oil designed for lubrication of mechanical parts (Super Oil; Singer Co Ltd, Elizabethport, NJ) was applied.

All instruments were rotated until fracture occurred. The time to fracture was recorded visually with a 1/100-second chronometer. The time to fracture was multiplied by the number of rotations per minute to obtain the number of cycles to failure (NCF) for each instrument. The length of the fractured tip was also recorded for each instrument. Means and standard deviations of NCF and fragment length were calculated for each system. Data were subjected to one-way analysis of variance to determine significant differences between groups. When the overall F test indicated a significant difference, the multiple-comparison Holm *t* test procedure was performed to identify the mean that differed from the others. Significance was set at the 95% confidence level.

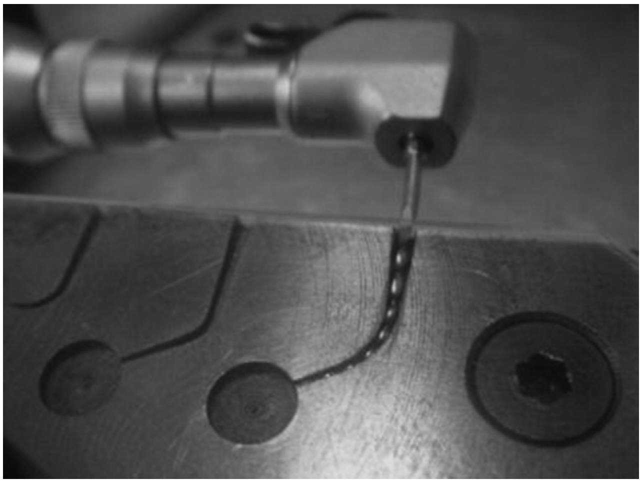

Figure 1. Artificial canal with 60° curvature and 5-mm radius.

TABLE 1. Fatigue Resistance of Size 25, Taper .06 Instruments

Instruments	NCF		FL	
	Mean	SD	Mean	SD
K3 25.06	552.5*	91.54	5.33†	0.25
TF 25.06	769.1*	123.77	5.29†	0.4
	$p = 0.000$		$p = 0.792$	

FL, fragment length; NCF, number of cycles to failure.

**Statistically significant difference for NCF between instruments ($p < 0.05$).*

†No statistically significant difference for FL between instruments ($p > 0.05$).

Results

Mean values ± standard deviation expressed as NCF are displayed in Tables 1 and 2. A higher number of cycles to failure is caused by a higher resistance to cyclic fatigue of the tested instruments. A statistically significant difference ($p < 0.05$) was noted between instruments from group A (Table 1). TF instruments, size 25 and .06 taper, showed a significant increase in the mean number of cycles to failure when compared with size 25 and .06 taper K3 files (769 vs 552 NCF).

No statistically significant difference ($p > 0.05$) was noted between instruments in group B (Table 2). Size 20 and .06 taper K3 instruments did not show a significant increase in the mean NCF when compared with size 20, .06 taper GT series X instruments (579 vs 570 NCF).

The mean length of the fractured segment was also recorded to evaluate the correct positioning of the tested instrument inside the canal curvature and whether similar stresses were being induced. No statistically significant difference ($p > 0.05$) in the mean length of the fractured fragments was evident for all of the instruments (Tables 1 and 2).

Discussion

In the present study, a comparison between instruments produced by using the twisting method (TF) and the M-wire alloy (GT Series X) versus instruments produced with the traditional NiTi grinding process (K3, SybronEndo) was performed by using two different files sizes. This choice was mandatory because there are no identical TF and GT Series X file sizes. Instrument sizes 20 and 25 with .06 taper were selected because the test device had two artificial canals of the same radius and angle of curvature (5 mm, 60°), each one suitable for one of these sizes. Previous studies (20, 21) have shown that the fatigue life of various NiTi instruments is affected by the radius and angle of the curvature and the

TABLE 2. Fatigue Resistance of Size 20, Taper .06 Instruments

Instruments	NCF		FL	
	Mean	SD	Mean	SD
K3 20.06	579.1*	60.1	4.8*	0.4
GTX 20.06	570.0*	144.98	4.75*	0.2
	$p = 0.855$		$p = 0.728$	

FL, fragment length; NCF, number of cycles to failure.

**No statistically significant difference for both NCF and FL between instruments ($p > 0.05$).*

instrument's size. K3 NiTi rotary instruments were selected for the comparative study because in previous studies they were found to be among the most cyclic fatigue-resistant NiTi rotary instruments produced by the traditional grinding method (22, 23).

TF size 25, .06 taper instruments were significantly more resistant to cyclic fatigue than K3 size 25, .06 taper, representing the major role of the new manufacturing process in increasing the resistance to fatigue of NiTi rotary instruments. The influence of the morphology of a NiTi rotary file on its fatigue resistance has been the subject of a number of recent investigations. However, how and why the design of the instrument could influence their behavior under cyclic fatigue stress remains unclear. In fact, some studies found that the fatigue life of various instruments did not seem to be affected by the instrument design, suggesting that the cross-sectional area or shape of the instrument is not the main determinant of the fatigue life (24, 25). Yet, other studies on cyclic fatigue suggested that a different cross-sectional design appeared to be an important determinant of cyclic fatigue resistance of different files (11, 20, 26–28). The results of the present study suggest that the improvement in fatigue resistance of TF files should be mainly related to the new manufacturing process involving twisting of a ground blank combined with heat treatment. This is confirmed by the fact that size 25, .06 taper TF instruments were significantly more resistant to fatigue than K3 size 20, .06 taper, despite the good resistance to fatigue that K3 instruments had shown in previous studies and the greater instrument dimensions (769 vs 579 NCF). Many researches (20, 21) have clearly shown that the fatigue life of various NiTi instruments is usually increased when the instrument's size is reduced.

On the contrary, cyclic fatigue resistance of instruments produced with the M-Wire was found to be no better than traditional NiTi rotary instruments (K3). The size 20, .06 taper K3 instruments showed a nonsignificant increase in the mean number of cycles to failure when compared with size 20, .06 taper GT series X instruments (579 vs 570 NCF).

A recent study that assessed 7,159 discarded NiTi rotary instruments showed that 5% had fractured during intracanal use and that 70% of these fractures were attributed to flexural fatigue (29). With cyclic fatigue failure appearing to be the main mechanism leading to intracanal failure, fatigue testing of NiTi rotary instruments is probably the most useful tool to understand an instrument's fatigue properties (30). Differences in testing devices used for evaluation can lead to different results, but so far there has been no device or method for fatigue testing incorporated into international standards for endodontic instruments. Additional studies are necessary to improve correlations between in vitro and in vivo fatigue resistance of NiTi rotary instruments and to validate test protocols to establish minimum standards for cyclic fatigue resistance. Under the experimental conditions of the present study and considering that the comparison was made between files of different morphology, the following conclusions can be drawn: (1) the new manufacturing process involving twisting of a ground blank combined with heat treatment produced new NiTi rotary files (TF) significantly more resistant to fatigue than instruments produced with the traditional NiTi grinding process (K3) and (2) size 20, .06 taper instruments produced by using the M-wire alloy (GT Series X) did not show any superiority in cyclic fatigue resistance when compared with instruments produced by using the traditional NiTi grinding process (K3).

The preliminary findings of the present study must be confirmed by further investigations that also evaluate other clinically relevant mechanical properties of the new NiTi rotary instruments manufactured by using the previously mentioned processes.

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