Cyclic Fatigue Resistance of K3, K3XF, and Twisted File Nickel-Titanium Files under Continuous Rotation or Reciprocating Motion

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Abstract

Introduction: New designs and alloys and different motions have been introduced to increase the cyclic fatigue (CF) resistance of nickel-titanium (NiTi) files. The aim of this study was to compare the CF resistance of K3 (SybronEndo, Orange, CA), K3XF (SybronEndo), and TF (SybronEndo) files under continuous rotation and reciprocating motion. **Methods:** A total of 210 files (30-tip diameter, 0.06 fixed taper), 60 K3, 60 K3XF, and 90 TF files, were divided into 7 groups (30 files each): K3-C, K3XF-C, and TF1-C were rotated at 300 rpm; TF2-C was rotated at 500 rpm; and K3-R, K3XF-R, and TF1-R were used in a reciprocating motion. CF resistance was tested in stainless steel, curved canals (60°, $r = 3$ mm) until fracture, and the time to fracture was recorded. The mean half-life, beta, and eta were calculated for each group and were compared with Weibull analysis. **Results:** The probability of a longer mean life was greater under reciprocating motion for all of the files (100% for K3, 87% for K3XF, and 99% for TF). Under continuous rotation, K3XF was more resistant than K3 and TF. TF lasted significantly longer than K3. TF was more resistant to CF when rotated at 300 rpm instead of 500 rpm. Under reciprocating motion, there were no significant differences between K3XF and TF mean lives, but both were significantly longer than the K3 mean life (78% for TF and 86% for K3XF). **Conclusions:** Reciprocating motion and R-phase increase CF resistance. *(J Endod 2013;39:1585–1588)*

Key Words

Cross-section, R-phase, reciprocation, rotational speed, Weibull analysis

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Since 1988, when nickel-titanium (NiTi) was proposed for use in the manufacturing of endodontic instruments (1), NiTi rotary files have become popular (2) because of their greater flexibility, cutting ability, and more rapid and centered root canal preparation (3, 4). However, these files tend to break unexpectedly because of cyclic fatigue (CF), which is induced by the alternating tension-compression cycles to which they are subjected when flexed in the maximum curvature region of the canal and are rotated (5).

To improve the CF resistance of files, manufacturers have introduced different designs and improved alloys. R-phase is an intermediate phase with a rhombohedric distortion of the cubic austenite phase created by a process of heating and cooling in which the final shape of the file is achieved, and different series of cooling and heating then convert the wire back to the austenite crystalline structure (5–8).

K3, Twisted File (TF), and K3XF are different NiTi rotary files developed by SybronEndo (Orange, CA). K3 was the first file developed (2002), and it was manufactured with a traditional grinding process. TF was developed in 2008 with a different manufacturing process including 3 new methods: heat treatment (R-phase), twisting of the metal wire, and special surface conditioning (9). In 2011, K3XF was developed with the same R-phase heating and cooling protocol as TF, but instead of being twisted, it was ground like K3 (10).

On the one hand, K3 and K3XF are made of a different NiTi alloy (K3 is made of conventional NiTi alloy and K3XF of R-phase); however, they have the same cross-section (a modified triple U: 2 reduced radial lands with a reduced zone to minimize friction and a third complete radial land), they undergo the same manufacturing method (grinding), and the same protocol of use is recommended by the manufacturer (continuous rotation at 300–350 rpm) (11, 12). On the other hand, TF has a different cross-section (triangular), it undergoes a different manufacturing method (twisting), and the manufacturer recommends that it be rotated at 500 rpm (5). TF and K3XF are made of the same R-phase alloy.

The thermal treatment of NiTi (9, 13, 14), cross-section of files (15, 16), speed in continuous rotation (17, 18), and manufacturing methods (5, 9, 19, 20) are parameters that are known to influence the CF resistance of files. Testing the CF resistance of these 3 different systems allows for analysis of the relative importance of these parameters that supposedly influence the behavior of NiTi rotary files in clinical situations because each of these systems has characteristics that make it different from the others but, at the same time, somewhat comparable.

Debate continues regarding the best motion of action for NiTi rotary files. Clinicians and researchers have suggested reciprocating motions instead of continuous rotation (21, 22), and scientific studies have shown a greater CF resistance of files when they are used with reciprocating movements (23–27).

No studies have compared CF resistance using 2 different motions (continuous rotation and reciprocation) among these 3 types of files, which have similar morphologies but are made of different alloys and undergo different manufacturing methods. Therefore, the aim of this study was to compare the CF resistance of K3, K3XF, and TF files at 5 mm from the tip under continuous rotation or reciprocating motion.

Materials and Methods

A sample of 210 new files (60 K3, 60 K3XF, and 90 TF) was used. All of the files had the same tip diameter (30) and a fixed taper (0.06). CF resistance was tested at 5 mm from the tip. The diameter at the tested length was 0.60 mm.

The files were divided into 7 groups (30 files each, Table 1). Continuous rotation at 300 rpm was used with the files in groups K3-C, K3XF-C, and TF1-C, and 500 rpm was used in group TF2-C. The files in groups K3-R, K3XF-R, and TF1-R were used with reciprocating motion in an ATR Tecnika Vision electric motor (Dentsply Maillefer, Ballaigues, Switzerland). Clockwise and counterclockwise rotations were set at four tenths and two tenths of a circle (144°–72°) as described by other authors (21–25).

The experiment was performed using a previously described device (28). The canal of 1-mm width was used because it was the width (to the nearest 0.1 mm) immediately beyond the diameter of the file at the entrance of the canal (0.9 mm) (Fig. 1*B*).

The device had a hardened stainless steel piece with 11 carved, open semicanals with 2 straight open portions joined by a 60° curvature with a 3-mm radius, with diameters ranging from 0.4–1.4 mm and a depth of 0.1 mm greater than each width. This piece was attached to a base that allowed for adjusting the positions of the files on the 3 axes of space(Fig. 1*A*). The x-axis held the dental handpiece and was approached or separated from a second platform, which held the stainless steel carved piece. This second platform adjusted the vertical (y-axis) and depth (z-axis) positions of the canals. A swiveling top face cover allowed for the visualization of the files and protected the operator (Fig. 1*B*).

Both the canal and the file were lubricated with synthetic oil (Singer All-Purpose Oil; Singer Sewing Company, Barcelona, Spain) to minimize friction. The motor and a 1/100-second chronometer were simultaneously activated, the file was monitored through the face cover until fracture, and the time (seconds) to fracture was registered.

Weibull analysis (Weibull++7; Reliasoft Corporation, Tucson AZ) was used to calculate different parameters and their 95% confidence intervals for each group including the following:

1. *Mean life (seconds)*: The expected or average time to failure
2. *Beta*: The slope or shape parameter (dimensionless), the values of which are equal to the slopes of the regressed lines in the Weibull probability plot and are particularly significant because they provide a clue to the physics of the failure
3. *Eta (seconds)*: Characteristic life or scale parameter. Eta is the typical time to failure in Weibull analysis related to the mean time to failure. It is defined as the expected time that 63.2% of the files will attain without breakage (ie, the probability of failure being 0.63 at this time point).

Comparison between the groups allowed for the determination of whether items from 1 set would outlast those of the others.

TABLE 1. Files and Conditions in the Study

Group	File	*n*	Speed (rpm)	Kinematics
K3-C	K3	30	300	Continuous rotation
K3XF-C	K3XF			
TF1-C	TF			
TF2-C	TF		500	
K3-R	K3		300	Reciprocation
K3XF-R	K3XF			
TF1-R	TF			

Results

The distribution of reliability versus time by group is shown in Figure 2. Table 2 presents the results and 95% confidence intervals for beta, eta, and mean life parameters.

Comparison of the datasets showed that mean life was significantly longer for all files when used with reciprocating motion compared with continuous rotation. The probability that the files used in reciprocation motion would last longer than the files used with continuous rotation was 100% for K3, 87% for K3XF, and 99% for TF.

When mean life was compared among the brands under continuous rotation (300 rpm), K3XF will last longer than K3, with a probability of 94%, and longer than TF, with a probability of 83%. In addition, TF will last longer than K3, with a probability of 93%.

When different rotational speeds were used, the probability that TF, rotated at 300 rpm, will last longer than if rotated at 500 rpm was 97%. Under reciprocating motion, there were no significant differences in mean life between K3XF and TF, but both will last longer than K3 (probability of 78% for TF and 86% for K3XF).

Discussion

The CF device and the statistical approach used in this study were previously discussed in a recent report (28). There are no standardized specifications to test the CF of rotary NiTi instruments—only to test the torsional load of .02 NiTi files used for hand instrumentation (29). An effort should be undertaken to minimize uncontrolled variables and to reproduce the same conditions when the CF resistance of files is tested (30).

This study tested static CF in a hardened steel canal. The design of the canals were not intended to simulate clinical conditions but rather to allow for precise testing of CF resistance at a given level of the file through the application of pure tension-compression cycles and excluding variables that cannot be reproduced in a tooth model.

Many studies have tested CF in metal devices with different designs including constricting the file into a curvature delimited by stainless steel pins (31, 32) or using different types of simulated canals (10, 14, 24, 33, 34). The device used in this study allowed for the selection of the exact point at which CF resistance was to be tested (5 mm). The device used different sizes of open-ended semicanals and provided a firm platform that allowed for the placement of the instrument in a curved and reproducible situation to test all of the files. All

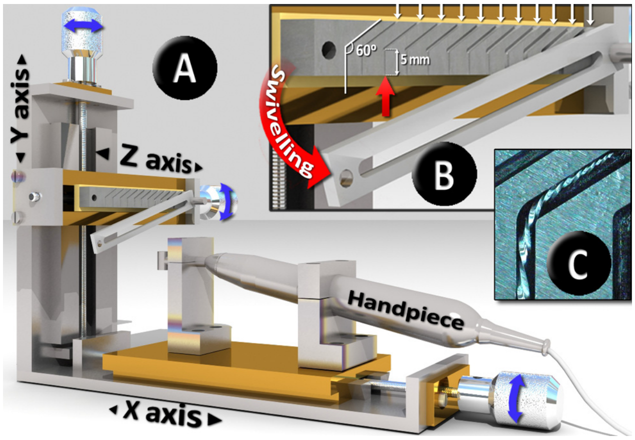

Figure 1. A cyclic fatigue testing device. A, A general view. Three axes are shown. B, The swiveling motion of grooved stainless steel top face cover and carved open semicanals (*white arrows*). A *red arrow* indicates the entrance of a canal. C, An image of the bending point of a file before testing.

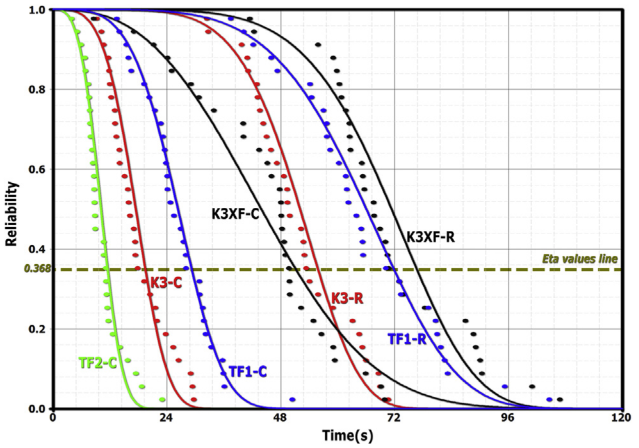

Figure 2. The distribution of reliability versus time by group. The *horizontal green dotted line* marks the eta parameter's values (ie, the time[s] at which 63.2% of the files would survive).

of the tested files had the same tip diameter and taper, so the diameters of all of the files were the same at the levels selected to be fatigued. Although 3 different instruments were tested in the present study, that they shared some characteristics allows for the discussion of the following 5 different factors: kinematics (rotation/reciprocation), manufacturing process (twisted/ground), alloy (NiTi/R-phase), cross-section (modified triple U/triangular), and rotational speed (300/500 rpm).

Kinematics

The results of this *in vitro* study showed that the CF resistance of the 3 tested files was significantly greater when the files were used in a reciprocating motion, rather than in continuous rotation, as in previous studies (24–26). These differences had not been analyzed for K3 and K3XF files. Some researchers have previously found that TF files were more resistant when submitted to reciprocation motion than under continuous rotation (23, 24) as in the present report.

Both TF and K3XF showed a significant longer mean life than K3 under reciprocating motion. Earlier studies have reported that thermal treatment of NiTi alloys resulted in greater CF resistance when used in continuous rotation (9, 34, 35), but until now this fact had not been tested under reciprocation.

The results of the present study showed that K3XF under continuous rotation showed a significantly longer mean life than TF and K3, whereas TF was better than K3. This finding suggests that the latest developments in files (trough improvements in constituent alloys, in their design, and/or in their manufacturing processes) have produced more resistant instruments.

In addition, the beta parameter was significantly lower for K3XF than for K3 under continuous rotation; not only was K3XF more resistant to CF, but the results were also more homogeneous for K3XF, suggesting that its behavior was more predictable. However, based on the results in Table 2, it is apparent that the beta parameter increased in the groups tested under reciprocation. CF resistance was significantly greater under reciprocation, but it was also less predictable, possibly because the files were manufactured to be used under continuous rotation.

TABLE 2. Results and 95% Confidence Intervals for Beta, Eta, and Mean Life Parameters

Group	Mean life	Beta	Eta
K3-C	17.4 (15.3–19.7)	3.8 (2.9–5)	19.2 (17.2–21.3)
K3XF-C	44.7 (38.5–51.8)	2.7 (2–3.7)	50.2 (43.6–57.9)
TF1-C	26.1 (23.4–29.2)	4 (3.1–5.1)	28.8 (26.2–31.9)
TF2-C	10.1 (8.8–11.7)	3.3 (2.6–4.2)	11.3 (10–12.8)
K3-R	51.3 (47.5–55.4)	6 (4.5–7.8)	55.4 (51.9–59.1)
K3XF-R	70.9 (64.9–76.4)	5.8 (4.5–7.5)	76 (71–81.5)
TF1-R	65.3 (59.6–71.5)	5 (3.8–6.4)	71.1 (65.8–76.9)

Alloys

Considering that other factors were the same for K3XF and K3 files (design and manufacturing process), the better results for K3XF, in lasting longer than K3 (probability = 94%), suggest that R-phase is more resistant than conventional NiTi under continuous rotation. These results are consistent with those of other studies (10, 20, 36, 37).

Manufacturing Processes and Cross-sections

K3XF was significantly more resistant than TF to CF under continuous rotation. Hence, either the differences in cross-section or in the manufacturing process (grinding or twisting an R-phase alloy wire) affected their behavior. The limitation of not having 2 files with the same design and alloy but with different manufacturing process made it difficult to determine precisely whether or to what extent the improvements in CF resistance were related to the different design or the different manufacturing process.

The twisting manufacturing process has been claimed to enhance CF resistance, supposedly because it sidesteps the grinding process, which can introduce microfractures into the wire (5, 20). However, although the results of the present study were similar in that TF was more resistant than K3, TF is made of R-phase and K3 of a conventional NiTi alloy, and K3XF resisted significantly more than TF.

Rotational Speed

This study also compared the CF resistance of TF files at different speeds (300 rpm, to be comparable with other groups, and 500 rpm, the speed that the manufacturer recommends). TF was significantly more resistant to CF when it was used at 300 rpm. There has been no agreement in the literature regarding whether a lower CF resistance is related to a higher speed (17, 38).

Based on these results and bearing in mind the limitations of this *in vitro* study, we conclude that CF resistance was greater for all files when used under reciprocating motion although the roles that the other analyzed parameters play in CF resistance must be interpreted with caution because, surprisingly, the significant differences found in CF resistance between TF and K3XF when they were rotated were no longer present when they were reciprocated. This finding suggests that the connection that has been found between the cross-section of the file or the manufacturing process and the CF resistance when the file is rotating is not important, and when the file is used with a reciprocating motion, the different thermal treatment of the wire is the only variable that is relevant to CF when the files are used in a reciprocating motion.

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