Cyclic Fatigue of EndoSequence and K3 Rotary Files in a Dynamic Model

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Abstract

The cyclic fatigue resistance of K3 and EndoSequence files was compared by rotating files against a highly polished surface inclined at 15 degrees to the horizontal. For each brand, files with a 25 tip in .04 and .06 taper and files with a 40 tip in .04 and .06 taper were tested at both 300 and 600 rpm. A 3-mm axial movement simulated a clinical pecking motion at 1 cycle per second. The number of rotations to failure was calculated and analyzed by using analysis of variance and Independent Student's *t* tests, with results confirmed by nonparametric Mann-Whitney *U* tests with a Bonferroni correction. At both 300 and 600 rpm, K3 files exhibited statistically significantly more cycles to fracture than their EndoSequence counterparts with the same tip size and taper. Scanning electron microscopy images demonstrated surface features consistent with fracture due to cyclic fatigue. In this model, file design appeared to be the most important determinant of cyclic fatigue resistance. *(J Endod 2007;33:1469–1472)*

Key Words

EndoSequence, fatigue, fracture, K3, rotary files

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The endodontic application of nickel-titanium (NiTi) was first forecast in 1975 by Civjan et al. (1). In 1988 Walia et al. (2) developed and tested the first NiTi file by milling a nitinol wire blank into a #15 file. They found these hand instruments possessed advantageous bending and torsional properties, which they attributed to a low modulus of elasticity. Further ingenuity led to handpiece-driven rotary systems with superior canal centering ability and reduced preparation time, as compared with stainless steel hand instruments (3, 4). Today, clinicians must technically discriminate among more than 20 rotary file systems with differing designs, techniques, and tapers.

During rotary instrumentation a file is inserted and withdrawn from diverse canal configurations, many of which are curved. As a NiTi file bends, it is subjected to compressive stress on the inside of the curvature and tensile stresses on the outside of the curvature (5). In addition, rotation in this curved posture subjects the file to hundreds of cycles of alternating compression and flexure. Memory characteristics and phase transitions of NiTi impart the ability to cycle through the bending demands of a curved canal without fracturing (2). However, inherent cyclic fatigue resistance is depleted with use, as the additive effects of flexural stress accumulate until they eventually exceed the elastic limit. In addition, files are challenged by torsional shear forces which are generated through friction and cutting of dentin or through a file tip binding in a tight canal or isthmus (6). Torsional fatigue and subsequent unwinding of stainless steel instruments are reasonably easy to detect. Conversely, NiTi files may not present stark signs of impending fracture (7). Thus, without warning, file separation may occur as a consequence of cyclic fatigue, torsional stress, or a combination of the two.

Factors influencing cyclic fatigue are often described individually, yet they act collectively. The radius of curvature is the most important factor; as the radius decreases, cycles to failure also decrease (5, 8). In addition, a more severe angle of curvature produces greater stress, especially if coincident with a small radius (5). Larger file diameters are more susceptible to cyclic fatigue than their smaller counterparts (5–10). File design features such as NiTi core diameter, cross-sectional shape, and flute depth may account for incongruent fatigue properties seen among different file brands (10, 11). A slower rotational speed may reduce the incidence of instrument separation (12, 13). Scanning electron microscopy investigations support the idea that files might fail as a result of propagation of manufacturing grooves and microcracks (14–16). A controlled chemical process called electropolishing minimizes surface defects and consequently may increase file longevity (17). Considered together, file design, instrumentation technique, and canal anatomy combine to determine the frequency of file separation.

Cyclic fatigue testing can be accomplished through static models, in which a file is flexed and then rotated until fracture occurs (5, 8). On the other hand, Dederich et al. (18) used a dynamic model and found that a cyclic axial motion significantly extended the life span of rotary files. This type of test more closely approximates a clinical brushing or pecking motion (13). The cyclic fatigue properties of electropolished EndoSequence (Brasseler, Savannah, GA) files have not been studied in such a model. K3 (Sybron Endo, Orange, CA) files have been shown to possess desirable cyclic fatigue resistance abilities in both static and dynamic models, despite possessing an unpolished surface with manufacturing grooves (11, 17). The purpose of this study was to compare the cyclic fatigue resistance of K3 and EndoSequence files in a model using reciprocating axial movement.

Materials and Methods

The study consisted of 8 different file types each rotated at 300 and 600 rpm, comprising 16 groups with 15 files per group. The following file types (all 25 mm in length) were tested: EndoSequence files (.04 taper size 25, .04 taper size 40, .06 taper size 25, .06 taper size 40) and K3 files (.04 taper size 25, .04 taper size 40, .06 taper size 25, .06 taper size 40).

Each file was rotated freely on a highly polished area of a stainless steel block with an incline of 15 degrees to a horizontal plane, similar to Li et al. (13). The files were rotated by an electric dental handpiece (Aseptico, Woodinville, WA), which was locked into a custom jig attached to the 500-g load cell of a universal testing machine (Instron, Norwood, MA). Starting position was determined by first lowering each file until it lightly touched the inclined surface and then lowering the file an additional 3.0 mm as determined on the Instron control panel. A simulated pecking motion was achieved as the system cycled the handpiece axially 1.5 mm (amplitude) above and below the starting position at 1 cycle per second (hertz). The file and the plane were lubricated with petroleum jelly. The handpiece began rotation, the system began cycling, and a stopwatch (Seiko USA, Mahwah, NJ) accurate to .01 second began timing simultaneously. Timing was stopped as fracture was detected visually and audibly. The length of each fractured file segment was measured to the nearest 0.5 mm. Each time value was converted to decimal units and then multiplied by the revolutions per minute to arrive at total revolutions to failure. The manufacturers recommend that K3 and EndoSequence files be rotated at 300–350 and 600 rpm, respectively. Files from each brand were rotated at both 300 and 600 rpm. At maximum flexure all file types produced an angle of 28 degrees, determined according to the Schneider method (19). Fracture characteristics were determined by examination under a LEO 435 VP scanning electron microscope (SEM) (Carl-Zeiss NTS GmbH, Oberkochen, Germany).

Data were initially analyzed with a 4-factor analysis of variance (ANOVA) to examine the main effects of file type, speed (rpm), file size, and taper. Because of significant interaction terms, the main effects were not interpretable. Therefore, the data were stratified on file type (EndoSequence and K3), and 2 separate 3-factor ANOVAs were done to examine speed, file size, and taper. Clear results were found for EndoSequence files, but significant interaction terms prohibited interpretation of the main effects for K3s. Therefore, the data set was further stratified to examine just the differences between EndoSequence and K3 files with the same tip and taper at the same speed. Independent Student's *t* tests were used to compare these data, and the results were confirmed by nonparametric Mann-Whitney *U* tests. A Bonferroni correction was applied to the *P* value to account for the multiple comparisons, and $P < .004$ was used as the cutoff for significance.

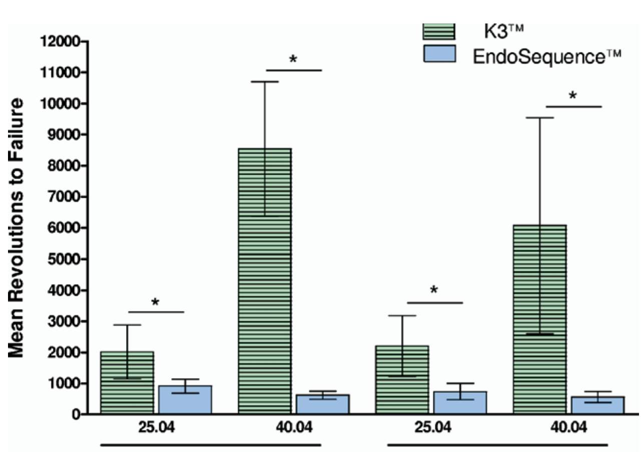

Figure 1. Mean revolutions to failure of .04 taper files at 300 and 600 rpm. *Significant differences ($P < .0001$) arising from independent Student's *t* tests. In addition, within EndoSequence file groups, 3-factor ANOVA results demonstrated significance for speed ($P < .003$), file size ($P < .001$), and taper ($P < .001$).

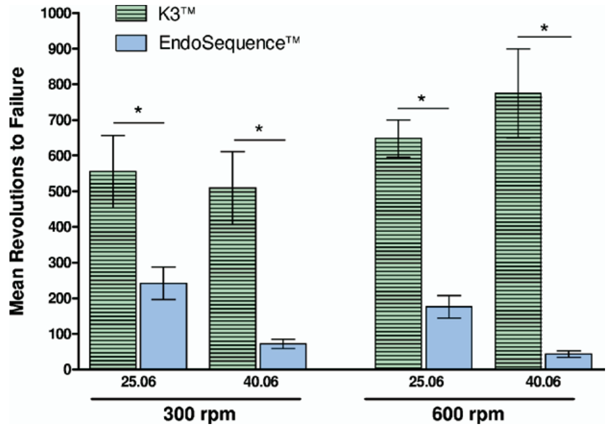

Figure 2. Mean revolutions to failure of .06 taper files at 300 and 600 rpm. Note that the ordinate scale differs from Figure 1. *Significant differences ($P < .0001$) arising from independent Student's *t* tests. In addition, within EndoSequence file groups, 3-factor ANOVA results demonstrated significance for speed ($P < .003$), file size ($P < .001$), and taper ($P < .001$).

Results

Independent Student's *t* tests showed that under all 8 scenarios, K3 outperformed EndoSequence files, with statistically significantly higher revolutions to failure ($P < .0001$). Figs. 1 and 2 show mean revolutions to failure for .04 and .06 taper files, respectively. The 3-factor ANOVA results for the EndoSequence file were more clear than those for the K3, as the main effects were all statistically significant (speed, $P < .003$; file size, $P < .001$; taper, $P < .001$) with no statistically significant interaction terms; whereas for the K3 file, the interaction terms were all statistically significant, resulting in uninterpretable main effects. SEM images demonstrated characteristic dimpling of the entire fractured surfaces, consistent with cyclic fatigue failure (Fig. 3). All files fractured between 3–7 mm from the tip as measured to the nearest 0.5 mm: 218 files (91%) between 3.0–4.0 mm, 14 files (6%) between 4.5–5.0 mm, and 8 files (3%) between 5.5–7.0 mm.

Discussion

American Dental Association Specification No. 28 prescribes specific tests to measure strength under torsion and flexibility of stainless steel hand files (20). Unfortunately, no universally accepted test exists to measure the cyclic demands of NiTi rotary files operated at 300+ rpm. As a result, diverse models have emerged to investigate this type of stress (5, 8, 9, 11, 13, 17, 18, 21). An ideal model would involve instrumentation of curved canals in natural teeth. However, in such tests a tooth can only be used once, making it impossible to standardize experimental conditions. We selected a previously described model that essentially eliminates torsional stress by allowing each file to rotate on a pristine highly polished surface (13). Pruett et al. (5) showed that instruments separate at the point of maximum flexure of the shaft, corresponding to the midpoint of the curvature. The majority (91%) of our files separated between 3–4 mm from the tip of the instrument, indicating a narrow