The Effect of Operational Speed on the Fracture of Nickel-Titanium Rotary Instruments

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Abstract

The purpose of this study was to compare the number of rotations to fracture of nickel-titanium (NiTi) rotary files operated at different speeds and different angles. We used 60 Profile NiTi rotary files, size 25 (30 each of 0.04 and 0.06 taper), operated at speeds of 350 or 600 rpm at angles of 25, 28, and 33.5 degrees. The time to fracture and number of rotations to fracture were recorded and calculated. A significant ($p < 0.001$) difference was found in the number of rotations to fracture according to taper and angle. Files of 0.06 taper fractured more readily than files of 0.04 taper. Increasing the angle at which the file was rotated decreased the number of rotations to fracture for both tapers; 0.04-taper files were more affected by an increase in the angle than the 0.06-taper files. However, the number of rotations to fracture was not related to the speed at which the files were operated. *(J Endod 2007;33: 52–54)*

Key Words

Fracture, rotary, speed

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The use of nickel-titanium (NiTi) rotary instruments is now commonplace in the field of endodontics. Civjan and associates (1) first suggested that NiTi alloy be used to fabricate hand and rotary instruments. However, it was Walia and associates (2) who first proposed that endodontic files be fabricated with this metal. One of the benefits of NiTi instruments is that they allow the practitioner to negotiate curved canals, while minimizing transportation (3) compared to stainless steel, because NiTi is more flexible and more resistant to torsional fracture (2).

Because canals tend to be curved (4), NiTi files undergo fracture as a result of cyclic fatigue (5) and applied torque (6). Fatigue fracture of a file because of failure of the material occurs in three steps. Crack initiation may be caused by surface irregularities that are produced during the manufacturing, handling, tooling process, or slip bands and dislocations that intersect the surface as a result of cyclic loading. Crack propagation takes place with continuously applied stress; ultimately, failure occurs when the material cannot withstand the applied stress (7). Flexural fracture occurs through the repeated bending of a file that occurs as the file is rotated inside a curved canal. Torsional fracture occurs when a portion of a file, usually the tip, binds in the canal and the remainder continues to rotate. Either of these factors or a combination of the two can produce fracture of NiTi rotary files.

A recent study by Li et al. (8) showed that as the speed of a NiTi file rotated at an angle increased, time to failure decreased. Each rotation of a file bent at a given angle produces flexural stressing of the metal. After a set number of flexures, or rotations, the metal will fracture. Therefore, the number of rotations should determine when failure will occur rather than the speed at which the file is rotated. The time to fracture depends on the speed at which the file is rotated only because more rotations and thus more flexures occur per unit time; therefore, fracture occurs sooner at higher speeds.

The angle of curvature of the canal may also be important. At 0 degrees a file could rotate infinitely without breaking because no flexure occurs. If the file is bent at an angle, however, as occurs when instrumenting a curved canal, the file will be flexed with each rotation. In addition, the time to failure may be a function of the angle of flexure. Pruett and associates found that the angle of curvature was a significant variable to consider when conducting studies that predict separation (9).

The purpose of this study was to test the number of rotations to fracture of NiTi rotary files when operated at different speeds and at different angles.

Materials and Methods

An adjustable apparatus was fabricated to produce the curvature to which a rotary instrument would be subjected in a canal (Fig. 1). The 65 mm × 25 mm × 3 mm block was made from hardened 316 stainless steel with polished chrome plating; a 2-mm-wide groove machined into the face to keep the file in place during testing. The 15 cm diameter aluminum baseplate and adjustable block holder were attached to the baseplate of the Instron machine with screws. The block holder was designed so it could be set at any angle for testing with the use of two hex screws and a sliding mount. Three angles of curvature were measured against the polished metal surface, using the Schneider method. Schneider defines the angle of curvature as the angle between a line parallel to the long axis of the canal, and another line from the apical foramen to the intersect point with the first line to the point where the canal begins to leave the long axis of the canal (10). The metal block was highly polished and lubricated with RC Prep before each file was tested. Periodic inspections were made of the polished surface

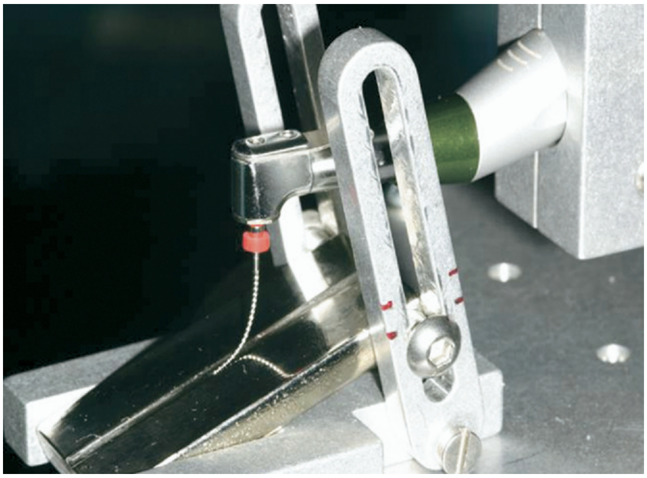

Figure 1. An electric motor and 8:1 contra-angle handpiece attached to a universal testing machine were used to rotate the files against a chrome-plated, hardened-steel block until failure occurred.

using 3.5-power loupes to ensure that there was no surface wear that could increase the friction and torque.

A total of 60 files were divided into two groups: Group A consisted of 0.04-taper 21-mm Profile size 25 NiTi rotary files (Dentsply, Tulsa Dental, Tulsa, OK), and group B consisted of 0.06-taper 21-mm Profile size 25 NiTi rotary files. The files in groups A and B were tested at one of two speeds, 350 or 600 rpm; and one of three different angles, 25, 28, or 33.5 degrees. To ensure consistency, testing was completed for all groups at a given angle before changing the angle on the apparatus.

The files were rotated by an electric motor (Aseptico Endo ITR, Aseptico Inc., Woodinville, WA) through an 8:1 contra-angle handpiece (Anthogyr, Aseptico Inc.). The handpiece was attached to a universal testing machine (Instron corp., Canton, MA) by a custom-fabricated jig. One researcher (G.G.K.) observed the files as they rotated with 3.5-power loupes. He started a stopwatch when the file began rotating and operated it until fracture occurred; at this time he stopped the watch and recorded the time to fracture. Times were rounded to the nearest second.

The formula [time to fracture × speed] was used to calculate the number of rotations to fracture. The experimental design was a three-way design: taper (two levels) by angle (three levels) by speed (two levels). The significance of each effect was assessed using multiway ANOVA followed by a Tukey-Kramer multiple comparison post hoc test.

Results

The mean number of rotations to failure for group A (0.04 taper) and group B (0.06 taper) are shown in Tables 1 and 2.

Taper

The taper of the files was found to significantly influence the number of rotations to fracture. The 0.06-taper files fractured after significantly fewer rotations than the 0.04-taper files. This finding was consistent at all angles and speeds. In addition, the significant interaction of taper and angle showed that the 0.04-taper files were affected more by an increase in angle than the 0.06-taper files.

TABLE 1. Mean number of rotations to fracture, group A (0.04 taper files)

Rotational Speed (rpm)	25.0 degrees	28.0 degrees	33.5 degrees
350	1867 ± 263	1166 ± 236	546 ± 101
600	1725 ± 334	1080 ± 193	520 ± 71

TABLE 2. Mean number of rotations to fracture, group B (0.06 taper files)

Rotational Speed (rpm)	25.0 degrees	28.0 degrees	33.5 degrees
350	919 ± 108	807 ± 117	522 ± 50
600	911 ± 172	841 ± 133	500 ± 51

Speed

Increasing the speed at which the files were rotated did not have a significant effect on the number of rotations to fracture.

Angle

There was a significant decrease in the number of rotations to failure associated with an increase in angle. The 0.04-taper files showed a larger decrease in the number of rotations to fracture in relation to an increase in angle than the 0.06-taper files.

Discussion

This study investigated the number of rotations required to fracture NiTi rotary instruments of various tapers at different speeds and angles.

To test the number of rotations to fracture, an apparatus was designed and fabricated to create a low-friction surface against which files could be rotated at various angles. The apparatus was polished and lubricated so that torsional stress would be negligible, because we focused on cyclic metal fatigue as a mechanism of file separation. As a file is rotated inside of a tooth with a curved canal, the file is bent back and forth with each revolution, subjecting it to repeated tension and compression at the same point. The repeated bending of the file leads to fatigue of the metal and eventually to fracture (11). The number of flexures is thus equivalent to the number of rotations, because every rotation of a file at an angle creates a flexure. Our null hypothesis was that increased speed would not change the number of rotations to fracture. Our results failed to reject this hypothesis, suggesting that the operational speed does not affect the number of rotations required to fracture NiTi rotary instruments.

Li and colleagues (8) reported that the time to failure significantly decreased as the rotational speed increased. If their data are transformed to rotations to failure rather than time to failure, they also found that speed does not affect this measure. Our data demonstrate that the number of rotations to fracture remains constant regardless of speed. For example, Table 1 (0.04-taper files) shows that a file rotated at 350 rpm at a 33.5-degree angle required 546 rotations until fracture occurred, and at 600 rpm it required 520. This is a statistically insignificant difference of only 26 rotations. Li and associates (8) used different speeds and angles but found 0.04-taper ProFiles rotated at 300 rpm at a 37-degree angle required 610 rotations to fracture; very similar to our findings.

Haikel and associates (5) found that files with greater taper are more sensitive to increased canal curvature than files with less taper, a finding supported by other studies as well (9, 12). Files with greater taper (and thus diameter) fracture more readily because of increased stresses applied during the fatigue cycles as a result of increased stress intensity at the point of flexure. Our results were in agreement with these previous studies. Clinically, it is important to note that a larger-diameter file should not be considered to be stronger or have a longer life simply because of its increased size.

In our study, and that of Haikel and associates (5), files were rotated freely without tip binding, which limited the stress on the files to that produced by flexural stress from the curve. In a recent study by Guilford and associates (13), however, the tips of the files were clamped with Vise-Grip pliers to simulate clinical binding in a canal. Under those conditions, the small files broke easily. In the case of hand filing, where cyclic fatigue is of less importance, torsional failure is potentially the greater concern; therefore, the smaller-diameter files will fracture more readily (11). Thus, the clinician must also be cautioned to avoid binding the tips of smaller files.

In addition, we found that a decrease in the number of rotations to fracture was associated with an increase in angle. Fatigue fractures begin as small stress cracks that grow under the action of cyclic stresses. Chaves Craveiro de Mellow and associates (14) showed small areas of nucleation and slow crack propagation associated with fracture because of fatigue. As the crack progresses into the interior of the file, it effectively reduces the cross-sectional area of the file until the file fractures in two. Increasing the angle increases the amount of stress at the point of flexure, leading to earlier failure, because the increased stress causes a greater propagation of the crack with each flexure.

In conclusion, several factors affect the number of rotations a NiTi file will withstand before fracture occurs. If the file is not bent, as when operated in a straight canal, it should not be subject to flexural failure and thus failure would be determined by the result of torsional stress alone. Clinically, torsional stress may be minimized by using the file passively with a pecking approach that minimizes dentinal engagement at each pass. Li et al. (8) demonstrated that as the length of this pecking motion increased, the number of rotations to fracture also increased.

If the file is operated in a curved canal, as we attempted to simulate in this study, the number of rotations before failure occurs will depend on the taper of the file and the angle at which the file is rotated. Files with greater taper will fracture sooner than those of lesser taper, and files rotated at a greater angle (more curved canal) will fracture before those rotated at a shallower angle. In addition, less tapered files are more affected by this greater propensity to fracture at increased angles than files of greater taper, so that at some angles (33.5 degrees in our study), the advantage of the less tapered files will be lost.

Finally, speed per se does not affect the number of rotations to fracture. Because the critical number of rotations will occur sooner at higher speed, the clinician must be aware that the files must be used for a correspondingly shorter length of time. This limitation, however, may be offset by increased cutting efficiency at higher speeds, which may approach 100% (15).

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