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Torque During Canal Instrumentation Using Rotary Nickel-Titanium Files

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Nickel-titanium engine-driven rotary instruments are used increasingly in endodontic practice. One frequently mentioned problem is fracture of an instrument in the root canal. Very few studies have been conducted on torsional characteristics of these instruments, and none has been done under dynamic conditions. The purposes of this study were to measure the torque generated and the apical force applied during instrumentation with a commercial engine-driven nickel-titanium file system, and to relate torque generated during simulated clinical use to torsional failure of the instruments. Ten extracted human teeth (five with small-sized and five with medium-sized straight root canals) were instrumented with Quantec Series 2000 files, and the torque and apical force generated were measured. The applied apical force was generally low, not exceeding 150 g in either small or medium canals. The torque depended on the tip size and taper of each instrument, and on canal size. Instruments with 0.05 and 0.06 taper generated the highest torque, which was greater in small than in medium canals. The torque at failure was significantly ($p < 0.001$) higher than torque during instrumentation, but with considerable variation in the extent of the difference.

Recent scientific and technological advancements in nickel-titanium alloys have led to the development of practical nickel-titanium endodontic files. These instruments exhibit more elastic flexibility in bending and torsion, as well as superior resistance to torsional fracture compared with stainless-steel files manufactured by the same process (1). Due to their flexural properties, coupled with the design of the cutting blades, it is feasible to use nickel-titanium files with a handpiece in rotary motion to prepare root canals.

Nickel-titanium instruments are manufactured by grinding rather than twisting (2), and many unique design features have been incorporated by different manufacturers. Sizes and tapers (up to 0.06 mm/mm) vary from conventional standards for root canal instruments (3), and some brands (such as the Lightspeed System (Lightspeed Technology, Inc., San Antonio, TX) (4) are entirely different from a conventional file. Also, the rotational speed varies, depending on which system is used.

The concept of maximizing cutting efficiency by minimizing surface contact area of the instrument with the root canal wall has led to development of variations in taper. It has been suggested that increasing instrument taper while maintaining the same size tip maximizes cutting efficiency (5). The Quantec Series 2000 (Tycom Corp., Irvine, CA) is one system that has a variation in taper, and it is said that this design minimizes instrument stress apically. However, there are no published data in relation to this claim.

Resistance to file fracture under torsional loading as stipulated by the American Dental Association specification No. 28 (for hand files) is measured under static conditions that rarely occur in clinical use. The only study published to date (6) of torque in nickel-titanium instruments was performed using static conditions. In clinical practice, a file is likely to bind and fracture during rotation at full speed in the canal.

The purpose of this study was to measure the torque generated during instrumentation of straight, small and medium canals with nickel-titanium rotary instruments in a conventional handpiece, and to relate the torque generated during simulated clinical use to torsional failure of the instruments under comparable conditions. Apical force applied during instrumentation was also measured in relation to canal size and torque.

MATERIALS AND METHODS

Tooth Selection and Preparation

Ten freshly extracted human maxillary and mandibular central and lateral incisors from patients of varying age were used in this study. All teeth demonstrated straight root canals in both mesiodistal and labiolingual views on radiographs, and had no visible defects on root surfaces such as caries or root fracture. Root apices were completely developed. The crown of each tooth was resected at the cementoenamel junction or until the root canal orifice was exposed. After the pulp tissue was removed, a #10 K-file was inserted into the root canal until the tip of the file was seen at the apical foramen. The working length (WL) was measured and recorded 1 mm short of the apical foramen. The teeth were divided into two groups of five each according to the size of the root canals. Group 1 consisted of five teeth with small root canals: only a #10 or #15 K-file could be inserted the entire length of the root canal and fit at the WL. Group 2 consisted of five teeth with medium root canals: a #25 or #30 K-file could be inserted into the root canal and fit at the WL. The root apex of each tooth was coated with pink wax to prevent epoxy resin (used in tooth mounting) from flowing into the root canal. The tooth was then mounted in a plastic holder with fast-setting epoxy resin (Araldite, Ciba-Geigy, Padstow NSW, Australia), using a mounting device to align the long axis of the root canal centrally in the plastic holder.

Torque Meter

The torque meter (Figs. 1 and 2) was custom designed for this study. It consisted of two supports holding the shaft of the torque meter, which was freely rotating (<0.2 g resistance). The lever arm, 4 cm radius, was attached perpendicularly to the long axis of the shaft. One end of the lever arm rested on a 100 g load cell (MTS Corp., Eden Prairie, MN) that was used to record the rotating force generated during instrumentation. A similar load cell of 10 kg capacity was placed against the end of the long axis of the torque meter to record the apical force exerted during instrumentation concurrently with rotating force or torque. Both load cells were connected to a computer with an enhanced multifunction I/O board (DAQ Series AT-MIO-16E-2; National Instruments Corp., Victoria, Australia) permitting continuous recording of torque and apical force during instrumentation. The plastic holder containing the tooth root was mounted on the other end of the shaft, so that the long axis of the canal was coincident with the axis of the torque meter (Fig. 2). This holder was later replaced by a simulated root canal for measuring torque at failure.

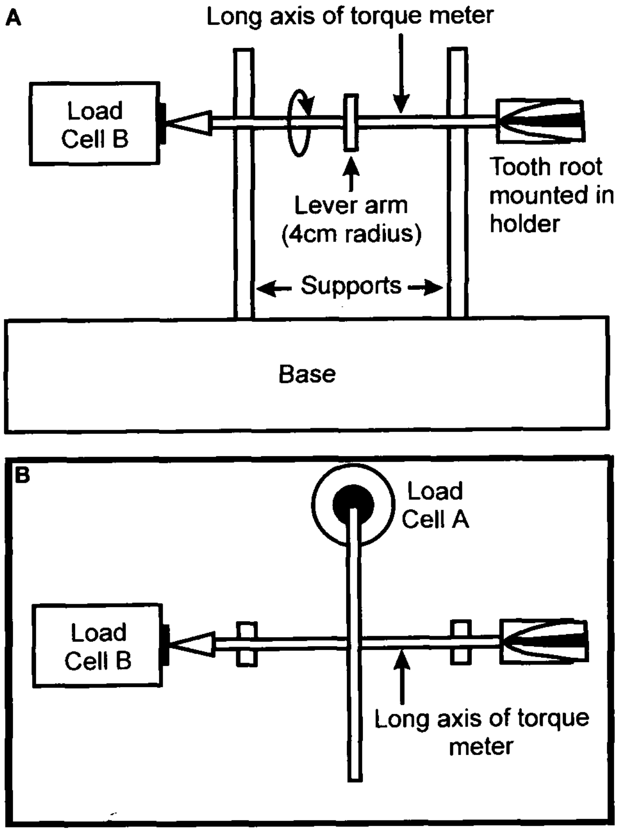

FIG 1. Diagram of the torque meter with mounted tooth. (*A*) Side view. (*B*) Top view. The tooth root was mounted at one end with the root canal centered on the long axis of the torque meter. A 4 cm lever arm was attached to the load cell A to measure torque. Load cell B measured the apical force exerted during instrumentation.

With this setup, torque was measured on the tooth root rather than on the file itself. This arrangement was necessary because the files were mounted in a standard handpiece to reproduce normal clinical usage.

Instruments and Instrumentation Method

Quantec Series 2000 engine-driven nickel-titanium files 21 mm in length (Tycom Corp., Irvine, CA) were used in this study (Table 1). The instruments were tested in simulated clinical use, and mounted in a commercially available electric handpiece and speed control unit (Aseptico, Inc., Woodinville, WA) provided by the file manufacturer. The speed was set at 340 rpm in accordance with clinical guidelines. One set of files (#1 to #10) was used with two teeth. A slight pumping motion with 1 mm increments was used with each file as it rotated in the canal, and each canal was instrumented sequentially using all files #1 to #10, with water irrigation between successive file sizes. File #1 (orifice opener) was used to instrument 5 to 8 mm from the orifice, #2 to #8 instrumented to the WL, and #9 to #10 instrumented 1 mm shorter than the WL (7).

Recording and Measuring Torque and Apical Force During Instrumentation

During instrumentation, both 100 g and 10 kg load cells were connected to a computer. Calibration was conducted with standard weights and recorded with commercial software (LabVIEW 4.0, National Instruments Corp.) before instrumentation of each tooth. The outputs from the load cells were recorded as voltages, as

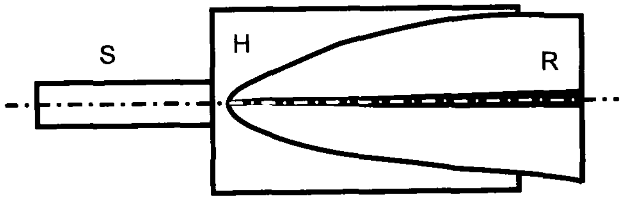

FIG 2. Diagrammatic representation of a tooth root mounted in the torque meter. The root *R* was embedded in epoxy resin within a plastic holder *H*, and mounted on the shaft of the torque meter *S*. The root canal was aligned in the long axis of the torque meter.

TABLE 1. **Instrument sizes, tapers, and lengths of Quantec Series 2000 nickel-titanium files**

File No.	Size (at tip)	Taper	Length (mm)
1	25	0.06	17
2	15	0.02	21, 25
3	20	0.02	21, 25
4	25	0.02	21, 25
5	25	0.03	21, 25
6	25	0.04	21, 25
7	25	0.05	21, 25
8	25	0.06	21, 25
9	40	0.02	21, 25
10	45	0.02	21, 25

shown in Fig. 3, and a spreadsheet program was used to convert the voltage values to units of torque (g • cm) and apical force (g).

Torque at Failure Using a Simulated Root Canal

A simulated root canal was designed to fracture the experimental files in a torsional manner. Two flat aluminum plates were clamped together and attached to one end of the long axis of the torque meter. A tapered groove between the plates was created to simulate a narrow canal. The rotary instruments (21 mm long) were inserted into this groove while rotating at full speed (340 rpm) in the same handpiece as was used for instrumentation, with sufficient force to cause binding and subsequent fracture of the instrument.

The technique for recording and measuring the torque at failure was the same as for recording and measuring torque generated during instrumentation. Testing began with file #2, and instruments were tested sequentially to #10 (five files of each number).

Analysis of Data

Separate two-way analyses of variance (2-way ANOVA) were used to analyze the effects of canal size and file number on both torque and apical force generated during canal instrumentation (dependent variable: torque or apical force; independent variables: canal size (small or medium), file number (#1 to #10)). The same analysis was used to compare torque during instrumentation of small canals with torque at fracture (dependent variable: torque; independent variables: file number (#2 to #10), testing condition (instrumentation, fracture)). Post-hoc comparisons were conducted to determine differences between torque during instrumentation and torque at fracture for each file size. In addition, correlations were performed to investigate relationships between torque and apical force, torque and file size (at the tip), torque and file taper, apical force and file size, and apical force and file taper.

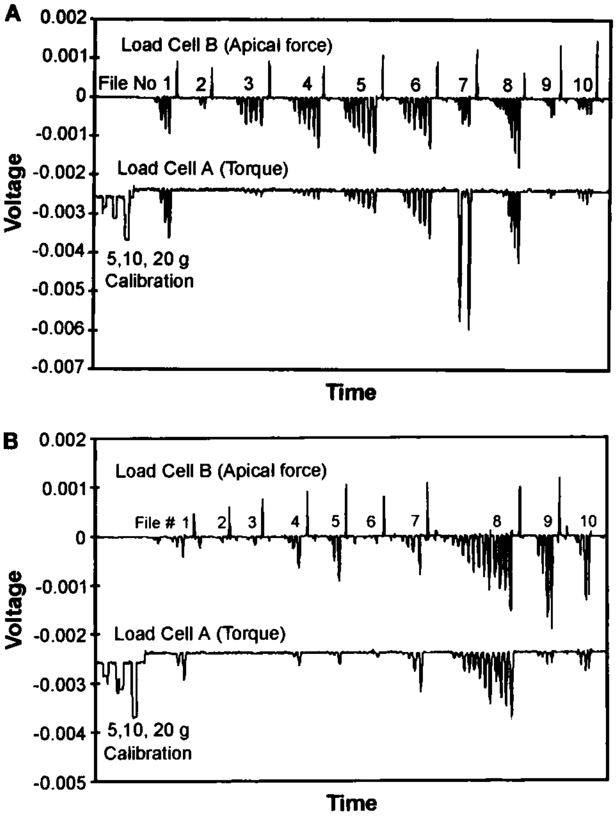

FIG 3. Typical recordings from the load cells used to measure torque and apical force during instrumentation. The voltage recorded from the load cells was subsequently converted to torque (g • cm) or apical force (g). (*A*) Small canal. (*B*) Medium canal.

RESULTS

Torque During Instrumentation in Small and Medium Root Canals

Figures 3*A* and 3*B* show actual recordings from representative instrumentation sequences of small and medium canals, respectively. Each tracing (in volts) was recorded over 2 to 4 min. The upper trace in each panel is from the load cell recording apical force exerted during instrumentation. Each upward spike represents a change between files from #1 to #10 and was artificially produced for easier interpretation of the data. The lower tracing is from the load cell attached to the lever arm to measure torque. Each downward spike represents an insertion of the file into the canal; typically 5 to 7 insertions were required to achieve instrumentation to the full WL with each file size. The only exception to this was instrument #8, which frequently required 10 to 15 insertions to achieve full instrumentation to the WL. The torque (as indicated by the height of each spike) increased with greater depth of penetration until the full WL was reached.

Torque generated during instrumentation in small and medium root canals showed similar patterns (Fig. 4 and Table 2), except that torque generated during instrumentation of small canals was higher ($p < 0.001$, 2-way ANOVA). Torque also varied significantly, depending on file number ($p < 0.001$, 2-way ANOVA). File #1 (orifice opener) created high torque, averaging 50 g • cm or more for both canal sizes. Apical preparation with instruments with standard size and taper (#2, #3, and #4: sizes 15, 20, and 25: 0.02 taper) generated much lower torque during instrumentation (<20 g • cm). The torque generated during coronal flaring with files #5 to #8 (0.03, 0.04, 0.05, and 0.06 taper) increased according

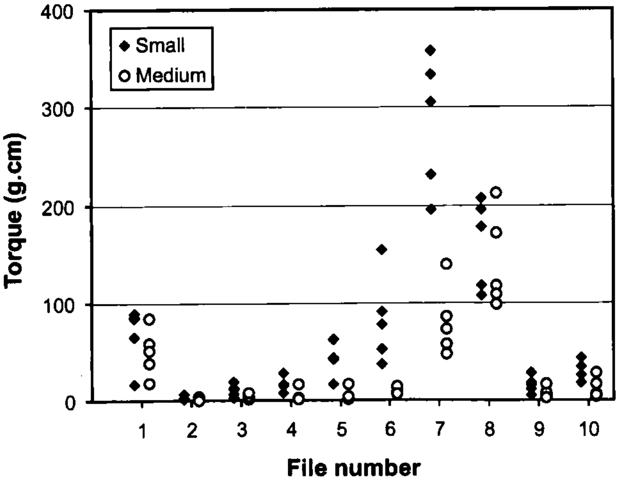

FIG 4. Scatter plot of torque generated during instrumentation of small and medium straight canals. Files were used in sequence in the same root canal ($n = 5$ for all files).

TABLE 2. Torque and apical force generated during instrumentation of small and medium straight canals, and torque at fracture (mean ± SD, $n = 5$ for all groups)

File No.	Small Canals		Medium Canals		Torque at Fracture (g · cm)
	Torque (g · cm)	Apical Force (g)	Torque (g · cm)	Apical Force (g)	
1	68.4 ± 30.3	92.6 ± 62.2	50.0 ± 24.5	59.1 ± 32.3	Not tested
2	2.6 ± 2.5	35.8 ± 16.4	1.2 ± 1.7	9.8 ± 2.2	23.0 ± 9.8*
3	10.4 ± 6.4	76.8 ± 24.0	3.8 ± 2.7	15.0 ± 5.6	31.2 ± 9.8*
4	16.8 ± 7.2	112.2 ± 14.6	4.8 ± 6.4	25.4 ± 24.2	45.8 ± 9.3*
5	36.4 ± 19.8	133.6 ± 30.6	5.2 ± 6.1	39.6 ± 30.5	65.8 ± 15.6
6	82.6 ± 45.7	140.2 ± 50.6	9.8 ± 3.4	26.2 ± 9.6	111.6 ± 47.6
7	284.4 ± 69.0	98.8 ± 44.4	80.6 ± 35.8	64.0 ± 31.2	156.8 ± 54.6
8	161.2 ± 45.8	143.7 ± 83.5	141.8 ± 48.1	106.4 ± 57.2	200.2 ± 66.4
9	15.6 ± 8.4	106.4 ± 54.1	7.0 ± 6.0	58.2 ± 74.1	120.8 ± 23.8*
10	31.2 ± 9.8	76.4 ± 31.3	12.3 ± 10.4	62.0 ± 58.5	134.0 ± 58.0*

* Torque at fracture was significantly ($p < 0.01$) greater than torque during instrumentation of small canals for files #2, #3, #4, #9, and #10.

to the taper, with the highest torque observed with file #7 in small root canals (mean: 284.4 g · cm) and file #8 in medium root canals (mean: 141.8 g · cm). Files #9 and #10 were always associated with low torque. Significant correlations were observed between torque and tip size for files of standard taper in small canals (files #2, #3, and #4; sizes 15, 20, and 25) ($r^2 = 0.56$, $p < 0.01$ for small canals; medium canals $p > 0.05$), and between torque and file taper (files #4 to #8, taper 0.02 to 0.06 mm/mm, all with tip size 25) ($r^2 = 0.52$, $p < 0.01$ for small canals; $r^2 = 0.68$, $p < 0.001$ for medium canals).

Apical Force During Instrumentation

In general, apical force exerted during instrumentation was low, averaging <150 g in small root canals and 110 g in medium root canals (Table 2). The apical force increased with each insertion of the instrument until the full WL was reached (Fig. 3). Overall, patterns of apical force during the instrumentation sequence were similar to (but more variable than) those observed for torque, with a high value for instrument #1, lower values for small files of standard taper (#2 to #4), and higher values with increasing instrument taper (#5 to #8). Two-way ANOVA indicated significant effects of both instrument number and canal size ($p < 0.01$). A significant correlation was observed between apical force and torque during instrumentation for all files on an individual tooth basis ($r^2 = 0.30$, $p < 0.01$), and between apical force and file tip size (#2 to #4; sizes 15, 20, and 25) and instrument taper (#4 to #8, tapers 0.02 to 0.06) in small canals only ($r^2 = 0.77$ and 0.87, respectively; $p < 0.001$).

Torque at Failure

The average torque at failure increased with both file tip size (#2 to #4; tip sizes 15 to 25) and taper (#5 to #8; tapers of 0.03 to 0.06 mm/mm) (Fig. 5 and Table 2). Under the conditions of this test, binding and fracture occurred close to the tip of each file. The torque at failure was compared with torque during instrumentation of small canals (Fig. 5). Overall, torque at failure was significantly ($p < 0.001$) higher than torque generated during instrumentation. For files of standard sizes and taper (#2, #3, #4, #9, and #10), the ranges of torque at failure were all much (3- to 8-fold) higher than the range of torque generated during normal instrumentation, and individual comparisons for each file were statistically significant (all $p < 0.01$). Files with increased taper (#5 to #8; taper 0.03 to 0.06) showed overlapping ranges of torque generated during instrumentation and torque at failure, and the differences were not statistically significant ($p > 0.05$).

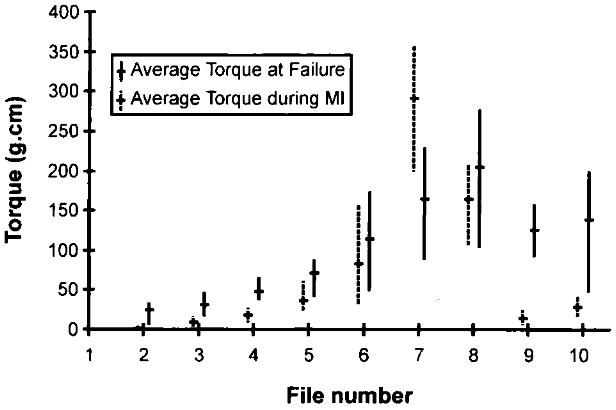

FIG 5. Torque during mechanical instrumentation (MI) versus torque at failure (fracture). The vertical lines represent the range of torque (5 files/group), and the horizontal bars represent the average torque for each instrument number.

DISCUSSION

Due to the flexural properties of nickel-titanium alloys and advancements in technology and instrument design, it is possible to use such instruments with an engine-driven handpiece in a rotary motion (8–10). Although these instruments have been developed only within the past few years, several brands have been produced commercially, each with its own design that is different from conventional standard files (3).

One distinctive characteristic of a nickel-titanium rotary instrument is increasing the taper from 0.02 mm/mm to variable greater tapers, up to 0.06 mm/mm. These files are used to achieve coronal flaring. However, no report has mentioned the torque generated during instrumentation with these instruments, which may be high enough to cause instrument fracture in the root canal.

American National Standards Institute/American Dental Association (ANSI/ADA) specification No. 28 stipulates the minimum values of torque and angular deflection of endodontic stainless-steel hand files (3). The test is conducted under a static mode that is appropriate for hand instruments. The latest nickel-titanium engine-driven rotary instruments have been designed to prepare root canals in a continuous rotary motion. To date, only one study has reported the torsional characteristics of nickel-titanium rotary instruments (6), but this study was conducted under a static mode, which does not simulate clinical use with a rotary instrument. Our study was planned to measure the torque generated during instrumentation under dynamic, clinically relevant conditions.

The torque meter used in this study was designed to measure torque generated during instrumentation, with the rotary files operating at recommended speed (340 rpm) in a conventional handpiece recommended for clinical use. Because the tooth was mounted in the torque meter, we chose to measure torque during instrumentation only in straight root canals with the canal coaxial with the shaft of the torque meter. Because the largest Quantec file at the time of this study was equivalent to size 45 (#10, 0.02 taper), only small and medium root canals rather than large root canals were chosen. Also, in large root canals, torque should not be a problem during instrumentation.

The results showed that torque generated during instrumentation in small and medium root canals followed a similar pattern. As anticipated, significantly lower torque was generated in medium-sized canals than in small canals, due to the difference of the size of the natural root canal. Instrument #1, which is the same size and taper as #8 (but shorter), generated a high torque that is consistent with its use as an orifice opener. The apical preparation with standard size and taper instruments (#2, #3, and #4, equivalent to standard sizes 15, 20, and 25, respectively) generated very low torque. This finding was anticipated, because the files would be expected to engage dentin only in the apical few millimeters of the canal. Torque generated during coronal flaring with greater taper instruments (#5 to #8: 0.03, 0.04, 0.05, and 0.06 mm/mm taper, respectively) gradually increased as the taper increased and reached a peak with instrument #7 in small root canals and with instrument #8 in medium root canals. The larger file sizes of a standard 0.02 taper (#9 and #10, equivalent to sizes 40 and 45) were associated with lower torque. These sizes of instruments were highly resistant to fracture and needed very high torque to fracture. From an analysis of files discarded during 6 months of normal clinical use (11), it was revealed that instruments #9 and #10 did not fracture from torsion.

It was consistently observed during instrumentation with instrument #7 that the file tended to be pulled automatically deeper into the root canal, such that the operator had to resist this tendency especially in small root canals. This observation was confirmed by the tracings of torque and apical force, showing that whereas the torque generated with instrument #7 was high, the apical force exerted was low (Fig. 3*A*) in comparison with other instruments. Endodontists who have been using these instruments have experienced this sense as well. The reason for this finding is not clear, but it is likely to be a feature of file design.

The instrumentation technique used in this study followed instructions given by the manufacturer. With a slight pumping motion, apical force exerted during instrumentation was relatively low (<200 g), even in small canals, for instruments of all sizes and tapers. Thus the technique seems to achieve the objective of a "light touch," which is likely to enhance tactile sensation. There are no other literature reports of apical force exerted using other instrumentation techniques, so no comparisons can be made. The levels reported herein are much lower than those exerted during obturation (12).

It was clear that the range of torque generated during instrumentation was substantially (3- to 8-fold) lower than the range of torque at failure in all instruments that follow the standard size and taper (#2, #3, #4, #9, and #10). If torque can be used as a measure of torsional failure, rotary instruments can be used safely for preparing the apical portion of root canals, at least when the canal is relatively straight and of moderate size. On the other hand, the range of torque generated with instruments that have greater taper tended to overlap the range of torque at failure. This finding is best explained by the conditions under which torque was measured in this study. The simulated canal created between the aluminum plates resulted in binding and fracture of the file close to the tip of the instrument. Clinically, files with increased taper are likely to bind further along the shaft, because they are used to enlarge the coronal portion of the canal. This part of the instrument, by virtue of its bulk and taper, will be much stronger than the tip. Hence our study tended to underestimate the torque necessary for fracture under normal clinical conditions. A clinical study (11) indicated almost zero torsional fractures among files with increased taper.

As previously described torque measured in this study was generated during instrumentation of straight root canals, which is the simplest model. However, it should be borne in mind that most root canals show some degree of canal curvature. Also, because of access limitation in posterior teeth, it is impossible that an instrument would remain straight during instrumentation. As a result, not only torsion but also flexural fatigue of an instrument will predispose an instrument to fracture. To reduce the risk of torsional fracture in the root canal, apical force should be moderate during instrumentation with nickel-titanium engine-driven rotary instruments.

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