

Defects in Rotary Nickel-Titanium Files After Clinical Use

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The purpose of this study was to analyze the type and frequency of defects in nickel-titanium rotary endodontic files after routine clinical use, and to draw conclusions regarding the reasons for failure. All of the files (total: 378, Quantec Series 2000) discarded after normal use from a specialist endodontic practice over 6 months were analyzed. Almost 50% of the files showed some visible defect; 21% were fractured and 28% showed other defects without fracture. Fractured files could be divided into two groups according to the characteristics of the defects observed. Torsional fracture occurred in 55.7% of all fractured files, whereas flexural fatigue occurred in 44.3%. The results indicated that torsional failure, which may be caused by using too much apical force during instrumentation, occurred more frequently than flexural fatigue, which may result from use in curved canals.

permanent deformation. Therefore, visible inspection is not a reliable method for evaluating used nickel-titanium instruments (8).

Fracture of endodontic rotary instruments could occur under two circumstances: torsional fracture and flexural fatigue (9). Torsional fracture occurs when the tip or any part of the instrument is locked in a canal while the shaft continues to rotate; the instrument exceeds the elastic limit of the metal and shows plastic deformation followed by fracture. The other type of instrument fracture is caused by work hardening and metal fatigue, resulting in flexural fracture (failure). With this type of fracture, the instrument is freely rotated in a curved canal. At the point of curvature, the instrument flexes until fracture occurs at the point of maximum flexure. It is generally believed that this mode of failure is an important factor in the fracture of nickel-titanium rotary instruments used clinically (8).

The purpose of this study was to analyze the types of defects observed in a single brand of nickel-titanium engine-driven rotary instruments discarded after normal clinical use in a specialist endodontic practice. This analysis was used to provide insights into the patterns of clinical usage in an attempt to minimize risk of instrument breakage within canals.

MATERIALS AND METHODS

Collection of Files

Three hundred and seventy-eight Quantec engine-driven nickel-titanium files (Quantec Series 2000, Tycom Corp, Irvine, CA), amounting to every file discarded during normal clinical usage over 6 months, were obtained from one specialist endodontic practice. These instruments were discarded because of a perceived decrease in cutting efficiency, fracture, or any defects observed with the naked eye (such as unwinding, curving, or bending). No record was kept of the number of times each file had been used. All files were cleaned and sterilized before inspection by placing in 1% sodium hypochlorite for 10 min, cleaning with an ultrasonic cleaner, and autoclaving.

Data Recording

Discarded files were sorted according to the file number (#1 to #10) and length (21 and 25 mm). The length of each file from the tip of the file to the base of the handle was measured (± 0.01 mm) using an electronic digital caliper (NSK, MAX-CAL, model 950-

Root canal preparation in narrow, curved canals is a challenge even for experienced endodontists. Recently, nickel-titanium hand files have played an important role in root canal preparation, particularly in curved roots. Nickel-titanium endodontic instruments were first investigated in 1988 by Walia et al. (1), who found that Nitinol files had two to three times more elastic flexibility in bending and torsion, as well as superior resistance to torsional fracture, compared with similar size stainless-steel files.

The torsional and flexural properties of nickel-titanium alloys, coupled with appropriate design of the cutting blades, make it feasible to use nickel-titanium instruments with a handpiece in a rotary motion to prepare root canals. This use is possible even in curved canals, and rotary instruments have been shown to result in little or no canal transportation (2-5). These instruments offer possibilities for improving the speed and efficiency of endodontic treatment, and it is likely that these instruments will become very widely used in the near future.

A major concern with use of nickel-titanium engine-driven rotary instruments is fracture. The clinical concern is that they have been reported to undergo unexpected fracture without warning (6, 7). Fracture can occur without any visible defects of previous

101 MAX-15, Japan) to determine the location of any fracture. Each file was inspected under the stereomicroscope ($\times 40$) for any visible defects: fracture, unwinding, curve, or bend.

Confirmation of Fracture Characteristics

Test fractures were produced in the laboratory to provide controls for identifying the characteristics of instrument fracture resulting from flexural fatigue and torsional fracture. Five files each (sizes #3, #7, #8, and #9) were tested to failure from flexural fatigue, and a similar number of files (sizes #2 to #10) were tested to produce torsional failure.

TORSIONAL FRACTURE

Each instrument (21 mm) was rotated at a speed of 340 rpm in a standard electrically driven handpiece (Aseptico, Woodinville, WA) as recommended by the manufacturer for clinical use. Each file was inserted into a simulated root canal made from aluminum, under sufficient pressure to cause wedging and fracture. Two aluminum plates with a tapering groove between them were clamped together to simulate the canal space. All instruments fractured close to the tip.

FLEXURAL FATIGUE

A cylindrical glass tube with an internal diameter of 1 mm was curved at 90 degrees, with a radius of curvature of 5 mm. Both ends were cut and adjusted so that the point of maximum curvature was ~ 16 mm from one end. Each instrument (21 mm) was rotated freely within the tube until fracture (as in ref. 9).

The upper part of the broken files was inspected using a stereomicroscope ($\times 40$) and scanning electron microscope ($\times 22.2$) (SEM 515, Phillips, Eindhoven, The Netherlands).

RESULTS

Summary of Samples

All nickel-titanium engine-driven rotary files discarded over 6 months of clinical practice were included in the study. The number and size of files obtained for analysis are shown in Table 1. The most frequently discarded files were #1 (with 0.06 taper, used as an orifice opener; 17.2% of all files discarded), followed by the small size files with 0.02 taper (#2, #3, and #4; each representing 13 to 14% of all files discarded). The files with a taper of 0.03 to 0.06 (#5 to #8) or larger size (#9 and #10, equivalent to sizes 40 and 45) were each $< 10\%$ of the total.

Defects Identified

Approximately one-half of all discarded files (49.2%) showed visible defects (Table 2). The major defects were fracture (20.9%) and unwinding (24.1%), whereas curves or sharp bends were infrequent (4.2%). The highest percentage of fractured files was found with #2 (37.7%), whereas the highest frequency of unwinding was associated with #1 (49.2%).

TABLE 1. Summary of all files discarded after normal clinical use over 6 months in an endodontic practice

File no.	Length (mm)	No. of files	Total	% of Total
1	17	65	65	17.2
2	21	28	53	14.0
	25	25		
3	21	28	49	13.0
	25	21		
4	21	32	48	12.7
	25	16		
5	21	14	27	7.1
	25	13		
6	21	16	26	6.9
	25	10		
7	21	12	24	6.3
	25	12		
8	21	17	35	9.3
	25	18		
9	21	19	28	7.4
	25	9		
10	21	13	23	6.1
	25	10		
Total			378	100

Fracture Characteristics

All files that were fractured experimentally under torsion clearly showed defects associated with the fracture (Fig. 1). These defects consisted of unwinding, reverse winding, reverse winding with tightening of the spirals, or a combination of these defects, above the fracture point. Unwinding defects occurred close to or several millimeters from the fracture site. On the other hand all files experimentally fractured from flexural fatigue showed a sharp break without any accompanying defects (Fig. 2). The fracture point of each file corresponded to the point of maximum curvature of the glass tube. These characteristics were then used to analyze the types of fracture occurring clinically.

Analysis of Fractures

More files showed fracture associated with unwinding defects (torsional failure) (55.7%) (Table 3 and Fig. 3) than fracture without any accompanying defects (flexural fatigue) (44.3%) (Table 3 and Fig. 4). Fracture from torsional failure occurred exclusively with files #1 to #5, with no files #6 to #10 fracturing from torsional failure. Fracture from flexural fatigue occurred with all file numbers except #10. Most files fractured 1 to 6 mm from the tip, with flexural fatigue occurring generally at a greater distance from the tip.

Analysis of Failures

Visible defects in instruments were divided into fracture (torsional and flexural) and nonfracture with plastic deformation (Figs. 5 and 6). Defects without fracture included unwinding, sometimes over a considerable length of the file (Fig. 5), and bending, frequently in association with unwinding (Fig. 6). An analysis of defects of discarded files is provided in Table 4. Only one-half (50.8%) of the instruments were discarded before visible signs of damage occurred. The most frequent defect observed was associ-

TABLE 2. Defects identified from discarded files

File Size	No. of Files	Fracture		Unwinding (without fracture)		Curve/Bend		No Visible Defect	
		No.	% of File Size	No.	% of File Size	No.	% of File Size	No.	% of File Size
1	65	13	20	32	49.2	4	6.2	16	24.6
2	53	20	37.7	11	20.8	8	15.1	14	26.4
3	49	13	26.5	19	38.8	1	2.0	16	32.6
4	48	10	20.8	11	22.9	2	4.2	25	52.1
5	27	4	14.8	2	7.4	0	0	21	77.8
6	26	1	3.8	3	11.5	0	0	22	84.6
7	24	3	12.5	7	29.2	1	4.2	13	54.2
8	35	9	25.7	6	17.1	0	0	20	57.1
9	28	6	21.4	0	0	0	0	22	78.6
10	23	0	0	0	0	0	0	23	100
Total	378	79	20.9	91	24.1	16	4.2	192	50.8

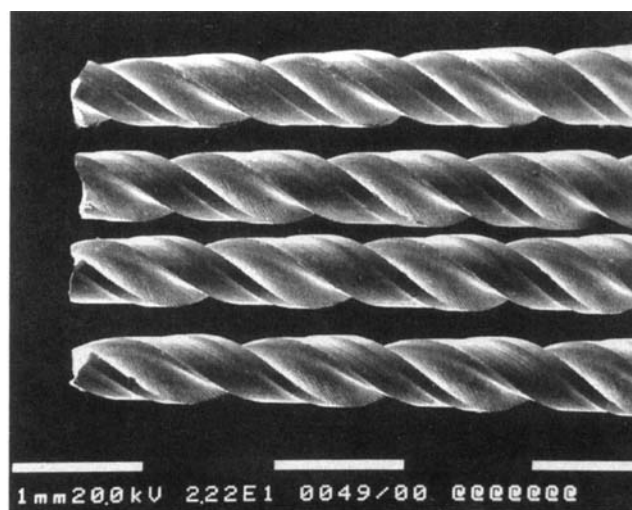
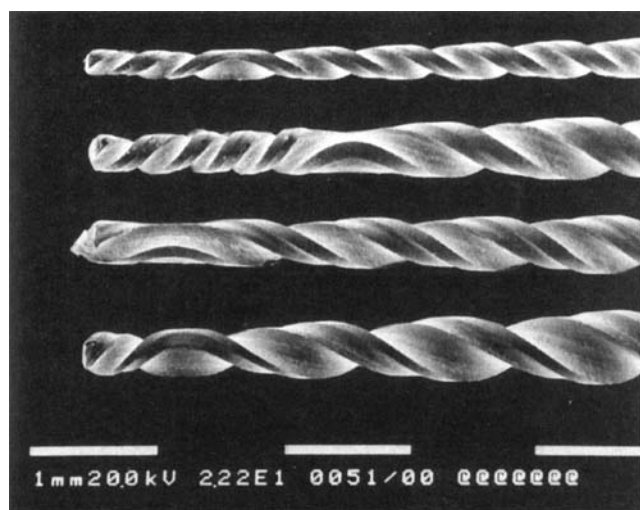


FIG 1. Experimental files fractured from torsional failure. The files shown are (from top to bottom): #2, #4, #4, and #6. Unwinding or twisting in the opposite direction can be seen proximal to the point of fracture. (Original magnification $\times 22.2$. Each white bar represents 1 mm.)

FIG 2. Experimental files fractured from flexural fatigue. All files shown are #9. No other defects are visible in association with the fracture. (Original magnification $\times 22.2$. Each white bar represents 1 mm.)

ated with torsional forces, which occurred in 39.9% of all discarded files (28.3% without fracture, 11.6% with fracture), whereas flexural fatigue with fracture was observed in 9.3% of discarded instruments. Overall, 20.9% of instruments underwent fracture.

DISCUSSION

Although it was shown from the analysis that the most frequently discarded file was #1, this finding needs to be understood within the context of frequency of use. It should be noted that the operators did not use the whole series of files in every patient. According to the manufacturer's instructions for use, only a few files need to be used to prepare many root canals. As a result, some file numbers were used more frequently than others. However, the first file to be used is always file #1 (orifice opener). Thus, it is not surprising that file #1 is discarded more frequently than any other.

It has been observed that fracture of nickel-titanium files could occur with little or no visible evidence of accompanying plastic deformation (7, 8). However, no scientific study of used nickel-

titanium files has been reported. From an analysis of discarded nickel-titanium rotary files in this study, two main characteristics of the fractured instruments were disclosed. One characteristic was demonstration of a visible defect associated with the fracture: unwinding, reverse winding, reverse winding with tightening of the spirals, or a combination of these defects. The other characteristic was fracture without any visible accompanying defects. We considered that these two fracture types were caused by different mechanisms: torsional fracture and flexural fatigue of the alloy. This is based on the experiment involving fracture of instruments under simulated dynamic torsional and flexural conditions. The results showed a consistent pattern for each fracture type (Figs. 1 and 2). All instruments subjected to torsional fracture showed defects similar to those found in fractured discarded instruments. On the other hand instruments fractured from flexural fatigue showed a sharp break without any accompanying defects. These criteria, fracture with deformation and without deformation of instruments, help to separate fractured files into two main groups that are more meaningful than the classification of fractured files into three groups by Sotokawa (10). The classification used in this study can identify the cause of fracture and could lead to changes in clinical usage to prevent instrument fracture.

TABLE 3. Analysis of fractures

File No.	Average Distance from Tip (mm)	Fracture Type	
		Torsional (with unwinding)	Flexural (without unwinding)
1	2.1	9	4
2	1.5	15	5
3	2.3	11	2
4	1.6	8	2
5	4.4	1	3
6	5.9	0	1
7	5.7	0	3
8	4.9	0	9
9	2.7	0	6
10	—	0	0
		44	35
		55.7%	44.3%

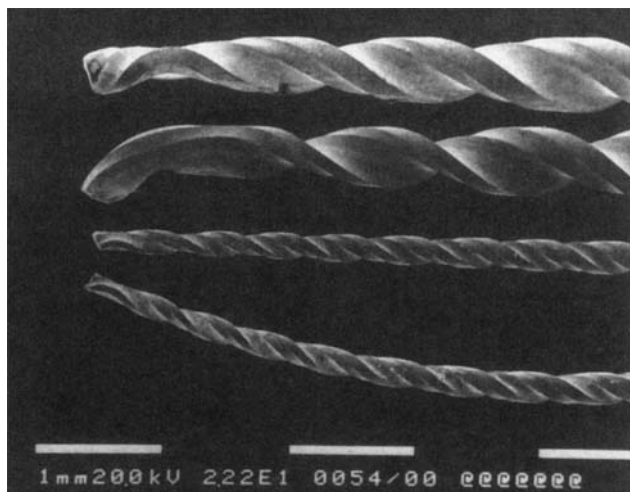


FIG 3. Discarded files fractured from torsional failure during clinical use. The files shown are (from top to bottom): #1, #1, #3, and #2. All files show unwinding. (Original magnification $\times 22.2$. Each white bar represents 1 mm.)

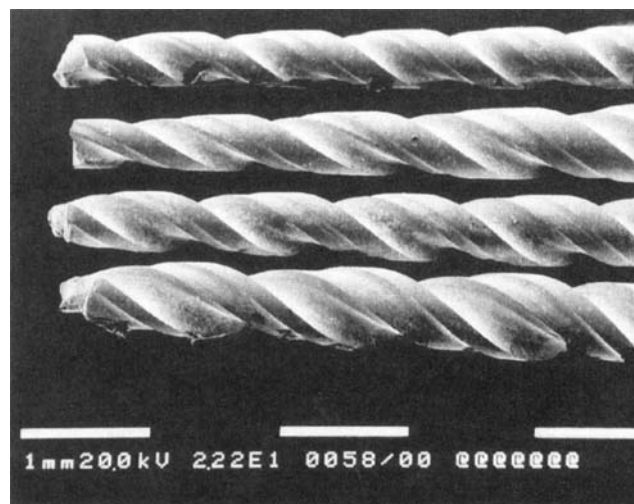


FIG 4. Discarded files fractured from flexural fatigue during clinical use. The files shown are (from top to bottom): #4, #5, #9 and #8. No unwinding defect is visible. (Original magnification $\times 22.2$. Each white bar represents 1 mm.)

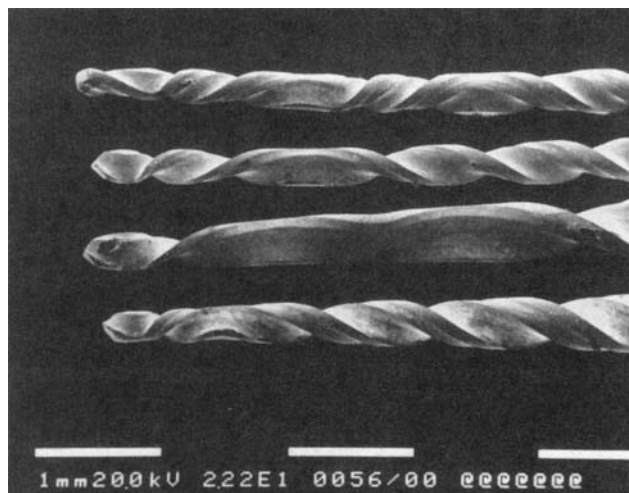


FIG 5. Discarded files showing visible defects without fracture. The files shown are (from top to bottom): #3, #4, #6, and #5. All files show unwinding, indicating a torsional defect. (Original magnification $\times 22.2$. Each white bar represents 1 mm.)

Using the above criteria, it was revealed that more instruments failed in torsion (55.7%) than from flexural fatigue (44.3%). This finding was unexpected, and may be limited to the particular brand of file used and the technique recommended by the manufacturer for its use. Although more files were fractured from torsional failure than from flexural fatigue, it should be noted that most failures occurred with small files that were not highly resistant to fracture from torsion. The small files are used for apical enlargement so that binding is likely to occur near the tip. The larger files, however, did not fracture from torsion because of their greater bulk and greater taper, which need high torque to fracture. This correlation was confirmed by our experimental study of file fracture under torsion, where we found that it was very difficult to produce torsional fracture for large files (11). When unwinding without fracture is included, torsional failure accounted for four times (39.9%) as many defects as flexural fatigue (9.3%). On the other hand, although flexural fatigue occurred with all file sizes except file #10, it seemed to occur more frequently with larger files, particularly #8 (Table 3). This finding was also confirmed in other

studies (8, 11), indicating that cycles to failure of larger instruments were less than for smaller instruments.

In general clinical usage, endodontic instruments are not subject to the number of stress cycles with slow-speed handpieces that are likely to lead to flexural failure (12). However, this study showed that nearly 45% of fractured instruments failed from flexural fatigue. Recently, a study of fracture of nickel-titanium rotary instrument emphasized the fatigue of instruments (8). It has been reported that the radius of curvature, angle of curvature, and instrument size were important factors in instrument fracture from cyclic fatigue. Our results confirm those of a previous study (8) indicating that large instruments were more subject to fracture from flexural fatigue.

Because torsional failure occurred more frequently than flexural fatigue, this finding suggests that a light touch without "forcing" of an instrument apically should be applied during instrumentation with rotary instruments. The result of a survey of Swiss clinicians

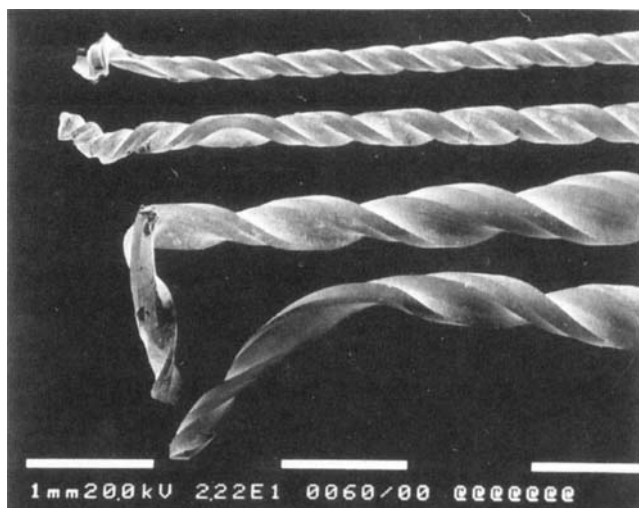


FIG 6. Discarded files showing other defects. The files shown are (from top to bottom): #2, #3, #7, and #6. (Original magnification $\times 22.2$. Each white bar represents 1 mm.)

TABLE 4. Analysis of defects

Type of Failure	No. of Files	% of Total Files
Torsional		
With fracture	44	11.6
Without fracture	107	28.3
Flexural with fracture	35	9.3
No visible defect	192	50.8
Total	378	100

also revealed that excessive force was the major cause of instrument fracture during clinical use (13). Nevertheless, many instruments are subject to fracture from flexural fatigue. To prevent this type of fracture, a limited duration of use for each instrument should be observed, and instruments should be discarded after substantial use, regardless of whether any defects are visible. However, no study or information is available to specify how many times rotary instruments can be used safely.

For nickel-titanium hand files, a preliminary study of number of uses has been undertaken (9). It was reported that all hand files could be used up to ten times (i.e. in 10 cases) without instrument fracture. Instrument failure seemed to depend on how the instruments were used rather than how long they were used.

For the question of how many times nickel-titanium rotary instruments should be used before being discarded, there can be no definite answer. Several factors must be considered such as the curvature and the complexity of the root canal system, the size of the instrument, and the action or method of instrumentation. Given the variability among clinical cases, the unpredictability of breakage and the consequences of breakage, a "safe" number of uses should be provided by manufacturers and strictly observed by clinicians.

Analysis of failure of instruments indicated that the number of files showing visible plastic deformation (such as unwinding, re-winding, twisting, bending, or curving) was greater than the number of files fractured from both torsional and flexural failure. If these files were used further, their potential for failure would have greatly increased. To reduce the risk of fractured instruments within root canals, all files should be examined after each use. Any files showing defects should be discarded immediately. Manufacturing defects can cause fracture of a new instrument even during the first use. Therefore every instrument should be examined before each use. Because minor defects, both manufacturing errors and plastic deformation, may not be detected with the naked eye, it is recommended that examination of instruments with a magnification of at least $\times 10$ be performed.

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