Defects in Nickel-Titanium Instruments after Clinical Use. Part 5: Single Use From Endodontic Specialty Practices

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Abstract

Introduction: Single use of endodontic nickel-titanium (NiTi) instruments has been recommended to reduce instrument fatigue and the possibility of cross-contamination. The purpose of this study was to evaluate the defects of three NiTi rotary systems (ProFile series 29 [Dentsply Tulsa Dental Products, Tulsa, OK], ProFile [Dentsply Tulsa Dental Products], and ProTaper [Dentsply Maillefer, Ballaigues, Switzerland]) that were discarded after single use by two endodontic clinics. **Methods:** A total of 1,071 ProFile .04, 432 ProFile series 29 .04, and 1,895 ProTaper rotary instruments were collected over 12 months and analyzed. These discarded files were ultrasonically cleaned and autoclaved. The lateral view of the deformed instruments and fracture surface of the separated instruments were examined by scanning electron microscopy. Qualitative X-ray energy-dispersive spectrophotometric (EDS) spot analyses were performed on particles adherent to the surface and those apparently wedged in surface microcracks. **Results:** There were no fractures or deformations in the ProFile Series 29. The overall prevalence of deformation was 2.9% in ProTaper and 0.75% in ProFile. The incidence of instrument separation was 0.26% in ProTaper, whereas no fractures occurred in ProFile instruments. The majority of instrument defects occurred in size 25 (6/8) for ProFile and in Sx for ProTaper (22/60). The separated ProTaper instruments failed mostly because of shear stress. Some surface deposits and microcracks were found in single-use NiTi instruments. EDS indicated that surface deposits may be dentin. **Conclusion:** The risk of NiTi rotary instrument fracture in the canal is low when a new instrument is used by experienced endodontists. The most common cause of failure, albeit rare, was shear failure. *(J Endod 2009;35:1363–1367)*

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Key Words

Clinic, defect, ProFile, ProTaper, shear, single-use

Nickel-titanium (NiTi) endodontic instruments were introduced to facilitate the instrumentation of curved canals with few or no procedural errors. Despite numerous advantages, there is concern about the incidence of instrument fractures during root canal preparation (1). The incidence of instrument fracture in clinical practice for files used multiple times has varied from 3% to 21% (2–6). Although fractured instruments may not compromise the outcome if the treatment is performed to a high standard (1), the retained file fragments may impede microbial control beyond the obstruction. Moreover, excessive removal of tooth structure in an attempt to retrieve the instrument fragment may be associated with root perforation and reduced root strength (7). Therefore, it is important to be aware of the factors that may lead to instrument fracture. It has been reported that fracture of a NiTi instrument may occur in either one or a combination of two ways: torsional and flexural (fatigue) (2, 8, 9).

The clinician is faced with two major concerns when considering the use of NiTi rotary instruments. The first one is the possibility of instrument fracture associated with increased instrument fatigue caused by repeated use. Cyclic fatigue is an important reason that has been reported to account for about one third to over half of instrument breakage encountered clinically (2, 3, 6, 9), with fatigue in the low-cycle region being most commonly implicated. The second one is the possibility of cross-contamination associated with the inability to adequately clean and sterilize endodontic instruments (10). A recent study found prions in human pulp tissue (11). Tooth structure and organic debris have been observed on the surface of NiTi rotary instruments in surface cracks despite meticulous ultrasonic cleaning and decontamination (10, 12, 13). Therefore, the single use of endodontic instruments has been recommended to reduce instrument fatigue and reduce the possibility of cross-contamination (10, 14). The aim of the present study was to evaluate the incidence and mode of rotary NiTi instrument defects after single-case use of three different systems at two endodontic clinics.

Materials and Methods

Three NiTi rotary systems, ProFile Series 29 .04 taper (PFS) (Dentsply Tulsa Dental Products, Tulsa, OK), ProFile .04 taper (PF) (Dentsply Tulsa Dental Products), and ProTaper (PT) (Dentsply Maillefer, Ballaigues, Switzerland) instruments, had been adopted at two endodontic offices in Canada. One office (clinic A) used PF 0.04 taper instruments, and the other (clinic B) used both PFS and PT instruments. Guidelines for instrument use differed between the two clinics. All instruments were new and were used by endodontists during a single visit. Canal preparation was carried out per manufacturer's recommendations in a crown-down approach. In clinic A, each set of PF 0.4 tapered instruments included the following: sizes 40, 35, 30, and 25, used in this order. As for the PFS instrument, it was used in combination with NiTi hand files in clinic B. Canals were shaped with the PFS from large to small in the following order: #8, #7, and #6, and then NiTi hand files were used to finish instrumentation. Two different preparation techniques were used in clinic B for PT instruments. The large root canal preparation was completed with an F2; after the canal was negotiated to the working length with a stainless steel (SS) size 15 hand file, the F2 was used in the canal with an extremely light apical pressure until resistance was encountered. The instrument was then pulled out of the canal, cleaned with gauze to remove the debris filling the flutes, and reinserted and employed in the same manner. This format was repeated until the F2 reached the working length. The other major approach was that after the access cavity was prepared, all canal orifices were found and the coronal third of the tooth was opened using PT Sx with lateral pressure followed by Gates Glidden drills #2, #3, and #4 in that order. Next, the working length was determined using a #10 or #15 SS hand file and an electronic apex locator and/or radiograph. The canals were then shaped to working length with S1, S2, F1, and F2 instruments. Sometimes, the S (shaping) files were skipped. A torque-control motor (ATR Technika Dentsply, Tulsa Dental, Tulsa, OK) was set at the recommended rotational speed and torque according to the manufacturer's recommendation for each instrument. All canal preparation was accomplished with continuous canal irrigation using a 5% solution of sodium hypochlorite (NaOCl), and at completion, canals were irrigated with 17% EDTA followed by a final rinse with NaOCl.

A total of 1071 PF instruments were collected after single use from clinic A in British Columbia, Canada, from March 2007 to March 2008. A total of 432 PFS and 1895 PT instruments discarded during such single use during a 12-month period from 2007 to 2008 were collected from clinic B in British Columbia, Canada. All discarded instruments were ultrasonically cleaned in absolute alcohol, autoclaved, and then examined by one investigator under a stereomicroscope at 10× magnification. Any defect was noted and classified into one of the following categories: (1) intact but deformed and (2) fractured. The defective instruments were further cleaned in an ultrasonic bath using absolute alcohol for 90 seconds. The presence of plastic deformation adjacent to the fractured surface was registered according to the description by Sattapan et al (2). Then, parts of the instruments were remounted on the microscope stage, with the fractured surface facing upward for fractographic examination under scanning electron microscope (Stereoscan 260; Cambridge Instruments, Cambridge, United Kingdom). The mode of fracture was classified as "fatigue" or "shear" (8). Qualitative energy-dispersive spectrophotometric (EDS) spot analyses were performed on adherent deposits on the surface and those present in "microcracks" or crack-like structures using a microanalysis system (Genesis 7000; EDAX, Mahwah, NJ).

Results

Of the 1071 PF instruments collected, no fractures were observed and only 8 (0.75%) revealed deformation without fracture (Table 1). Three quarters of these instruments (six/eight) were size 25 (Fig. 1*A*-*C*). No fractures or deformations were detected on the 432 PFS instruments (Table 2). Of the 1895 PT instruments, 60 (3.17%) were deformed: 55 (2.9%) revealed deformation without fracture, and 5 (0.26%) were fractured (Table 2). Of all defective instruments, the majority (57/60; 95%) had a macroscopic plastic distortion, whereas 36.67% (22/60) were bent, 48.33% (29/60) showed unwinding, and 10% (6/60) of the instruments revealed both twisting and unwinding on the same instrument. One third of the defective instruments (21/60) were Sx. Of all the unwound PT instruments (n = 29), Sx unwound the most often (n = 18) followed by S1 (n = 9).

Of the five fractured PT files, three revealed shear (torsional) failure under fractographic examination (Fig. 1). Only one instrument (Sx) showed fatigue failure. The proportion of deformed instruments affected by torsion, with or without fracture, was 96.67% (58/60). The fatigue crack of Sx file initiated at the cutting edge as seen in the cross-section of the fracture site surface.

Surface microcracks could be found in the used instruments. These cracks ran in the general direction of the machining grooves (machine tool scratches) and often involved the cutting edge of the instrument (Fig. 1*B*). Debris could be observed in the single-use instruments in both deformed and fractured files as either smeared over the surface or in a microcrack (Fig. 1*C*), the former being more common. EDS spot analysis indicated the presence of calcium, phosphorus, oxygen, and carbon in the debris (Fig. 1*D*).

TABLE 1. Occurrence and Type of Deformation in Single-use Profile .04 Taper Instruments from a Specialist Clinic (% of All Instruments)

Size	n	Distorted		
		Bending	Unwinding	Subtotal
PF #25	235	3	3	6 (2.55)
PF #30	263	0	0	0
PF #35	280	1	0	1 (0.36)
PF #40	293	1	0	1 (0.34)
Total	1071	5	3	8 (0.75)

Discussion

Instrument separation has been recognized as a potential risk for all files, including NiTi instrument. In most studies of the (simulated) shaping ability of NiTi root canal instruments, the rotary files were either used as disposable instruments (ie, single use) or in a limited number of teeth, and access to the root canal was likely to be optimal. Hence, results from laboratory usage tests would only indicate the relative risk of deformation or separation under a particular set of conditions for those brands of instrument being examined (15–17). Many variables, such as accessibility of the canal, apically directed force, and use of a hybrid technique, have not been reproduced in the laboratory setting. Operator-related variables may be more important factors that are associated with instrument fracture than the design of the instrument (3, 18). Therefore, it should be appreciated that the factors will only be identified and the desired result achieved through the evaluation of large clinical samples. Reusing an instrument carries a potentially higher risk of separation. The resistance of an instrument to fatigue failure is jeopardized after repeated clinical use (19, 20), even though there may not be any visibly detectable sign of defects (21). Although brand-new instruments are not immune from breakages (14), single-case use may be a positive move to prevent fracture of a rotary instrument. An added advantage is the facilitation of cross-infection control. This study should give an indication of the incidence of defects and of the mode of failure for ProTaper and ProFile rotary instruments that are subjected to single-case use, comprising a wide range of tooth types and canal configurations, by two groups of experienced endodontic practitioners.

Although the record regarding the type of teeth treated was not available in this study, it was conjectured that the incidence of file distortion and separation could be estimated for those single-case used instruments after a relatively long period of clinical use in the same office. One study has been published (14) that showed that 0.9% ProFile series 29 rotary fractured after single use; the result was based on a total of 786 clinical samples from one endodontic office. Parashos et al (3) reported a fracture rate for single-use NiTi instruments with cross-section shape as S-shaped and triple-U ranging from 0% to 1%, which varied among different endodontists worldwide. Their finding lends support to our result here; none of the ProFile Series 29 .04 and ProFile .04 taper instruments fractured. The incidence of separation was 0.26% for ProTaper. It was obvious that even with single use, NiTi instruments still undergo defects. Indeed, the operator and root canal anatomy might be more influential than the instruments per se on the fracture rate (3, 18).

Because of its wide range of elastic deformation, NiTi alloy may be strained much further than stainless steel before it is permanently deformed. Resistance to fracture, however, measured as angular

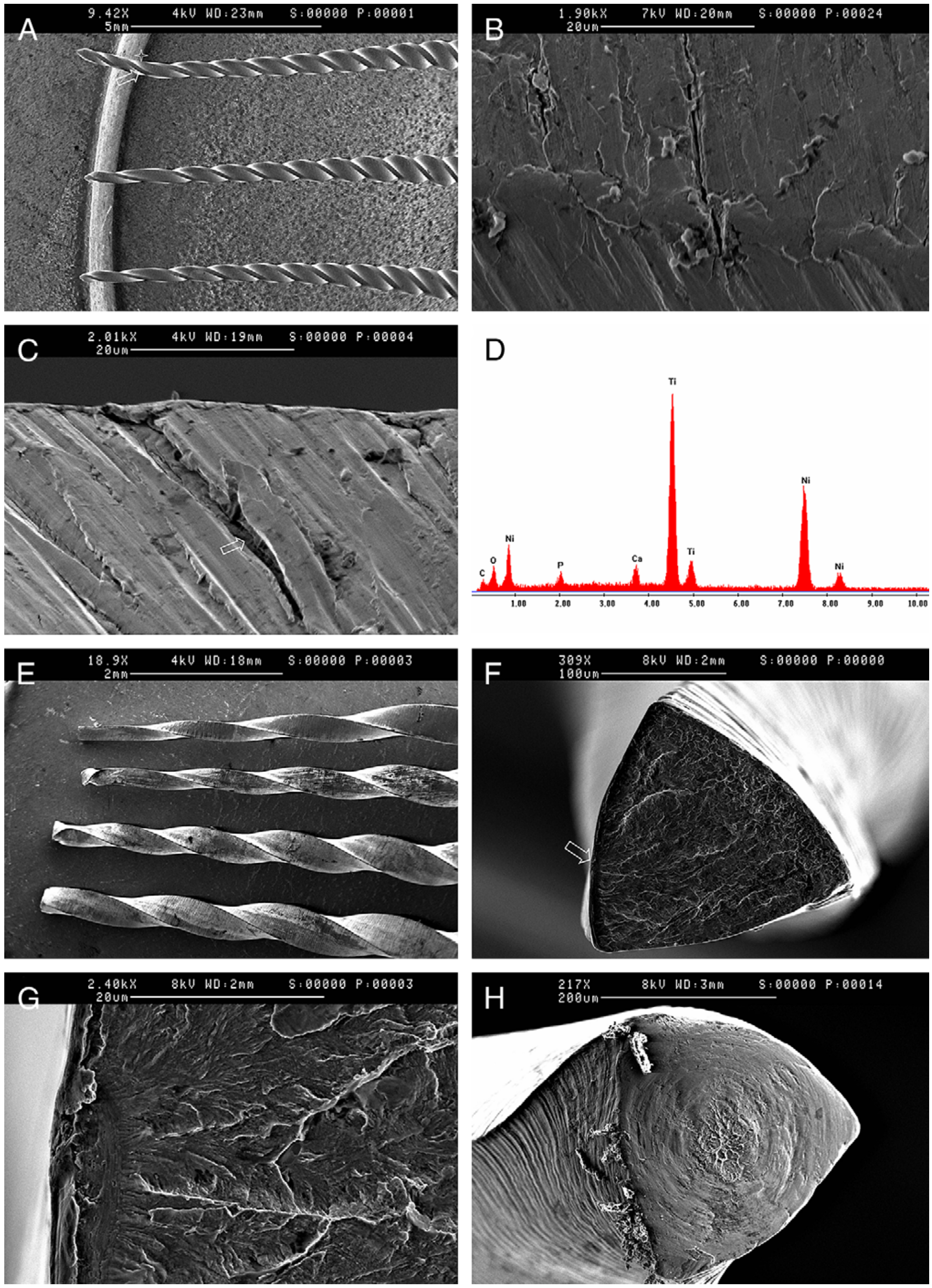

Figure 1. (*A*) A longitudinal view of deformed ProFile size 25 instruments. (*B*) A high magnification view of the top specimen in *A* (arrow) showing a crack at the cutting edge. (*C*) A high-magnification view of the top specimen in *A* showing contaminating material remaining in the microcrack (arrow). (*D*) EDS analysis indicated the presence of calcium, phosphotus, oxygen, carbon, nickel, and titanium. (*E*) Scanning electron micrographs of fractured ProTaper instruments. (*F*) Fracture surface of the top specimen (PT Sx file) in *E* showing fatigue failure. (*G*) A higher-magnification view of *F* (arrow) showing a crack origin on the flute. (*H*) Fracture surface of the third specimen (PT F1) in *E* showing shear failure.

deflection before fracture, is lower for the NiTi instruments (22). Torque experienced by the root canal wall is correlated with the contact areas (ie, the friction between the instrument and the root canal wall [23] and the load required to cut dentin). If the instrument is stalled in the canal, torsional (shear) stress builds up in the instrument, which, when the elastic limit of the material is exceeded, would lead to plastic deformation and, ultimately, to failure by shear. Alapati et al (12) hypothesized that the clinical fracture of NiTi rotary files is usually caused by a single overload incident during instrumentation. That may explain the higher proportion of defects caused by torsion, manifesting either as unwinding of flutes or shear failure observed in single-use ProTaper instruments.

Early studies have shown that smaller instruments are prone to distortion in clinical or simulated use rather easily, probably as a result of stressing on the relatively small cross-section (6, 24, 25). In this study, three quarters of the deformed ProFile .04 taper instruments were found to be size 25 instruments. This figure seemed to agree with previously reported findings (6, 24, 25). Root canal instruments

TABLE 2. Occurrence of Deformation or Fracture of Single-use ProFile Series 29 .04 Taper and ProTaper Rotary Instruments Used in a Specialist Clinic (% of All Instruments)

			Deformation, no fracture				Fracture		
Size	n	Defect	Bending	Unwinding	Unwinding & twist	Subtotal	Shear	Fatigue	Subtotal
Ser. 29#8	55	0							
Ser. 29#7	157	0							
Ser. 29#6	220	0							
Total	432	0							
PT Sx	302	21 (6.95)	1	18	1	20	0	1	1
PT S1	291	14 (4.81)	3	9	1	13	1	0	1
PT S2	346	11 (3.18)	10	1	0	11	0	0	0
PT F1	467	12 (2.57)	7	1	2	10	2	0	2
PT F2	487	2 (0.4)	1	0	0	1	0	0	1*
PT F3	2	0	0	0	0	0	0	0	0
Total	1895	60 (3.17)	22	29	4	55 (2.9)	3	1	5 (0.26)

*One fractured F2 file was lost during processing and not analyzed.

are subjected to various stresses during clinical use. Both the instrument design and instrumentation technique can influence the magnitude of stress concentration and the likelihood of instrument fracture (26–28). It is accepted that the provision of a glide path should facilitate the work of subsequent instruments, which can smoothly clean and shape root canals. Enlarging the canal to a size of 15 or 20 before using the rotary NiTi instrument would help to reduce the torsional stress experienced by the instrument (29) and lower the risk of shear fracture. Also, it creates an understanding of the root canal anatomy and allows a glide path for the instrument tip. A high incidence of instrument distortion and separation in Sx instruments was possibly because the major preparation technique of used ProTaper in clinic B did not include the use of small hand files in the canals before using Sx. Therefore, rotary instruments should be introduced into root canal after sufficient enlargement with fine hand instruments has been accomplished.

Considering the significant economic and potential medical impact of reuse of endodontic instruments, a novel canal preparation technique has been introduced using only one F2 ProTaper rotary instrument in a reciprocating movement by Yared (30). In the standard NiTi techniques using continuous rotation, it is crucial to enlarge the canal to at least a size 15 file before the use of rotary instruments. The F2 instrument, with a 8% taper at its tip, would provide adequate taper to allow the filling of the root canal system even with the vertical compaction of warm gutta-percha. Another important aspect of the F2 instrument is its variable taper. This feature would provide an increased flexibility for this larger instrument. Some large root canals were prepared by fine hand file and only one F2 in clinic B. Only two F2 (0.4%) files suffered from deformation and fracture. The fact that in some cases only one rotary instruments (F2) was needed to complete instrumentation is encouraging; however, the number of cases treated by F2 file only was not available in this study.

It is noteworthy, but not surprising, that surface microcracks were found along and often associated with the machining grooves. These grooves are expected to be sites of stress concentration, hence potentially of crack initiation. Once a microcrack is initiated, dentin debris may be lodged within. Some studies have shown that ultrasonic cleaning could not completely clean the surface of these deposits (31); this was also confirmed in the present study. However, Linsuwanont et al (32) have shown that the complete removal of organic debris from clinically used NiTi instruments is feasible using a combination of mechanical and chemical means. A possible approach to preventing such effects may be the modification of the instrument surface through processes such as electropolishing, ion implantation, and chemical or physical vapor deposition, which can produce a hard surface layer and retard the initiation of surface microcrack.

In conclusion, although no scientific methods have been developed to date that evaluate the functional lifespan of NiTi rotary instrument, the number of fractures would be low (0%-0.26%) if an engine file was to be treated as a disposable instrument. The frequency of distortion is also low (0%-2.9%). Instrument fracture is a complex and multifactorial clinical problem. NiTi rotary instruments failed mainly because of shear failure during a single clinical use.

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