Defects in Nickel-Titanium Instruments after Clinical Use. Part 3: A 4-Year Retrospective Study from an Undergraduate Clinic

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Abstract

The purpose of this study was to analyze the incidence and mode of ProFile (Dentsply Tulsa Dental, Johnson City, TN) instrument separation during a predefined schedule of clinical use by the undergraduate students in a dental school over 4 years. A total of 3,706 ProFile instruments discarded from the same undergraduate students program between 2003 and 2007 were analyzed. The lateral and fracture surfaces of 12 separated instruments were examined by scanning electron microscopy, and the location of the fractures was recorded. The overall proportion of instrument defects was 1.3%; deformation without fracture occurred in 1% and separation in 0.3%. The majority of instrument defects occurred in size 20 (34/48). The ProFile instruments (10/12) failed mostly because of shear stress, whereas only two failed because of fatigue fracture. The results of this study indicated that NiTi rotary instrument system was successfully introduced into an undergraduate endodontic program. Small size files should be considered as single-use, disposable instruments because of the higher possibility of torsional deformation. *(J Endod 2009;35:193–196)*

Key Words

Clinical, fatigue, fracture, instrument, nickel-titanium, shear, undergraduate

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The advent of nickel-titanium (NiTi) rotary instruments has revolutionized root canal treatment by reducing operator fatigue and the time required to finish the preparation and minimizing procedural errors associated with hand instrumentation. This benefits both experienced and inexperienced operators (1–4). Some surveys in dental schools showed that the perception of students using NiTi rotary instruments was positive in the majority of dental facilities. They noted it was easier to learn and more rapid and more effective during clinical use (5). These statements are subjective and expressed by inexperienced subjects, but they reflect the attitude of dental students.

There are many reports on NiTi rotary instruments and their properties, but studies relating to the teaching of these systems in dental schools throughout the world are few. Guidelines for undergraduate curricula in endodontics have stressed the importance of a high standard of education. Teaching a NiTi rotary system should, like any other dental procedure, include adequate preclinical training and clinical courses. Studies evaluating the properties of NiTi instruments have used simulated root canals in resin blocks and root canals in extracted human teeth for inexperienced operators (6–8). While permitting predictions to be made, these investigations allow no evidence-based statements to be made on rotary preparation in dental education.

Despite their increasing popularity, a major concern with the use of NiTi rotary instruments is the possibility of unexpected separation during use. Numerous factors have been implicated in the separation of NiTi instruments, including operator proficiency, method of use, rotational speed, anatomic configuration of the canals, design of the instrument, and number of sterilization cycles. Interestingly, factors related to operators, such as experience, were ranked as the most important (9). The majority of research on NiTi instrument defects has been performed on instruments collected from specialists, general dentists, or postgraduate students (4, 9–14), whereas little information is available regarding undergraduate dental students. The purpose of this study was to analyze the incidence and mode of a NiTi rotary instrument system deformation in the treatment of a large number of patients by the same undergraduate student endodontic program in a dental school over a 4-year period.

Materials and Methods

This was a historic retrospective cohort study. ProFile rotary systems (Dentsply Tulsa Dental, Johnson City, TN) have been adopted for use by the third- (the last 3 months) and fourth-year dental students at the Faculty of Dentistry, the University of British Columbia (UBC), Canada, from 2003 to 2007. During the period of this study, a total of 115 undergraduate students participated; the third-year students were able to treat endodontic patients for the last 3 months of their academic year, whereas the fourth-year dental students were able to treat such patients for their entire year. Cases with very complex, severely curved, or calcified canals would be referred to specialist care. Each set of ProFile instruments was limited to use on three clinical cases. In the order of clinical use, each set of ProFile instruments included the following: Orifice Shapers (Dentsply Tulsa Dental) sizes 30, 50, and 40 followed by ProFile 0.4 tapered instruments sizes 40, 35, 30, and 25; further enlargement with the size 20 was performed out only when necessary. Canal preparation was performed according to the manufacturer's recommendations in a crown-down fashion. The instruments were used in an electric motor with a 1:8 reduction handpiece at the recommended setting of 300 rpm (AEU-20 Endodontic System, Dentsply-Tulsa Dental). To eliminate debris

accumulation, approximately 0.5 to 1 mL of (1%) sodium hypochlorite was used as an irrigant between file sizes. After each use, instruments were wiped with a piece of gauze soaked with isopropyl alcohol and inspected for signs of fracture and flute distortion. Instruments were discarded when they had reached the designated number of uses or when they were worn, fractured, or had visual signs of any other defects.

A total of 3,706 ProFile instruments were discarded after normal clinical use over a 4-year period. This amounted to all rotary instruments being discarded from the clinic during the aforementioned period. All discarded instruments were ultrasonically cleaned, autoclaved, and then examined by one investigator (YS) under a stereomicroscope (Microdissection; Zeiss, Bernried, Germany) at 10× magnification. Any defect was noted and classified into one of the following categories: (1) intact but with unwinding defects and (2) fractured. The fractured instruments were further cleansed in an ultrasonic bath in absolute alcohol for 90 seconds, and the remaining length measured using a stereomicroscope at 30× magnification with a precision of 0.1 mm and examined first in the lateral view using a scanning electron microscope (Stereoscan 260; Cambridge Instruments, Cambridge, UK). The presence of plastic deformation adjacent to the fractured surface was registered according to the description by Sattapan et al. (10). Then, parts of the instruments were remounted on the microscope stage, with the fractured surface facing upward, for fractographic examination. The mode of fracture was classified as "fatigue" or "shear" (15).

Results

Of the 3,706 ProFile instruments collected, 48 (1.3%) were defective, 36 (1%) revealed deformation without fracture, and 12 (0.3%) were fractured. All defects had occurred on .04 tapered instruments (48/2261; 2.1%); no Orifice Shaper files had defects (0/1445; 0%). Of all defected instruments, the majority (45/48; 93.8%) had a macroscopic plastic distortion, about 35.4% (17/48) were bent, 39.6% (19/48) showed unwinding (Fig. 1*A* and *B*), and 16.7% (8/48) of the instruments showed both twisting and unwinding on the same instrument (Fig. 1*A*). Two thirds of the defected instruments (34/48) were of size 20. Often each defected instrument showed more than one type of defect (eg, microcrack, blunting, and debris).

Of the 12 fractured instruments, 9 exhibited plastic deformation near the fracture site in the lateral view (Fig. 1*A* and *B*); 10 exhibited shear or so-called torsional failure under fractographic examination, in which all those instruments were size 20. Two of the 12 fractured instruments, one size 20 and the other size 30, exhibited fatigue failure (Table 1). The proportion of instruments affected by torsion, with or

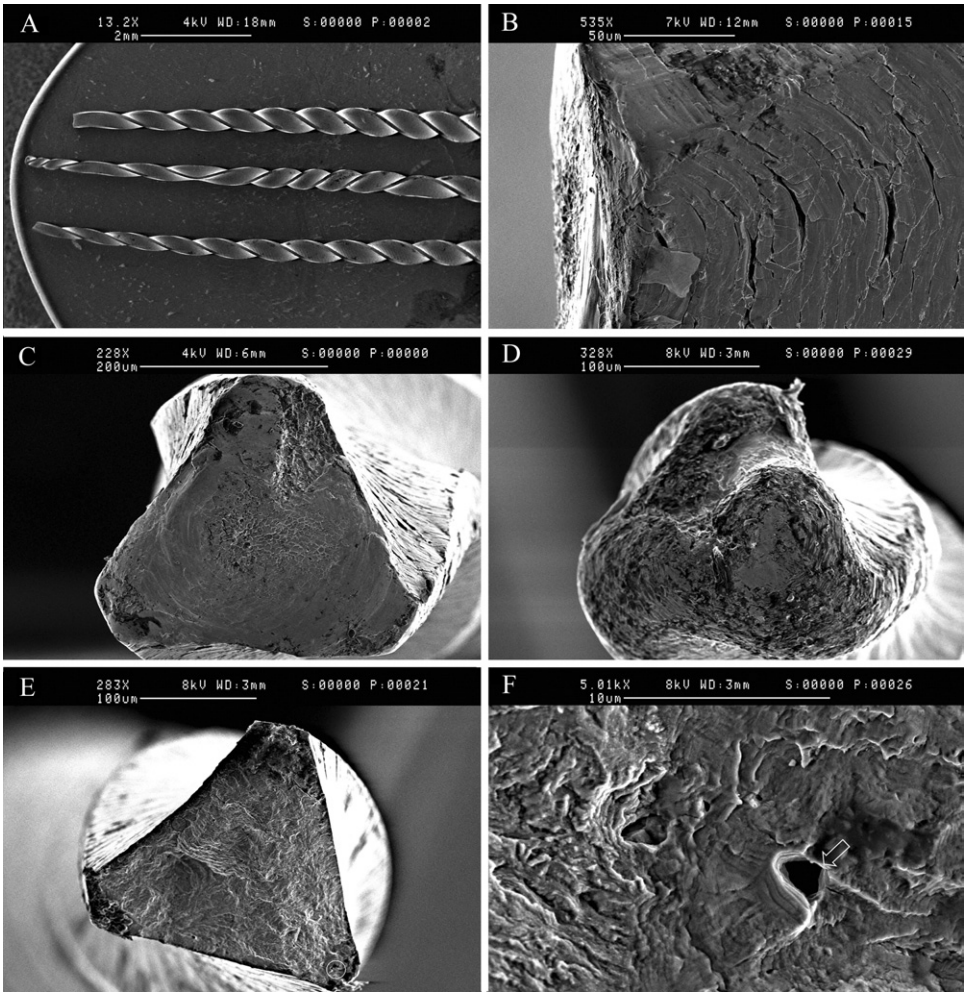

Figure 1. (*A*) Longitudinal examination of fractured .04 taper ProFile size 20 instruments. (*B*) A higher magnification view of the top specimen in A showing plastic deformation. (*C*) Fracture surface of *B* showing shear failure. (*D*) Fracture surface of the middle specimen with both twist and unwinding parts in *A* indicating shear failure. (*E*) Fracture surface of the bottom specimen in *A* showing fatigue failure. (*F*) A higher magnification view of *E* showing one crack initiation site located at a subsurface void (arrow).

TABLE 1. The Number of Discarded Instruments Showing Defects (% of Total No. of Instruments)

Size	N	Defect	Deformation, No Fracture	Fracture			
				Deform*	Shear	Fatigue	Subtotal
O.S. #50	471	0	0	0	0	0	0
#40	480	0	0	0	0	0	0
#30	494	0	0	0	0	0	0
.04 #40	472	0	0	0	0	0	0
#35	460	4 (0.9)	4 (0.9)	0	0	0	0
#30	435	3 (0.7)	2 (0.4)	0	0	1	1 (0.2)
#25	448	7 (1.6)	7 (1.6)	0	0	0	0
#20	446	34 (7.6)	23 (5.2)	9	10	1	11 (2.5)
Total	3,706	48 (1.3)	36 (1.0)	9	10	2	12 (0.3)

*Deformation was found in lateral view.

without fracture, was 95.8% (46/48), which was greater than that caused by fatigue (2/48; 4.2%). In the cases of shear failure, there were regions of obvious plastic deformation and surface cracks adjacent to the fracture site (Fig. 1*B*). Fractographically, fractured instruments had concentric abrasion marks produced by rubbing and abrasion of the opposing surface. Microscopic dimples, signifying the last step of crack propagation, were typically elongated or skewed (Fig. 1*C* and *D*). Fatigue striations were found on two specimens in which one is size 20 and the other is size 30. The fatigue crack initiated at the cutting edge of the fracture cross-section. When a subsurface void was present, it was invariably identified as the crack origin (Fig. 1*E* and *F*). The broken fragment resulting from shear failure (2.7 ± 1.5 mm) was shorter than that for fatigue failure (2.9 mm and 4.7 mm) of all specimens.

Discussion

Although rotary techniques do not constitute the basic procedure taught at the undergraduate level, both general dentists and endodontists use such instruments. Consequently, it seems logical for dental schools to teach at least one rotary technique at the undergraduate level. The ProFile system is one of the earliest and basic NiTi systems introduced; it possesses 3 U-shaped flutes in a cross-section with 3 radially symmetrical "land" areas. One survey showed that among the rotary techniques, ProFile and Lightspeed (LightSpeed Technology, Inc., San Antonio, TX) were predominant in North American, Scandinavian, European, and UK dental schools (16). Another French survey also confirmed that the most taught and clinically used instruments were ProFile, Hero 642 (Micro-Mega, Besancon, France), and ProTaper (5). Increasing numbers of NiTi rotary instruments of various designs are now commercially available (17). Although the ProFile system was selected by the UBC Dental School, other accepted NiTi rotary systems can be equally well introduced.

Several studies have evaluated the properties of NiTi instruments discarded from endodontists and general dentists after clinical use (9–13). A small number of studies have focused on NiTi instruments coming from postgraduate endodontic programs (4, 14). The mean clinical fracture frequency of NiTi rotary instruments is approximately 1.0%, with a range of 0.4% to 3.7% (2, 18–21). On the other hand, the single-use ProFile instruments were reported by Arens et al. (22) to have a fracture incidence of 0.9% in 786 new instruments used in cases of varying degrees of difficulty in a specialist endodontic practice. To date, only one study has investigated the incidence of separation using the Lightspeed system in an undergraduate endodontic program over a 24-month period, and the separation rate was 1.3% (3). The present retrospective study attempted to assess defects in NiTi instruments after normal clinical use by undergraduate students of UBC over 4 years.

The main problem inherent in rotary preparation by inexperienced operators is the risk of instrument fracture (6, 8). The incidence of fracture of NiTi instruments was low in the present study, which might be explained as follows. Studies have shown that proper experience was necessary to minimize the incidence of instrument separation (8, 23). In the preclinical endodontic training, one premolar and two molar teeth were prepared using rotary NiTi instruments. Clinical supervision of undergraduate students was undertaken by endodontists, and the ratio of clinical staff to students varied between 1:5 and 1:9 in the present study. Although many different techniques have been advocated for the ProFile instruments, the crown-down approach remains the primary technique. In the present study, a manual glide path was prepared to working length with at least a size 20 stainless steel K-file, before rotary instrumentation was performed in the apical third. This may have reduced the instrument "taper locking" or "jamming" in the canal. Finally, torque-controlled motors are generally used for rotary preparation with NiTi systems. The use of such motors seems to offer the advantage of reducing the fracture rate because fractures can occur even with torque values as low as 1 Ncm (24). Yared and Kulkarni (25) investigated different torque control levels (high, moderate, and low) in motors during NiTi canal preparation. With inexperienced operators, the lowest fracture rate (1.1%) occurred when preparations were completed with ProFile instruments using a low torque-controlled motor. However, no differences in fracture rate were observed when experienced operators used either a high torque– or a moderate torque–controlled motor for NiTi preparation. In the present investigation, a low torque-controlled motor with adjustable torque values of 1 Ncm and an auto-torque reverse function was used for preparation by inexperienced operators. In addition, instrument fracture is a complex, multifactorial clinical problem, and many factors such as the operator, root canal anatomy, and usage can influence the fracture.

The trend toward a high incidence of instrument distortion and separation in smaller NiTi instruments corroborated the findings of other studies (8, 9, 12, 26). From a mechanical viewpoint, the maximum shear stress always occurs on the surface and is proportional to the shear moment or torque applied, and it is inversely proportional to the third power of radius for a circular cross-section (27). Given the same torque, smaller instruments would therefore be more susceptible to torsional failure than larger instruments. It has been suggested that the 0.04 taper ProFile size 20 should be considered as single-use, disposable instruments because of the likelihood of being distorted (12, 26, 28). Hence, it is not surprising that shear fracture in all separated instruments occurred on size 20.

Excessive monotonic torsional stress would be the main cause of shear fracture of NiTi instruments. When the shear stress rises beyond the yield point of the material, the instrument undergoes plastic deformation and ultimately fails producing the characteristic concentric marks on the fracture surface. In a previous study (29), the effect of the operator on ProFile instrument fracture was evaluated. The results in-

dicated that a greater number of instruments failed during the "learning period" than during the "application period." This confirmed the necessity of mastering this rotary canal preparation technique and the importance of improving competence through learning and experience. Also, Blum et al. (30) analyzed the vertical forces and torque in the root canal systems of extracted teeth during mechanical preparation using ProFile instruments. The students initially showed wide variations in generated forces compared with the endodontists, which indicated that satisfactory performance of crown-down technique requires the development of fine sensation. This would explain the present finding that shear failure predominated in ProFile instruments used by inexperienced operators.

Fatigue is also of concern because it may lead to instrument separation during clinical use (10, 12, 13). Indeed, NiTi instruments used in a low-speed handpiece are more likely to succumb to breakage by cyclic fatigue than manually operated ones (13, 31). Sites fostering fatigue crack initiation include inclusions, second-phase particles, voids, machining marks, and other surface flaws. ProFile instruments have regular flutes with slightly concave or flat bottoms that rarely became the fatigue-crack origin (32). In this study, only two instruments failed because of fatigue failure. The crack origin in one specimen was found at the cutting edge, whereas in the other specimen it occurred at the voids. A similar pattern of voids typically detected next to inclusions in alloy structures has also been reported on ProTaper, HERO, (Micromega) and K3 (SybronEndo, Orange, CA) instruments (33). The number of such specimens was too small to allow any further analysis. However, this underlines the importance of improving the mechanical properties of the NiTi alloy.

Teaching and the implementation of a NiTi rotary system to the undergraduate dental students at UBC can be regarded as successful since its introduction. This positive outcome of introducing rotary instruments to the undergraduate student program in UBC could help motivate more dental schools to consider such a change. Safe clinical usage of NiTi instruments requires an understanding of basic fracture mechanisms and their correlation to canal anatomy for the undergraduate students. Small size files should be considered as single-use, disposable instruments because of the likelihood of being torsionally separated.

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