Defects in ProTaper S1 instruments after clinical use: longitudinal examination

B. Peng[1], Y. Shen[1], G. S. P. Cheung[2] & T. J. Xia[1]

[1]Key Laboratory for Oral Biomedical Engineering of the Ministry of Education, School of Stomatology, Wuhan University, Wuhan, China; [2]Discipline of Conservative Dentistry, Faulty of Dentistry, The University of Hong Kong, HKSAR, China

Abstract

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Aim To evaluate defects in ProTaper shaping instrument S1 after a defined schedule of clinical use.

Methodology Among all ProTaper files discarded from an endodontic clinic at a stomatological school in China over a period of 17 months, 122 S1 instruments were collected. They were ultrasonically cleaned, autoclaved and then examined in the laboratory. Any instrument separation was noted; the average length involved was determined. The 0.5 mm region on either side of this length of discarded but intact instruments was examined circumferentially by scanning electron microscope. The region adjacent to the broken end of the fractured instruments was also examined in the same way.

Results One specimen was lost during processing. Of the remaining 121 instruments, 27 were separated with a mean fracture length of 3.67 mm from the tip. Of these, two files showed macroscopically torsional fracture and the others showed signs of flexural fatigue. Only one file that had not fractured showed visible unwinding defects. Examination of the 3.1–4.1 mm region of other unfractured instruments revealed the presence of microcracks, surface debris, pitting and/or wear of their cutting edges. Some debris particles seemed to have been trapped in crack-like structures.

Conclusions Multiple use of ProTaper S1 predisposed the instrument to microcrack formation and wear of the cutting edges. There was a low prevalence of plastic deformation and most ProTaper S1 instruments failed without discernible sign of unwinding of the flutes. Further studies should address the mode of failure and the role of debris particles in the fracture mechanism.

Keywords: flexural fatigue, fracture, nickel–titanium, rotary instrument.

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Introduction

Since the introduction of rotary nickel–titanium (NiTi) instruments, various brands such as LightSpeed (LightSpeed Inc., San Antonio, TX, USA), ProFile and GT-Rotary (both by Dentsply Tulsa Dental, Tulsa, OK, USA), Quantec (Tycom – now SybronEndo, Orange, CA, USA) and K3 (SybronEndo) have been marketed for creating within the root canal system a continuously tapered funnel shape. Many studies have shown that these NiTi rotary systems are able to prepare root canals with excellent taper, less canal transportation, greater conservation of tooth structure, and at a much faster rate than hand files (Thompson & Dummer 1997, Gluskin *et al.* 2001). Despite the increasing acceptance of these instruments, their unexpected fracture remains an issue during their clinical use. The propensity of NiTi rotary instruments to break or distort has been a subject of many investigations. For instance, Gabel *et al.* (1999) reported that doubling the rotation rate when using ProFile instruments would lead to a four-fold increase in the chance of distortion or breakage. The use of electric or air motors did not

Correspondence: Dr Gary Shun-pan Cheung, Faulty of Dentistry (Conservative Dentistry), The Prince Philip Dental Hospital, 34 Hospital Road, Saiyingpun, Hong Kong SAR, China (e-mail: spcheung@hkucc.hku.hk).

result in significantly different degrees of file distortion (Bortnick *et al.* 2001). Sattapan *et al.* (2000) has classified the separation of one make of NiTi instruments into 'torsional failure' and 'flexural fatigue' according to the presence of plastic deformation near the fracture site. Mechanically, how breakage may occur would depend on the magnitude and direction of the applied stress. It has been shown that the stresses acting on an instrument will vary with its design (Berutti *et al.* 2003), method of use (Blum *et al.* 1999) and its size relative to the canal (Peters *et al.* 2003).

The ProTaper system (Dentsply Maillefer, Ballaigues, Switzerland) is a relatively new NiTi rotary system that was designed to enhance cutting efficiency and improve flexibility (West 2001, Ruddle 2002a). The 'Shaper' instruments of the system have increasingly larger tapers over the length of their cutting blades from the tip. The manufacturer states that one of the benefits of such a progressively tapered instrument system is that each instrument engages a smaller zone of dentine, thus reducing torsional loads and the chance for instrument fatigue and breakage (Ruddle 2002a). Although the stresses developed over the ProTaper instruments may be less intense and more uniformly distributed mathematically (Berutti *et al.* 2003), they have been reported to fail more frequently and without warning (Ankrum *et al.* 2004). After clinical or simulated uses, an instrument is likely to be worn to a certain degree which may pre-dispose it to breakage. There have been some reports on the alterations of the instrument surface and of the cutting edges of some NiTi systems after use (Marending *et al.* 1998, Eggert *et al.* 1999, Tripi *et al.* 2001, Svec & Powers 2002, Alapati *et al.* 2003). The purpose of this study was to evaluate the defects found in ProTaper S1 instruments that were discarded after a defined schedule of clinical use in an endodontic practice. A detailed, longitudinal examination of the discarded instruments was carried out, in which the incidence of deformation and breakage, presence of surface anomalies, and wear were assessed.

Materials and methods

A total of 325 ProTaper instruments, of which 122 (38%) were S1, were discarded from an endodontic clinic at the School of Stomatology, Wuhan University, Hubei, China from January 2003 to May 2004. In that clinic, each ProTaper instrument was limited to a maximum number of uses according to the tooth being treated: four molars, 20 premolars, or 50 incisors and canines. Instruments would also be discarded after a single use in very complex, severely curved, or calcified canals.

Instrumentation technique

All root canals were prepared using a crown-down approach (Ruddle 2002b). After access cavity preparation, canals were initially scouted with size 10 and 15 K-files. Preliminary instrumentation to the estimated working length (EWL) with size 15 K-files was performed before using ProTaper instruments. The shaping file no. 1, or S1, was carried into the canal and allowed to advance just short of EWL or where resistance was met. The next rotary instrument used was the auxiliary shaping file, denoted as Sx, which was passively fed into the canal until it reached the EWL or encountered light resistance. Then, after the working length (WL) had been determined at 0.5 mm from the apical foramen using an electronic apex locator (Root ZX, J. Morita, Kyoto, Japan), a size 15 K-file was used to that length before the S1 instrument was used. ProTaper S2 and the finishing file F1 were then used, in turn, to the WL. Generally, the preparation was completed with either F1 or the F2 instrument. The F3 was only used occasionally; its use was determined by the canal curvature and cross-sectional diameter encountered. All instruments were used with light apical pressure at 300 rpm in an electric motor (ATR Tecnika, Dentsply Tulsa Dental, Tulsa, OK, USA) at the recommended programme and torque settings. Canals were irrigated with 1% sodium hypochlorite and patency was confirmed after every instrument. All canals were finally obturated with warm vertical or cold lateral compaction of gutta-percha in the same or a subsequent visit.

Collection and examination of discarded S1 instruments

After each use, every ProTaper instrument was wiped with isopropyl alcohol and inspected under ×2.5 magnification. If any distortion was found, the instrument was eliminated from the clinic. An instrument would also be discarded if it had reached the designated number of uses, or if there was a subjective, discernible decrease in cutting efficiency, fracture or any other defect. All discarded instruments were collected, ultrasonically cleaned and autoclaved. The S1 instruments were identified and examined in detail. They were classified into one of the following categories (Table 1):

Table 1 Summary of discarded ProTaper S1 according to prepared tooth types

		Unfractured (n = 94)		Fractured (n = 28)		
Teeth treated	No.	No defects	Unwinding	'Flexural'	'Torsional'	Unclassified[a]
Anterior	24	23	0	1	0	–
Premolars	43	33	0	9	1	–
Molars	55	37	1	15	1	1
Total	122	93	1	25	2	1

[a]One fractured file was lost during processing and hence not classified
Testing all groups for amount of fractures: χ^2 = 6.76, df = 2, P = 0.034.
Pair-wise comparison: Anterior vs. premolars: Fisher's exact test, P = 0.08.
Anterior vs. molars: Fisher's exact test, P = 0.009.
Premolars vs. molars: Yates' corrected χ^2 = 0.38, P = 0.54.

Table 2 Type and frequency of defects found on the surface of discarded ProTaper S1

Defects	Fractured (n = 10)	Unfractured (n = 10)
Surface debris	9	9
Microcracks	8	7
Pitting	4	5
Blunted edges (rolling-over)	4	5

No significant difference between the two groups (χ^2 = 0.269, df = 3, P = 0.97).

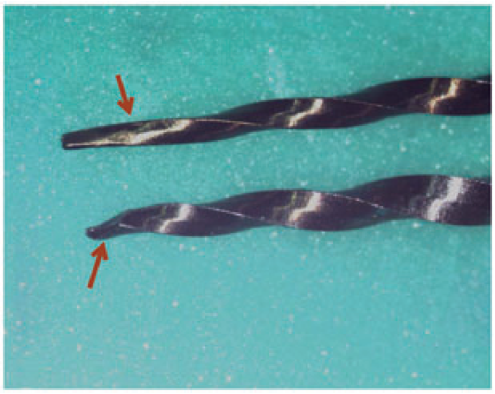

Figure 1 Photograph of the two discarded, fractured S1 files with associated unwinding defects (arrows).

(i) intact, i.e. unfractured, with or without discernible defect or unwinding; (ii) fractured instruments which were further categorized into 'torsional' (associated with unwinding defects) and 'flexural' according to the classification proposed by Sattapan *et al.* (2000). For the fractured group, the distance between the separated end and the base of the handle was measured to calculate the length of the broken fragment. Ten fractured and 10 intact files were randomly selected for examination under a scanning electron microscope (SEM) (Sirion-FEG, Philips, Eindhoven, The Netherlands) to compare the prevalence of surface defects. Overall low-power as well as high-power photomicrographs were taken of defects adjacent to the broken end of the fractured instruments and in a region 3.1–4.1 mm away from the tip of the intact instruments. The defects were classified into various types (Table 2). Findings were analysed using the Chi-square or Fisher's exact test, where appropriate.

Results

General observations and length measurements

Of the 122 ProTaper S1 instruments collected, 28 (23%) were fractured. One of the fractured S1 file was lost during processing. Of the fractured instruments, only two fell in the 'torsional' group that showed a macroscopic plastic deformation near the fracture site (Fig. 1). The number of apparent 'flexural' fractures was much higher than 'torsional' failure (Table 1). Most separations occurred in molars ($n = 17$; 31% of discarded instruments in the molar group), which were greater than in the premolar group ($n = 10$; 23%) that was, in turn, greater than for anterior teeth ($n = 1$; 4%). The difference between the anterior and molar groups was significant (Table 1). The mean length of all broken fragments was 3.67 ± 1.81 mm (SD), ranging from 1 to 7 mm. That for 'flexural' and 'torsional' failure was 3.66 and 3.77 mm, respectively. No statistical analysis was performed because of the extremely small number of 'torsional' fractures. Of those 94 instruments that had not fractured, only one showed unwinding detects macroscopically at some 3.4 mm from the tip (Fig. 2).

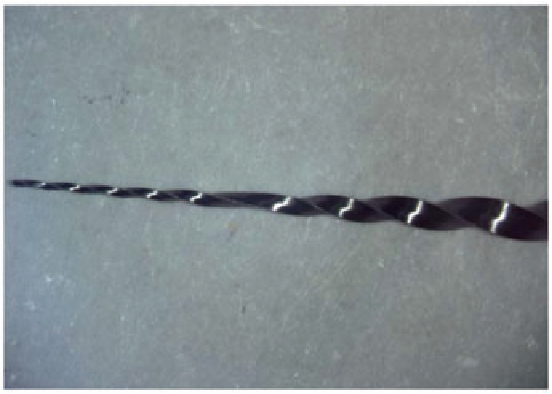

Figure 2 Discarded file showing unwinding defects without fracture.

Scanning electron microscopic analysis

The presence of defects and other anomalies on the surface of the intact and fractured S1 instruments were summarized in Table 2. Often, each instrument showed more than one type of defect. The presence of debris on the instrument surface was a common finding (Fig. 3); some seemed to have wedged within the machine grooves that now appeared to be crack-like structures (Fig. 4). In the region 3.1–4.1 mm from the tip of unfractured specimens, microcracks could be observed running perpendicular to the machine grooves (Fig. 5). Other defects found were pitting and widening of machine grooves (Fig. 6), and blunting (rolling-over) of the cutting edges (see Fig. 3). Cracks could readily be observed adjacent to the end of those fractured instruments (Fig. 7). For the instrument with obvious unwinding but no fracture, considerable distortion of the machine grooves, and presence of pitting defect and microcracks were observed at the unwound region (Fig. 8).

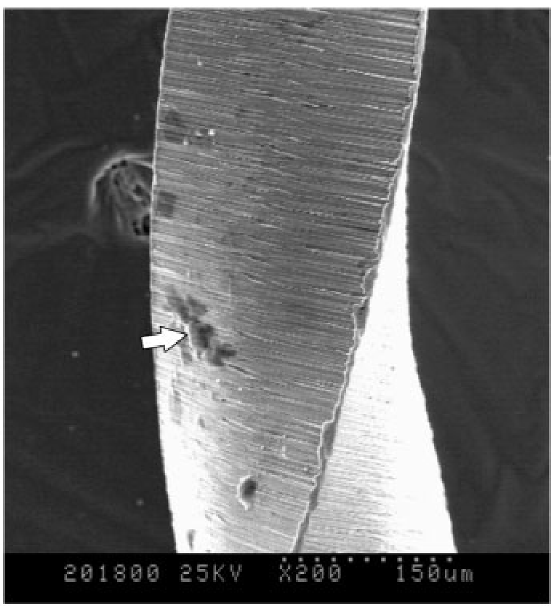

Figure 3 Photomicrograph of a discarded S1 instrument showing the presence of surface debris (arrow) and substantial 'roll-over' at the cutting edge.

Discussion

The ProTaper system was designed to have a small number of instruments (total of six) that would afford superior flexibility, unmatched efficiency and improved safety (Ruddle 2002a). The system consists of three shaping (Sx, S1 & S2) and three finishing instruments (F1, F2 & F3). The ProTaper S1 is used to prepare the coronal one-third of the canal initially, and then to enlarge the middle one-third when the WL is known. Thus, for each canal the ProTaper S1 instrument is used twice, instead of the one use for other instruments in the system. Logically, it is more likely to suffer from wear or damage and, indeed, the manufacturer suggests that the instrument be replaced more frequently. Some 38% of all discarded files were the S1 instruments in this study; nearly one-quarter of discarded S1 files had separated.

A NiTi rotary instrument that is 'working' in a curved root canal is subjected to torsional and fatigue damage, and ultimately failure. A previous study (Sattapan *et al.* 2000) classified instrument fracture into two apparent modes, namely, 'torsional' and 'flexural' based on the presence of associated plastic deformation near the fracture site. The same was also adopted by Parashos *et al.* (2004), but for that classification a detailed examination of the fracture surface was not carried out. In this study, the discarded ProTaper S1 files seldom exhibited any unwinding or macroscopic distortion, regardless of whether they had fractured or not. Only one out of the 94 intact, discarded S1 instruments showed visible signs of unwinding, and the majority of those that had fractured showed no sign of plastic deformation. Accordingly, these were classified as 'flexural' failure, implying fatigue being the predominant mechanism for the material failure. In a related study (Cheung *et al.* 2005) which examined the fracture surface of these instruments, a number that were classified initially as

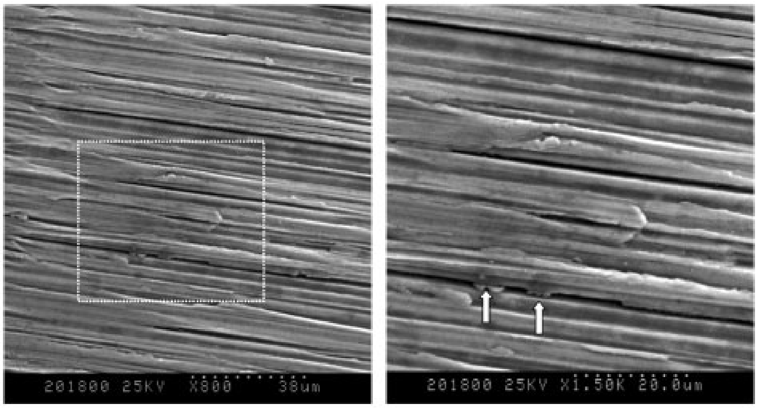

Figure 4 Photomicrograph of an intact S1 instrument showing numerous machine grooves running near-parallel to one another (across the entire field) on its surface, and the presence of debris particles (arrows) within a crack-like structure at the 3.1–4.1 mm region from the instrument tip.

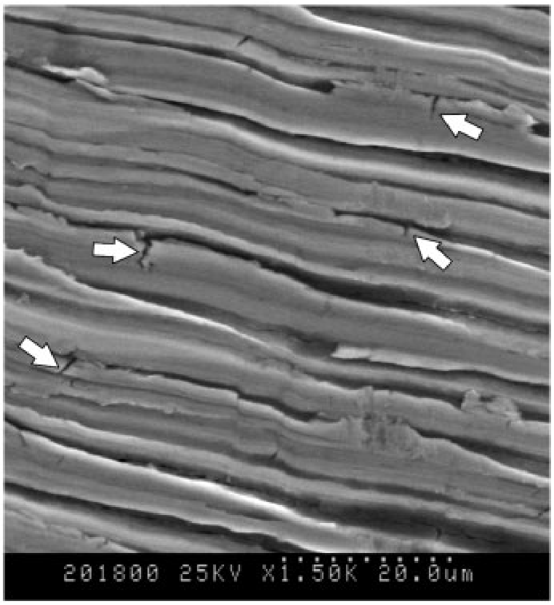

Figure 5 Photomicrograph of an intact, discarded S1 instrument at the 3.1–4.1 mm region from the tip showing the presence of microcracks (arrows) running perpendicular to the machine grooves on the instrument surface. Tip of the instrument was towards the upper edge of the picture.

'flexural' failure, indeed, failed because of fatigue. Thus, merely examining the presence of plastic deformation would fail to reveal the true mode of material failure. It is obvious that the classification by Sattapan *et al.* (2000) does not indicate the underlying fracture mechanism, and therefore is misleading. Detailed examination of the topographical features of the fracture surface is required for studying the mode of material failures.

Material fatigue will affect instruments that are rotating in the confines of a curved root canal. Such rotational bending will lead to the formation of microcracks on the surface, which will coalesce to become the fatigue crack(s) (Schijve 2001). The crack then propagates transgranularly with little to no discernible macroscopic plastic deformation of the adjacent material. To prevent fatigue failure, instruments should be discarded after a certain number of uses, regardless of whether any defects are visible (Pruett *et al.* 1997). However, there has been no consensus concerning the number of times which NiTi rotary files may be reused safely; indeed 1–27 canals have been recommended (Yared *et al.* 2000, Gambarini 2001, Peters & Barbakow 2002, Alapati *et al.* 2003, Arens *et al.* 2003). The maximum number of uses for the ProTaper instruments in this study was set arbitrarily, and was a compromise between the possible number and size of the canals in each tooth type and cost of the instruments. Although the permitted usage for each instrument appeared quite high, a 'safety' net was provided by allowing disposal of instruments when any signs of distortion or wear were noted.

Nearly all fractured S1 instruments in this study had been used in molars (61% of all fractured files, or 31% of discarded instruments in the molar group) and premolars (37 and 23%, respectively). It has been suggested that instrument fracture is a complex, multifactorial clinical problem with variables due to the operator and root canal anatomy being more influential than the instruments themselves (Parashos *et al.* 2004). The fact that posterior teeth often have limited accessibility, and smaller or more variable canal anatomy than anterior teeth might partly explain the findings of this study. Torsional fracture might occur when the apical portion of a rotating file was forced

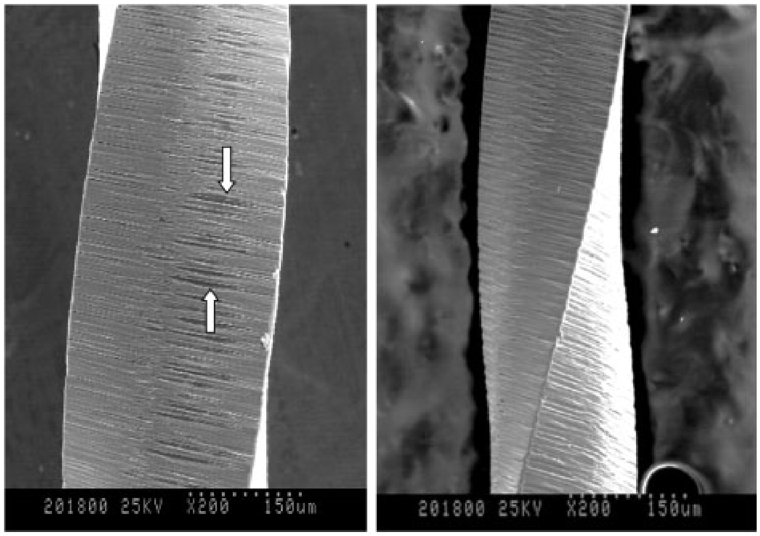

Figure 6 (left) Photomicrograph of an intact, discarded S1 instrument showing the presence of pitting (arrows) and wear of the cutting edge. Note the considerable widening of the machine grooves close to the centre of the flutes, compared to a new S1 file (right).

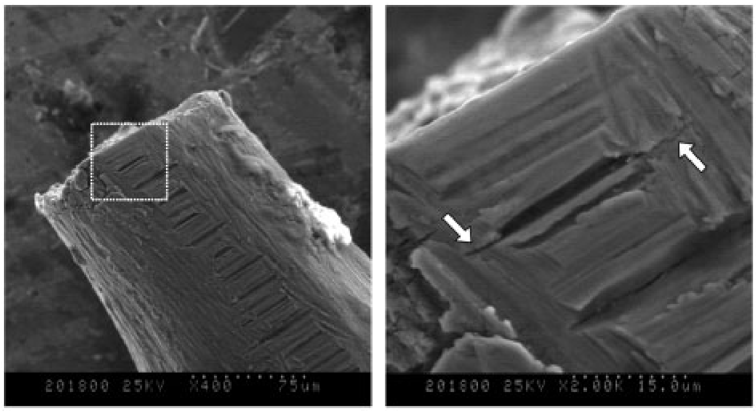

Figure 7 Photomicrograph of a fractured S1 instrument showing the presence of surface cracks close to the fracture site.

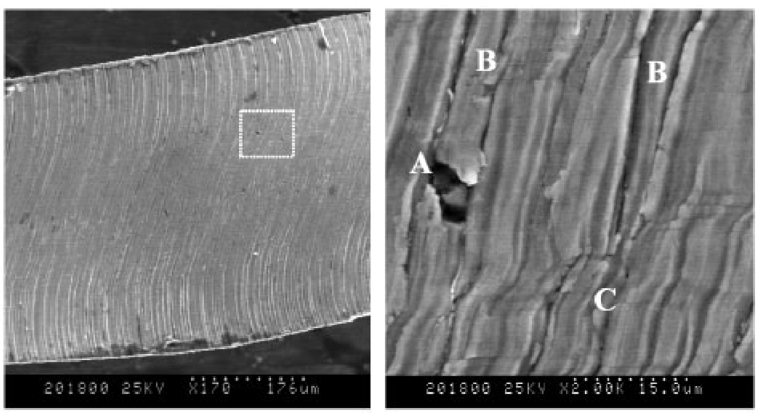

Figure 8 Photomicrograph of an unwound but intact S1 instrument showing considerable defects at the unwound region, including pitting (a), microcracks (b), and severely distorted machine grooves (c).

into a narrow lumen. Friction would increase and a high torque would be required to prevent the instrument from stalling – the small, fragile instrument tip is thus susceptible to excessive torsion (Blum *et al.* 1999). This effect has been described as 'taper lock' which could occur with regularly tapered instruments (Yared *et al.* 2002). ProTaper S1 file has 12 increasingly larger tapers ranging from 0.02 at D1 to 0.11 at D14. This variable-taper design might have reduced the risk of 'taper lock' fracture, which might partly explain the small amount of apparent 'torsional' failure reported here. The S1 instrument has a rather small and thin tip (approximate size 18). If this tip should become stalled in a constricted canal, the stress that builds up would quickly exceed the ultimate strength of the material of such a small dimension. An apparent 'brittle' failure is the result, although the true mechanism is due to shear i.e. torsional failure. This has been shown to be the case in a follow-up study that examined the separated instruments fractographically (Cheung *et al.* 2005).

Microcracks often are first formed on the surface of the instrument, signifying the very first stage of the fatigue phenomenon (Schijve 2001). In the specimens from this study, surface defects could often be found near the region that might or actually had fractured. All instruments demonstrated one or more defects not only at the cutting edges, but also on the surface of the flutes. It was both interesting and alarming to note the presence of microcracks that run perpendicular to the machine grooves (see Fig. 5). Their orientation might be an indication of the direction of the resolved stress on the surface of the instrument under torsional load. Debris particles that adhered tenaciously on the instrument surface could be seen in many cases, despite the ultrasonic cleaning process before SEM examination. Some appear to be trapped in the machine grooves that now appeared as crack-like structures. Alapati *et al.* (2004) completed an X-ray energy-dispersive analysis and reported that the debris particles are likely to be dentine chips. The exact nature of the debris particles, however, was not determined in the present study. It is possible that they could either be of metal origin from the manufacturing process (Eggert *et al.* 1999) or dentine particles from preparation of the root canal. Further studies are necessary to confirm the nature and origin of these adherent particles on the surface of used instruments.

Wear of some other brands of NiTi files in the form of pitting defects and blunting (rolling-over) of the cutting edges, which have been reported in previous studies (Eggert *et al.* 1999, Tripi *et al.* 2001, Svec & Powers 2002, Alapati *et al.* 2003), could also be found in the specimens. The presence of microcracks, pitting and blunted edges indicated that used instruments invariably have been worn. In fact, the presence of these defects suggested an increased potential for failure with further use because the defects could act as local stress-raisers and a potential origin of cracks. However, there is controversy as to whether NiTi rotary files should be treated as single-use, disposable instruments (Arens *et al.* 2003). To prevent the risk of instrument fracture within the root canal, it is necessary to improve operator proficiency and devise a conscientious practice to limit the use of these instruments. When surface defects can be detected, the instrument should never be used again.

Conclusion

Multiple use of ProTaper S1 instruments pre-disposed to microcrack formation and wear of cutting blades. There was a low prevalence of plastic formation prior to the fracture of S1 instruments. That is, most of them separated with little sign of macroscopic distortion in the form of unwinding. The amount of unwinding in discarded, unfractured instruments was minimal. Further studies are required to determine the actual mode of failure involved and the role of debris particles in the fracture mechanism.

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