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Nickel–titanium rotary instrument fracture: a clinical practice assessment

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Abstract

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Aim To prospectively determine the incidence of nickel–titanium rotary instrument fracture in an endodontic clinical practice setting.

Methodology Eleven second year endodontic residents, using four nickel–titanium rotary instrument systems (ProFile, ProTaper, GTRotary and K3Endo) according to the recommendations of the manufacturers, instrumented 3181 canals in 1403 teeth of 1235 patients, in a dental school post-graduate endodontic clinic, in 1 year. The incidence of instrument fracture was determined based on the number of instruments used. When fracture occurred, data were collected concerning the type, size, taper and prior use of the fractured instruments, the length and location of the fragment within the root canal and the curvature of the canal.

Results The overall incidence of instrument fracture was 0.39%. The incidence of fracture for ProFile, ProTaper, GTRotary and K3Endo files was 0.28%, 0.41%, 0.39% and 0.52%, respectively. There was no statistically significant difference between instrument systems. The percentage of teeth in which instruments fractured was 1.9% (0.28% for anterior teeth, 1.56% for pre-molars and 2.74% for molars). A total of 26 instruments fractured, of which 23 had tapers of 0.06 or greater. Most of the fragments were located in the apical third of the root canal, and both the median and mode amongst the fragment lengths were 2 mm.

Conclusions The low incidence of nickel–titanium rotary instrument fracture supports the continued use of these instruments in root canal treatment.

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

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Introduction

Nickel–titanium rotary instruments have become a standard armamentarium in endodontic practice. It has been demonstrated that these instruments greatly improve the operators' ability to effectively and efficiently prepare root canals, without significantly altering their centricity, curvature or length (Short *et al.* 1997, Schafer & Zapke 2000, Iqbal *et al.* 2003). However, during root canal instrumentation, nickel–titanium rotary instruments are subjected to torsional stress and can fracture because of cyclic fatigue (Pruett *et al.* 1997, Haikel *et al.* 1999, Li *et al.* 2002).

There are a number of factors that can influence the potential for rotary instrument fracture. Used instruments have a greater propensity for fracture than new ones. Gambarini (2001a) found, by cyclic fatigue testing, that the rotation time to fracture for clinically used ProFile instruments (Dentsply Maillefer, Ballaigues, Switzerland) was significantly lower than for new ones. Yared & Kulkarni (2003) and Yared (2004) investigated the torsional properties of new ProFile instruments (Dentsply Tulsa Dental, Johnson City, TN, USA) and those that had been used to instrument canals in resin blocks and found that the used instruments had significantly lower torque values at fracture than did the new ones. Instruments rotated at

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higher rotational speeds and higher torque levels are more susceptible to distortion and fracture (Gabel *et al.* 1999, Gambarini 2001b, Zelada *et al.* 2002). Dietz *et al.* (2000) determined the resistance of nickel–titanium rotary instruments to fracture at different rotational speeds. They measured the depth of penetration at fracture of rotating instruments moving at a constant rate into standardized semicircular bovine bone canals. A greater depth of penetration, measured in degrees, indicated a greater resistance to fracture. Instrument penetration at fracture was found to be significantly greater with rotational speeds of 150 rpm compared with 350 rpm. Gambarini (2001b), by measuring the number of cycles of rotation to fracture, determined the cyclic fatigue resistance of nickel–titanium instruments rotated at a constant speed in low and high torque motors, and found that those used in motors with low torque levels (<1 N cm^{-1}) were more resistant to fracture than those used in motors with high torque levels (>3 N cm^{-1}).

The clinical ability to perceive binding of a rotating instrument within a root canal and to withdraw it before the level of torsional stress on the instrument reaches its elastic limit is a critical skill for preventing fracture. Realistically, however, this level of perception is not always attainable and can vary depending upon the proficiency of the operators (Yared *et al.* 2001, 2002, 2003). Consequently, electric motors have been developed to control the rotational speed delivered to the instrument and to sense the level of torque generated. During root canal instrumentation, when the torque on an instrument rotating at a constant speed reaches a pre-set level, the motor automatically reverses rotation allowing it to be withdrawn from the canal, thereby preventing the development of torsional stress that can lead to distortion and fracture.

Even, when operational and technical precautions are taken to prevent instrument failure, the chance of fracture because of the development of cyclic fatigue within the nickel–titanium metal alloy increases during instrumentation of curved canals (Pruett *et al.* 1997, Haikel *et al.* 1999, Booth *et al.* 2003). Pruett *et al.* (1997) determined the number of cycles to fracture of freely rotating flexed nickel–titanium instruments in pre-curved metal tubes, and found that fracture occurred at the point of maximum flexure, and that the cycles to fracture significantly decreased as the angle of curvature increased and the radius of curvature decreased. Haikel *et al.* (1999) showed that the fracture time for instruments rotated at a constant speed in curved canal simulations decreased as the angle of curvature increased. Booth *et al.* (2003) found that less torque was necessary to cause fracture of rotary instruments in a canal with a 3-mm radius of curvature than one with a 5-mm radius.

Manufacturers continue to develop and produce newer nickel–titanium rotary instruments with a variety of design features that facilitate root canal instrumentation. But irrespective of these innovations, fracture still occurs and is a major issue in clinical endodontic practice (Parashos & Messer 2004). Mandel *et al.* (1999) studied the incidence of nickel–titanium rotary instrument fracture in 125 simulated resin canals of the same geometric dimensions and curvatures, which were instrumented by five operators, each using ProTaper (Dentsply Maillefer, Ballaigues, Switzerland) instruments in 25 simulated canals. They found that 21 instruments fractured, a 16.8% (21/125) fracture rate based on the number of canals instrumented. Veltri *et al.* (2004) in a computer-assisted radiographic comparison of the shaping ability of ProTaper (Dentsply Maillefer) and GTRotary (Dentsply Tulsa Dental, Johnson City, TN, USA) instruments, used in two different groups of 10 curved canals in extracted teeth, found that two fractured in each group, a fracture rate of 20% (4/20), based on the number of canals instrumented. Ankrum *et al.* (2004) in an investigation of the fracture rates of three types of nickel–titanium rotary instruments used in three groups of 15 curved canals in extracted teeth found that 1 ProFile (Dentsply Tulsa Dental, Johnson City, TN, USA), 1 K3Endo (SybronEndo, Orange County, Los Angeles, CA, USA) and 5 ProTaper (Dentsply Maillefer) instruments fractured, an overall fracture rate of 16% (7/45), based on the number of canals instrumented. These fracture rates are high compared with those experienced in previous studies, where Bryant *et al.* (1999) found that no 0.04 or 0.06 tapered ProFiles (Dentsply Tulsa Dental) fractured during the instrumentation of 40 simulated root canals in resin blocks and where Yared & Steiman (2002) also found that no fractures occurred during the instrumentation of 120 root canals of extracted teeth with ProFiles (Dentsply Tulsa Dental) used at high and low torque levels.

Studies that assess the properties of nickel–titanium rotary instruments used to prepare simulated root canals in resin blocks and natural root canals in extracted teeth offer valuable information that can be extrapolated to clinical situations; however, they produce inconsistent results on fracture that does not necessarily represent what may occur in clinical endodontic practice. It also appears that none of the various types of nickel–titanium rotary systems are failsafe for fracture (Mandel *et al.* 1999, Ankrum *et al.* 2004, Veltri *et al.* 2004). Instrument fracture is a serious iatrogenic complication in endodontics because it compromises achieving the treatment goals of thorough debridement and complete filling of the root canal system (Schilder 1967, 1974). Whether or not a certain degree of rotary instrument fracture may be inevitable and impossible to completely eliminate in clinical practice is a question that continues to be a major concern for practitioners.

The purpose of this study was to prospectively determine the incidence, as well as the clinical circumstances, of nickel–titanium rotary instrument fracture, during root canal preparation, in the treatment of a large number of patients, by a group of second year endodontic resident clinicians, practising in a dental school post-graduate endodontic clinic, over a 1-year period.

Materials and methods

The proposal for this clinical research study was submitted and approved by the University Institutional Review Board Committee on Activities Involving Human Subjects.

Subjects, setting and participants

The patients in this study were referred for endodontic treatment to New York University College of Dentistry post-graduate endodontic clinic, and were treated by second year endodontic residents under the supervision of attending faculty endodontists. All teeth that received root canal preparation with nickel–titanium rotary instruments during the study period were included in this study. Residents maintained records of the number of patients, the number of teeth and the number of canals that they treated for the study on a monthly basis. These numbers were submitted to the department clinic director and recorded. The number of patients, the number of teeth and the number of canals treated for the entire study period of one year were computed for each resident and combined for all residents participating in the study. During the study period, whenever a rotary instrument fracture occurred, the residents were required to follow the clinic policy for the management of treatment mishaps. This included immediately informing the attending faculty, performing the appropriate treatment, informing the patient, recording the incident in the patient's record and providing the proper follow-up care. Residents strictly adhered to this requirement and this assured that all incidents were reported and accounted for. When an instrument fracture occurred, the residents followed a specific protocol for the collection of data concerning the clinical and technical circumstances of the fracture, which is described later. Data were prospectively collected for rotary instrument fracture during the endodontic treatment of patients, by 11 second year post-graduate endodontics residents, for 1 year, from May 2003 to April 2004.

Treatment

A medical and dental history, clinical and radiographic examination, diagnosis and treatment plan were completed for each patient. The treatment, risks and alternatives were explained to each patient, and after informed consent was given, patients received endodontic treatment. After administration of local anaesthesia, application of rubber dam and achievement of adequate coronal access, the debridement and disinfection of the pulp chamber was carried out using an aqueous solution of 3% sodium hypochlorite (Sultan Chemists Inc. Englewood, NJ, USA). Fine stainless steel hand K-files (Brassler USA Inc. Savannah, GA, USA) were used to explore the root canal, negotiate the apex and establish a patent pathway through the canal. Working length measurements were determined by electric apex location and radiographic evaluation. For all teeth treated, root canal instrumentation was performed with nickel–titanium rotary instruments sequenced in a crown-down manner utilizing an electric motor hand-piece (Model AEU-20; Aseptico, Inc. Woodville, WA, USA) set at a medium torque level of three and a rotational speed of 350 rpm. During rotary instrumentation, canals were lubricated with a preparation of urea peroxide 10% and ethylenediamine tetra-acetic acid 15% (RC Prep; Premier Dental Co. Philadelphia, PA, USA) and irrigated with a 3% sodium hypochlorite solution (Sultan Chemists Inc.).

Instruments

Four different rotary instrument systems were used for root canal preparation, according to the manufacturer's recommended protocol for each of the systems. The rotary instrument systems used were: ProFile, ProTaper, GTRotary and K3Endo. Each rotary system consists of a specific number of instruments and each instrument has both a tip and taper size (Table 1).

Table 1 Rotary instrument systems (number of instruments)

ProFile (9)	ProTaper (6)	GTRotary (12)	K3Endo (6)
Instrument Sizes	Tip/Taper		
30/0.06	17/0.11	20/0.04	25/0.10
40/0.06	20/0.11	20/0.06	25/0.08
50/0.07	19/0.19	20/0.08	40/0.06
40/0.04	20/0.07	20/0.10	35/0.06
35/0.04	25/0.08	30/0.04	30/0.06
30/0.04	30/0.09	30/0.06	25/0.06
25/0.04		30/0.08	
20/0.04		30/0.10	
15/0.04		40/0.04	
		40/0.06	
		40/0.08	
		40/0.10	

These rotary systems were selected according to the individual preference of each participating resident clinician. Each resident exclusively used one of the four rotary systems during the entire study period to instrument the root canals of all types of teeth with a wide range of canal configurations and curvatures. Three residents used the ProFile system, three residents used the ProTaper system, two residents used the GTRotary system and three residents used the K3Endo system. The standards that had to be achieved for proper root canal preparation were the same irrespective of which rotary system was used. These standards included a coronally flared and apically tapered canal preparation, with an adequate apical preparation of at least a size 30. The root canal instrumentation for each tooth treated was accomplished in one visit of 1–2-h duration. Rotary instruments were examined for signs of failure during and after each use by the practising resident clinicians. Instruments that exhibited deformations were discarded and replaced with new ones whenever observed. Instruments that were reused were cleaned with All-Purpose Cleaner (Henry Schein Inc. Melville, NY, USA) and then placed in bags for autoclave sterilization. Residents individually kept track of instrument usage and routinely discarded and replaced instruments after being used for the instrumentation of three canals.

Fracture

When a nickel–titanium rotary instrument fracture occurred, data concerning the clinical and technical circumstances of the incident were collected by the resident clinician, under the direction of the supervising attending faculty endodontist, according to the following protocol. Direct and angled periapical radiographs were taken and the tooth number was recorded. The curvature of the root canal (straight <10°, moderate 10–25°, or severe >26°) was determined and classified according to the method described by Schneider (1971). The position of the broken fragment in the canal (whether in the apical, middle or coronal third, or in the entire canal) and the canal in which the instrument fractured were determined by clinical and radiographic examination. The remaining portion of the fractured instrument was measured to establish the length of its missing portion, and this instrument fragment length as well as the instrument type, size, taper and usage was recorded. Instrument usage was determined by the number of canals instrumented. If an instrument that fractured had not been previously used, the usage was one, and if it had been previously used for one canal, the usage for that file was two, and so forth. All fractured instruments were collected and replaced with new ones. All fractured instrument data collected were recorded in a log without any patient or resident clinician identifiers. All patients who experienced an instrument fracture event were informed, and received appropriate treatment.

Results

A total of 26 nickel–titanium rotary instruments fractured during the treatment of 1403 teeth (354 anterior teeth, 320 premolar, 729 molars), in 1235 patients, by 11 endodontic residents in a 1-year period. The average number of teeth treated by a resident was 127 (1403/11) and the average number of instruments fractured by a resident was 2.4 (26/11). The overall incidence of fracture for all instruments used was 0.39% (26/6661). The percentage of canals in which instruments fractured was 0.82% (26/3181). The percentage of teeth in which instruments fractured was 1.9% (26/1403) with percentages of 0.28% (1/354) for anterior teeth, 1.56% (5/320) for pre-molar teeth and 2.74% (20/729) for molar teeth. Amongst the 26 instruments that fractured, seven were ProFile, seven were ProTaper, three were GTRotary and nine were K3Endo. Three residents used 2476 ProFile instruments to prepare 925 canals in 394 teeth in which seven fractured – an incidence of 0.28% (7/2476). Three residents used 1689 ProTaper instruments to prepare 828 canals in 368 teeth in which seven fractured – an incidence of 0.41% (7/1689). Two residents used 771 GTRotary instruments to prepare 573 canals in 245 teeth in which three fractured – an incidence of 0.39% (3/771). Three residents used 1725 K3Endo instruments to prepare

855 canals in 396 teeth in which nine fractured – an incidence of 0.52% (9/1725).

The fractured instrument data are summarized in Table 2. Of the 26 rotary instruments that fractured, 20 (77%) fractured in molars (12 in maxillary molars and eight in mandibular molars), five (19%) fractured in pre-molars (four in maxillary pre-molars and one in a mandibular pre-molar), and one (4%) fractured in a maxillary lateral incisor. Of the 12 that fractured in maxillary molars, 10 were in mesiobuccal canals and two were in palatal canals. Of the eight that fractured in mandibular molars, five were in mesiobuccal canals, two were in mesiolingual canals and one was in a distal canal. Of the five that fractured in pre-molars, two were in buccal canals, one was in a lingual canal and two were in single canal pre-molars. Concerning instrument fracture in relation to root canal curvatures, two (7%) fractured in straight canals, nine (35%) fractured in moderately curved canals and 15 (58%) fractured in severely curved canals. With respect to the position of the fragments in the root canals, 17 (65%) were located in the apical third, four (15%) in the middle third, two (8%) in the coronal third and three (12%) within the entire canal. Fragment lengths ranged from 1 to 25 mm, two of which were 25-mm length, giving an average mean length of 4.4 mm. However, the median and mode amongst the fragment lengths were both 2 mm. The tip sizes of the instruments that fractured ranged from sizes 20 to 40, (five of size 20, five of size 25, six of size 30, five of size 35, and five of size 40). The taper sizes of the instruments that fractured ranged from 0.04 to 0.09 (three of 0.04 taper, 14 of 0.06 taper, three of 0.07 taper, three of 0.08 taper and three of 0.09 taper). Six instruments fractured at their first canal use whilst 17 fractured at their third canal use and three fractured after being used for more than three canals.

Statistics

The overall incidence of instrument fracture was 0.39% over a 1-year interval. The incidence of fracture for ProFile, ProTaper, GTRotary and K3Endo instruments was 0.28%, 0.41%, 0.39% and 0.52%, respectively. Chi-squared analysis showed that there was no statistically significant difference amongst the instrument systems ($P = 0.68$).

Discussion

Nickel–titanium rotary instruments are an integral part of the armamentarium for root canal preparation and are used extensively in endodontics. There is a wide variety of rotary systems available from which clinicians can choose. These rotary systems have specific design features to facilitate root canal preparation, but all of them have the potential for failure and are vulnerable to fracture. In endodontic practice, certain clinical factors, such as the type of teeth treated, the morphology of the root canals instrumented including their curvature, length and width, cannot be controlled and these circumstances in addition to individual variations in the skill of operators in the manipulation of rotary instruments may have an impact on fracture. This study did not attempt to control any of these specific types of variables, but rather attempted to determine what the fracture incidence would be during the endodontic treatment, of a large number of clinical cases with a wide range of tooth types and canal configurations, in a population-based sample of patients, by a group of experienced second year endodontic resident clinicians using contemporary rotary instrument systems. At the time that this study was undertaken, there were no similar clinical studies available that examined the incidence of rotary instrument fracture during root canal treatment and no clinically derived information was accessible to the dental profession on how often rotary instrument fracture might occur as an iatrogenic instrumentation mishap in endodontic practice.

This clinically based study, which assessed the incidence of fracture, based on the total number of instruments used, in the treatment of 1403 teeth, may represent a realistic appraisal of the incidence of fracture that can occur in endodontic practice, and could provide a basis and a format for further similar clinical investigations. Under the parameters of this study, the overall incidence of fracture was 0.39%, with no statically significant difference amongst instrument systems. Although there was no statistical difference in the fracture characteristics amongst the different instrument systems, this does not imply that they were alike. A larger sample size with the same fracture rate could have produced statistical significance or a model that statistically adjusted for other independent predictors could have shown significant differences. Therefore, a failure to reject the null hypothesis with these data and analyses cannot be interpreted as proof that the instrument systems were equivalent.

Fracture occurred in 1.9% of the teeth treated and 0.82% of the canals prepared with nickel–titanium rotary instruments. Previous investigations on the

Table 2 Fractured instrument data ($n = 26$)

System	Size Tip/ Taper	File usage (by no. of canals)	Tooth number	Root canal: B, buccal; L, lingual; MB, mesiobuccal; ML, mesiolingual; P, palatal; D, distal	Root canal curvature: ST, straight; MD, moderate; SV, severe	Fragment position: A, apical; M, middle; C, coronal; E, entire canal	Fragment length (mm)	Fragment removal: Y, yes; N, no	Tooth treatment: O, obturation; S, surgery
ProFile	35/0.06	3	18	ML	MD	M	2	N	O
	40/0.06	3	31	D	MD	E	10	Y	O
	35/0.06	3	13	–	MD	A	3	N	O
	35/0.06	3+	20	–	ST	A	2	N	O
	25/0.04	3	30	MB	SV	A	1.5	N	O
	40/0.06	3+	18	ML	SV	A	1	N	O
	25/0.04	1	12	B	SV	A	1	N	O
ProTaper	20/0.07	1	4	L	SV	A	6	N	O
	25/0.08	3	3	MB	SV	C	2	N	O
	20/0.07	3	2	MB	MD	A	2	N	O
	30/0.09	3	30	MB	SV	A	3	N	O
	30/0.09	3	3	MB	SV	M	1.5	N	O
	30/0.09	3	5	B	ST	M	3	N	S
	20/0.07	1	3	MB	SV	C	3	N	O
GTRotary	30/0.06	3	30	MB	MD	A	3	N	O
	20/0.06	3	15	MB	SV	A	1	N	O
	20/0.04	3	15	MB	SV	A	2	N	O
K3Endo	30/0.06	3	2	MB	SV	A	4	N	O
	35/0.06	3	14	MB	SV	A	2	N	O
	25/0.08	3+	7	–	MD	A	2	N	O
	30/0.06	1	15	MB	SV	A	3	N	O
	35/0.06	3	30	MB	SV	A	2	N	O
	40/0.06	3	30	MB	SV	M	1.5	N	O
	25/0.06	3	2	MB	MD	A	2	N	O
	40/0.08	1	14	P	MD	E	25	Y	O
	40/0.06	1	14	P	MD	E	25	Y	O

instrumentation of root canals in extracted teeth with nickel–titanium rotary instruments reported fracture rates that were relatively high (Veltri *et al.* 2004, Ankrum *et al.* 2004). However, these laboratory studies on small size samples do not necessarily reflect the fracture rates that may occur under clinical conditions. The findings of the present study suggest that although fracture incidence is relatively low in clinical practice, it can occur with any nickel–titanium rotary instrument system.

A secondary purpose of this study was to evaluate the clinical circumstances of each incident of fracture. With respect to the data that were gathered for each of the incidents, certain clinical and technical findings were observed. Of the 26 instruments that fractured 20 (77%) occurred in molars, five (19%) in pre-molars and only one (4%) in an incisor. Also, the percentages of molars, pre-molars and anterior teeth in which instruments fractured were 2.74%, 1.56%, and 0.28%, respectively. These findings imply that fracture is more likely to occur in teeth with more complex root canal configurations.

In the present study, canal curvatures were classified according to the method described by Schneider (1971). This method was used because it has been widely applied and cited as a standard for classifying root canal curvatures in numerous studies (Pruett *et al.* 1997, Gabel *et al.* 1999, Mandel *et al.* 1999, Yared *et al.* 1999, 2000, 2001, Li *et al.* 2002, Peters & Barbakow 2002). Two instruments (7%) fractured in canals classified as straight, nine (35%) fractured in canals classified as having moderate curvatures, whilst 15 (58%) fractured in canals classified as having severe curvatures. These findings are not surprising since canal curvature has been shown to be a significant factor for fracture (Pruett *et al.* 1997, Peters & Barbakow 2002, Booth *et al.* 2003). Zelada *et al.* (2002) found that fracture was significantly greater in root canals of extracted molars with curvatures of more than 30° than those with curvatures of <30°, in which the angle of curvature was determined by radiographs in both mesiodistal and buccolingual directions. However, in the present study, the clinical radiographs which were taken to determine the root canal curvatures may not have accurately detected the degree of curvatures in buccal or lingual directions. Therefore, the possibility exists that some of the canals, which were classified as straight or moderately curved, may have had severe buccal or lingual curvatures.

In relation to the specific instrument characteristics that might have influenced fracture, there were two interesting findings. First, there was a relatively equal distribution of fractures amongst the instrument sizes 20–40 and secondly, the overwhelming majority of the instruments that fractured 88% (23/26) had large tapers ranging from 0.06 to 0.09. This suggests that tip size alone may not be as important a factor as taper is for fracture, and may imply that a more rapid increase in diameter from the tip along the shaft to the rotating source, may cause excessive torsional stress that creates a critical amount of cyclic fatigue that cannot be tolerated by the alloy without rupturing. This concept is supported by Haikel *et al.* (1999) who found when dynamic stress testing three types of nickel–titanium rotary systems that as the taper increased the time to fracture decreased, and also by Sattapan *et al.* (2000a) who found that the torque generated during canal instrumentation with rotary instruments increased as the taper increased.

Instrument usage can significantly influence the potential for fracture (Gambarini 2001a, Yared and Kulkarni 2003, Yared 2004). This is supported by scanning electron microscopic observations demonstrating that used instruments deteriorate and develop defects and cracks on their surfaces that can be nidi for the propagation of fractures (Tripi *et al.* 2001, Svec & Powers 2002, Alapati *et al.* 2003). The results of the present investigation found that six instruments fractured at their first canal use, 17 at their third canal use and three at more than three canal uses. This suggests that although new instruments can fracture at their first canal use, those that are used for three or more canals may have a higher susceptibility for fracture. Gambarini (2001a) demonstrated, in cyclic fatigue to fracture tests of rotary instruments after prolonged clinical use, that the used instruments had a lower resistance to fracture than new ones. However, Gambarini also reported that the used instruments that were tested had been successfully operated in up to 10 clinical cases without any failures. Investigations by Yared *et al.* (1999, 2000) in which cyclic fatigue tests were performed and compared for new and used ProFile instruments concluded that they could be safely used for the instrumentation of up to 10 canals in extracted molars or for the clinical treatment of four molar teeth. Additionally, it was noted by Yared *et al.* (1999, 2000) that contact with sodium hypochlorite solution and autoclave or dry heat sterilization did not increase the susceptibility of these instruments to cyclic fatigue. The findings of these studies question the extent to which usage influences breakage.

Operator proficiency is an important consideration when evaluating the frequency of fracture. Mandel *et al.* (1999) in a study that evaluated the influence of the operator's experience on rotary instrument fracture found that a lower rate of fracture occurred for operators who had completed a training period than those who had not. In the present study, all of the operators were second year residents who had prior clinical experience in the use of rotary systems for root canal instrumentation during the first year of their residency, and on the basis of that experience, they were considered to be proficient operators.

An unexpected and unusual finding was that two K3Endo instruments fractured at the junction of the shaft and the handle, which may have been due to defects in the union of these connections. This created two 25-mm fragments, whereas all the other instruments fractured along the shaft within the area of the flutes. In spite of the creation of these two large broken instrument fragments, the median and the mode amongst the entire distribution of fragment lengths were both 2 mm. These finding are in concert with the test fracture results obtained by Sattapan *et al.* (2000b), which demonstrated that nickel–titanium rotary instrument fractures tend to occur close to the tip as well as with the observations of Zelada *et al.* (2002) who found that most fractures occurred 1–3 mm from tip.

This study did not aim to evaluate the patient management for each of the fractured instruments incidents. However, only three of the 26 fragments, of which two were 25-mm long and one was 10-mm long, were successfully removed from the canals in which they fractured, demonstrating that small fragments which cannot be mechanically secured are unlikely to be retrieved from root canals. This observation coincides with a study by Hülsmann & Schinkel (1999) in which they found that removal was easier and more successful when fragments were longer (>5 mm) and when the fractured end of the fragment extended into the coronal portion of the canal, where it could be engaged. Of the remaining 23 fragments, four were bypassed, one in the coronal, two in the middle and one in the apical portion of the root canal. The rest of the remaining 19 fragments were not removed or bypassed and remained in the canal as obstructions, 16 in the apical, two in the middle and one in the coronal third of the root canal. The root canals in which fragments were removed or bypassed, and the unobstructed portion of the root canals in which fragments remained as obstructions were prepared and filled. One canal, with a 3-mm fragment in the middle portion of a maxillary pre-molar root canal, was surgically treated.

Conclusion

The low overall incidence (four per thousand) of nickel–titanium rotary instrument fracture in this study presents a realistic clinical assessment of the incidence of fracture in a large population sample of endodontic patients and supports the careful and prudent use and full integration of these instruments in the root canal preparation phase of endodontic treatment. However, further research of this type is needed in order to fully substantiate the incidence of rotary instrument fracture as an iatrogenic complication of root canal preparation and precisely identify the clinical and technical factors that can affect instrument fracture in endodontic practice.

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