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Fracture of ProFile nickel–titanium rotary instruments: a laboratory simulation assessment

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Abstract

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Aim To determine the incidence of ProFile nickel–titanium rotary instrument fracture in an endodontic laboratory simulation.

Methodology Three hundred and sixty dental students used 2880 ProFile nickel–titanium rotary instruments to prepare 1440 simulated root canals in 720 plastic teeth, and another 2880 ProFile nickel–titanium rotary instruments to prepare 1440 natural root canals in 720 extracted teeth. A standardized crown-down rotary instrumentation technique was used, which included measures to prevent fracture. Rotary instrument fracture was monitored during and after completion of the laboratory simulation exercises to determine the incidence of fracture. When fracture occurred, data were collected concerning the size of the instrument, the length of the instrument fragment, the location of the fragment in the canal and the curvature of the canal in which the instrument fractured.

Results The incidence of instrument fracture was 0.41% in plastic simulated canals and 0.31% in natural root canals. The overall incidence of instrument fracture was 0.36%. Of the instruments that fractured 67% were size 25, 0.04 taper; and 81% of the fragments were located in the apical third of the canal. The mean, median and mode of the fragment lengths were all 3 mm.

Conclusions The low overall incidence of fracture in this study suggests that ProFile rotary instruments are safe for use by dental students in laboratory simulations and that if preventive measures are taken the incidence of instrument fracture can be minimized.

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

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Introduction

The use of nickel–titanium rotary instruments has increased the effectiveness and efficiency of root canal preparation. Short *et al.* (1997) demonstrated by serial cross-section examination of prepared curved root canals in extracted molar roots, that nickel–titanium rotary instruments remained more centred within the canal than did stainless steel hand instruments. Schafer & Zapke (2000) showed by scanning electron microscopic examination, that the root canals of extracted teeth had less debris and smear layer after preparation with nickel–titanium rotary ProFile (Dentsply Maillefer, Ballaigues, Switzerland) instruments than after preparation with hand instruments. Iqbal *et al.* (2003) revealed with computer aided radiographic analysis, that nickel–titanium rotary ProFile (Dentsply Maillefer) instruments created only a minimal degree (<0.1 mm) of apical transportation at the D1 level in root canals of extracted molar teeth. Extensive investigations by Thompson & Dummer (1997) and Bryant *et al.* (1998, 1999) on the shaping ability of Series 29 and ISO sized 0.04 and 0.06 ProFile (Dentsply Maillefer) instruments in simulated curved root canals in resin blocks, concluded that although these instruments caused some minor aberrations in terms of a limited degree of transportation along the outermost aspect of

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the canal curvature, the canal preparations were well tapered and adequately shaped without significant alterations.

However, nickel–titanium rotary instruments are subject to torsional stress and cyclic fatigue resulting in distortion and fracture during root canal shaping. Pruett *et al.* (1997) performed cyclic fatigue testing by determining the cycles to fracture of freely rotating flexed nickel–titanium instruments in pre-curved stainless steel tubes and found that they always fractured at the point of maximum flexure. Sattapan *et al.* (2000a) measured the torque generated during the instrumentation of root canals in extracted teeth with nickel–titanium instruments rotated at a constant speed and determined that the torque generated at the moment of rotary instrument fracture was greater than at any other time during canal instrumentation. Sattapan *et al.* (2000b) observed, under stereomicroscopic examination, that the fracture sites of nickel–titanium rotary instruments exhibited signs of both torsional and flexural fatigue. Li *et al.* (2002) found that rotary instruments subjected to cyclic fatigue testing were more susceptible to fracture when they were severely flexed. Scanning electron microscopic examination of the fractured surfaces of nickel–titanium rotary instruments revealed the presence of peripheral cracks, craters and dimples indicative of a ductile type fracture that occurs when a metal is unable to withstand deformation without rupture (Pruett *et al.* 1997, Haikel *et al.* 1999, Li *et al.* (2002). Thus, nickel–titanium rotary instrument fractures are ductile in nature and occur because of torque-generated cyclic fatigue at the point of maximum flexure.

In light of these findings, a great deal of attention has been given to the reduction and control of both the rotational speed and torque that is delivered to the instrument as it rotates within the root canal. Independent investigations concerning the effect of rotational speed on nickel–titanium rotary instrument fracture indicated that instruments rotated at higher rotational speeds of 300–350 rpm are more susceptible to fracture than at lower rotational speeds of 150–200 rpm (Gabel *et al.* 1999, Dietz *et al.* 2000, Zelada *et al.* 2002). With respect to the effect of torque on fracture, Gambarini (2001a) studied the cyclic fatigue resistance of nickel–titanium instruments rotated at a constant speed at high (>3 N cm^{-1}) and low (<1 N cm^{-1}) torque levels, and found that those rotated at low torque levels were more resistant to cyclic fatigue and fracture. Other factors that have been identified that can increase the potential for rotary instrument fracture are the severity of root canal curvatures (Haikel *et al.* 1999, Booth *et al.* 2003), the overuse of instruments (Gambarini 2001b), and the inexperience of the operators (Mandel *et al.* 1999). Haikel *et al.* (1999) assessed cyclic fatigue for three types of nickel–titanium instruments by measuring the time it took for dynamic fracture to occur when they were rotated at a constant speed in a curved tempered steel simulated canal. They found that fracture time decreased as instrument size and canal curvature increased. Booth *et al.* (2003) demonstrated that significantly less torque was required to fracture nickel–titanium rotary instruments around acutely curved simulated canals than around those that were not as acutely curved. Cyclic fatigue tests performed by Gambarini (2001b) found that used ProFile (Dentsply Tulsa Dental, Tulsa, OK, USA) instruments were less resistant to fracture than new ones. Mandel *et al.* (1999) in a study using simulated root canals in resin blocks found that instrument fractures occurred more frequently when operators had no previous training with the use of rotary instruments. Procedural methods that can be used to reduce the potential for rotary instrument fracture include, pre-flaring the root canal with hand instruments to decrease the risk of binding (Roland *et al.* 2002), and using a pecking motion which does not allow the rotating instrument to stay in one position within the canal and prevents the development of torsional stress which can lead to cyclic fatigue and fracture (Haikel *et al.* 1999, Sattapan *et al.* 2000a, Li *et al.* 2002).

Although techniques have been devised to successfully attempt the removal of fractured instruments from root canals, the retrieval of fractured instrument fragments without further complications is difficult and unpredictable (Hulsmann & Schinkel 1999, Ward *et al.* 2003). Clinicians must consistently be attentive to the factors that can influence the risk of rotary instrument fracture and take precautions to prevent it (Blum *et al.* 2003, Martin *et al.* 2003).

The purpose of this study was to determine the incidence of nickel–titanium rotary instrument fracture, for dental students using a standardized endodontic instrumentation technique, during a dental school laboratory simulation course.

Materials and methods

The proposal and protocol for this research was reviewed and granted an exempt status by the University Institutional Review Board.

Setting

This study was conducted at New York University, College of Dentistry, within an endodontic pre-clinical laboratory course for dental students, when nickel–titanium rotary instruments were first introduced into the endodontic instrumentation technique curriculum in January 2003.

Subjects

A total of 360 dental students participated in this laboratory simulation, under close supervision of faculty, with one instructor for 12 students.

Simulation

This laboratory simulation was an endodontic educational and technical course for dental students as a prerequisite to their clinical practice experience and was designed to teach students how to use rotary instruments effectively and efficiently for the preparation of root canals and avoid fracture during instrumentation. Therefore, appropriate measures for preventing fracture were incorporated into the laboratory simulation exercise protocol.

Two plastic teeth (Kilgore International, Coldwater, MI, USA), consisting of one maxillary central incisor and one mandibular first molar, for a total of four simulated canals of consistent size, shape, and length in clear plastic blocks, and two autoclave-sterilized extracted teeth, consisting of one anterior or premolar tooth with a single canal and one molar tooth with three canals, for a total of four root canals, were used in a hand-held manner by each student. Extracted teeth collected by students were radiographically examined prior to selection for simulation exercises. Teeth with pulpal calcifications, extremely large canals, root dilacerations, open apices, lengths of over 25 mm, or extensive restorations were excluded. The roots of the selected extracted teeth were set in 2.5 cm^3 plaster blocks with crowns exposed and then radiographed to obtain a preoperative working length.

According to the manufacturer's specifications, the plastic simulated teeth consisted of an anatomically correct crown affixed to a clear plastic root block with a single straight canal for the maxillary central incisor, and three moderately curved canals with angles of curvature ranging between 10 and 20° for the mandibular first molar. These simulated canals were oval shaped in cross-section, and had a minor diameter of 0.10 mm and a major diameter of 0.30 mm, at their apical ends. The oval canal orifice diameters were 1.4 × 2.4 and 2.4 × 4.2 mm for the maxillary central incisors and mandibular first molars, respectively. The length measurement of the maxillary central incisor from the incisal edge to the canal terminus was 25 mm. The length measurement for the mandibular molar canals, from their corresponding cusp tips to their apical termini, were mesiobuccal 18 mm, mesiolingual 17 mm and distal 19 mm. These plastic-simulated root canals became abruptly narrow 5 mm from their apical ends.

Instrumentation

Prior to commencement of the laboratory exercise, the dental students viewed a descriptive video presentation and received a comprehensive lecture with detailed instructions on the standardized endodontic instrumentation technique which they used and precisely followed during the simulation course. Students had a heightened awareness of the possibility of rotary instrument fracture and knew that fracture, although an iatrogenic complication, would not affect their performance evaluation. Rather, if it occurred, the detection and reporting of it would demonstrate their attentiveness and compliance with clinical and ethical standards of care. Each student used eight brand new ProFile nickel–titanium rotary instruments to prepare four simulated root canals in two simulated plastic teeth (one maxillary central incisor with one canal and one mandibular molar with three canals) and another set of eight new ProFile nickel–titanium rotary instruments, to prepare four root canals in two extracted teeth (one single canal tooth and one molar with three canals). After proper coronal access was accomplished using sizes 6 and 4 round burs (SS White Inc., Lakewood, NJ, USA) in high and low speed handpieces, the pulp chambers were cleaned, the root canal orifices were located, and the root canal working lengths were determined. For plastic teeth, a 25 mm long, size 10 stainless steel hand K-File (Brassler Inc., Savannah, GA, USA), with a rubber stop on its shaft for reference, was placed to within 1 mm of the apical end of the simulated root canal and visualized through the clear plastic root block to establish the working length. For extracted teeth, a 25 mm long stainless steel hand K-File (Brassler Inc.), with a rubber stop on its shaft for reference was used to assess working length. The largest file size of which would fit and negotiate the apex to the pre-operative working length was inserted into the canal, radiographically examined and adjusted to within 1 mm of the apex to determine the working length measurement. This size was then designated as the first instrument size to fit at working length.

The standardized endodontic instrumentation technique used in this study consisted of the sequential use of seven 25 mm long 0.02 taper stainless steel hand K-Files (Brassler Inc.) from ISO sizes 10–40 in a step-back manner to an apical file size of 20 at working length, followed by three Orifice Shapers (Dentsply Tulsa Dental) sizes 30, 0.06 taper; 50, 0.07 taper; 40, 0.06 taper and then five ProFiles (Dentsply Tulsa Dental) from sizes 40, 0.04 taper to 20, 0.04 taper in a crown-down manner, to achieve at least a final apical size of 30, 0.04 taper, to the full working length. This protocol was used exactly for plastic canals since they had sizes and shapes that were consistently narrow. However, for extracted teeth, with a wide range of canal sizes and configurations, to assure that canals were adequately prepared, the final apical size for the canal preparation had to be at least three sizes larger than the size of the first instrument to fit at working length. If the first instrument to fit was a size 15 then the final apical size had to be at least a size 30. If the first instrument to fit was size 25 or larger, then that was the only one used for hand instrumentation. The student operator then proceeded directly with rotary instrumentation in a crown-down manner as described, with Orifice Shapers and ProFile instruments, to achieve a final apical instrument size for the canal preparation of at least three sizes larger than whatever the size of the first instrument to fit was at working length.

During canal preparation instruments were coated with a lubricating medium of commercially available liquid soap (Purell; Gojo Industries, Akron, OH, USA), and passively placed into canals. Forceful pushing and pulling motions were avoided. Canals were copiously irrigated after each instrument use with tap water delivered into the root canals with a 21 gauge irrigating probe attached to a 5 cc plastic syringe (Max-i-Probe, Dentsply Rinn, Elgin, IL, USA). Hand files were used with a one-quarter turn clockwise rotation apically and a filing motion in the middle and coronal thirds of the canal. Recapitulation with small size hand instruments to full working length was performed during step-back instrumentation. For nickel–titanium rotary instrumentation electric motors (Model AEU-20; Aseptico, Woodville, WA, USA) were used and were set at a rotational speed of 150 rpm and a rotation reversal low torque level of 1 (<1 N cm^{-1}). Rotating instruments were used in the canal with an in and out light pecking or pumping motion for no more than 5 s at any one time for each use during crown-down instrumentation. All instrumented simulated canals in the plastic root blocks and root canals in the extracted teeth were examined by the attending instructors to make sure that they were adequately cleaned and shaped. The standards for proper canal preparation were that the final canal preparation had to be clean, adequately tapered and flared without a deviation or perforation and be able to passively accept the correct final apical instrument size to full working length. These criteria were evaluated by faculty instructors, with instruments as well as by direct visualization for the simulated root canals in clear plastic blocks and by radiographic examination for natural root canals in extracted teeth.

Fracture

During the canal preparation exercises, all rotary instruments were examined by faculty instructors and any that became distorted were collected and replaced with new ones. Students and faculty instructors inspected and measured all rotary instruments after use to detect any length discrepancies and all fractures were reported to the course directors. When rotary fractures occurred, all fractured instruments were collected and replaced with new ones. The remaining canals in the plastic or extracted teeth in which the instruments fractured were prepared and then these teeth were collected. The type and size of the fractured instruments were recorded. The lengths of the fractured instruments were measured, and then those lengths were subtracted from the original instrument lengths to obtain the lengths of the instrument fragments remaining in the canals. The clear plastic root blocks and the extracted teeth with instrument fragments were examined independently by three endodontic resident instructors with 2.5× magnification using trans-illumination and radiography, respectively, and the positions of the fragments, whether located in the apical, middle or coronal portion of the canal, were recorded. Radiographs of the extracted teeth were taken both buccolingually and mesiodistally to ascertain the direction of the most prominent curvature of the canals with fragments. The angle of curvature of the root canals with fragments were categorized as straight ($<10°$), moderate (10–25°), or severe ($>25°$), according to the method described by Schneider (1971). The pre-existing curvatures of the simulated canals in the clear plastic blocks with fragments were categorized as either straight for the plastic maxillary central incisor or moderate for the plastic mandibular first molar. At the completion of the laboratory exercise to detect every incidence of fracture all the clear plastic root blocks and extracted teeth used in the exercises were collected, examined and evaluated similarly by three endodontic residents instructors with 2.5× magnification using trans-illumination and radiography, respectively.

Results

A total of 2880 nickel–titanium rotary instruments were used to prepare 1440 simulated root canals in 360 plastic maxillary central incisors with one canal and 360 plastic mandibular first molars with three canals. A further 2880 nickel–titanium rotary instruments were used to prepare 1440 natural root canals in 360 single canal extracted teeth and 360 extracted molars with three canals. A total of 21 ProFile instruments fractured, 12 in plastic canals and nine in natural canals. The overall incidence of fracture was 0.36% (21/5795). The incidence of fracture in plastic canals was 0.41% (12/2898) and in natural canals was 0.31% (9/2897). Of the twelve that fractured in plastic canals, five were in straight canals and seven were in moderately curved canals. Of the nine that fractured in natural canals, two were in moderately curved premolar canals and seven were in severely curved molar canals. Fourteen rotary instruments distorted (six of size 25, 0.04 taper which were used in plastic canals, and two each of sizes 20, 0.04 taper, 30, 0.04 taper, 35, 0.04 taper and 40, 0.04 taper which were used in natural canals).

The data for the fractured instruments are summarized in Table 1. The most common ProFile instrument size that fractured was 25, 0.04 taper (67%). With respect to the position of the fragments in the canals, 17 (81%) fractured in the apical third, four (19%) fractured in the middle third and none fractured in the coronal third. In relation to the curvature of the canals, five (24%) fractured in straight canals, nine (43%) fractured in moderately curved canals, and seven (33%) fractured in severely curved canals. Fragment lengths ranged from 1.5 to 4.5 mm, with a mean, median and mode length, of 3.0 mm.

Table 1 Fractured instrument data ($n = 21$)

ProFile size (tip/taper)	Fractured instruments	Canal type	Canal curvature	Fragment position	Fragment length (mm)
30/0.06	0	–	–	–	–
50/0.07	0	–	–	–	–
40/0.06	0	–	–	–	–
40/0.04	(2)	P (2)	ST (2)	A (2)	3.0 (2)
		N (0)	MD (0)	M (0)	
			SV (0)	C (0)	
35/0.04	(1)	P (0)	ST (0)	A (1)	3.0 (1)
		N (1)	MD (0)	M (0)	
			SV (1)	C (0)	
30/0.04	(3)	P (1)	ST (0)	A (3)	3.0 (2)
		N (2)	MD (2)	M (0)	4.5 (1)
			SV (1)	C (0)	
25/0.04	(14)	P (8)	ST (2)	A (10)	1.5 (0)
		N (6)	MD (7)	M (4)	2.0 (3)
			SV (5)	C (0)	2.5 (5)
					3.0 (3)
					3.5 (1)
					4.0 (1)
					4.5 (1)
					5.0 (0)
20/0.04	(1)	P (1)	ST (1)	A (1)	1.5 (1)
		N (0)	MD (0)	M (0)	
			SV (0)	C (0)	

Number of fractured instruments in parenthesis.
P, plastic; N, natural; ST, straight; MD, moderate; SV, severe; A, apical; M, middle; C, coronal.

Discussion

This appears to be the first study to assess the incidence of nickel–titanium rotary instrument fracture amongst a large number of dental students in a dental school endodontic laboratory simulation course. Since dental students are inexperienced in endodontic instrumentation procedures, it was important that the technique used to accomplish proper root canal preparation included preventive measures to reduce the risk of fracture. Therefore, as a consequence of this, several reasons can be proffered to explain the low incidence of rotary fracture noted in the present study. The low rotational speed and low torque level, which were used during rotary preparation, have been shown to reduce fracture (Gabel *et al.* 1999, Dietz *et al.* 2000, Gambarini 2001a, Zelada *et al.* 2002). Additionally, in a study using nickel–titanium rotary instruments in a crown-down manner to prepare the root canals of extracted molar teeth under access limitations, it was found that a low (<1 N cm^{-1}) torque motor reduced the incidence of fracture when the operator was inexperienced (Yared & Kulkarni 2002a). In the present study, hand instrumentation was performed as a preliminary procedure, since it has been shown that pre-flaring root canals before the use of rotary instruments significantly reduced fracture (Roland *et al.* 2002). Rotating instruments were used in the canals with an in and out light pecking or pumping motion for no more than 5 s with each instrument during crown-down instrumentation, since this type of manipulation has been advocated as a means to reduce torque and cyclic fatigue which are major causes of failure (Haikel *et al.* 1999, Sattapan *et al.* 2000a, Li *et al.* 2002). These procedural measures which were used to avert fractures could have been important contributing factors for the low incidence achieved in this study.

In the present investigation, new sets of rotary instruments were used in both the plastic and natural canals, and this may have decreased the incidence of fracture, as it has been shown that new rotary ProFile instruments are less prone to fracture than those that have been used excessively (Gambarini 2001b). Copious irrigation of the canals to remove debris and the use of a lubricating medium during rotary instrumentation could have reduced considerably the frictional binding of the instruments in the canal and the potential for fracture. Soap and water were used as lubricating and irrigating agents because they were conveniently available, inexpensive and effective for cleaning both plastic and natural canals during instrumentation. Since the rotary instruments that distorted were collected and eliminated, this measure probably reduced the overall fracture incidence because distorted instruments become highly susceptible to fracture with further use (Sattapan *et al.* 2000b).

Student operators strictly followed the standardized instrumentation technique which included specific measures to reduce the risk of instrument fracture. They had a heightened awareness of the possibility of fracture and were careful in using rotary instruments during canal preparation. This general sensitivity on the part of the dental student operators may have influenced the low incidence of instrument fracture. The frequency of instrument fracture was marginally higher in plastic canals than in natural canals even though there were no severely curved plastic canals. Whether or not this was related to the narrow sizes of the plastic canals or the soft nature of resin especially when frictional heat is generated during rotary instrumentation, is speculative. It has been suggested that whilst standardized plastic canals in resin blocks reduce variations in canal length, width and curvature, in comparison with natural canals, they may not actually simulate instrument use in dentine (Yared *et al.* 2003a, Yared & Kulkarni 2003b).

The low incidence (0.41%) of fracture noted in this study for plastic canals differs from that found in a previous study by Mandel *et al.* (1999) in which they reported, that amongst five operators each using sets of five ProFile instruments to prepare 25 resin canals, a total of 21 fractured. Thus, a total of 625 instruments were used in which 21 fractured resulting in a fracture rate of 3.4%. Their higher frequency could be related to their use of both 0.04 and 0.06 taper instruments in resin canals all of which had severe 50° angles of curvature, whereas in the present study only 0.04 taper ProFile instruments were used in plastic canals that were straight or had moderate angles of curvature ranging from 10 to 20°. Other studies although on smaller sample sizes would seem to support a low fracture rate. Thompson & Dummer (1997), Bryant *et al.* (1998, 1999), in studies on ProFile instruments used to prepare a total of 120 simulated root canals in resin blocks, found that only three fractured.

The low incidence (0.31%) of rotary instrument fracture noted in this study for extracted teeth is in agreement with that conducted by Yared & Steiman (2002b), where no fractures occurred with ProFile instruments during the preparation of 120 root canals in extracted teeth. With the large sample of extracted teeth that was used for the present study, where 75% of all the root canals prepared were in molars and the other 25% in teeth with a single canal, it was likely that a large representative portion of the extracted teeth had roots with curved canals. Canal curvatures were classified according to the method described by Schneider (1971). This method was used because it has been widely applied and cited in numerous studies for classifying root canal curvatures (Pruett *et al.* 1997, Gabel *et al.* 1999, Mandel *et al.* 1999, Li *et al.* 2002, Peters & Barbakow 2002, Roland *et al.* 2002). In the present study, the finding for extracted teeth, that seven (78%) of the nine fractured instruments were in severely curved canals of molars, was not surprising and correlates with studies showing that the severity of root canal curvatures significantly increases the chance for rotary instrument fracture (Haikel *et al.* 1999, Booth *et al.* 2003).

In the present study, 67% of the instruments that fractured were of size 25, 0.04 taper, which seems to indicate that smaller instruments may be more prone to fracture than larger sized ones. This finding coincides with other studies performed in which it was found that amongst ProFile instruments the smaller sizes had the greatest number of fractures and distortions (Gabel *et al.* 1999) and that ProFile instruments size 25 fractured more frequently than any other size (Zelada *et al.* 2002). Zelada *et al.* (2002) also showed that ProFile instrument fractures occurred within 5 mm and mostly 1–3 mm from the tip. Additionally, test fractures performed on nickel–titanium rotary instruments have demonstrated that fractures tend to occur close to the tip (Sattapan *et al.* 2000b). The results of these studies support the finding of the present study that showed a strong central tendency for a small fragment, with a mean, median and mode of 3 mm.

The low overall incidence (0.36%) of instrument fracture found in this study was based on the total number used. However, if the total number used to prepare ($360 \times 8 \times 4 = 11\ 520$) plastic canals and ($360 \times 8 \times 4 = 11\ 520$) natural canals, the percentage in which instruments fractured is ($21/23\ 040 = 0.09\%$), representing the probability for an instrument fracture, since every time a rotary instrument is used to prepare a canal, there is a chance of fracture. Therefore, in this study the chance of an occurrence of an instrument fracture during preparation was about one in a thousand canals.

In summary, the factors that could have contributed to the low incidence of nickel–titanium rotary instrument fracture in this laboratory simulation assessment are enumerated as follows:

1. Using an electric motor with low rotational speed and low torque settings.
2. Pre-flaring root canals with hand files before rotary instrumentation.
3. Manipulating rotary instruments with a light pecking motion for 5 s.
4. Using new sets of rotary instruments.
5. Lubricating instruments and irrigating canals during preparation.
6. Discarding distorted instruments.
7. Being aware of the possibility of instrument fracture.

The combined application of all of these precautions more than likely had an influence on the fracture assessment outcome of this laboratory simulation study.

Conclusion

The low overall incidence of nickel–titanium rotary instrument fracture (four per thousand) demonstrates that these instruments are safe for use by inexperienced dental student operators in endodontic laboratory exercises. It also suggests that if appropriate preventive measures are taken the incidence of fracture may be greatly reduced.

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