

Rotary NiTi Instrument Fracture and its Consequences

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Abstract

The fracture of endodontic instruments is a procedural problem creating a major obstacle to normally routine therapy. With the advent of rotary nickel-titanium (NiTi) instruments this issue seems to have assumed such prominence as to be a considerable hindrance to the adoption of this major technical advancement. Considerable research has been undertaken to understand the mechanisms of failure of NiTi alloy to minimize its occurrence. This has led to changes in instrument design, instrumentation protocols, and manufacturing methods. In addition, factors related to clinician experience, technique, and competence have been shown to be influential. From an assessment of the literature presented, we derive clinical recommendations concerning prevention and management of this complication. (*J Endod* 2006;32:1031–1043)

Key Words

Fracture, instrument design, instrumentation protocols, rotary nickel-titanium instruments

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0099-2399/\$0 - see front matter

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doi:10.1016/j.joen.2006.06.008

In the practice of endodontics, clinicians may encounter a variety of unwanted procedural accidents and obstacles to normally routine therapy, at almost any stage of treatment (1). One of these procedural problems is intracanal instrument fracture. Fractured root canal instruments may include endodontic files, Gates Glidden burs, lateral or finger spreaders, and paste fillers (Fig. 1), and they can be made from nickel-titanium (NiTi), stainless steel or carbon steel. Fracture often results from incorrect use or overuse of an endodontic instrument (2), and seems to occur most commonly in the apical third of a root canal (3–6). The relatively recent advent of rotary NiTi root canal instruments has led to a perceived high risk of instrument fracture (6). Furthermore, fracture of rotary NiTi instruments may occur without warning (5, 7–10), even with brand new instruments, whereas fracture of stainless steel files is preceded by instrument distortion serving as a warning of impending fracture. In any case, distortion of rotary NiTi instruments is often not visible without magnification (11–13).

The potential difficulty in removing instrument fragments (14, 15) and a perceived adverse prognostic effect of this procedural complication is a main reason for resistance to adoption of this innovation (6, 16). Consequently, a great deal of research has been undertaken to understand the reasons for instrument fracture and how it may be prevented rather than treated. The purpose of this review is to summarize current understanding of the prevalence, causes, management of instrument fracture and its impact on prognosis, and to make recommendations concerning clinical decision-making associated with fractured rotary NiTi instruments.

Prevalence

A common clinical belief within the dental profession is that rotary NiTi instruments fracture more frequently than stainless steel hand instruments. This perception is based primarily on anecdotal evidence diffused via informal communication channels (16), on *in vitro* or *ex vivo* research (17), but possibly also on studies that have examined clinically discarded instruments (13, 18, 19). Sattapan et al. (18) reported a fracture frequency of 21% from 378 discarded Quantec instruments collected over a six-month period from a specialist endodontic practice. A larger study involving 7,159 discarded rotary NiTi instruments from 14 endodontists worldwide reported a much lower frequency of 5% (13). The recent paper by Alapati et al. (19) found a similar rate of 5.1% of 822 rotary NiTi instruments discarded from a graduate endodontic clinic. On the other hand, a study by Arens et al. (10) reported a fracture incidence of 0.9% of 786 new rotary NiTi instruments that had only been used once in cases of varying degrees of difficulty in a specialist endodontic practice.

Although such studies on discarded instruments provide interesting data, they cannot be considered representative of the far more clinically important issue of *retained* fractured instruments. These studies are not able to provide data on instruments retained in the canals or instruments fractured and successfully removed, because they are based only on collections of used instruments. Only a small number of studies have looked specifically at how frequently a fractured instrument is left behind in a canal. A review of the literature reveals that the mean prevalence of retained fractured endodontic hand instruments (mostly stainless steel files) is approximately 1.6%, with a range of 0.7 to 7.4% (3, 20–31). It should be noted that many of these studies are outcome studies that did not specifically evaluate prevalence of instrument fracture. On the other hand, the mean clinical fracture frequency of rotary NiTi instruments is approximately 1.0% with a range of 0.4 to 3.7% (4, 28, 30–34) (Table 1). Hence, based on the best available clinical evidence the frequency of fracture of rotary NiTi instruments may actually be lower than that for stainless steel hand files. It is important to remember that

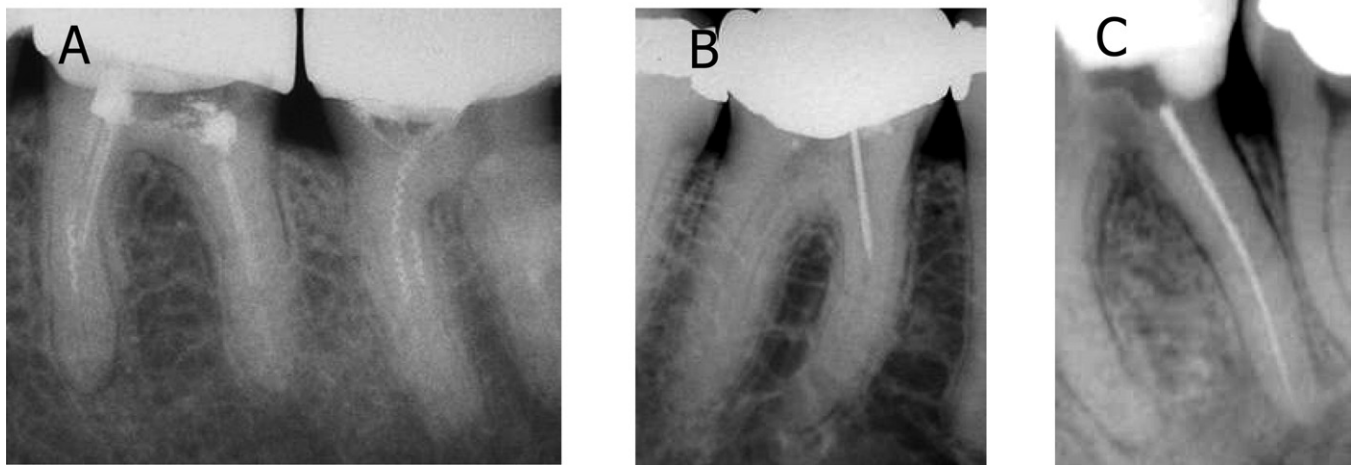


Figure 1. Examples of various types of fractured endodontic instruments. (A) Lentulo-spiral burs, (B) Gates Glidden drill, (C) whole length of a rotary NiTi instrument (courtesy of Dr. Peter Spili).

reasons for fracture of rotary NiTi instruments are complex and multifactorial, one of the most important of which may be the operator’s skill and experience (4, 9, 13, 35–40). Operator-related factors such as their proficiency with the instruments and the decision on the number of uses of the instruments (13) may help to explain the variation in the prevalence of fractured instruments reported among the various studies.

Metallurgy and Fracture

NiTi alloys are one of several shape memory alloys, but they have the most important practical applications in dentistry because of their biocompatibility and corrosion resistance (41, 42). Their super-elasticity, shape memory effect, and corrosion resistance have led to the alloy having many dental, medical, and commercial applications (42). The properties of the alloy occur as a result of the austenite to martensite transition, which in turn is because of the alloy having an inherent ability to alter its type of atomic bonding (42, 43). The martensitic transformation requires a reversible atomic process termed twinning that allows reduction of strain during the transformation (42). A disadvantage of NiTi alloy is its low ultimate tensile and yield strength compared with stainless steel, making it more susceptible to fracture at lower loads (44). This property may play a role in the influence of the operator on fracture prevalence as discussed above.

In general, fracture of metals can be classified as either brittle or ductile (45). Ductility refers to the ability of a material to undergo plastic deformation before it breaks, whereas brittle fractures are asso-

ciated with little or no plastic deformation. Hence, brittle fractures usually occur in metals with poor ductility. Typically there is an initiation of cracks at the surface of the metal, and stress concentration at the base of the crack results in its propagation either along grain boundaries (intergranular) or between specific crystallographic planes (cleavage fracture) (45). The crack thus behaves as a stress-raiser, because an applied load, instead of being spread over a smooth surface, will be concentrated at one point or area. The unit stress applied will be much higher and can exceed the tensile strength at that point or surface (46).

Examination of a fracture surface (fractography) using the scanning electron microscope (SEM) (Figs. 2-4) usually reveals certain distinct features that help identify the type of fracture mechanism involved (47). In brittle fractures crack fronts create ridges that spread along different planes within the alloy and generally radiate away from the origin of the crack, producing the so-called chevron pattern (48). In ductile fractures microvoids are produced within the metal and nucleation, growth, and microvoid coalescence ultimately weaken the metal and result in fracture (45). Plastic deformation because of slip, the process by which a dislocation moves in response to shear stresses, also contributes to ductile fracture. The fracture surface resulting from these two processes is generally characterized by a dull dimpled surface. The shape and slope of the dimples may indicate the type of load applied as well as the origin of the fracture. For example, round dimples indicate normal rupture caused by tensile stresses, whereas oval or elongated dimples suggest tearing or shear forces. Oval-shaped dimples generally point toward the origin of the fracture (45). Features of both brittle and

TABLE 1. Studies reporting clinical prevalence of fractured instruments

| Authors | Canals (n) | Files (n) | % |
|-----------------------------|------------|------------------------|------|
| Ramirez-Salomon et al. (32) | 162 | 6 (but 5 bypassed) | 3.70 |
| Pettiette et al. (28) | 570 teeth | 2 | 0.35 |
| Al Fouzan (4) | 1,457 | 21 (but 7 bypassed) | 1.44 |
| Schäfer et al. (33) | 110 | 2 | 1.81 |
| Kohli et al. (30) | 12,038 | 81 | 0.67 |
| Leseberg et al. (34) | 3,530 | 50 | 1.41 |
| Spili et al. (31) | 23,456 | 235 (but 32 retrieved) | 1.00 |
| Totals | 40,753* | 397 | 0.97 |

*The totals in this row do not include the data from the Pettiette et al. paper because the number of canals is not known. However, even if each tooth was considered to have three canals, the overall percentage would decrease by only 0.05%.

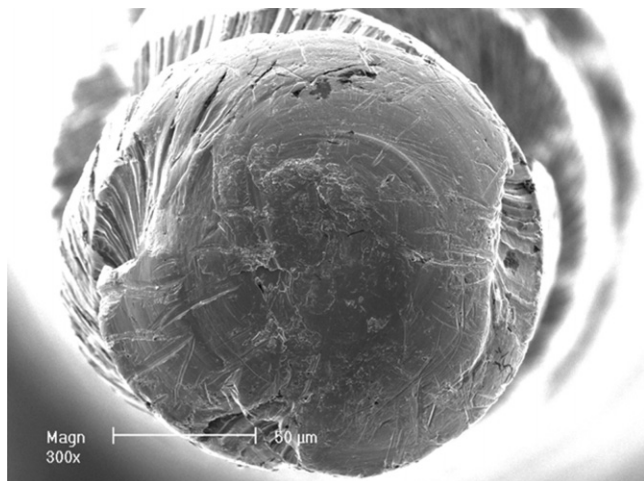


Figure 2. Severe distortion of fracture surface of ProFile instrument clinically torsionally fractured. The extent of distortion is apparent when compared with the undistorted surfaces of Figs. 34 and 44.

ductile fractures have been identified in fractured rotary NiTi endodontic instruments (19, 49–51).

Metal fatigue results from repeated applications of stress, leading to cumulative and irreversible changes within the metal. It may be caused by tensile, compressive, or shear forces as well as corrosion, wear, or changes produced by thermal expansion and contraction (46). Fatigue crack growth can be identified by striation marks on fracture surfaces, and has been demonstrated in fractured rotary NiTi instruments (51–53). Most of the few studies that have assessed fractured rotary NiTi instruments microscopically suggest that metal fatigue leads to ductile fracture (7, 51–56). However, recent evidence suggests that fracture may occur following a single overload event, based on observations of the absence from the fracture surface of the characteristic striations associated with fatigue fracture (19, 57).

Fractured rotary NiTi instruments have been classified into those that fail as a result of cyclic flexural fatigue or torsional failure (18) or a combination of both (41). This is based on low power microscopic examination of the lateral surfaces of instruments subsequent to laboratory fracture experiments (18, 58). Recently, Cheung et al. (56) have questioned this classification suggesting that fractography techniques are required. Borgula (51) found that accurate SEM examination of fracture surfaces of clinically used instruments was infrequently possible because of the severe distortion of the surface, presumably because of rubbing of the fragments immediately upon fracture (Fig. 2). However, in a laboratory follow-up ensuring no or minimal rubbing of fracture surfaces, Borgula (51) confirmed that the lateral inspection classification was validated under the SEM examination of the fracture surfaces. Clearly, these differing findings highlight the great difficulty in accurate assessment of clinically used instruments because of the distortion they often suffer in complex root canal anatomy.

Cyclically fatigued instruments show no macroscopic evidence of plastic deformation, but instruments that fracture as a result of torsional overload demonstrate variable deformation such as instrument unwinding, straightening, reverse winding, and twisting (13, 18). NiTi instruments rotating around a curvature for a prolonged period of time are subjected to repeated tensile and compressive stresses such that during each rotation the inner surface of the instrument is compressed and the outer surface is under tension. This results in work hardening within the metal and initiation of cracks leading to eventual cyclic flexural fatigue.

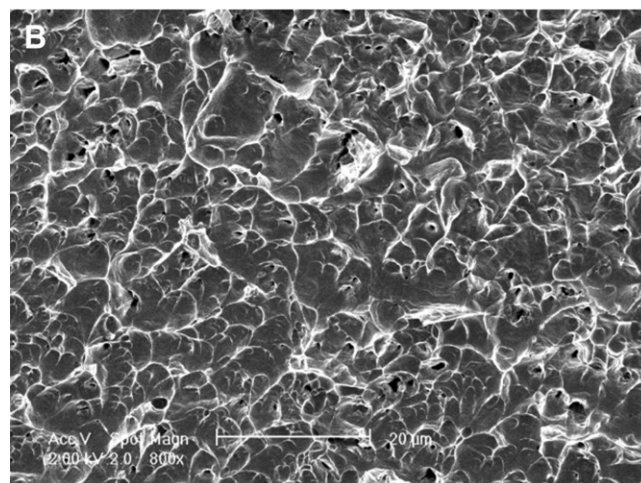
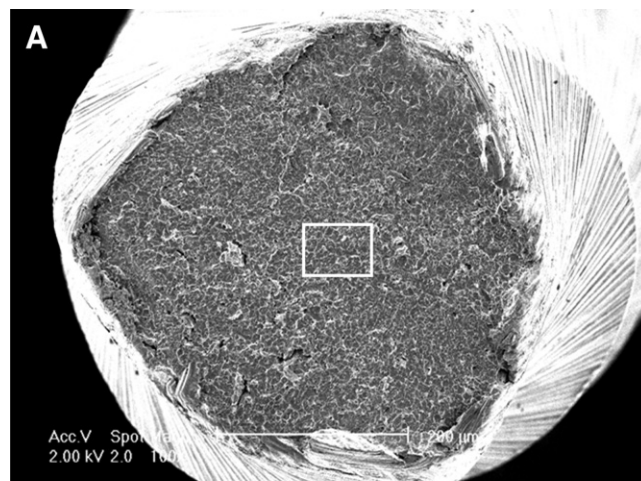


Figure 3. (A) Fracture surface of rotary NiTi instrument demonstrating the characteristic dimpling resulting from flexural (cyclic) fatigue. The dimpling involves the whole fracture surface. Boxed region magnified in (B). (B) Higher magnification of the dimpling. There is also evidence of the presence of microvoids (black dots).

Factors Predisposing to Fracture

In many cases, rotary NiTi instrument fracture occurs because of incorrect or excessive use (2, 18), which stresses the importance of correct training in the use of rotary NiTi technology (6, 36, 38). However, many factors have been linked to the propensity for fracture of rotary NiTi instruments and these can be grouped under a number of subheadings, as follows.

Instrument Design

Both cross-sectional area and file design (influencing stress distribution during load) may affect an instrument's resistance to fracture when subjected to flexural and torsional load. Instruments with larger diameters have been found to succumb to flexural fatigue earlier than those with smaller diameters (7, 54), and they appear to have greater internal stress accumulation (59). Borgula (51) and Miyai et al. (60) reported that this relationship was not always the case, possibly because of tests that do not accurately simulate clinical use, or because of alloy characteristics. However, an increase in instrument diameter and corresponding increase in cross-sectional area may contribute to increased resistance to torsional failure (51, 61, 62). On the other hand,

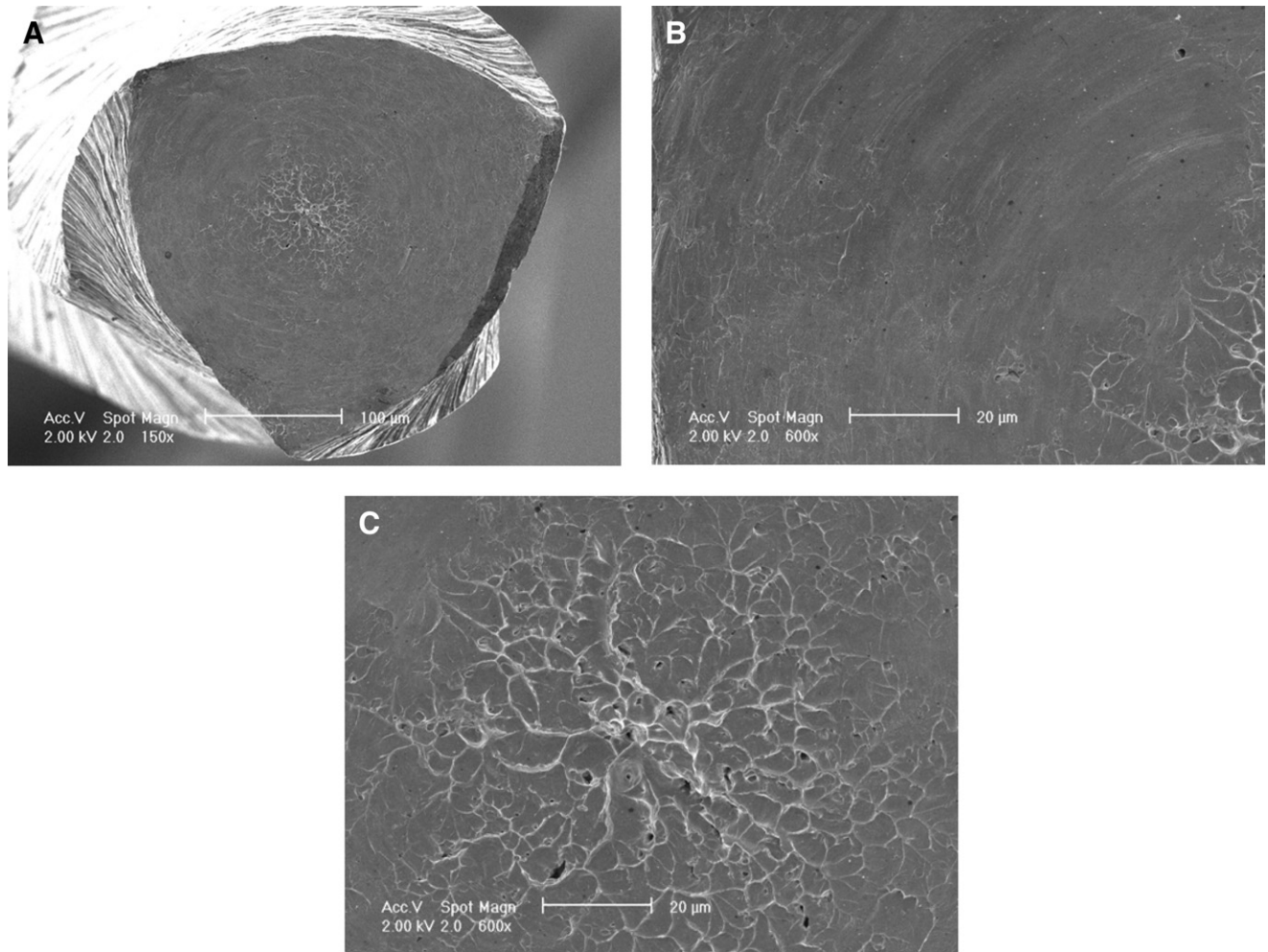


Figure 4. (A) Fracture surface of rotary NiTi instrument demonstrating the characteristic smooth surface [magnified in (B)] and central dimpling [magnified in (C)] resulting from torsional failure. (B) Higher magnification of the smooth surface demonstrating the presence of microvoids. (C) Higher magnification of the central dimpling, again also demonstrating the presence of microvoids.

other work has found no difference in frequency of fracture of different instrument designs in *ex vivo* work (5).

Mathematical modeling to evaluate the effect of the design of rotary NiTi instruments has concluded that instruments with a U-flute design and smaller cross-sectional area were more flexible than the triangular triple-helix design, but weaker when subjected to torsional stress (63, 64). However, stress distribution in the triangular ProTaper instruments was more favorable, being lower and more evenly distributed than in U-fluted ProFile instruments, suggesting that ProTaper instruments may be stronger because of their ability to resist external forces more effectively (64). Schäfer et al. (65) confirmed experimentally the relationship between cross-sectional area and flexibility by comparing five popular brands of rotary NiTi instruments (FlexMaster, Hero 642, K3, ProFile, and RaCe). They reported that the ProFile and RaCe instruments were most flexible, whereas K3 instruments, with the largest cross-sectional area, were the stiffest.

Other design factors that may affect instrument fracture include brand of instrument (i.e. alloy composition), instrument size, and taper (13). Flute pitch length may also affect fracture (66), but the ratio of the dimensions of the shank to the dimensions of the flute (shank-to-flute ratio) is preserved with instrument taper and so is not a contributing factor to the occurrence of fracture (67).

Manufacturing Process

Very importantly, during the manufacture and processing of NiTi alloy, a variety of inclusions, such as oxide particles, may become incorporated into the metal resulting in weaknesses at grain boundaries. Some surface voids of rotary NiTi instruments are presumed to be because of small amounts of oxygen, nitrogen, carbon, and hydrogen dissolving in the alloy to form various precipitates (19, 68). Cracks may then propagate along these boundaries (48). Furthermore, the manufacture and machining of rotary NiTi instruments often results in an instrument having an irregular surface characterized by milling grooves, multiple cracks, pits, and regions of metal rollover (19, 51, 69–75). These irregularities have been recently confirmed in a topographic study of rotary NiTi instruments using atomic force microscopy that also found more surface irregularities with instruments of greater taper (76). Possibly, more surface irregularities may occur on instruments manufactured using a more complex process such as that required for instruments of greater taper (76). These sites may act as areas of stress concentration (stress raisers) and crack initiation during clinical use (41, 72). The direction of the cracks is usually approximately perpendicular to the long axis of the instrument but the presence of axially propagating cracks connecting pitted regions has been recently reported (19, 51). Such axial cracks may be because of the shear

stresses of torsional load, leading to axial shear slip in the plastically deformed regions.

An interesting observation by Alapati et al. (75) was the apparent widening of original machining grooves and cracks by embedded dentinal debris after clinical use of rotary NiTi instruments, which the authors proposed caused a wedging action leading to further crack propagation. However, only ultrasonication in ethanol was used to clean the instruments to remove debris before SEM examination, which, on its own, is an unreliable means of cleaning endodontic instruments (77–80). Reliable cleaning of endodontic instruments requires a protocol involving chemical and mechanical steps (79, 80). Furthermore, dentin fragments appear to adhere to deposits of carbon and sulfur resulting from the decomposition and oxidation of the lubricating oil used during machining (81). Hence, the observations of wedged debris (75) may simply have been debris that was tenaciously adherent. In addition, Borgula (51) observed that ultrasonication in ethanol was very poor at debris removal from the actual fracture surfaces of instruments and required a more efficient protocol (80).

X-ray diffraction (XRD) analysis (useful for determining the crystallographic structure of a metal), microhardness tests, and differential scanning calorimetry have confirmed that the manufacturing process leads to work hardening of rotary NiTi instruments resulting in areas of brittleness prone to cracking (72, 82). Such residual stresses, whether tensile or compressive, occur very close to the machined surfaces and have a major influence on the fatigue life of materials (83). Furthermore, the repeated loading and unloading of the instruments during use leads to repetitive transformation of the alloy between the austenitic and martensitic phases, that may then lead to detrimental changes in the mechanical properties of instruments (60). Slight changes in the composition of the NiTi alloy may lead to large changes in mechanical properties (60).

Ion implantation has been proposed as a method of modifying file surfaces to make them more resistant to wear (41, 84), whereas boron implantation produced a NiTi surface harder than stainless steel (85). Physical vapor deposition and thermal metal organic chemical vapor deposition of titanium nitride particles have shown promise (86–88), and cryogenic treatment increased surface hardness of NiTi but not to clinically detectable levels (89). Such implantation techniques are not routinely or commonly utilized by manufacturers, presumably because of cost-effective considerations.

Electropolishing is another method used by some manufacturers to improve the strength of rotary NiTi instruments, and involves a controlled chemical process for surface finishing of metals (90). The process involves the alloy (acting as the anode) being submerged into an electrolytic solution (usually a combination of acids) containing a negatively charged cathode. A low current is passed through the solution, causing selective removal of protruding surface defects for NiTi alloys at a rate of 2.1 to 3.5 $\mu\text{m}/\text{min}$ (91). Electropolishing thus eliminates or reduces the number and extent of surface defects, and preliminary experimental data indicates that the resulting smoother surface of the rotary NiTi instrument results in a stronger instrument that is more resistant to fracture (51). Electropolished instruments survived a higher number of cycles before fracture than nonelectropolished instruments, but there was no difference in torsional resistance. Nevertheless, surface defects and metal rollover are still occasionally observed after electropolishing (51).

The knowledge base concerning the metallurgy of rotary NiTi instruments and predisposing factors is incomplete but continues to grow rapidly. We need more information but manufacturers need to take note of the increasing influence that manufacturing defects have on fracture frequency.

Dynamics of Instrument Use

The speed at which instruments operate seems to have no effect on the number of cycles to fracture, but higher speeds reduce the period of time required to reach the maximum number of cycles before fracture (92–94). Some authors have reported that the rotational speed of instruments did not seem to influence the frequency of file fracture (36, 95), which does not agree with other studies (11, 93, 94, 96, 97) but may have been because of varying test conditions, different operators, and different instrument types. Thus, the effect of speed is uncertain at this time.

No difference in instrument fracture was reported when air driven or electric handpieces were used (98). However, the use of an electric low torque motor may limit damage to instruments clinically and ultimately reduce the risk of cyclic flexural fatigue (99). On the other hand, Berutti et al. (39) found that rotary NiTi instruments worked better at high torque, speculating that the auto-reverse function at low torque may result in unnecessarily stored stress thus reducing the instrument's useful life. Similarly, Bahia et al. (100) found that an accumulation of internal stresses did not produce unfavorable changes in the superelastic properties of NiTi but will eventually lead to fatigue failure of the instruments. Yared et al. (36, 101) observed that high torque was safe for experienced operators and that novices would benefit most from low-torque controlled motors. However, it has been noted that the torque values indicated on various electric motors may, in any case, be unreliable (102–104).

Light apical pressure and brief use of instruments may contribute to prevention of fracture of rotary NiTi instruments (12), as may a continuous pecking motion (92).

Canal Configuration

Instruments subjected to experimental cyclic stress fracture at the point of maximum flexure, which corresponds to the point of greatest curvature within the tube (7, 54). Files fractured with fewer rotations as the radius of curvature decreased or the angle of curvature increased, and similar results have been reported for other instrument types (92, 93). A reduction in the radius of curvature similarly reduces the instrument's ability to resist torsional forces (105, 106). Along the same lines, instrumentation of teeth with complex root canal anatomy (107–109) may lead to torsional failure. The effect of double curvatures has not been reported but the consequences of stresses on the instrument intuitively would be the same as for single curvatures although occurring at more than one site.

Preparation/Instrumentation Technique

During canal preparation, taper lock (107) and the familiar clicking sound may be produced by the repeated binding and release of the rotary instruments during canal preparation, which together with the repeated locking of the instrument during dentin removal (110) could subject these instruments to higher torsional stress. Schrader and Peters (111) have found that varying instrumentation sequences and using combinations of different tapers seemed to be safer regarding torsional and fatigue failure, but necessitates using a greater number of instruments. Instrumentation sequences recommended by manufacturers may lead to difficulty in preventing the instruments being drawn into the canal, and may require the clinician to develop modified instrumentation sequences to avoid binding and threading (112, 113). Further, vertical load on the instruments decreases with instrument designs that minimize the contact area between the instrument and the root canal walls (110, 114).

Importantly, preflaring of the root canal with hand instruments before use of a rotary NiTi instrument (115) creates a glide path for the

instrument tip and is a major factor in reducing the fracture rate of rotary NiTi instruments (39, 116, 117).

Number of Uses

Partially fatigued instruments, when flexed, reveal fractures associated with surface flaws (7), and prolonged clinical use of rotary NiTi instruments significantly reduces their cyclic flexural fatigue resistance (2, 53, 61, 118, 119). Svec and Powers (120) found signs of deterioration of all instruments in their study after only one use. However, others have reported that rotary NiTi instruments may be used up to ten times, or to prepare four molar teeth, with no increase in the incidence of fracture (12, 121, 122). Furthermore, no correlation has been found between number of uses and frequency of file fracture (13). Therefore, it can be concluded from these differing findings and recommendations that the number of uses of rotary NiTi instruments will depend on a number of variables including instrument properties, canal morphology, and operator skill.

Manufacturers continue to give advice concerning recommended number of uses and most advocate discarding instruments after the preparation of one severely curved canal (123), but offer no real basis for their recommendations (4). The discrepancies among many studies concerning reasons for instrument fracture related to number of uses as well as torque, speed, and motors in general, may be fundamentally related to operator proficiency, including the finding that operators may use a characteristic range of force on instruments regardless of the file type or size (124). Therefore, advocacy for single use of rotary NiTi instruments for reasons of reducing fracture frequency (10) is not supported by the literature (13) and is best regarded as an opinion.

Cleaning and Sterilization Procedures

The issue of influence of sterilization of the instruments on their resistance to fracture is still uncertain, with the literature not reaching a consensus (41, 52, 120, 125–128), but it seems not to be an important factor in the fracture of NiTi instruments (40).

Corrosion of NiTi instruments potentially could influence their mechanical properties and lead to fracture, and this is a relevant concern given that sodium hypochlorite (NaOCl) is used as a root canal irrigant and lubricant during rotary NiTi instrumentation of root canals, as well as a cleaning solution for endodontic instruments (79). However, it has been shown that NaOCl did not significantly reduce the torque at fracture or the number of revolutions to flexural fatigue of NiTi instruments (129) and was unlikely to cause pitting or crevice corrosion of NiTi instruments (130). Similarly, Haikel et al. (131) reported that mechanical properties of NiTi instruments were not affected by NaOCl, nor was the cutting efficiency (132). Nevertheless, at concentrations of 5 to 5.25%, NaOCl can lead to measurable corrosion (133).

From the available information it is apparent that we still do not fully understand the mechanisms of fracture of rotary NiTi instruments nor can we predict when it will occur. However, we can predict how it will occur, and often when it occurs we can determine why it has occurred, which are major steps toward prevention of instrument fracture. An appreciation of root canal morphology, particularly the angle and radius of curvature, should alert the clinician to adopt techniques to minimize the torsional and flexural forces on the instruments. The literature highlights the importance of undertaking training in the correct techniques of use of rotary instruments, and it is essential that this training be sought from experienced clinicians. Although there are many techniques and types of rotary NiTi instruments currently available (40, 109, 134–140) the recommendations given by all authors concerning the safety of rotary NiTi use are very similar. These include the following guidelines, but no less important is operator competence and experience (13, 109).

In summary, to minimize the risk of fracture in clinical practice, the following guidelines are recommended:

- Always create a glide path and patency with small (at least #10) hand files.
- Ensure straight line access and good finger rests.
- Use a crown-down shaping technique depending on the instrument system.
- Use stiffer, larger, and stronger files (such as orifice shapers) to create coronal shape before using the narrower, more fragile instruments in the apical regions.
- Use a light touch only, ensuring to never push hard on the instrument.
- Use a touch-retract (i.e. pecking) action, with increments as large as allowed by the particular canal anatomy and instrument design characteristics.
- Do not hurry instrumentation, and avoid rapid jerking movements; beware of clicking.
- Replace files sooner after use in very narrow and very curved canals.
- Examine files regularly during use, preferably with magnification.
- Keep the instrument moving in a chamber flooded with sodium hypochlorite.
- Avoid keeping the file in one spot, particularly in curved canals, and with larger and greater taper instruments.
- Practice is essential when learning new techniques and new instruments.

Impact on Prognosis

The prognostic impact of a retained fractured instrument on endodontic treatment and retreatment has been investigated in only a few studies, most of which are based on either small numbers of cases (Table 2) or an unknown number (23, 141, 142). Insufficient sample sizes do not allow any meaningful comparisons with other studies nor do they constitute adequate evidence. Furthermore, case series studies offer only a low level of evidence in the levels of evidence hierarchy (143, 144). The only two true case-control studies are those of Crump and Natkin (3) and Spili et al. (31). Importantly though, retrospective case-control studies realistically and ethically provide the highest level of evidence for such studies of the impact of fractured instruments on treatment outcome.

Strindberg's (20) follow-up investigation of factors related to the results of pulp therapy, was the first published study to report on the influence of retained fractured instruments on the prognosis of endodontic treatment. While reporting a 19% lower rate of healing when a fractured instrument was present, this study was based on only 15 fractured-instrument cases, of which only four were associated with periapical lesions; cases of incomplete healing were categorized as failure. Strindberg suspected that prognosis would be poorer in the presence of a periapical radiolucency (20). Further, he speculated that in cases where there was intracanal infection apical to the retained fragment, subsequent conservative therapy alone would probably not eradicate such infection or eliminate its potential consequences. Grossman (145) substantiated Strindberg's speculation by reporting that prognosis was considerably reduced only for fractured-instrument cases with a concomitant preoperative periapical lesion. This radiographic case-series survey involved 66 (mainly molar) root-filled teeth with fractured carbon steel instruments (seven projecting beyond the apex) that were treated in a university clinic, and had an average follow-up period of 2 years. The reported healing rate for fractured-instrument cases was considerably lower in the presence of a periapical lesion (47% versus 89%).

Similar conclusions were published by Fox et al. (146) who conducted a study to evaluate the intentional obturation of root canals with

TABLE 2. Studies reporting the effect on healing, overall and in the presence and absence of a preoperative periapical radiolucency, of a retained fractured instrument on the outcome of endodontic treatment (based on the more detailed summary by Spili et al 2005)

| Study | Lesion <i>n</i> | No lesion <i>n</i> | Healing <i>n</i> | Effect* |
|----------------------------|-----------------|--------------------|------------------|----------|
| Strindberg (20) | 2/4 | 9/11 | 11/15 | Reduced† |
| Engström et al. (21) | NR | NR | 6/9 | Nil |
| Engström and Lundberg (22) | 0 | 5/5 | 5/5 | Nil |
| Grossman (140) | 9/19 | 42/47 | 51/66 | Reduced† |
| Crump and Natkin (3) | 27/29 | 21/24 | 48/53 | Nil |
| Fox et al. (146) | NR | NR | 93/100 | Reduced† |
| Kerekes and Tronstad (24) | NR | NR | 9/11 | Reduced† |
| Cvek et al. (25) | 3/4 | NA | 3/4 | NR |
| Sjögren et al. (26) | NR | NR | 9/11 | NR |
| Molyvdas et al. (147) | 8/11 | 32/35 | 40/46 | Reduced† |
| Spili et al. (31) | 51/56 | 62/63 | 113/119 | Nil |
| Totals | 90/123 (73%) | 171/185 (92%) | 388/439 (88%) | |

*Reduced only in the presence of a necrotic pulp or when a preoperative periapical lesion was present, NR = not reported.

†Included incomplete healing cases.

files. These researchers performed a radiographic examination of 304 predominantly molar teeth that were filled with broken carbon steel or stainless steel hand files either accidentally (33% of cases) or intentionally (67% of cases) and followed for at least 2 years. They concluded that the presence of a periapical radiolucency rather than the fractured instrument *per se* was the cause of treatment failure. Also, they recommended that, in cases of intracanal file breakage, orthograde endodontic treatment should be completed with incorporation of the fractured instrument into the final obturation and the tooth then kept under observation. Molyvdas et al. (147) also stressed the negative prognostic influence of pre-existing periapical pathology in such cases. Forty-six root-filled teeth with 70 retained fractured instruments in 66 canals were followed-up, with no controls, over an average of 32 months. The authors also distinguished between vital and necrotic pulps preoperatively, reporting healing rates of 100% and 75%, respectively. Additionally, prognosis was more favorable when the fractured instrument was bypassed. The classic Washington study also concluded that treatment outcome was unaffected by a retained fractured instrument (142). During the 8 years of the study only one case of the 104 failures from 1,229 cases at the 2-year recall could be attributed to a broken instrument. The authors hypothesized that a broken instrument itself could serve as an adequate root canal filling, thereby supporting the views of Fox et al. (146).

Conversely, some studies report no effect on the healing of root-filled teeth with a retained instrument fragment. The study of Crump and Natkin (3) was a well-controlled clinical study drawing from a pool of 8,500 endodontic cases. These cases involved predominantly silver cone obturation and were treated by supervised University of Washington dental students between 1955 and 1965. Of these, 178 cases were found to have a retained fractured hand instrument that was either stainless steel or carbon steel. Most instrument fragments were located within a range of ± 1 mm of the radiographic apex and only two were bypassed. The 178 fractured-instrument cases were matched with nonfractured-instrument controls for four potential outcome-influencing variables, including presence or absence of a preoperative periapical lesion. Fifty-three matched pairs (mainly maxillary and mandibular molars) with a 2-year minimum clinical and radiographic recall were available for assessment. Masked and standardized radiographs of all matched-pair cases were evaluated by an independent, noncalibrated examiner. Additional unmatched, potentially prognostic variables, such as preoperative pulpal status and root filling quality, were also evaluated for both groups after radiographs were unmasked. Cases that showed incomplete healing of less than 75% or a widened periodontal ligament space of up to 1 mm at final recall were judged as uncertain. No statis-

tically significant difference in failure rates between the fractured-instrument and control groups was found, even when the uncertain cases were treated as either successes or failures, or when the preoperative pulpal and periapical status were considered. Additionally, two potentially important prognostic variables not assessed in any other study to date, specifically, inadequate size and apical extent of the fractured instrument, had no impact on prognosis. The authors therefore concluded that a retained fractured instrument *per se* generally did not adversely affect endodontic case prognosis. In agreement with Fox et al. (146), the authors suggested that in most cases, regardless of the pre-treatment pulpal and periapical diagnosis, a fractured instrument should be left in the canal and conservative endodontic treatment should then be completed coronal to the retained fragment, and the case then placed on periodic review.

Overall, the conclusions of many of these papers have been subjective, contradictory, and unsubstantiated, and were based on small and often unstated numbers of cases. A major shortcoming of most of these studies is that the effect of only one factor was studied without regard for other variables (20). Furthermore, these studies were based on carbon- or stainless steel instruments.

Recently, Spili et al. (31) published the first outcome study to investigate the influence of retained fractured rotary NiTi instruments on the prognosis of endodontic treatment. From a pool of 8,460 cases, the authors conducted a case control study of 146 teeth with a retained fractured instrument (plus 146 matched controls), for which clinical and radiographic follow-up of at least 1 year was available. Radiographs were masked and assessed by two calibrated examiners. The overall healing rates were very high both for cases with a fractured instrument (91.8%) and for the matched controls (94.5%) but with no statistically significant difference. When a preoperative periapical radiolucency was present, healing was lower in both fractured instrument (86.7%) and control groups (92.9%). A stepwise logistic regression analysis showed that only the presence of a preoperative periapical radiolucency was significantly associated with a reduced chance of healing. This study confirmed yet again that the presence of a preoperative periapical radiolucency rather than the fractured instrument *per se*, is clinically more significant and demonstrates the major negative influence of established and advanced root canal infections (148).

Techniques for Removal

The removal of fractured instruments from the root canal is, in most cases, very difficult and often ineffective (149). Various methods have been proposed for removing objects fractured and/or wedged

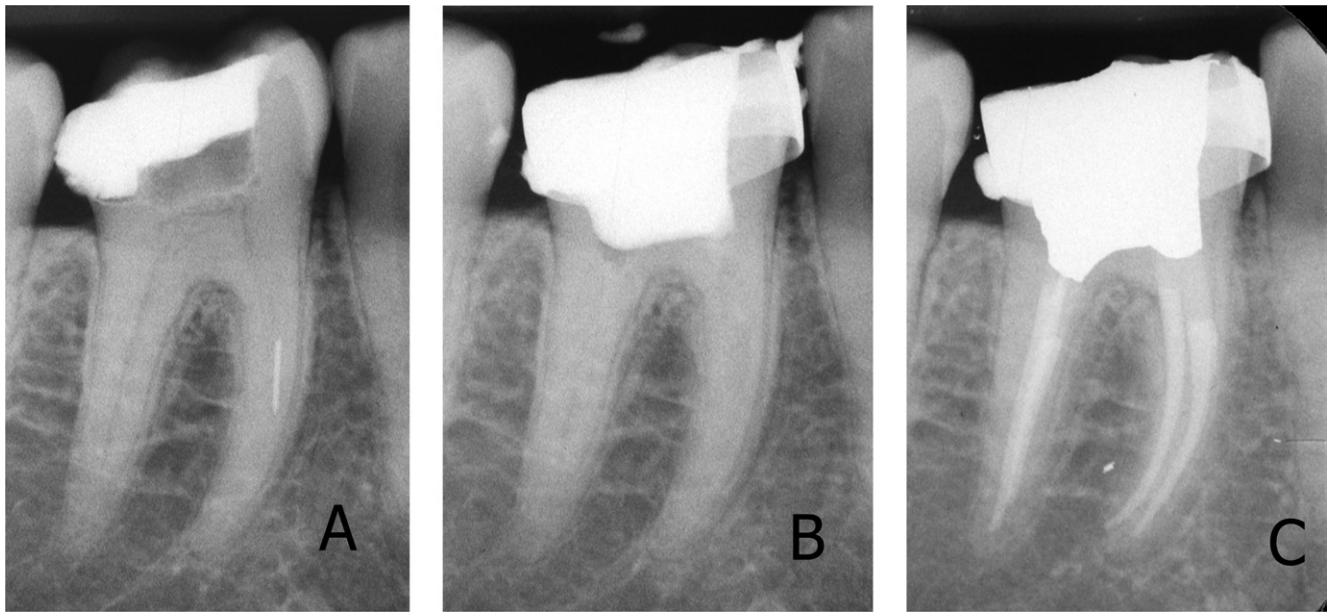


Figure 5. Radiographs demonstrating removal of a fractured rotary NiTi instrument with minimal dentin sacrifice. (A) At time of fracture, (B) immediately after removal, (C) immediately after completion of endodontic treatment (courtesy of Dr. Jeff Ward).

within the root canal system, the most common being stainless steel or rotary NiTi root canal files. In the past chemicals such as hydrochloric acid, sulfuric acid, and concentrated iodine-potassium iodide were used in an attempt to dissolve the metal obstruction (150), which is now irrelevant because of the metals used today as well as the obvious safety issues. In more recent times, specialized devices and techniques have been introduced specifically to remove fractured instruments (151). The evaluation of fractured instrument removal systems and techniques such as the Masserann Kit (152), Endo Extractor (Brasseler USA Inc., Savannah, GA) (153, 154), wire loop technique (Roig-Greene 1983), the Canal Finder System (Fa.Société Endo Technique, Marseille, France) (149), long-shank burs and ophthalmic needle-holders (155), and ultrasonic devices (156–159) have all shown limitations. The problems associated with these devices include excessive removal of root canal dentin, ledging, perforation, limited application in narrow and curved roots, and extrusion of the fractured portion through the apex (150, 156, 158, 160).

However, the incorporation of the operating microscope into procedures for removal of fractured instruments has considerably improved the chances of removal, as have fine ultrasonic tips and other innovations such as staging platforms (14, 15, 161) and the Instrument Removal System (iRS) (162). The technique is considerably more conservative of dentin (Fig. 5), and less stressful for the operator (14, 15, 151, 161, 163–166). Nevertheless, successful removal of such obstructions relies on factors such as the position of the instrument in relation to the canal curvature, depth within the canal, and the type of fractured instrument (14, 15, 160, 167). The more apical the location of the fractured instrument the greater the potential for root perforation (165) and the lower the fracture resistance of the root after removal of the instrument (166). Straight-line access is mandatory for successful removal of instruments (151), but conservation of tooth structure is paramount to the tooth's resistance to fracture (168). In some instances it may be prudent to forgo instrument removal to prevent subsequent complications (151, 160, 165, 166), particularly when the fragment is at or around the curve in the canal (14, 15), and especially given the minimal impact on prognosis (31).

An attempt to bypass a fractured instrument should always be initially considered because it can often be successful (4), particularly in those situations where the root has more than one canal and if they join before the apical foramen (Fig. 6). Another consideration is that the prognosis is reduced because microbial control is compromised when instrument breakage occurs in the early stages of canal preparation without at least minimal debridement, either short of the apex or beyond the apical constriction, and the instrument cannot be bypassed (1, 169). On the other hand, prognosis is favorable in cases where canals have been usually adequately debrided leading to sufficient microbial control, where larger instruments have fractured in the apical third (Fig. 7), or where the broken fragment has been satisfactorily bypassed (1, 169). It should be stated that there is no evidence to support these contentions concerning time of instrument fracture but rather it appears to be based on inference.

Dentolegal Implications

The literature indicates that fracture of rotary NiTi instruments is not as frequent as it may anecdotally seem, and it may be that growing concerns of medico-legal implications have resulted in greater clinician awareness of instrument fracture consequences. At least one dental insurance company reports that a number of claims arise as a result of broken and retained instruments in root canals (170). However, it is not that the event has occurred, but that patients have not been warned of the possibility and, much worse, that a patient has not been told of the fractured instrument (171). A disgruntled patient with a fractured instrument is more easily managed legally if the patient is initially forewarned, advised if fracture occurs, and if meticulous records are kept substantiating good communication (172). Furthermore, outcome of poor endodontic treatment (173, 174) is considerably worse than fractured instrument cases (31), so it does not seem logical to have to warn a patient of the prospect of fracture of an endodontic instrument but not of a technically poor result.

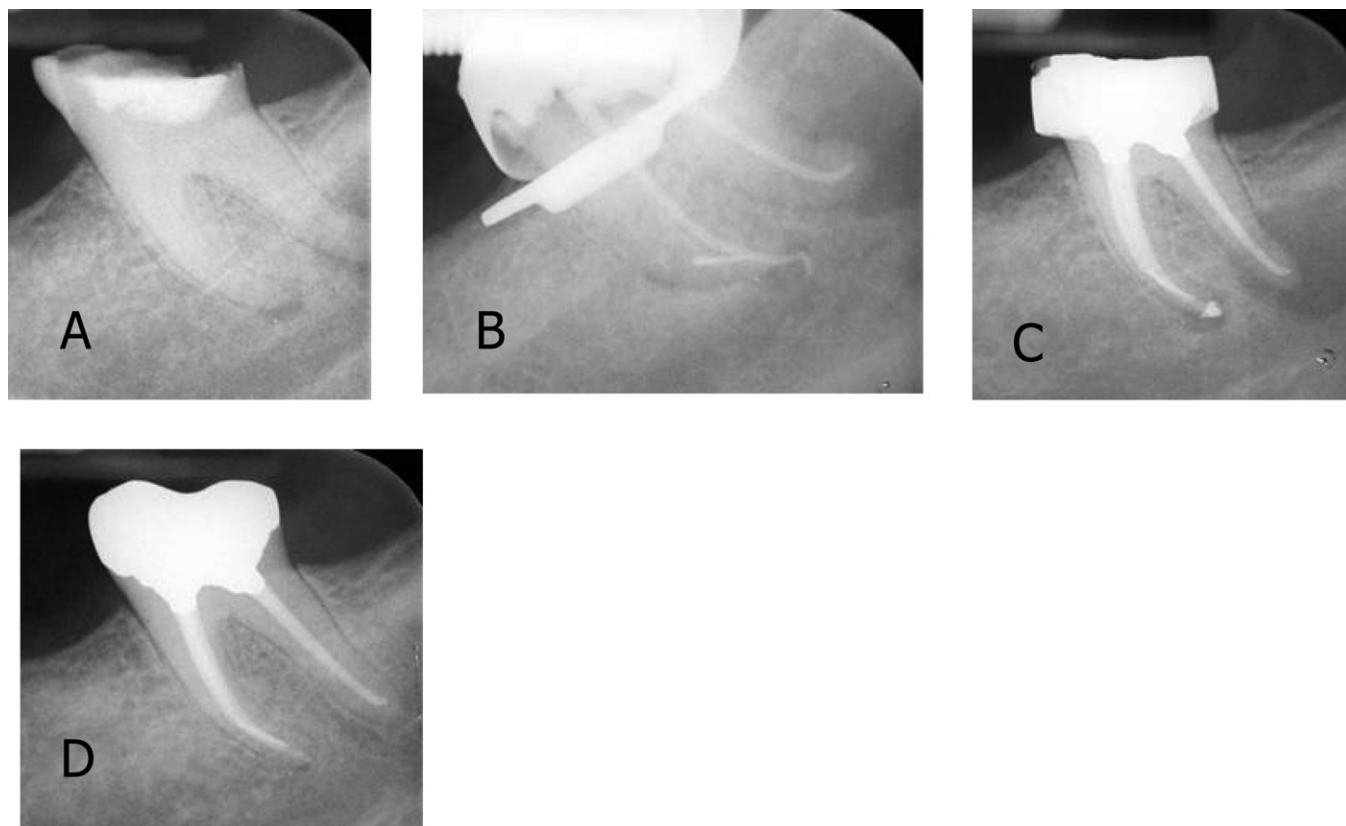


Figure 6. Radiographs demonstrating a fractured rotary NiTi instrument in the apical third of the MB canal of a lower third molar with difficult access. Attempt at retrieval was not indicated in this case. (A) Preoperative, (B) trial gutta-percha showing that the two mesial canals join before apex, (C) immediate postoperative, (D) 1 year review (courtesy of Dr. Jeff Ward).

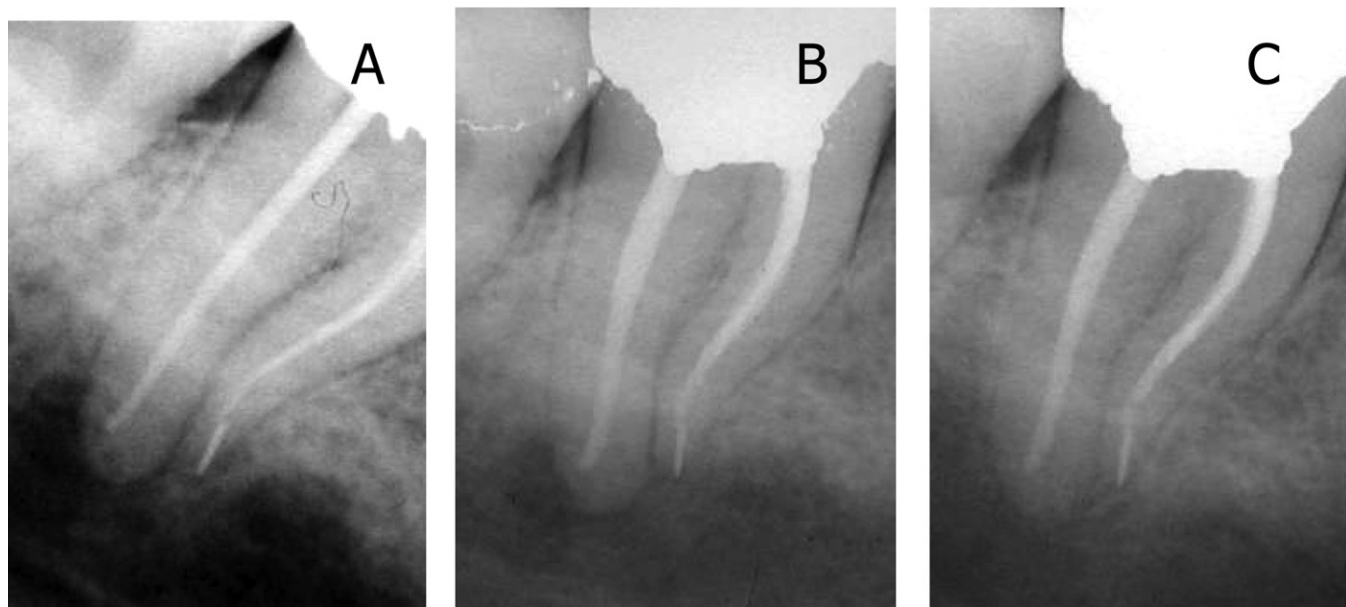


Figure 7. Fractured rotary NiTi instrument protruding through apex. (A) Gutta-percha selection, (B) immediate postoperative, (C) 4 year review (courtesy of Dr. Peter Parashos).

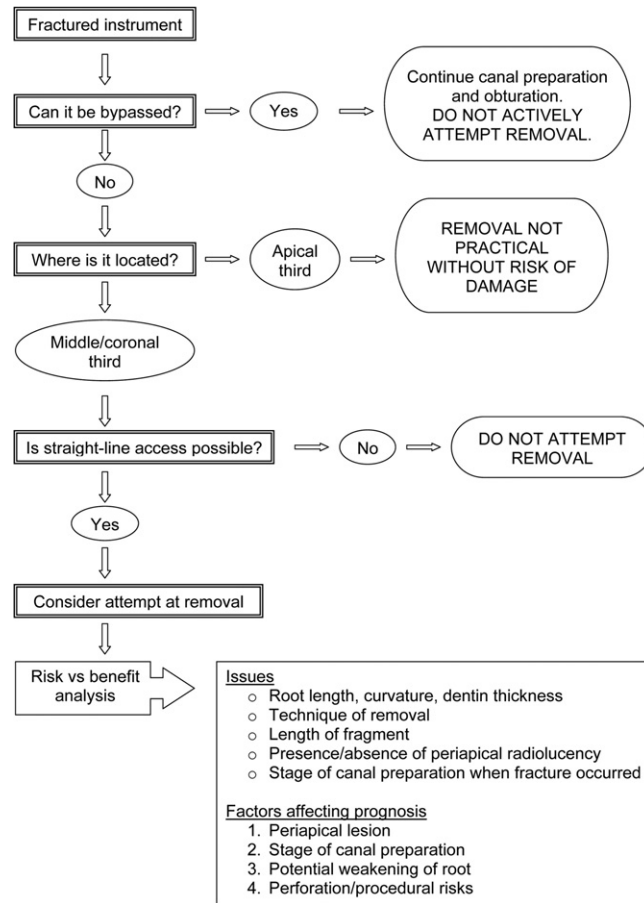


Figure 8. Decision making flowchart for fractured endodontic instruments.

Conclusions and Clinical Recommendations

1. Careful application of principles of use will minimize occurrence of instrument fracture.
2. Recent clinical studies document that the prognosis is not significantly affected by the fracture and retention of a fractured instrument. However, this evidence must be weighed up with the fact that the presence of preoperative apical periodontitis is a confounding variable. Further, the influence on outcome of the stage of fracture of an instrument remains unexplored.
3. Clinical recommendations

We recommend consideration being given to the following factors related to the individual case being managed (Fig. 8):

- a. Establish the location of the instrument fragment radiographically and by tactile sensation—if the fragment is at or beyond the canal curve, retrieval is much less predictable.
- b. Consider the time of fracture—the earlier in the instrumentation procedure, the greater the likelihood of inadequate debridement.
- c. Consider the presence or otherwise of a periapical radiolucency—this will compromise prognosis somewhat.
- d. Initially attempt to directly bypass the instrument fragment by the very careful use of hand instruments—in some instances where the root has more than one canal it may be possible to bypass the instrument indirectly, using the other canal(s), provided they join well before the apical foramen.
- e. After this attempt and after due consideration of the first three factors above, as well as symptomatology, justify the need to undertake more invasive measures.

- f. If the decision is made to attempt to remove the fragment a staging platform technique is recommended—it is *sine qua non* that this be undertaken using the operating microscope and using appropriate ultrasonic instrumentation.
- g. Should retrieval attempts prove unsuccessful without further compromising the tooth, and the case continues to be symptomatic or fails to show any signs of healing at periodic recall reviews, alternative treatment options such as apical surgery, intentional replantation, or even extraction can always be considered.
- h. The patient must always be informed at that appointment of the presence of the fragment and your proposed management, if any. The only exception would be if the fragment were easily and successfully removed at the same appointment.

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