Probability of removing fractured instruments from root canals

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Abstract

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Aim To evaluate in a clinical case series the location of fractured instruments, how many of them could be removed and to compare these findings with the results of a similar study.

Methodology Within an 18-month period all referred endodontic cases involving fractured instruments within root canals were analysed. The protocol for removal of fractured instruments was: create straight-line access to the coronal portion of the fractured instrument, attempt to create a ditched groove around the coronal aspect of the instrument using ultrasonic files and/or to bypass it with K-Files. Subsequently, the fractured instrument was vibrated ultrasonically and flushed out of the root canal or an attempt was made to remove the instrument with the Tube-and-Hedström file-Method or similar techniques. The location of the fractured instrument and the time required for removal were recorded. Successful removal was defined as complete removal from the root canal without creating a clinically detectable perforation.

Results In total, 97 consecutive cases of instrument fracture were included in the time period. In all, 84 instruments (87%) were removed successfully. There was a significant correlation between the time needed to remove fractured instruments and a decrease in success rate. Curved canals had significantly more fractured instruments than straight canals ($P < 0.05$). Rotary instruments fractured significantly more often in curved canals ($P < 0.05$) compared with other instruments. Half of all instrument fractures occurred in mesial roots of lower molars and most often when using rotating instruments. There was no statistically significant difference in the success rate with respect to the location of the fractured instrument (tooth/root type), the type of fractured instrument or the different methods of instrument removal.

Conclusions Curved canals are a higher risk for instrument fracture than straight canals. In curved canals rotary instruments (including lentulo spirals) fractured more often than other instruments. In all, 87% of the fractured instruments were removed successfully. A decrease in success rate was evident with increasing treatment time. The use of an operating microscope was a prerequisite for the techniques used to remove the fractured instruments.

Keywords: fractured instrument, instrument removal, operating microscope, root canal retreatment, separated instrument, ultrasonics.

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Introduction

When an endodontic instrument fractures during use in a root canal, the best option is to remove it (Machtou & Reit 2003). Only after removal of the fractured instrument can the root canal be negotiated, cleaned and shaped optimally. If the root canal cannot be cleaned and shaped successfully, remnants of pulp tissue and bacteria may remain and compromise the outcome of root canal treatment (Sjogren *et al.* 1990, Rocke & Guldener 1993).

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However, attempts to remove fractured instruments may lead to ledge formation, overenlargement and transportation of the prepared root canal or perforation (Fig. 1). Thus, the clinician has to evaluate the options of attempting to remove the instrument, bypassing it or leaving the fractured portion in the root canal. This decision should be made with consideration for the pulp status, canal infection, the canal anatomy, the position of the fractured instrument and the type of the fractured instrument (Rocke & Guldener 1993).

Since the mid-1990s, two important innovations in endodontic treatment procedures may have influenced the probability of successful removal of fractured instruments from root canals:

1. NiTi rotary instruments have become an important and popular technique for root canal preparation. Some of the instruments may fracture if used inappropriately (Suter 1999, Saunders & Saunders 2003). Due to their increased flexibility and elasticity the removal of fractured NiTi instruments may be more difficult compared with stainless steel instruments. An additional factor may be that when ultrasonic vibration is used in an attempt to loosen the fractured instrument from the root canal, the NiTi instruments have a greater tendency to fracture repeatedly. A further reason for the more difficult removal may be that many of the fractured NiTi instruments are 'locked' into the canal because they may screw in.

2. The introduction of new devices such as the operating microscope, ultrasonic devices, Cancelliers (Carr 1992), hypodermic needles (Eleazer & O'Connor 1999), blunt needle and core paste (Machtou & Reit 2003), Instrument Removal System (IRS) (Ruddle

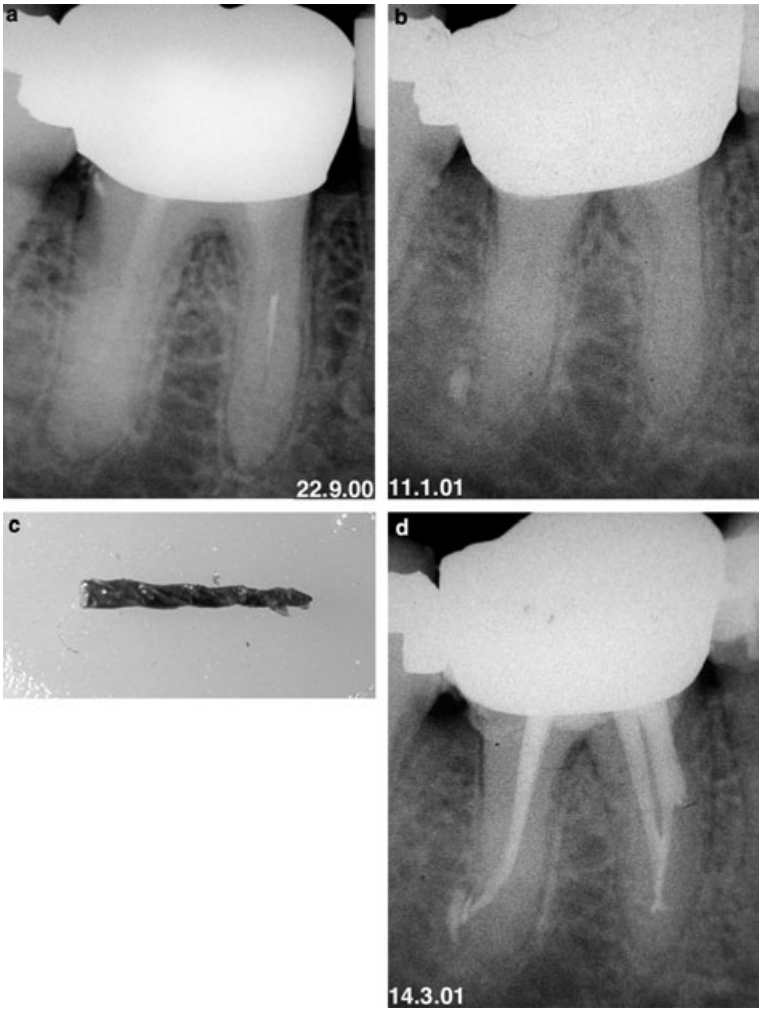

Figure 1 (a) Fractured instrument (GT Rotary 20.06T) in mesiobuccal canal of a mandibular right first molar. (b) Instrument removed using ultrasonically activated file. Removal time: 45 min. (c) Instrument fragment. (d) Root canal obturation after successful removal of the instrument: significant ledge formation is evident.

2003) or the Tube-and-Hedström file-Technique (Suter 1998) may result in easier and more controlled removal of fractured instruments. Indeed the experience developed during the study of Suter (1998) showed that the use of the operating microscope was essential for the removal of fractured instruments.

Hülsmann & Schinkel (1999) report a 68% overall success rate for removing or bypassing fractured instruments from root canals *in vivo*. Ward *et al.* (2003) using more modern techniques introduced by Carr (1992) reported an overall success rate of 73% for complete removal of broken instruments *ex vivo*.

The aim of this study was to evaluate the following five points in an endodontic practice setting over a period of 18 months:

- The number of fractured instruments referred.
- The time needed to remove fractured instruments.
- The number of successfully removed instruments.
- The location of fractured instruments.
- The results of this study compared with those of a similar study (Hülsmann & Schinkel 1999).

Materials and methods

This clinical endodontic study was performed in an endodontic practice in Berne, Switzerland by one operator. It commenced on 1 January 2001 and ended on 30 June 2002. The inclusion criteria of the study were: a fractured instrument was located in a tooth referred for endodontic retreatment, the case was referred specifically for instrument removal or an instrument fractured whilst performing endodontic treatment in the practice of the operator. If an ultrasonic file fractured during treatment and could be removed in <3 min (or flushed out by itself), the case was excluded. For the purpose of this study, buccal canals of maxillary molars and mesial canals of mandibular molars were considered as curved.

Depending on the individual case, the following treatment steps were undertaken in strict order:

1. Where possible, straight-line access to the coronal portion of the fractured instrument was created. The intention of this first step was to visualize the fractured instrument under the operating microscope. Straight-line access was created using the SonicFlex Endo System (KaVo, Biberach, Germany) with tip types 67, 68 and/or 70 (Suter 2001). In some cases Gates Glidden burs (Dentsply Maillefer, Ballaigues, Switzerland) were used.

2. An attempt was made to create a groove around the coronal end of the fractured instrument using a size 25 K-File mounted on a ultrasonic handpiece (Satelec, Merignac, France) and/or to bypass it with K-Files.

3. The fractured instrument was loosened with an ultrasonically activated file and flushed out of the root canal. At any stage if visualization was impossible, an attempt was made to remove the fractured instrument using tactile sense. In this way the instrument was bypassed using precurved ultrasonic files; when successful, the instrument was flushed out of the canal.

4. If ultrasonic vibration was ineffective, an attempt was made to remove the fractured instrument with the Tube-and-Hedström file-Method (Suter 1998).

5. If possible, at all stages, an attempt was made to remove a loosened and bypassed instrument with the help of a microdebrider, a Hedström file, a Masserann trephine or with pliers.

Time was recorded from starting straight-line access preparation until the instrument was either successfully removed or, in cases of failure when attempts to do so were halted for the following reasons: perforation, or lack of visualization of the fractured instrument as a result of dislocation or secondary fracture. In the interests of safety the removal of instruments was only attempted for a short time when visualization was impossible.

When instrument removal was completed and before obturation, a radiograph was taken to confirm whether the instrument was absent as in successful cases or in the case of failure, the size and location of the remaining fragment.

Success was defined as complete removal of the fractured instrument from the root canal without creating a perforation.

Failed cases included situations when:

1. The instrument was not removed completely;
2. The instrument could only be bypassed;
3. A perforation was detected visually with the operating microscope;
4. A perforation resulted in bleeding into the canal; or
5. A perforation was detected electronically with an apex locator (Root ZX, Morita, Japan) (Fig. 2).

The distribution of fractured instruments amongst different root types (i.e. anterior teeth, premolars, buccal roots of maxillary molars, mesial roots of mandibular molars or distal roots of mandibular molars and palatal roots of maxillary molars) was recorded, as well as the anatomical location of the fractured

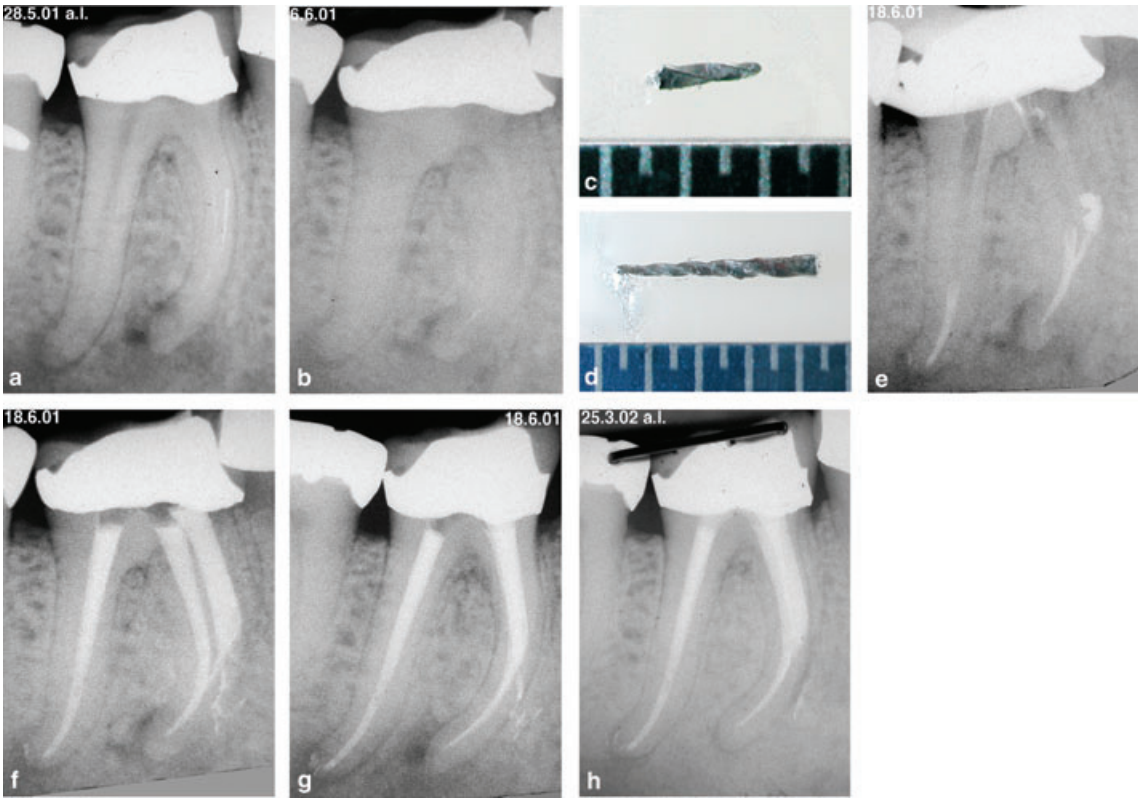

Figure 2 (a) Two fractured instruments: GT Rotary 20.06T in mesiolingual canal and GT Rotary 20.08T in mesiobuccal canal of a mandibular right first molar. (b) Instruments removed: success mesiolingual, failure mesiobuccal because of perforation. (c) Instrument removed from mesiolingual canal after bypassing with hand instruments: removal time: 15 min. (d) Instrument removed from mesiobuccal canal using ultrasonics: removal time: 2 h; perforation. (e) Mesiobuccal canal was no longer negotiable after perforation but was obturated when downpacking the mesiolingual canal. (f) The perforation was obturated when backpacking the mesiobuccal canal, ledge formation is also evident. (g) Final radiograph. (h) 9-month recall: tooth is symptomless.

instruments (coronal third, middle third, apical third, whole length of the root canal or through the apical foramen).

Multiple fractures of instruments in the same root canal, root or tooth were also recorded.

Information about the type of broken instrument was usually conveyed by the referring dentist. If this was not the case, the type of instrument was identified by means of high magnification with the operating microscope and compared with new instruments until the same type of instrument was matched.

A record was made when an instrument fractured further on attempted removal.

The methods used to remove the fractured instrument were recorded as follows:

- 'Ultrasonics': the creation of a straight-line access and removal by means of an ultrasonically activated file only.
- 'Tube-and-Hedström file-method': use of ultrasonics as above plus the use of the 'Tube-and-Hedström file Method' (Suter 1998).
- 'Bypass': following bypassing without the help of an ultrasonically activated file.
- 'Pliers': recorded when pliers were utilized to remove the instrument at any stage but without other adjunct techniques.
- 'Masserann': recorded when the Masserann instrument system was used to remove the instrument at any stage.

Statistics

The statistical significance of the differences between the methods was determined using the chi-square test. When individual cells showed expected frequencies <5, categories were combined for statistical analysis (Systat

5.2; Systat Inc., Evanston, IL, USA). Correlations were tested using the Spearman test. A significance level of $P < 0.05$ was employed.

Results

According to the endodontic practice patient data bank, 1177 root canals were treated within the same 18-month time period in all types of teeth. In 97 of these cases a fractured instrument was present that required an attempt at removal. Of these 97 cases, seven instrument fractures occurred in the hands of the study operator: two were prototype rotary instruments and fractured whilst performing conventional root canal treatment, one was an ultrasonic file that fractured unknowingly and was pushed towards and through the apex and four instruments fractured whilst attempting to remove another fractured instrument.

Figure 3 shows the dependency of the success rate according to the different treatment time groups: there was a significant correlation between the amount of time needed to remove the fractured instrument (respectively, to the time at which failure occurred) and a corresponding reduction in the success rates ($P < 0.05$).

Under the definition of success, 84 of the 97 fractured instruments were removed successfully. This resulted in a success rate of 87%; 13 cases failed for the following reasons:

1. Root perforation (seven; five with treatment time over 90 min; four of the seven instruments were located in the apical third of the root canal or extended through the apical foramen, none were located in the coronal third of the root canal)

2. Incomplete removal (six; three of which were further fractured leaving the most apical part in the canal; one was bypassed and two could not be removed)

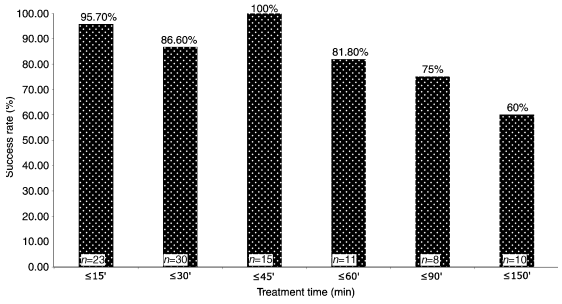

Figure 3 Success rate (%) according to the different treatment times.

The distribution amongst root types was as follows:

- Anterior teeth: eight (8%), one failure;
- Premolars: 10 (10%), one failure;
- Buccal roots of maxillary molars: 24 (25%), three failures;
- Mesial roots of mandibular molars: 48 (50%), seven failures;
- Distal roots of mandibular molars and palatal roots of maxillary molars: seven (7%), one failure.

There were no significant differences in the success rates according to the type of root the fractured instrument was removed from. The success rates were:

- Anterior teeth: 88%;
- Premolars: 90%;
- Buccal root of maxillary molars: 88%;
- Mesial roots of mandibular molars: 85%;
- Distal roots of mandibular molars and palatal roots of maxillary molars: 86%.

The localization of the fractured instruments in the root canals was as follows:

- Fractured instrument in the coronal third of the root canal: 19 (20%), two failures.
- Fractured instrument in the middle third of the root canal: 31 (32%), four failures.
- Fractured instrument in the apical third: 40 (41%), five failures.
- Five fractured instruments were so long they filled the entire root canal (5%). All were successfully removed.
- Two instruments were located partially beyond the apex (2%). Neither could be removed successfully. The success rate of these two instruments was statistically significantly lower compared with the five instruments which filled the entire root canal and also compared with all other instruments together ($P < 0.05$).

For statistical reasons, comparison of the individual thirds of each root canal was not appropriate) (Fig. 4).

Multiple instrument fractures occurred:

- fifteen times with instruments in the same root canal,
- five times with instruments in the same root type (but in different canals within the root type) and
- three times with instruments in different roots of the same tooth.

The distribution of the types of fractured instruments within the different root types was even. However, if curved canals (buccal canals of maxillary molars and mesial canals of mandibular molars) were compared with straight canals (incisors, canines, premolars and palatal or distal roots of molars), curved canals had significantly more fractured instruments than straight canals ($P < 0.05$). Further, rotary instruments (NiTi and Lentulo) fractured significantly more in curved

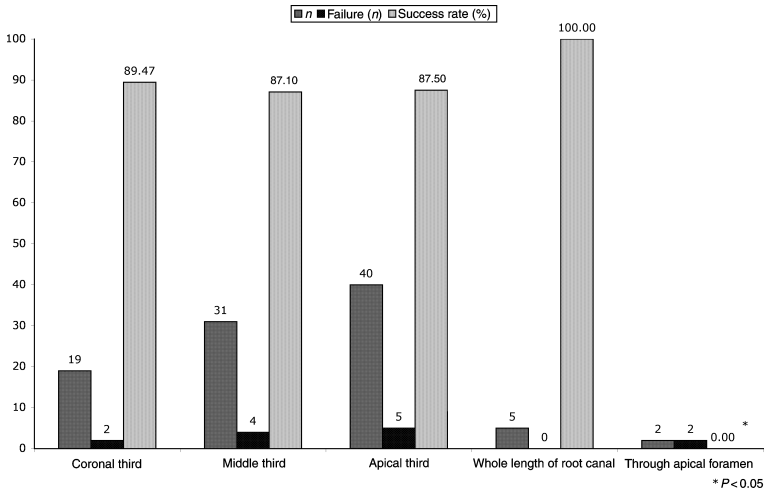

Figure 4 Localization of the fractured instruments within the root canal by success rate.

canals compared with other instruments ($P < 0.05$) (Fig. 5).

Fractured instrument types and their respective fracture rates were:

- Nickel-Titanium Rotary instruments: 50 (52%), seven failures;
- Steel instruments (hand): 27 (28%), three failures;
- Lentulo spirals: 14 (14%), two failures;
- Others (GG, Giromatic, etc.): six (6%), one failure.

There was no statistical difference in the success rate according to the type of fractured instruments (Table 1).

When attempting to remove fractured instruments with ultrasonic vibration, in 28 cases (29%) they fractured into two or more pieces (secondary fracture). This occurred with 14 of 50 (28%) Nickel-Titanium Rotary instruments, eight of 14 (57%) Lentulo spirals and six of 27 (22%) steel instruments.

The methods of removal used were:

- Attempt to remove the instrument only with ultrasonics: 78 (80%), 12 failures;
- Attempt to remove the instrument with the Tube-and-Hedström file-Method: 11 (11%), one failure;
- Other methods: eight (8%) six times removal with pliers, one with the use of the Masserann instrument system, and one bypassed and removed using a microdebrider, no failure.

There was no statistical significant difference in the success rate amongst the different methods of instrument removal. The respective success rates were: Ultrasonics: 85%; Tube-and-Hedström file-Method: 91%; other methods: 100%.

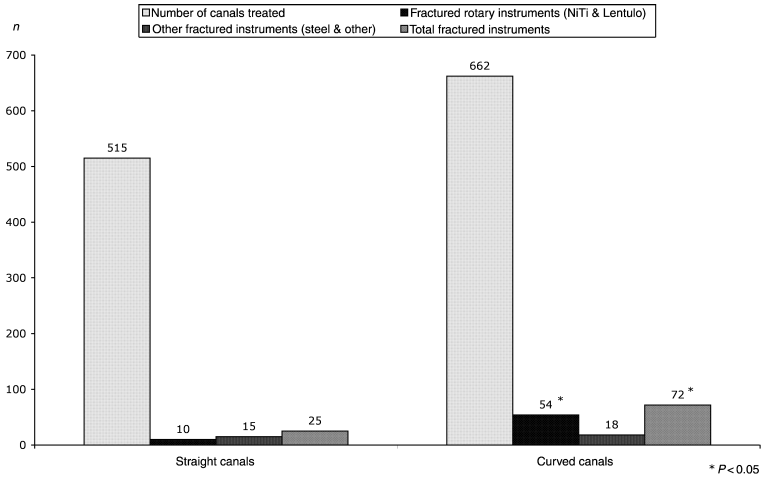

Figure 5 Total number of root canals treated and number of fractured instruments.

Table 1 Number and types of fractured instruments by tooth and canal

Instrument type	*n*	Root type				
		Anterior teeth	Premolars	Buccal roots of maxillary molars	Mesial roots of mandibular molars	Distal and palatal roots (molars)
NiTi	50	3	0	13	29	5
Steel	27	2	9	8	7	1
Lentulo	14	0	1	3	9	1
Others	6	3	0	0	3	0

Discussion

In this study the overriding criterion for success was the complete removal of the fractured instrument without creating a perforation. This is a clinician-derived technical outcome. Another study (Hülsmann & Schinkel 1999) reported a success rate of 68% whilst accepting the bypassing of instruments as a successful outcome. Even when measuring with a modern electronic apex locator, from a clinical perspective it is often difficult to differentiate between bypassing a fractured instrument and perforating. The reason for this is that the instrument may have fractured at the working length and electrical impulses will be conducted into the apical area and result in a false reading. This reading is difficult to differentiate from a perforation. On the contrary, the preparation of a false canal, created parallel to the original canal can mimic the preparation of the 'true' canal.

In certain clinical situations it may also be better to leave a fractured instrument in the root canal. For example, when the instrument fractures in a canal with a vital pulp towards the end of the cleaning and shaping phase or if it fractures when removing a calcium hydroxide dressing in an uncomplicated case (Rocke & Guldener 1993).

Van Beek (1983) described in detail the anatomy of permanent teeth. It was noted that in maxillary first permanent molars, the buccal root canals had a marked distal curvature with respect to the wide palatal canal. In mandibular first permanent molars the distal root canal was less curved than the two mesial root canals. For practical reasons in this *in vivo* study buccal root canals of maxillary molars and mesial root canals of mandibular molars were defined as curved and all other root canals as straight.

One of the criticisms that could be levelled at this study relates to the statistical analyses, and specifically the total number of cases, which affect the power of the findings. The reasons for this were twofold. First many different parameters were examined and second the number of fracture cases was limited. The option to reduce the number of parameters and increase the duration of the study, which was already running for 18 months, was not considered practicable. A similar problem was reported by Hülsmann & Schinkel (1999) in their retrospective study. Data acquisition could be increased using a multicentre approach. That would also have the advantage that it would reduce inter-operator bias.

Hülsmann & Schinkel (1999) did not describe the time required for instrument removal. The present study demonstrated that success rates may drop with increased time of treatment. This may be related to operator fatigue, or overenlargement of the root canal owing to ultrasonic abrasion (see Fig. 1). This in turn may correspond with a higher risk for perforation. The difficulty of the case may also explain the reduction in success rates. Attempts to remove fractured instruments from root canals should not take longer than 45–60 min. It is recommended that after this period of time serious consideration be given to other treatment options.

Hülsmann & Schinkel (1999) reported an overall success rate of 68% including bypassed instruments. This lower success rate in comparison with the present study may be explained by the following reasons:

- It was a retrospective study: the primary goal of the clinical work was to treat the case successfully. Often bypassing a fractured instrument may be an acceptable treatment option to achieve clinical success. However the experience of the present study was that once bypassed, the instrument could then be removed; amongst the failure group only one bypassed instrument was not subsequently removed.
- They did not report using the operating microscope for removal of fractured instruments that were located deeper within canals. In the present study, there was no relationship in terms of the failure rate with the location of the fractured instrument within the root canal.
- They used the Canal-Finder-System for bypassing fractured instruments. This system was not used in the present study. However, 11 instruments (13%) were successfully removed using the Tube-and-Hedström

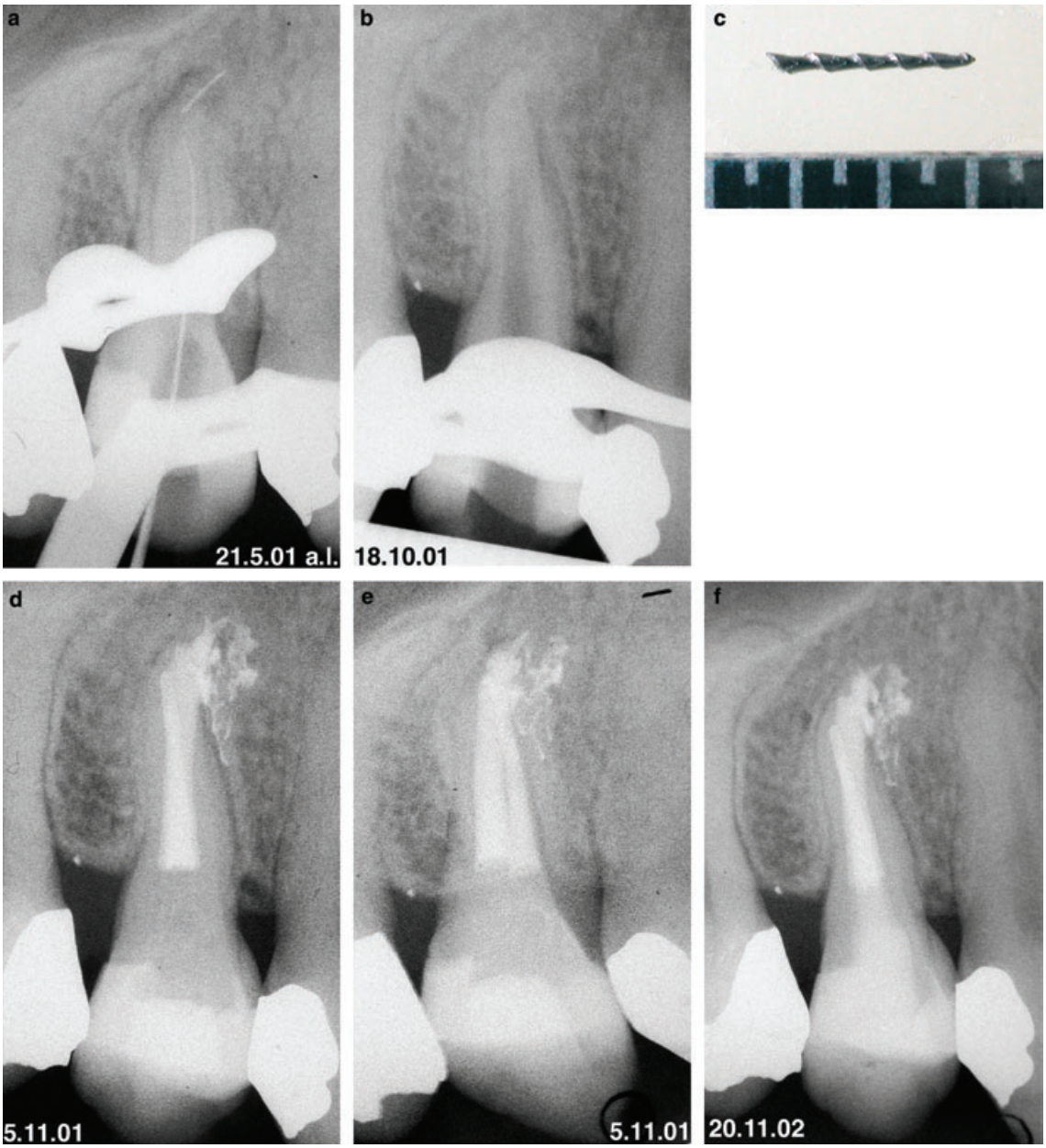

Figure 6 (a) Fractured size 20 H-File in the apical region of the palatal root canal of a maxillary right first premolar: patient was informed that the instrument could not be removed and that apical surgery would be necessary. (b) Surprisingly the instrument was removed after 60 min using an ultrasonically activated file; clinically no perforation could be detected. (c) Removed size 20 H-File. (d) Control radiograph after obturation: radiographically perforation cannot be excluded; nevertheless because of the study protocol, the case was judged as successful removal of a fractured instrument. (e) Control radiograph with eccentric projection after obturation. (f) 1 year recall: no clinical signs or symptoms.

file-Method (Suter 1998). This technique was not used by Hülsmann & Schinkel (1999).

One of the cases in this study deserves further attention, where the patient was informed prior to the treatment, that she would need surgery after conventional root canal treatment in order to remove the apical part of the root together with the fractured instrument (Fig. 6a). However, the instrument was removed conventionally and no signs of perforation were detected (Fig. 6b). The final radiograph seems to show sealer

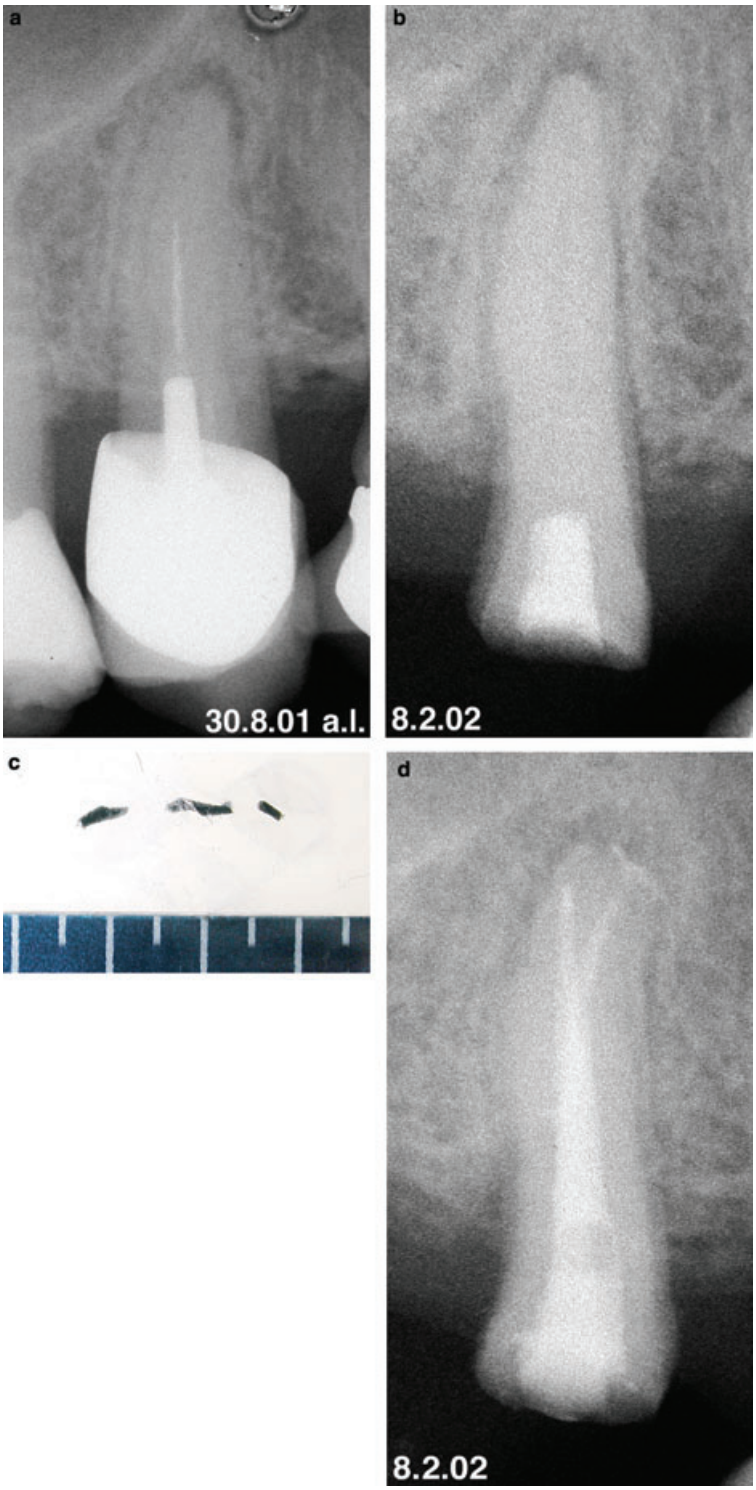

Figure 7 (a) Fractured H-File in palatal canal of an maxillary right second bicuspid. (b) Instrument removed successfully using ultrasonically activated file. Removal time: 45 min. (c) Instrument fractured further into three parts upon removal. (d) Final radiograph after root canal obturation using vertical condensation with System B and Obtura II.

extrusion through a perforation (Fig. 6d–f). Nevertheless, this case was judged as a success according to the protocol of this study. The time for removal was 60 min.

An interesting finding was the large number of instrument fractures in the mesial roots of mandibular molars: Hülsmann & Schinkel (1999) reported this

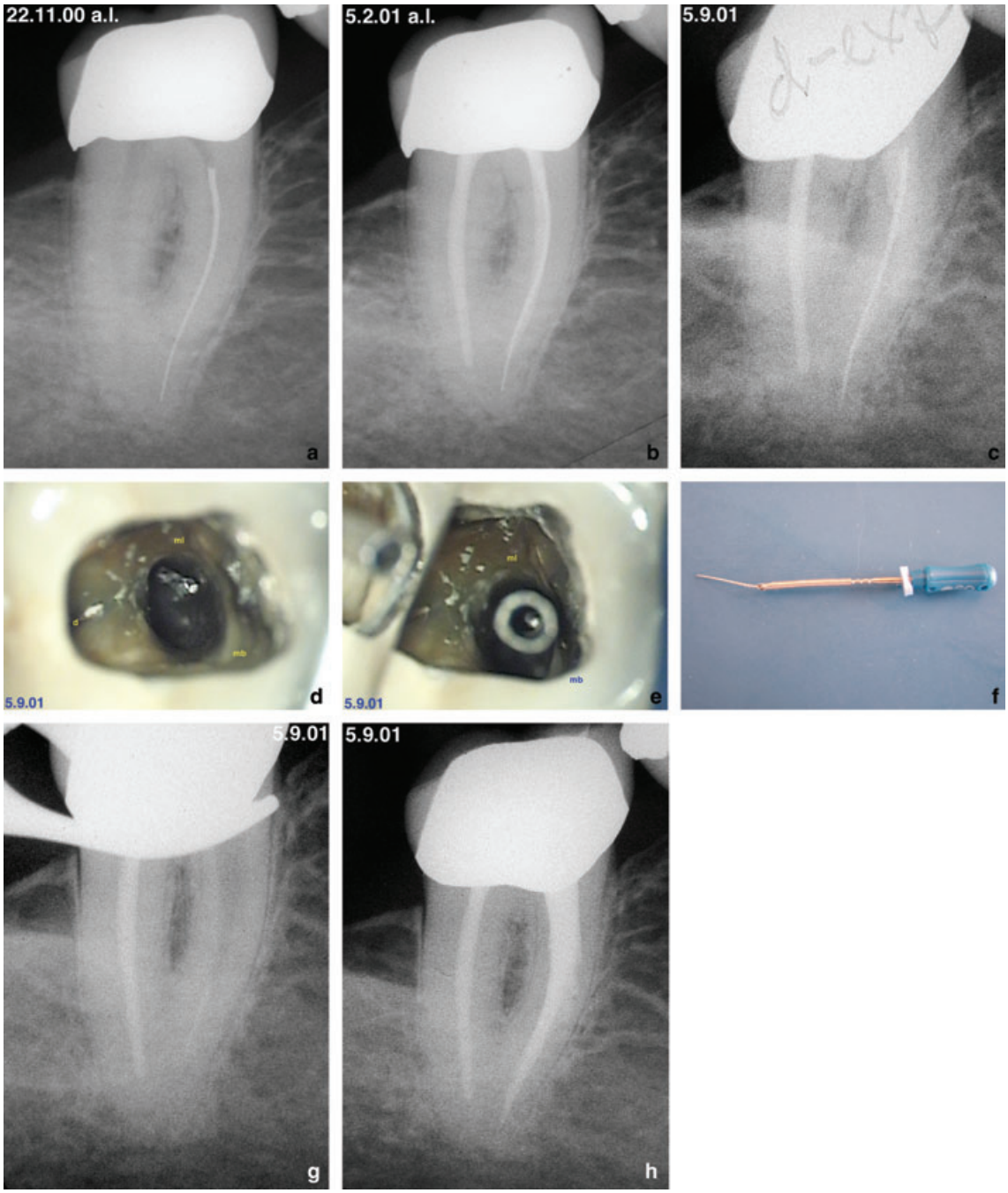

Figure 8 (a) Size 20 reamer fractured by preceding operator. (b) Root canal obturation performed by first dentist without trying to remove the fractured instrument. (c) Radiograph taken after a first attempt to remove the fractured instrument by the referring dentist: most of the old obturation material was removed but the fractured instrument was still tightly sealed into the root canal. (d) Clinical view on the fractured instrument before removal: instrument is located in the mesiolingual canal. (e) Clinical view after pushing a steel tube over the fractured instrument and before introducing a H-File into the tube. (f) Fractured instrument, tube and H-File after successful removal from the tooth. Removal time: 30 min. (g) Radiograph showing empty root canal. (h) Final radiograph after root canal obturation.

finding in 34% of all cases. In the present study, the figure was 50% of all instruments and was comprised as follows: 58% of all NiTi rotary instrument fractures, 26% of all steel instrument fractures, 64% of all Lentulo spiral fractures and 50% of all other instrument fractures ($n = 6$, including GGs) located in mesial roots of mandibular molars (Table 1). It seems therefore that the use of rotary instruments (i.e. NiTi rotary and Lentulo spirals) in mesial canals of mandibular molars may lead to a higher risk of instrument fracture.

Approximately the same percentage of fractured instruments (25%) was found for buccal roots of maxillary molars in this study and that of Hülsmann & Schinkel (1999). Fewer fractured instruments were found in all other types of roots than in the study of Hülsmann & Schinkel (1999).

Hülsmann & Schinkel (1999) reported different success rates in different roots, with different types of instruments and with the length of the fragment. The present study showed no such findings with the exception of fragments extending over the complete length of the root canal or extending beyond the apex.

Two fractured instruments in the present study extended beyond the apical constriction. In the first case a 3 mm long fragment of a fractured ultrasonic K-File extended approximately 2 mm through the apex of a maxillary right canine. Whilst attempting to remove it, the fragment was pushed out of the root. In the second case a 7 mm long fragment of a fractured reamer extended approximately 3 mm through the apex of the mesiobuccal canal of a maxillary left molar. The fragment was located beyond the severe curve of the canal. The attempt to remove it resulted in perforation. Hülsmann & Schinkel (1999) report removal of three of six instruments extending beyond the apical constriction.

In the present study, it was often found that when using ultrasonic vibration for removal there was a tendency for further fracture of the instrument (Fig. 7). However, this did not affect the likelihood of successful removal of the fractured instrument. Clinically such cases may become more difficult, especially if the fractured instrument was no longer visible with the operating microscope. In such cases straight-line access was taken to its limits and if necessary the most apical portion of the fractured instrument was removed in a 'blind' fashion from beyond the curve with a much higher potential for perforation. Hülsmann & Schinkel (1999) did not recount a similar finding. This may be due to the fact that in the present study ultrasonics were used for longer and with a higher power setting. For this reason it was not possible to correlate the length of the fractured instrument and the success rate. However, in both studies all the fractured instruments that extended over the whole length of the root canal were removed (Fig. 8).

Some cases demonstrate more than the preferred enlargement of the root canal after removal of the instrument. This may be related to the study protocol where one of the goals was to determine the optimal time an attempt to remove a fractured instrument should take. The clinical experience was that the power setting and the working time may be more critical for root canal over enlargement than the design of the ultrasonic tip. The potential for excess dentine removal through lateral cutting by the ultrasonically activated K-Files is minimized using visual control with the operating microscope (Zaugg *et al.* 2004). It should be noted that K-Files for the ultrasonic unit are more cost-effective, versatile and could be pre-bent more easily than ultrasonic tips.

Conclusion

In this study half of all instrument fractures occurred in mesial roots of mandibular molars and most of them whilst using rotating instruments. In total 66% of the fractured instruments had been used in a rotating motion.

There was an increased failure rate when treatment time exceeded 45–60 min. The deeper within the root canal that the fragment was located and the longer ultrasonic vibration was used in order to loosen it, the greater potential for perforation resulted. The use of the operating microscope was a prerequisite for the techniques applied to remove the fractured instruments.

Under the conditions of this study 87% of the fractured instruments were removed completely from the root canal without creating clinically detectable root perforation.

References

Carr GB (1992) Microscopes in endodontics. *Journal of the Californian Dental Association* **20**, 55–61.

Eleazer PD, O'Connor RP (1999) Innovative uses for hypodermic needles in endodontics. *Journal of Endodontics* **25**, 190–1.

Hülsmann M, Schinkel I (1999) Influence of several factors on the success or failure of removal of fractured instruments from the root canal. *Endodontics and Dental Traumatology* **15**, 252–8.

Machtou P, Reit C (2003) Non-surgical retreatment. In: Bergenholtz G, Hørsted-Bindslev P, Reit C, eds. *Textbook of Endodontology*, 1st edn. Oxford: Blackwell Munksgaard, pp. 300–10.

Rocke H, Guldener PHA (1993) Obstruktion des Wurzelkanals. In: Guldener PHA, Langeland K, eds. *Endodontologie*, 3rd edn. Stuttgart: Thieme, pp. 293–312.

Ruddle CJ (2003) Removal of broken instruments. *Endodontic Practice* **6**, 13–9.

Saunders WP, Saunders E (2003) Root canal instrumentation. In: Bergenholtz G, Hørsted-Bindslev P, Reit C, eds. *Textbook of Endodontology*, 1st edn. Oxford: Blackwell Munksgaard, pp. 236–60.

Sjogren U, Hagglund B, Sundqvist G, Wing K (1990) Factors affecting the long-term results of endodontic treatment. *Journal of Endodontics* **16**, 498–504.

Suter B (1998) A new method for retrieving silver points and separated instruments from root canals. *Journal of Endodontics* **24**, 446–8.

Suter B (1999) Die Wurzelkanalaufbereitung mit GT Rotary Files. *Endodontie* **3**, 247–57.

Suter B (2001) Sonoabrasive instrumentation for root canal retreatment – a new and efficient help. *Oral Presentation, ESE Congress*, Munich.

Van Beek GC (1983) Endodontic anatomy of the permanent teeth. In: Van Beek GC, ed. *Dental Morphology*. 2nd edn. Bristol: Wright, pp. 109–22.

Ward JR, Parashos P, Messer HH (2003) Evaluation of an ultrasonic technique to remove fractured rotary nickel-titanium endodontic instruments from root canals: an experimental study. *Journal of Endodontics* **29**, 756–63.

Zaugg B, Stassinakis A, Hotz P (2004) Influence of magnification tools on the recognition of artificial preparation and restoration defects (in German). *Schweiz Monatschr Zahnmed* **114**, 890–6.