International Endodontic Journal (1989) 22, 64–74

Odontiatrogenic tooth fracture

J. L. SCHWEITZER, J. L. GUTMANN* & R. Q. BLISS† *Department of Endodontics, Marquette University School of Dentistry, Milwaukee, Wisconsin, USA, *Department of Endodontics, Baylor College of Dentistry, Dallas, Texas, USA and †Private Practice in Jacksonville, Florida, USA*

Summary. While the awareness of vertical tooth fractures, whether incomplete or complete, is increasing, sufficient attention has not been paid to the manner in which the dentist may contribute to the occurrence of these fractures. This paper focuses on the most likely areas in which the practitioner can either misdiagnose the presence of a fractured tooth or where dental procedures contribute to fracture of the tooth structure. For this type of fracture the authors propose the term 'odontiatrogenic tooth fracture'.

Introduction

The diagnostic dilemmas that dental practitioners face with incompletely fractured teeth were reviewed at length by Cameron (1964). He identified these teeth, with their bizarre symptoms, as exhibiting the 'cracked-tooth syndrome'; the term is widely used today. Luebke (1984) defined an incompletely fractured tooth as one with a demonstrable fracture line but with no visible separation of segments along the plane of the fracture. He further classified a complete tooth fracture as one in which there was a visible separation of the fractured segments which could easily be wedged apart. Other authors have used various terms to describe essentially the same phenomenon seen in the cracked tooth: greenstick fracture of the tooth (Sutton 1962), split-root syndrome (Silvestri 1976), and vertical root fracture (Lommel *et al.* 1978, Meister *et al.* 1980, Luebke 1984). These fractures can be further categorized as a crown fracture (fracture limited to the crown portion of the tooth) or a root fracture (vertical root fracture). The latter often involves both the crown and the root (complete tooth fracture).

Correspondence: Dr J. Gutmann, Department of Endodontics, Baylor College of Dentistry, 3302 Gaston Avenue, Dallas, Texas 75246, USA.

Early reports concerning fractured teeth tended to emphasize factors or variables which the practitioner could not alter, which Maxwell & Braly (1977) later referred to as predisposing factors. These include masticatory accidents (Cameron 1964, 1976, Wiebusch 1972, Rosen 1982), tight cusp-fossa relationships or steep intercuspation (Sutton 1962, Cameron 1964, 1976, Bender & Freedland 1983), bruxism and thermal cycling (Cameron 1964, Luebke 1984). Other contributing factors, identified as precipating factors by Maxwell & Braly (1977), were due, in large part, to operator errors.

Ritchey *et al.* (1957) and Cameron (1964) found that a large number of incompletely fractured teeth were restored with soft gold inlays. Also, large two, three, and four surface amalgam restorations were commonly found in many fractured teeth (Cameron 1976, Maxwell & Braly 1977, Gher *et al.* 1987). High speed instrumentation and the increased use of rotary instruments resulting in excessive removal of tooth structure have been postulated as weakening the tooth and predisposing to fracture (Cameron 1964, Rosen 1982, Bender & Freedland 1983). Reinforcing pins have also been known to cause microcracks, leading to possible fractures in teeth (Silvestri 1976, Meister *et al.* 1980, Pitts *et al.* 1983). Intraradicular posts, when incorrectly used, may also damage the root or crown of the tooth (Maxwell & Braly 1977, Re *et al.* 1982, Pitts & Natkin 1983, Luebke 1984). Forces generated during the insertion of restorations such as crowns, onlays, or posts may also lead to tooth fractures. Finally, hydrostatic pressures which can develop during cementation, especially of posts, have been identified as contributing to vertical root fractures (Maxwell & Braly 1977, Wechsler *et al.* 1978, Luebke 1984).

Recently, attention has been directed toward endodontic procedures as major contributors to fractured teeth. Excessive forces used during lateral and vertical condensation of gutta-percha have been cited as a cause of vertical root fracture (Sinai & Katz 1978, Meister *et al.* 1980, Luebke 1984, Maxwell *et al.* 1986). Bender & Freedland (1983) proposed that placing of silver cones could also damage the root. Excessive removal of both coronal and radicular tooth structure during access and canal preparation have been cited as factors which will weaken the crown, root, or both (Cameron 1964, Johnson *et al.* 1976, Maxwell & Braly 1977, Bender & Freedland 1983). Lastly, failure to place a veneer or post-retained crown on every endodontically treated tooth has been a long-held, empirical belief that predisposes to the fracture of these teeth.

The purpose of this paper will be to discuss operator contribution as a possible source of tooth fracture for which the authors suggest the term *odontiatrogenic tooth fracture*. Just as the Greek term iatrogenic refers to harm or injury caused by the physician (ιατρos), odontiatrogenic refers to the adverse sequelae caused by the dentist (oδovτατρos). Possible ways to avoid practitioner contribution to this clinical malady will be suggested. In pursuit of this discussion, the aetiological factors will be grouped into three areas of clinical practice: diagnosis and treatment planning, endodontic procedures, and restorative procedures.

Diagnosis and treatment planning

Early diagnosis and/or detection of tooth fracture is essential for successful treatment. Undetected, the fracture may lead to pulpal degeneration (Walton *et al.* 1984), periodontal problems (Hiatt 1973), and the eventual loss of the tooth in some cases. Only a brief review of some of the key elements in diagnosis and detection will be discussed. The practitioner should be cognizant of the signs and symptoms of tooth fracture during treatment planning and should take measures to avoid either missing or contributing to this mishap.

In 1964, Cameron identified the most important factor in the diagnosis of a cracked tooth as an awareness of the problem. Several authors have since supported this (Maxwell & Braly 1977, Rosen 1982, Gher *et al.* 1987) and reports have served to elucidate this problem (Hiatt 1973, Meister *et al.* 1980, Pitts & Natkin 1983, Maxwell *et al.* 1986, Gher *et al.* 1987). However, the clinical detection of these fractures can be difficult, especially in the initial stages, and radiographs are of little value (Matusow 1987). In addition, the patient's symptoms may mimic many other possible diagnoses, such as temporomandibular joint syndrome, sinus problems, vague headaches, and ear pain, thereby misleading the practitioner.

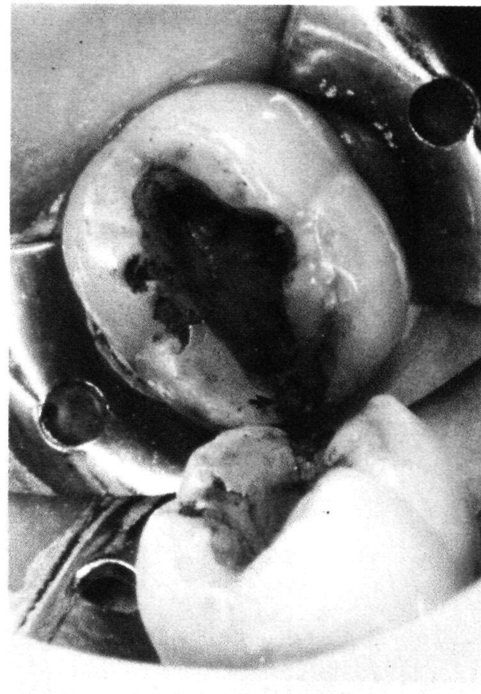

Fig. 1. One per cent methylene blue was used to disclose multiple craze lines in the pulpal roof of a mandibular molar. A major fracture line is visible across the distal marginal ridge (arrow).

Although detection is difficult, there are several techniques and clinical aids that may help in identifying fractured teeth. While it is unlikely that the fracture line may always be seen, careful visual examination of the tooth in a dry field is essential. Occasionally it is possible to 'highlight' a fracture by staining the tooth with 1 per cent methylene blue, iodine, or disclosing agent (Fig. 1). A sharp explorer can sometimes localize or catch the fracture

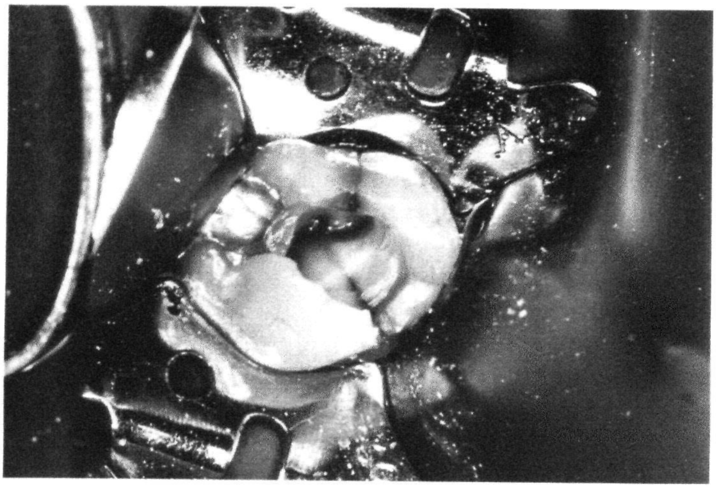

Fig. 2. Fracture lines are visible down the mesial and buccal surfaces of maxillary molar (case courtesy of Dr David Parkins).

line. If wedging a probe tip between the fractured segments or biting on a wood stick reproduces the patient's complaint, a diagnosis of cracked tooth may be considered. Often, removal of the restoration, if present, will reveal the crack or fracture. Particular attention should be paid to the mesial or distal marginal ridges (Fig. 2), as these are considered a weak area of the tooth and so susceptible to fracture (Hiatt 1973). Transillumination is also useful for detecting fracture lines that are not readily apparent (Cameron 1964, Luebke 1984) (Fig. 3).

In the advanced stages of a vertical fracture, periodontal probing of the involved tooth gives a characteristic picture. Unlike a periodontal pocket which is wide and does not restrict movement of a probe as it is moved circumferentially, the osseous defect caused by the vertical fracture is narrow and does not allow lateral movement of a probe (Pitts & Natkin 1983, Luebke 1984), and has been likened to a narrow subgingival dehiscence (Gerstein 1987, personal communication).

In some instances, a diagnostic surgical procedure is indicated to confirm the presence of a vertical root fracture. However, the fracture, if incomplete in a buccolingual direction, may not be located without both buccal and lingual tissue reflections. Periodontal probing, prior to flap design, will usually indicate the anticipated location of the fracture and serve as a guide for the surgical intervention. Surgical exploration should only be used when all other diagnostic means cannot confirm the presence and location of the fracture (Fig. 4). Certainly, in many cases, surgical exploration is indicated before tooth extraction.

The above techniques, when used in combination, can become effective in finding cracked or fractured teeth. But unless the practitioner is aware that cracked or fractured teeth are common, their presence may go unnoticed.

Generally, radiographs will not show fractures unless there is actual separation of the root (Fig. 5). The fracture line will not be seen unless the central beam is parallel to the fracture line or is within a few degrees of it (Andreasen 1986) and the radiograph is of good quality and contrast (Stewart 1988). Rosen (1982) identified radiographs as useful in discerning some of the other possible causes for the patient seeking dental treatment, and whose signs and symptoms may indicate a cracked or fractured tooth. These include root perforations, internal or external resorption, and endodontic failures. Radiographs may also give some suggestive or presumptive evidence of a fracture. Since many fractured teeth eventually develop periodontal defects, these defects have been radiographically described as an area of radiolucency step-like in shape, having an angular rather than rounded appearance at its most apical level (Pitts & Natkin 1983). An indistinct radiolucent 'halo' or 'balloon' along the root wall or length may

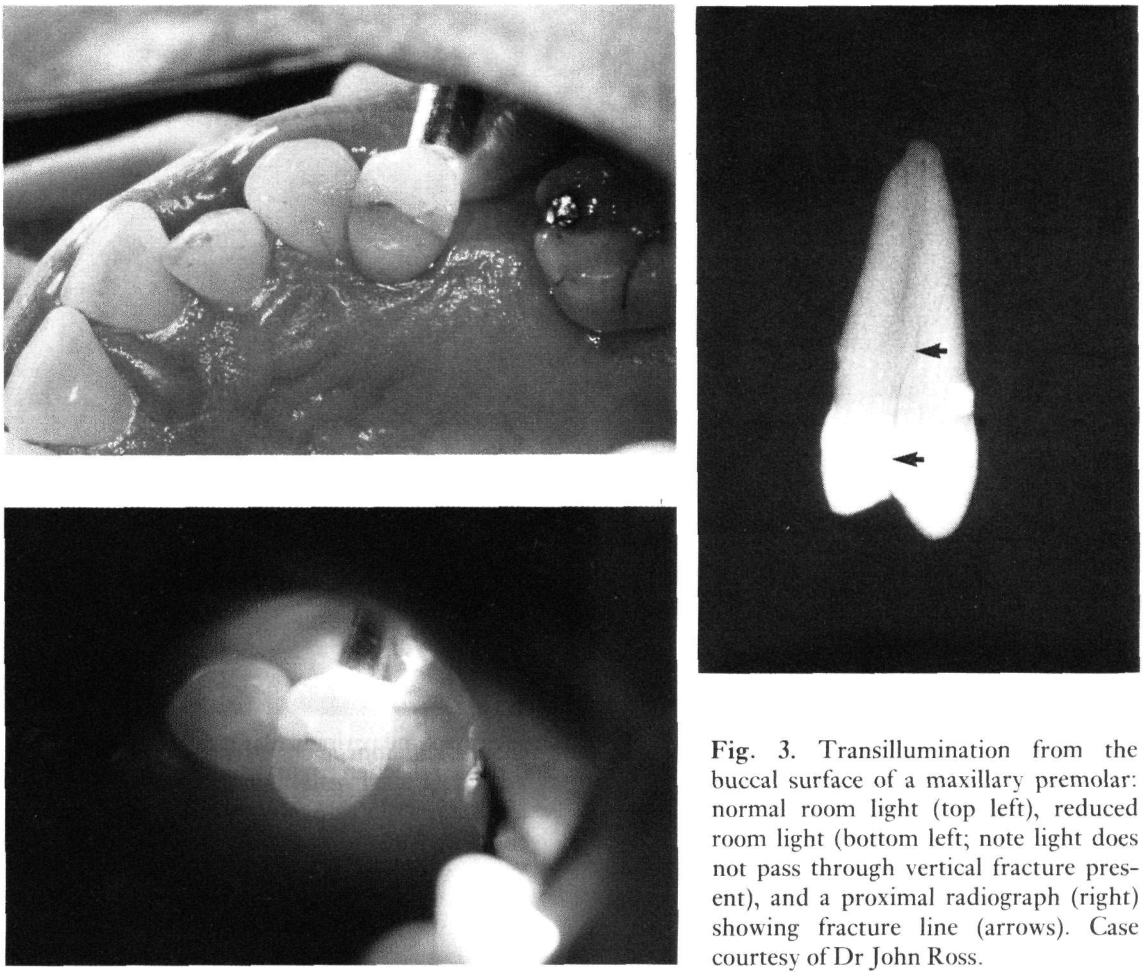

Fig. 3. Transillumination from the buccal surface of a maxillary premolar: normal room light (top left), reduced room light (bottom left; note light does not pass through vertical fracture present), and a proximal radiograph (right) showing fracture line (arrows). Case courtesy of Dr John Ross.

indicate a possible vertical root fracture (Fig. 6). A radiolucent line adjacent to the root canal filling material may indicate that there is a space between the root canal wall and the filling material possibly created by a fracture (Fig. 6). This space, however, must be differentiated from a spreader or plugger void. When radiopaque filling material is expressed through the fracture, it may appear on a radiograph as an intensely radiopaque line within the obturated canal (Pitts & Natkin 1983).

While the diagnosis of fractured teeth is further complicated by bizarre symptoms, an accurate assessment is still possible when all the facts are considered. Although the classical symptom of a fractured tooth is pain during mastication, usually upon release (Cameron, 1964, Silvestri 1976, Pitts & Natkin 1983), even this may not always be true. Patients have reported pain ranging from none to severe, with or without thermal or percussion sensitivity. Often, patients may be referred to several dental practitioners or physicians in an attempt to identify the source of their pain. A history of repeated occlusal adjustments with only temporary relief, may signal the presence of a fracture. Occasionally the patient may report having heard a crack during root canal obturation. A history of a masticatory accident, such as biting on a bone, is not an uncommon recollection by patients with a cracked tooth. Cameron (1964) eloquently stated that 'many of those (patients) with cracked teeth delighted in exerting maximum pressure on foods whether needing it or not. They took pleasure in biting hard'.

Some clinical features, previously mentioned, may aid in diagnosis and treatment planning. Some of these are bruxism, occlusal disharmonies, large intracoronal restorations,

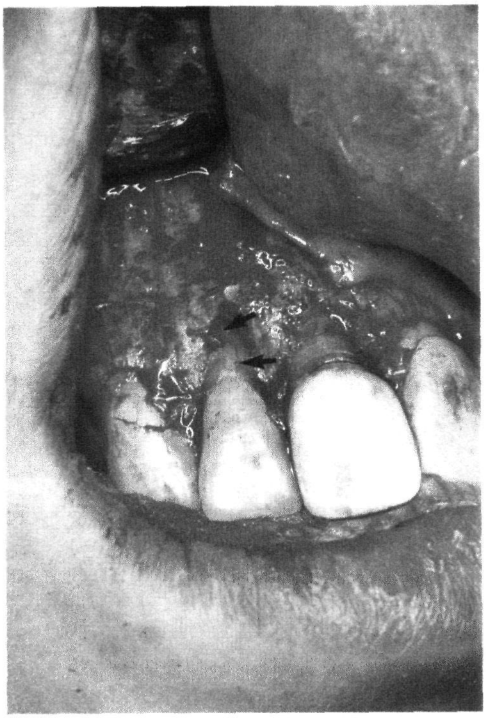

Fig. 4. A radiograph of the maxillary lateral incisor with an open apex and periradicular rarefaction (left); a hint of a radiolucent line can be seen in coronal half of root. Soft tissue reflection (right) reveals a bony defect and vertical fracture (arrows).

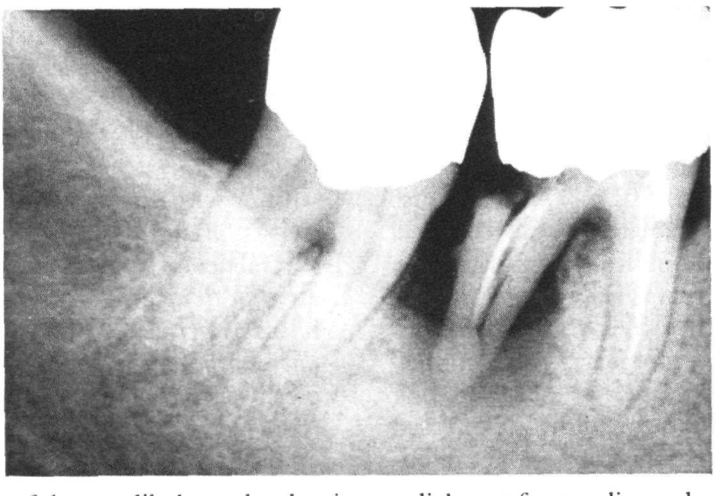

Fig. 5. A radiograph of the mandibular molar showing a radiolucent fracture line and separation of the root segments.

and aged patients. According to several studies, mandibular first and second molars are the most frequently fractured teeth (Cameron 1964, Hiatt 1973, Maxwell & Braly 1977, Gher *et al.* 1987), due to the increased number and extent of restorations, the presence of periodontal disease, their proximity to the fulcrum of the jaw, and the increased presence of root canal fillings.

Bender & Freedland (1983) classified an additional type of fracture, the pathological fracture, which may occur subsequent to periodontal disease and weakened osseous radicular support. Nyman & Lindhe (1979)

Fig. 6. A radiograph of the mandibular canine which shows diffuse longitudinal bone loss along the distal aspect of the root. Also discernible is a radiolucent line adjacent to the distal margin of the gutta-percha filling (arrows).

found that the potential for fracture of periodontally involved teeth was increased if endodontic treatment had been performed. This risk was further increased if the tooth was later restored extensively. Reinhardt *et al.* (1983), studying dentine stresses in reconstructed teeth with decreased bone support, concluded that after 4–6 mm of supporting bone had been lost, the potential for root fracture would be greater than if the tooth had normal support or even a 2 mm loss of bone height. Subsequently, if a large post was inserted into an endodontically treated tooth which had 40 per cent bone loss, and served as an abutment, the strain might lead to vertical root fracture. Fractures may be prevented as early as the planning stage of treatment. Identification of predisposing factors for fractured teeth during the oral examination should lead to adjustments in the treatment plan. Instead of large three and four surface amalgam restorations being the final restorations in patients with tightly interdigitating cusps and fossae, crowns may be more appropriate. When teeth are planned to receive root canal therapy and factors exist which predispose to fractures, banding of the tooth prior to treatment should be considered (Fig. 7). In many endodontically treated cases, restorations should include well-placed cores and crowns without posts. Extensive restorative work may need to be reconsidered in the patient who has suffered severe periodontal disease, especially if the teeth have been endodontically treated.

Endodontic procedures

During endodontic treatment, the practitioner may either cause tooth fracture, most often a vertical root fracture, or contribute to its eventual development. The most commonly cited cause is the use of excessive force during lateral condensation of gutta-percha (Maxwell & Braly 1977, Sinai & Katz 1978, Meister *et al.* 1980, Bender & Freedland 1983, Pitts *et al.* 1983, Gher *et al.* 1987, Holcomb *et al.* 1987). Excessive removal of tooth structure during access to the root canal system is also considered to contribute to crown fracture (Cameron 1976, Bender & Freedland 1983, Maxwell *et al.* 1986). Although the use of silver cones for obturation has decreased, Bender & Freedland (1983) discussed them as a factor in some fractures, especially when a large cone had been wedged in a root which was narrow apically. The effect of failing to restore teeth adequately after endodontic treatment has also been known to result in fractures and sometimes loss of teeth.

Meister *et al.* (1980) attributed 84 per cent of all vertical fractures to excessive condensation forces. Harvey *et al.* (1981) found that a group of eight endodontists exerted between 1–3 kg of force during lateral condensation. Pitts *et al.* (1983) demonstrated that 7.2 kg of force could cause vertical fractures, from this study it was conjectured that 5 kg of force was reasonable to achieve obturation without damaging the tooth. However, recent findings by Holcomb *et al.* (1987) showed that spreader loads of 1.5 kg produced fractures and that 13 per cent of the sample (54 teeth) fractured at loads of 3.5 kg or less. Therefore, it was recommended that condensing instruments should not be wedged against the root canal walls.

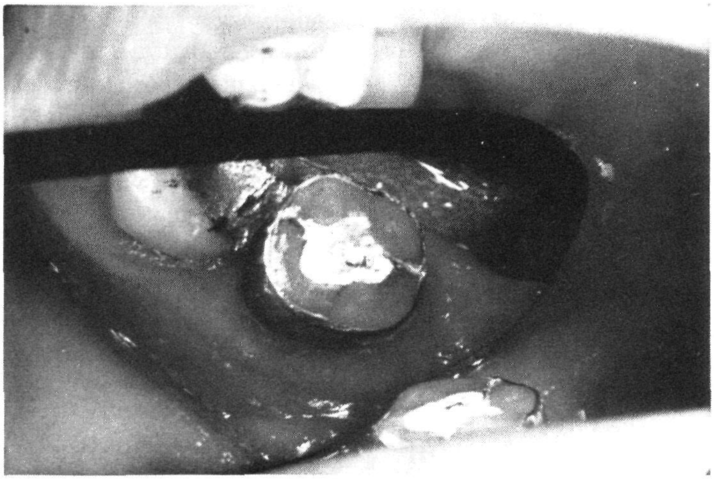

Fig. 7. A mandibular molar with a crown fracture banded for endodontic treatment; note the mesial and distal fracture lines.

During endodontic access preparation, canal cleaning and shaping, and preparation of the canal space to receive a post, excessive amounts of tooth structure may be removed intentionally or unintentionally. Some authors (Bender & Freedland 1983) attributed fractures to the recent introduction of techniques that advocate the use of rotary instruments within the root canal. Instruments such as Peeso reamers and Gates Glidden burs cut in a straight line, resulting in the removal of significant amounts of dentine, especially in naturally thin areas of roots (Abou-Rass *et al.* 1982). Care and caution must be exercised when using these instruments; this also applies to sonic and ultrasonic instruments. Preservation of not only coronal, but also radicular tooth structure is needed for successful treatment of the tooth.

While endodontic procedures may contribute to the fractures of teeth, Matusow (1987) is of the view that many of fractures are present prior to endodontic diagnosis and treatment, and are often overlooked as aetiological factors in pulpal demise and patient discomfort. This could be especially true where rubber dam clamp pressure, pre-endodontic banding, or crowns temporarily mask pre-existing hairline fractures. Although evidence for this is empirical, the possibility of a fracture in posterior teeth requiring endodontic treatment should always be considered.

Restorative procedures

An increase in dentine brittleness has been postulated by many as a contributing factor to the increased susceptibility to fracture of pulpless teeth. Helfer *et al.* (1972) found a 9 per cent moisture loss in the calcified tissues of pulpless dog's teeth compared with vital teeth. Carter *et al.* (1983), using a punch shear test, found that dentine from endodontically treated molars was weaker and more brittle than vital dentine. However, Lewinstein & Grajower (1981), testing the Vicker's hardness of dentine, found that endodontic treatment did not significantly affect the hardness of dentine. They indicated that the mechanical properties of teeth may change after root canal treatment and that microcracks may develop as a result of canal preparation and water loss.

While the view that endodontically treated teeth are more brittle is controversial, it is known that the architecture of the tooth has been altered, sometimes significantly (Tidmarsh 1976). Therefore, it is advisable that the majority of posterior teeth and some anterior teeth should receive a restoration which will protect the tooth during function. It has been recommended that all teeth should have full cuspal coverage (Johnson *et al.* 1976, Rosen 1982, Goerig & Mueninghoff 1983). However, excessive removal of enamel and dentine may lead to fractures by weakening the remaining tooth structure. With the advent of stronger

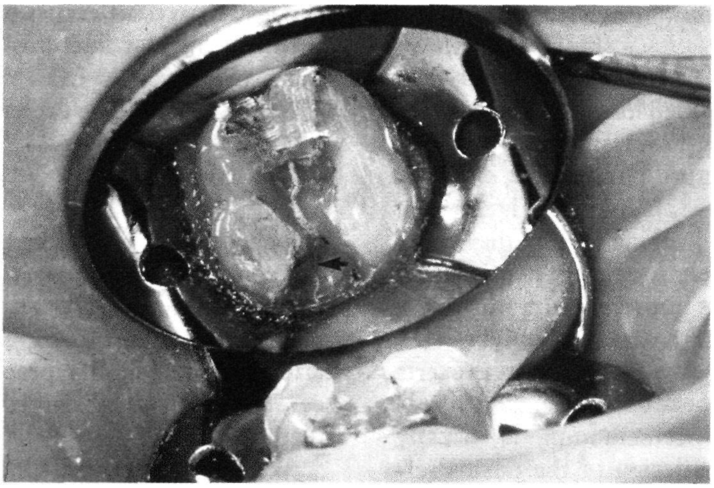

Fig. 8. Presence of a crown fracture (arrow) under a gold inlay; the patient had experienced severe pulpitis.

amalgam alloys and resin bonded to acid etched enamel, an increasing number of studies have identified these newer materials and techniques as alternatives to crowns for multilated tooth (Brown *et al.* 1979, Nayyar *et al.* 1980, Oliviera *et al.* 1987). Re *et al.* (1982) concluded that there was no statistical difference in the fracture strength of teeth with three surface alloys and unrestored teeth. When large alloys did fracture, the resultant fracture left the tooth unrestorable in a majority of cases. On the other hand, Gher *et al.* (1987) found that multisurface amalgam restorations were the most common restoration in fractured teeth. Comparing both amalgam restorations and acid-etched posterior composite resins on endodontically treated teeth, Oliviera *et al.* (1987) showed that the composite enhanced the resistance to fracture. While definitive guide-lines for the effective use of all materials in the restoration of endodontically treated teeth are unknown, it is commonly believed by all investigators that the greatest factor influencing the strength of endodontically treated teeth is the amount of remaining tooth structure, and that all reasonable efforts should be expended to preserve it.

Often, large three and four surface amalgam restorations are made possible by the use of pins, although pins do not strengthen the restoration. If too many pins are used, or if improperly placed, they can cause crazing and microcracks in the tooth, thus contributing to fracture (Cameron 1976, Johnson *et al.* 1976, Mazwell & Braly 1977, Rosen 1982). However, pin-retained amalgam restorations have been recommended for incompletely fractured teeth to bind the segments and provide internal stabilization (Clark & Caughman 1984). Recently Stewart (1988) demonstrated the use of reinforced glass ionomer cements to bind tooth segments together in the presence of vertical fractures.

Cameron (1964, 1976) and Ritchey *et al.* (1957) noted that many cracked or fractured teeth had inlays, particularly those made of soft gold. This restoration, by design, can act as a wedge during function thereby forcing the tooth apart (Fig. 8). The effect may be exacerbated if the patient has occlusal disharmonies which are thought to predispose to fractures.

Many teeth are severely mutilated, requiring some type of post along with coronal buildup. Posts used either alone or in combination with a core, may cause root fractures (Maxwell & Braly 1977, Meister *et al.* 1980, Pitts & Natkin 1983, Luebke 1984), therefore, proper post preparation, design, and insertion are needed to protect against such accidents (Abou-Rass 1985).

There are two basic prefabricated post designs, tapered and parallel, and there are two design modifications, threaded and grooved. While a detailed analysis of posts is outside the scope of this paper, factors which have a bearing on odontiatrogenic tooth fractures will be addressed. The use of posts and cores in the restoration of endodontically treated teeth has been reviewed by Stokes (1987).

Overenlargement of the root canal may weaken the root through loss of dentine (Leary *et al.* 1987, Stokes 1987) and may result in perforation or fracture (Johnson *et al.* 1976, Abou-Rass *et al.* 1982). A knowledge of root canal morphology, along with diagnostic radiographs, will help to prevent overenlargement of the canal or improper post selection.

The insertion of a tapered prefabricated post or a custom cast post and core exerts minimal stress on the root walls as the hydrostatic pressure of cementation is usually relieved due to the design of the post. Preference is often given to the prefabricated post because it is easier to use and the tooth can be rebuilt and prepared in one appointment (Abou-Rass 1985). The cast post and core, however, possesses superior adaptation to the canal walls and distributes stresses generated during function more evenly throughout the root structure and supporting bone. Both systems are, however, minimally retentive and can exert a wedging effect on the root during function.

The parallel-sided post has more retention and distributes forces better than the tapered post (Standlee *et al.* 1972, Johnson *et al.* 1976). During post space preparation, perforation or fracture of the root is possible due to the post's configuration and the apical tapering of the root. With a radiograph, it is simple to compare two dimensionally the post configuration with that of the root; root concavities in the third dimension must also be considered. During cementation it is advisable to vent the post to alleviate the hydrostatic pressures which can produce high apical stresses and ultimate fracture. The apically tapered, parallel-sided post was introduced to prevent apical perforations in roots which are narrow and thin in their middle and apical portions. However, Cooney *et al.* (1986) found that this post design produced a wedging stress at its apical extent which was not found with the parallel-sided post.

Threaded posts exhibit the most retention and exert the least apical stress on the root when used correctly (Standlee *et al.* 1972, 1978). However, the tapping or threading required to prepare the root for their insertion can lead to stress. Because of the high reported incidence of root fractures with these type of posts (Sorensen & Martinoff 1984, Stewart 1988), care should be exercised in their use.

Conclusions

Within the past 25 years it has become clinically accepted that cracked or fractured teeth are common. Early reports identified factors over which the dental practitioner had no control. However, in this paper the authors have attempted to identify practitioner generated causes which may contribute to fractured teeth.

With a sizeable array of clinical tests available, the practitioner should be able to diagnose the presence of fractured teeth. Patients complaining of bizarre symptoms should be thoroughly evaluated for the presence of fractures prior to referral to a specialist. In addition, the ability to diagnose the presence or possibility of a fractured tooth during treatment planning will enhance the interception and correction of those clinical features which have contributed to the fracture.

Because there is an increased awareness of periodontal disease by the general population, larger numbers of patients are retaining their teeth longer. With longer retention, more endodontic treatment will be initiated. This could lead to an increase in the number of pathological fractures seen in dental practice. It behoves the practitioner to identify those clinical situations which predispose to the fracture of teeth. It is also necessary to exercise good clinical judgement during treatment to avoid contributing to the fracture of teeth. This will often necessitate modification of endodontic or restorative techniques. *Most odontiatrogenic tooth fractures can be prevented.*

References

Abou-Rass, M. (1985) The prefabricated post: selection and use in endodontic and restorative therapy. In *Clinical Dentistry*, Vol. 4, Chap. 10B, pp. 1–27. Harper & Row, Philadelphia.

Abou-Rass, M., Jann, J.M., Jobe, D. & Tsutsui, F. (1982) Preparation of space for posting: effect on thickness of canal walls and incidence of perforation in molars. *Journal of the American Dental Association*, **104**, 834–837.

Andreasen, J.O. (1986) Management of soft tissue trauma and alveolar fractures. In *Proceedings of* *the International Conference on Oral Trauma* (eds J.L. Gutmann and J.W. Harrison), pp. 147–154. American Association of Endodontists, Chicago.

BENDER, I.B. & FREEDLAND, J.B. (1983) Adult root fracture. *Journal of the American Dental Association,* **107,** 413–419.

BROWN, D.R., BARKMEIER, W.W. & ANDERSON, R.W. (1979) Restoration of endodontically treated posterior teeth with amalgam. *Journal of Prosthetic Dentistry,* **41,** 40–44.

CAMERON, C.E. (1964) Cracked-tooth syndrome. *Journal of the American Dental Association,* **68,** 405–411.

CAMERON, C.E. (1976) The cracked-tooth syndrome: additional findings. *Journal of the American Dental Association,* **93,** 971–975.

CARTER, J.M., SORENSEN, S.E., JOHNSON, R.R., TEITELBAUM, R.L. & LEVINE, M.S. (1983) Punch shear testing of extracted vital and endodontically treated teeth. *Journal of Biomechanics,* **16,** 841–848.

CLARK, L.L. & CAUGHMAN, W.F. (1984) Restorative treatment for the cracked tooth. *Operative Dentistry,* **9,** 136–142.

COONEY, J.P., CAPUTO, A.A. & TRABERT, K.C. (1986) Retention and stress distribution of tapered-end endodontic posts. *Journal of Prosthetic Dentistry,* **55,** 540–546.

GHER, M.E., DUNLAP, R.M., ANDERSON, M.H. & KUHL, L.V. (1987) Clinical survey of fractured teeth. *Journal of the American Dental Association,* **114,** 174–177.

GOERIG, A.C. & MUENINGHOFF, L.A. (1983) Management of the endodontically treated tooth. Part I. Concept for restorative designs. *Journal of Prosthetic Dentistry,* **49,** 340–345.

HARVEY, T.E., WHITE, J.T. & LEEB, I.J. (1981) Lateral condensation stress in root canals. *Journal of Endodontics,* **7,** 151–155.

HELFER, A.R., MELNICK, S. & SCHILDER, H. (1972) Determination of the moisture content of vital and pulpless teeth. *Oral Surgery, Oral Medicine and Oral Pathology,* **34,** 661–670.

HIATT, W.H. (1973) Incomplete crown-root fracture in pulpal-periodontal disease. *Journal of Periodontology,* **44,** 369–379.

HOLCOMB, J.Q., PITTS, D.L. & NICHOLLS, J.I. (1987) Further investigation of spreader loads required to cause vertical root fracture during lateral condensation. *Journal of Endodontics,* **13,** 277–284.

JOHNSON, J.K., SCHWARTZ, N.L. & BLACKWELL, R.T. (1976) Evaluation and restoration of endodontically treated posterior teeth. *Journal of the American Dental Association,* **93,** 597–605.

LEARY, J.M., AQUILINO, S.A. & SVARE, C.W. (1987) An evaluation of post length within the elastic limits of dentin. *Journal of Prosthetic Dentistry,* **57,** 277–281.

LEWINSTEIN, I. & GRAJOWER, R. (1981) Root dentin hardness of endodontically treated teeth. *Journal of Endodontics,* **7,** 421–422.

LOMMEL, T.J., MEISTER, F., GERSTEIN, H., DAVIES, E.E. & TILK, M.A. (1978) Alveolar bone loss associated with vertical root fractures. Report of six cases. *Oral Surgery, Oral Medicine and Oral Pathology,* **45,** 909–919.

LUEBKE, R.G. (1984) Vertical crown-root fractures in posterior teeth. *Dental Clinics of North America,* **28,** 883–894.

MATUSOW, R.J. (1987) Endodontic implications of root fractures. *Journal of the American Dental Association,* **114,** 766.

MAXWELL, E.H. & BRALY, B.V. (1977) Incomplete tooth fracture—prediction and prevention. *California Dental Association Journal,* **5**(10), 51–55.

MAXWELL, E.H., BRALY, B.V. & EAKLE, W.S. (1986) Incompletely fractured teeth—a survey of endodontists. *Oral Surgery, Oral Medicine and Oral Pathology,* **61,** 113–117.

MEISTER, F., LOMMEL, T.J. & GERSTEIN, H. (1980) Diagnosis and possible causes of vertical root fractures. *Oral Surgery, Oral Medicine and Oral Pathology,* **49,** 243–253.

NAYYAR, A., WALTON, R.E. & LEONARD, L.A. (1980) An amalgam coronal-radicular dowel and core technique for endodontically treated posterior teeth. *Journal of Prosthetic Dentistry,* **43,** 511–515.

NYMAN, S. & LINDHE, J. (1979) A longitudinal study of combined periodontal and prosthetic treatment of patients with advanced periodontal disease. *Journal of Periodontology,* **50,** 163–167.

OLIVEIRA, F.C., DENEHY, G.E. & BOYER, D.B. (1987) Fracture resistance of endodontically prepared teeth using various restorative materials. *Journal of the American Dental Association,* **115,** 57–60.

PITTS, D.L., MATHENY, H.E. & NICHOLLS, J.I. (1983) An in-vitro study of spreader loads required to cause vertical root fractures during lateral condensation. *Journal of Endodontics,* **9,** 544–550.

PITTS, D.L. & NATKIN, E. (1983) Diagnosis and treatment of vertical root fractures. *Journal of Endodontics,* **9,** 338–346.

RE, G.J., NORLING, B.K. & DRAHEIM, R.N. (1982) Fracture strength of molars containing three surface amalgam restorations. *Journal of Prosthetic Dentistry,* **47,** 185–187.

REINHARDT, R.A., KREJCI, R.F., PAO, Y.C. & STANNARD, J.G. (1983) Dentine stresses in post-reconstructed teeth with diminished bone support. *Journal of Dental Research*, **62**, 1002–1008.

Ritchey, B., Mendenhall, R. & Orban, B. (1957). Pulpitis resulting from incomplete tooth fracture. *Oral Surgery, Oral Medicine and Oral Pathology*, **10**, 665–670.

Rosen, H. (1982) Cracked tooth syndrome. *Journal of Prosthetic Dentistry*, **47**, 36–43.

Silvestri, A.R. (1976) The undiagnosed split-root syndrome. *Journal of thje American Dental Association*, **92**, 930–935.

Sinai, I.H. & Katz, H.R. (1978) Management of a vertical root fracture. *Journal of Endodontics*, **4**, 316–317.

Sorensen, J.A. & Martinoff, J.T. (1984) Clinically significant factors in dowel design. *Journal of Prosthetic Dentistry*, **52**, 28–35.

Standlee, J.P., Caputo, A.A., Collard, E.W. & Pollack, M.H. (1972) Analysis of stress distribution by endodontic posts. *Oral Surgery, Oral Medicine and Oral Pathology*, **33**, 952–960.

Standlee, J.P., Caputo, A.A. & Hanson, E.C. (1978) Retention of endodontic dowels: effects of cement, dowel length, diameter and design. *Journal of Prosthetic Dentistry*, **39**, 401–405.

Stewart, G.G. (1988) The detection and treatment of vertical root fractures. *Journal of Endodontics*, **14**, 47–53.

Stokes, A.N. (1987) Post crowns: a review. *International Endodontic Journal*, **20**, 1–7.

Sutton, P.R.N. (1962) Greenstick fracture of the tooth crown. *British Dental Journal*, **112**, 362–363.

Tidmarsh, B.G. (1976) Restoration of endodontically treated posterior teeth. *Journal of Endodontics*, **2**, 374–375.

Walton, R.E., Michelich, R.J. & Smith, G.N. (1984) The histopathogenesis of vertical root fractures. *Journal of Endodontics*, **10**, 48–56.

Wechsler, S.M., Vogel, R.I., Fishelberg, G. & Shovlin, F.E. (1978) Iatrogenic tooth fractures: a case report. *Journal of Endodontics*, **4**, 251–253.

Wiebusch, F.B. (1972) Hairline fracture of a cusp: report of a case. *Journal of the Canadian Dental Association*, **38**, 192–194.