

# Predictable management of cracked teeth with reversible pulpitis

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## ABSTRACT

**Background:** The aims of this study were to assess symptoms and signs caused by cracks in teeth and to assess a conservative management protocol.

**Methods:** The symptoms and signs of 100 consecutive teeth that had reversible pulpitis associated with cracks were compared to findings from other reports. Teeth were managed with a conservative protocol which involved removal of cracks, caries and restorations, followed by placement of a sedative lining and interim restoration unless there were pulp exposures or insufficient tooth structure remaining. Teeth were monitored for pulp healing after three months and for up to five years.

**Results:** Eighty teeth did not require endodontic treatment. One tooth had an uncertain pulp status at review appointments. Fifteen teeth required endodontic treatment at the initial appointment because of carious pulp exposures (4 teeth), cracks extending into the pulp (2), and posts required (9). Four other teeth required endodontic treatment later following conservative pulp treatment due to continued pulpitis under the temporary restoration (1), pulpitis after core restoration (2), and pulp necrosis diagnosed at the review (1).

**Conclusions:** Provided there is an accurate diagnosis of the pulp status and its cause, teeth with reversible pulpitis due to cracks can be treated conservatively without endodontic treatment in about 80 per cent of cases.

**Keywords:** Reversible pulpitis, cracked teeth, endodontics.

**Abbreviations and acronyms:** CTS = cracked tooth syndrome; RCF = root canal filling.

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## INTRODUCTION

Cracks and fractures in teeth are relatively common problems in general and specialist dental practices. Bader *et al.*<sup>1</sup> reported that approximately one in 20 people fracture a tooth each year although the authors of that study did not define what they meant by a fracture. Since these fractures had varying consequences ranging from no treatment being required to extraction of the tooth, it is likely that some of these fractures were cracks. The lack of definition of a crack is typical of most studies regarding cracks and therefore it is difficult to quantify the number of patients who have pulp problems from cracks in teeth. Although many studies have been published regarding this subject, there is considerable confusion<sup>2–5</sup> and many varying opinions with the result that no common understanding about the diagnosis and management of cracked teeth has been developed.

The first report where the symptoms of incomplete fracture of posterior teeth involving cusps were detailed

was by Gibbs in 1954.<sup>6</sup> He termed the condition as “cuspal fracture odontalgia”. Later, Cameron<sup>7</sup> suggested the term “cracked tooth syndrome” (commonly abbreviated to CTS) for the collective signs and symptoms associated with cracked teeth. In 1976, Cameron further stated that only 75 per cent of teeth with CTS will have “vital pulps”.<sup>8</sup> The term CTS was re-defined in 1990 as an “incomplete fracture of a vital posterior tooth involving the dentine and possibly the dental pulp”.<sup>9</sup>

Since 1954, this condition has been continually re-defined and re-named by various authors in different journal articles. However, there has been no common definition and no common terminology with the result that there is now much confusion amongst practitioners. The use of the term “syndrome” is particularly misleading because a syndrome is defined as “a number of symptoms occurring together and characterising a specific disease”.<sup>10</sup> Clearly, a crack in a tooth is not a disease and therefore the term syndrome is inappropriate. Although cracks can be associated with a number

of symptoms that occur together, these symptoms vary considerably from case to case. The usual symptoms are those of one of the various forms of pulpitis with some cases also having symptoms of apical or lateral periodontitis.<sup>2,5,11</sup> However, each of these broad categories of diseases (i.e., pulpitis and periodontitis) has a wide range of symptoms and signs depending on the exact condition being experienced by the patient.<sup>12,13</sup> For example, a tooth with acute reversible pulpitis has a different set of symptoms and signs than a tooth with acute irreversible pulpitis. Furthermore, cracks may also be present in teeth that have necrotic pulps, those that have become pulpless due to infections, or those that have had previous endodontic treatment. Therefore, there are many different symptoms and signs that may be present in teeth with cracks.

In 1997, the American Association of Endodontists defined five types of tooth cracks<sup>4</sup> but these five categories are not entirely clear and overlap to some extent. A clearer and simpler classification is suggested below with just three categories:

(1) Enamel crazing (or enamel infraction) – small cracks on the surface of teeth; hence craze lines in teeth involve only the enamel and there are no pulp symptoms. No treatment is required but enamel crazes have the potential to progress to become cracks in the tooth and should therefore be monitored.

(2) Crack – a crack is a defect where there is a break between two parts but without separation of the fragments; hence, a crack in a tooth involves the dentine and the enamel and/or cementum. A crack may extend into the pulp space in some cases. A crack may or may not cause pulp diseases (inflammation and eventually necrosis and infection) and periradicular diseases, depending on whether bacteria can penetrate the tooth via the crack to reach the pulp space. Cracks do not require treatment unless they are causing pulp and/or periradicular diseases. However, all cracks have the potential to progress to become a fracture of the tooth and therefore they should be monitored if not treated immediately to help prevent or manage pulp and/or periradicular disease. Cracks that are causing pulp and periradicular diseases require treatment, the nature of which varies considerably depending on the position, direction and extent of the crack.

(3) Fracture – a fracture is a defect where there is a break between two parts and the fragments have separated; hence, a fracture of a tooth involves the dentine and either only the enamel or cementum, or both of these tissues. A fracture may or may not extend into the pulp space. A fracture may or may not cause pulp diseases (inflammation and eventually necrosis and infection) and periradicular diseases, depending on whether bacteria can penetrate the tooth via the fracture to reach the pulp space. The

treatment required for fractures varies considerably depending on the position, direction and extent of the fracture.

Attempts to describe the “classic” symptoms associated with cracks in teeth have only led to confusion amongst practitioners<sup>4</sup> as there are no classic symptoms. The presenting symptoms are dependent on the underlying disease processes in the dental pulp and periradicular tissues that have been caused by the crack. The result of the various definitions and attempts to classify and list the symptoms of cracked teeth is that there are many varied management protocols recommended by authors and clinicians. The lack of a universal appreciation of what cracks are, what they do and what they cause has created much debate and confusion about what is clinically effective and acceptable when handling cracks in teeth. Hence, there is no standard management protocol to follow and there are no studies that have followed teeth for sufficient times to be able to adequately analyse the various treatment approaches. This results in uncertainty amongst practitioners and patients. In the worst case scenario, poorly handled cases of cracked teeth may progress to undesirable manifestations of pulp and periradicular disease, all as a result of inadequate understanding of the original problem. As an example, the so-called “CTS” is often confused with vertical root fractures.<sup>14</sup>

The management of cracks in teeth should be based on the concept of a crack being a biological problem rather than a mechanical problem in the tooth. The simplest way to consider a crack in a tooth is that it is a potential cause of pulp and periradicular diseases in the same manner that caries and breakdown of restoration margins can cause these diseases by allowing bacteria to enter the tooth and produce endotoxins that can reach the pulp or ultimately the bacteria themselves can reach the pulp. Thus, cracks should be thought of as a cause of disease (especially pulp disease), rather than being considered as a syndrome or a disease in itself. The noting of the presence of a crack should be considered as a clinical finding or observation, and not a diagnosis. Cracks should be considered as a potential pathway of entry for bacteria into the tooth.<sup>15–17</sup>

It is important to note that not all cracks will lead to pulp and periradicular diseases. These problems will only occur if a sufficient number of bacteria are present in the crack and if the particular bacteria are virulent enough to cause pulp and periradicular diseases. Further factors are the state of health of the particular pulp at the time of bacterial invasion and whether the pulp can resist the invasion of bacteria or the irritation created by their endotoxins.

The aim of this research was two-fold; firstly to assess the symptoms and signs caused by cracks in order to simplify guidelines for the diagnostic process and

management planning of teeth with cracks. The second aim was to assess the outcome of a conservative management protocol for teeth with reversible pulpitis caused by cracks.

## MATERIALS AND METHODS

This study was a prospective study of a series of 100 cracked teeth diagnosed with reversible pulpitis. These patients were all referred to an endodontist in private practice for the management of their complaint of pain associated with the tooth/teeth included in this study. Data were recorded on a proforma developed for the study by the treating endodontist at the time of examination of the patient and at follow-up appointments. The data were then de-identified, collated and assessed.

Upon thorough examination, 100 consecutive teeth diagnosed with reversible pulpitis (according to the criteria defined by Abbott and Yu<sup>13</sup>) due to cracks were identified. Commonly reported signs of cracked teeth and pulpitis were identified and assessed. Patient reports of sensitivity to various stimuli were recorded. Pain associated with biting was assessed by using the Tooth Slooth and in particular the presence of pain on application and/or release of pressure was noted. Various other factors were also assessed. These included the reason for referral to the endodontist, the pain symptoms reported by the patient, the duration of pain after removal of the stimulus and the time that the pain had been present prior to examination.

Once the specific tooth had been identified and the diagnosis was confirmed, the patients were provided with a detailed explanation of the presenting problem and the proposed management plan in order to obtain their informed consent to proceed with treatment.

The specific protocol used for the management of teeth with reversible pulpitis is a conservative approach, as outlined in the flow chart presented as Fig 1. It is important to note that the cracks in the teeth were managed using the same principles as those traditionally used for managing caries, i.e., the cracks were removed so that all potential pathways of entry for bacteria were removed. The protocol is outlined below.

The first stage was termed “investigation” of the tooth and this involved removal of all restorations, caries and cracks from the teeth. The teeth were then assessed to determine whether there was a pulp exposure (either by caries or the crack), whether a post or other form of intraradicular retention was required in order to help retain the eventual restoration, or whether the crack extended too far into the root and therefore the tooth was not suitable for restoration in which case extraction was required. When the first two situations were present, endodontic treatment was

commenced immediately. None of the teeth required extraction in this study.

Teeth that did not require immediate endodontic treatment (for the reasons outlined above) had a sedative lining (Ledermix cement, Lederle Laboratories, Wolfratshausen, Germany) placed to sedate the pulp and help with the healing response. The teeth were then restored with an interim restoration using traditional chemical-set glass ionomer cements – either Ketac Silver or Ketac Fil (3M-ESPE, Seefeld, Germany), depending on the aesthetic requirements of each particular tooth. A stainless steel (SS) band (“A” Bands, Ormco, USA) was utilized as part of the interim restoration when extra retention was required. The SS band served to retain the interim restoration, and not as a “splint” to hold the cracks or cusps together since all cracks were removed from the tooth along with any unsupported tooth structure that would have to be removed as part of the definitive restoration once the pulpitis symptoms had resolved. Some cases required a temporary crown which was cemented with a soft mix of a zinc oxide-eugenol cement (IRM, Dentsply Caulk, Milford, USA) with the aim of the eugenol acting as a sedative for the pulp.

After placing the lining and interim restoration, patients were warned about possible postoperative pain and they were asked to record when their pain disappeared. If the pain continued, they were instructed to contact the endodontist for re-evaluation and further treatment. If the pain resolved within the first few days, the patients were re-appointed for a three-month postoperative clinical and radiographic review in order to assess the pulp status and healing response. Normal responses to cold pulp sensibility tests at the three-month review indicated that the pulpitis had resolved, thus confirming the original diagnosis of reversible pulpitis. These patients were then referred back to their general dentist for restoration with an overlay or crown. Further follow-up examinations were arranged for up to five years to monitor the pulp status of these teeth.

If there was no response to pulp sensibility tests at the three-month review, then this indicated possible pulp necrosis and the patient was scheduled for a further three-month review or for the commencement of endodontic treatment, depending on how definitive the diagnosis was at that time. These patients were also scheduled for further follow-up examinations for up to five years to monitor the pulp status of these teeth.

Data were collated and analysed by frequency to determine whether any particular sign or symptom of cracked teeth and reversible pulpitis helps to formulate a diagnosis. Furthermore, the data were used to determine the efficacy of the treatment regime outlined for cracked teeth with reversible pulpitis.

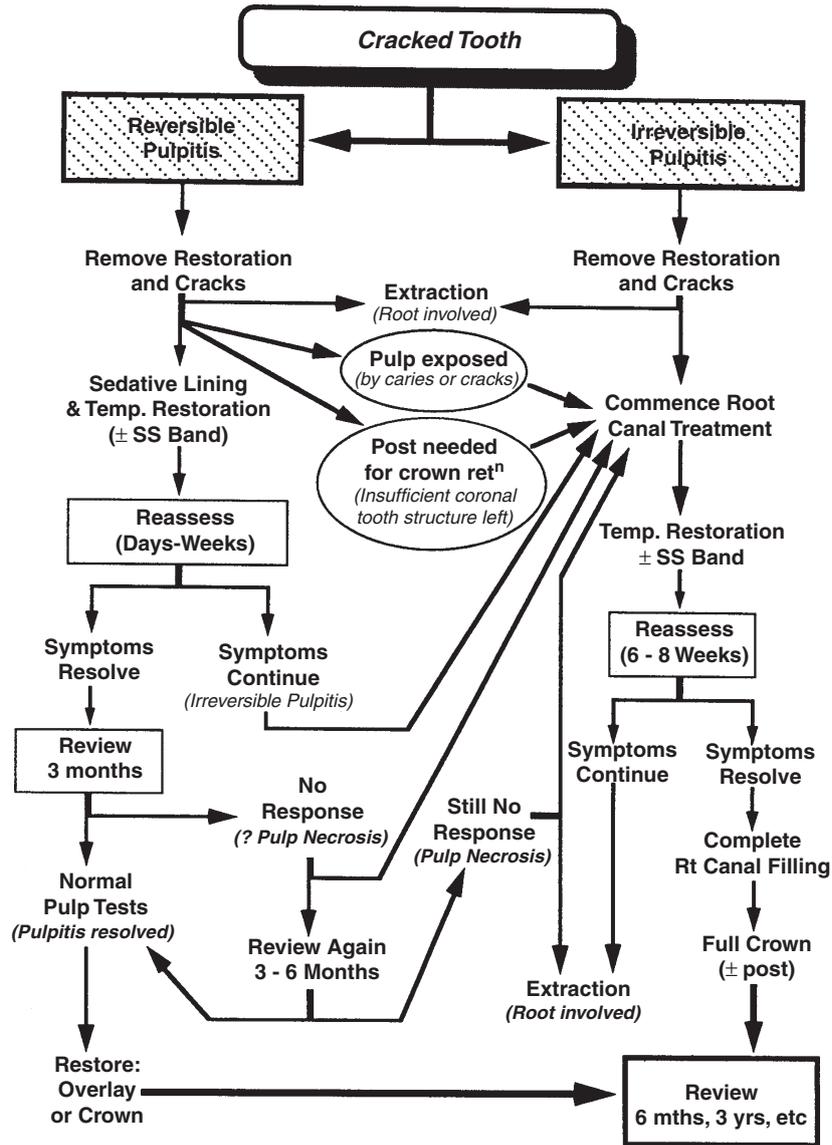


Fig 1. Flow chart outlining the protocol for managing teeth with cracks and pulpitis. The aim of managing teeth with reversible pulpitis due to cracks is to follow the arrows down the left side of the flow chart from the diagnosis of reversible pulpitis to the restoration of the tooth. However, there are various stages where endodontic treatment may become necessary.

**RESULTS**

A total of 100 consecutive teeth in 76 patients diagnosed with reversible pulpitis due to cracks were included in this study. The patients were between 17 and 68 years of age (mean = 42.5 years old). The majority of the teeth (72 per cent) were in patients in the 30–50 years age group whilst 32 per cent of the patients were male and 68 per cent were female.

Most patients had just one tooth treated (65 per cent) but some had two to three teeth treated, and one patient had 10 teeth treated as a result of a motor vehicle accident (Table 1). There were various reasons for referral with the most common being for “endodontic treatment” (Table 2). Cracks were initially

**Table 1. Number of teeth treated per patient**

Number of teeth treated	Number of patients
1	65
2	5
3	5
10	1
100	76

identified by the referring dentists as being associated with the presenting pain and requiring treatment in only 9 per cent of the cases (Table 2). Molar teeth were the most common tooth group (82 per cent) with the maxillary first molar tooth being the most common tooth involved (29 per cent) (Table 3).

**Table 2. Reasons for referral**

Reason stated by referring dentist	Number
Endodontic treatment	43
Referred for another tooth	18
Diagnosis	17
Not specified	13
Investigate crack	9
<b>Total</b>	<b>100</b>

**Table 3. Teeth types**

Tooth type	Maxillary	Mandibular	Total
Incisor/canine	2	–	2
1st premolar	6	–	6
2nd premolar	5	5	10
1st molar	29	19	48
2nd molar	13	19	32
3rd molar	–	2	2
<b>Total</b>	<b>55</b>	<b>45</b>	<b>100</b>

The pain symptoms reported by the patients varied with half of the teeth having sensitivity to cold, heat and biting, whilst the other half had variable combinations of these three stimuli causing pain (Table 4). The majority of the cases (91 per cent) had pain associated with biting tests using the Tooth Slooth (Professional Results Inc, Laguna Niguel, CA, USA) although pain upon application of pressure was the most common (Table 5) and pain on release of pressure alone only occurred in eight teeth, which is contrary to many reports which claim that this is a classic sign of cracks in teeth. The duration of pain after the stimulus was removed varied between one second and five minutes (Table 6). Pain was present prior to seeing the endodon-

**Table 4. Pain symptoms (as reported by patients)**

Sensitivity to	Number of teeth
Cold	1
Heat	–
Biting	10
Cold + heat	19
Cold + biting	17
Heat + biting	3
Cold + heat + biting	50
<b>Total</b>	<b>100</b>

**Table 5. Biting pain (tested with Tooth Slooth)**

When pain experienced	Number of teeth
On application of pressure	68
On release of pressure	8
On both application + release of pressure	15
No pain when biting	9
<b>Total</b>	<b>100</b>

**Table 6. Duration of pain (after stimulus removed)**

Duration of pain after stimulus removed	Number of teeth
1–2 secs	37
3–5 secs	27
10–15 secs	21
20–30 secs	8
30–60 secs	5
1–2 mins	1
4–5 mins	1
<b>Total</b>	<b>100</b>

**Table 7. Time pain had been present prior to seeing the endodontist**

Time pain present	Number of teeth
< 1 month	12
1–3 months	40
4–6 months	15
7–12 months	24
1–3 years	8
> 5 years	1
<b>Total</b>	<b>100</b>

tist for a wide variety of times ranging from less than one month up to approximately five years (Table 7).

Despite 83 teeth having no missing cusps pre-operatively, only 17 teeth had no missing cusps after treatment (Table 8) which indicates that most of the cracks in this study were undermining cusps. After removing the restorations, caries and cracks (i.e., investigation of the tooth), 85 teeth were treated conservatively with a Ledermix cement sedative lining and an interim restoration using either Ketac Silver or Ketac Fil, depending on the aesthetic requirements. Most teeth (76) also had a SS band applied to help retain the interim restoration and three teeth required a temporary crown (Table 9). These 85 teeth were then reviewed after three months to determine whether the pulpitis resolved and the pulps returned to normal. The other 15 teeth required endodontic treatment due to carious exposure (4 teeth), cracks extending into the pulp chamber (2 teeth) or the need for a post or other form of intraradicular retention to help retain the restoration (9 teeth) (Table 10).

**Table 8. Number of missing cusps**

Number of missing cusps	Number of teeth pre-operative	Number of teeth postoperative
0	83	17
1	16	42
2	1	33
3	–	5
4	–	3
<b>Total</b>	<b>100</b>	<b>100</b>

**Table 9. Interim restorations used**

Interim restoration	Number of teeth
Ketac Silver	18
Ketac Silver + SS Band	71
Ketac Fil	3
Ketac Fil + SS Band	5
Temporary crown	3
<b>Total</b>	<b>100</b>

**Table 10. Pulp treatment at the investigation appointment**

Treatment	Number of teeth
Ledermix cement lining	85
Endodontic treatment due to:	
• carious exposure	4
• crack into pulp chamber	2
• for post retention	9
Sub-total:	15
<b>Total</b>	<b>100</b>

Of the 85 teeth that were treated with Ledermix cement, the symptoms resolved immediately in 60 teeth and over the following 1–3 days for the remaining 25 teeth (Table 11). At the three-month review, the pulpitis had resolved in 98 per cent of the 85 teeth treated with Ledermix cement (Table 12). The pulpitis continued in one tooth prior to the three-month review

**Table 11. Time taken for the symptoms of reversible pulpitis to resolve in the 85 teeth that had conservative pulp treatment with Ledermix cement. (Note: the other 15 teeth in this study had endodontic treatment started at the “investigation” appointment.)**

Time for symptoms to resolve	Number of teeth (%)
Immediately	60 (70.6%)
1 day	18 (21.2%)
2 days	5 (5.8%)
3 days	2 (2.4%)
<b>Total</b>	<b>85 (100%)</b>

**Table 12. Pulp status at the three-month review for the 85 teeth that had conservative pulp treatment with Ledermix cement. (Note: the other 15 teeth in this study had endodontic treatment started at the “investigation” appointment.)**

Pulp status	Number of teeth (%)
Pulpitis resolved	83 (97.6%)
Pulpitis continued	1 (1.2%)
Pulp necrosis	1 (1.2%)
<b>Total</b>	<b>85 (100%)</b>

**Table 13. Pulp status at later reviews (up to 5 years) of 46 of the 85 teeth that had conservative pulp treatment with Ledermix cement. (Note: the other 39 teeth were not reviewed as the patients did not attend their review appointments.)**

Pulp status at further reviews	Number of teeth (%)
After amalgam core placed – pulpitis recurred	2 (4.3%)
After core and crown placed – no pulp changes	43 (93.5%)
Uncertain pulp status	1 (2.2%)
Tooth extracted	Nil
<b>Total</b>	<b>46 (100%)</b>

**Table 14. Overall summary of the management and treatment outcomes of 100 cracked teeth with reversible pulpitis**

Treatment outcome	Number of teeth
No endodontic treatment – pulpitis resolved	80
Uncertain pulp status – patient did not return for further follow-up as scheduled	1
Endodontics required	19
1. At investigation appointment due to:	15
• exposed by caries	4
• crack into pulp chamber	2
• post required	9
2. At later times due to:	4
• pulpitis continued with temp. rest <sup>n</sup>	1
• pulpitis after core	2
• pulp necrosis at 3 months	1
<b>Total</b>	<b>100</b>

*n* = 100.

and therefore this tooth required endodontic treatment. Pulp necrosis was diagnosed in one other tooth at the three-month review appointment.

Of the 85 teeth treated conservatively, 46 (54.1 per cent) were reviewed at various times for up to five years (Table 13) – 43 had no pulp changes but irreversible pulpitis occurred in two teeth after the amalgam core restorations had been placed (and prior to the teeth being prepared for crown restorations). In one other tooth, the pulp status was uncertain at the three-month review and again after another three months but the patient did not return for any further reviews so the final pulp status could not be determined. It is likely that the pulp in this tooth became necrotic and would eventually require endodontic treatment.

Table 14 provides an overall summary of the treatment provided and the outcomes of this treatment. Overall, 80 per cent of the teeth in this study did not require endodontic treatment.

## DISCUSSION

The use of 100 consecutive teeth diagnosed with reversible pulpitis due to cracks resulted in a wide

range of cases and a relevant sample of patients with no bias associated with the selection of the cases. The ratio of females to males was approximately 2:1 which is similar to that found in other studies of cracks in teeth<sup>8,18</sup> as well as being typical of patients treated in general dental and specialist endodontic practices.<sup>19,20</sup> The majority of patients belonged to the 30–50 years group, which is also comparable with other studies<sup>7,21</sup> and typical of specialist endodontic practice.<sup>20</sup>

Almost half of the teeth (43 per cent) were referred for endodontic treatment even though the initial provisional diagnosis was reversible pulpitis. In particular, this was confirmed after investigation of 85 teeth with the other 15 requiring endodontic treatment for carious exposures or for “mechanical reasons” and not because of the presence of irreversible pulpitis. Cracks were initially identified by general dentists and referred for further investigation in only 9 per cent of cases. This suggests that the referring dentists had not accurately assessed the pulp status of these teeth but this is likely to be a reflection of the confusion regarding this topic that exists within the dental profession.<sup>2–5</sup> This also emphasizes the need for a thorough history, examination and appropriate tests so an accurate diagnosis can be formulated.

Many authors have tried to classify cracks according to symptoms emanating from the pulp.<sup>2–9,11,14</sup> These include thermal sensitivity (to heat and/or cold), pain to biting (on application and/or release), duration of pain (after the stimulus is removed) and history of pain (prior to seeing the dentist). Results of this study, as well as the results of other studies, demonstrate that these so-called classic or typical symptoms vary considerably.<sup>4</sup> This can be easily explained since the crack is not the disease. Rather, it is the cause of one or more diseases. The symptoms will be the result of pulp or periradicular diseases caused by the crack. The symptoms will vary depending on the stage of the pulp and periradicular disease present at the time the patient attends for treatment, as well as the extent of the crack or fracture and the position of the crack or fracture. Hence, the status of the pulp and periradicular tissues must be diagnosed and then the cause (which may be a crack) should be identified.

A thorough and comprehensive history must be taken to develop a provisional diagnosis. Clinical examination, tests and radiographs are performed to confirm the diagnosis of pulp/root canal status and periradicular status and to identify the tooth involved. The cause of the disease should also be determined during the clinical examination. Further investigation of the tooth by removing all the restorations, caries and cracks can then confirm the above and allow the operator to reassess the prognosis of the tooth and plan further treatment.

Many authors and clinicians believe that pain on release of biting pressure is a classic sign of a cracked cusp.<sup>6,9</sup> However, this was not the case in this study. The Tooth Slooth was used to test biting pain and only 8 per cent of the teeth had pain on release of biting pressure as a sole finding related to biting, and another 25 per cent had pain on both application and release of pressure. It was far more common to have pain when pressure was applied (68 per cent had this without any pain on release of pressure) and some teeth had no pain related to biting. Hence, the so-called classic sign of pain on release of pressure cannot be relied upon to identify a crack in a tooth. The position, direction and extent of the crack will determine whether or not there is any pain associated with biting, as well as determining whether the pain is associated with application or release of pressure. It is also likely that the method used to test biting pressure and the direction of biting will play important roles.

It is essential to visualize a crack in a tooth so its presence, extent and direction can be determined as these will all affect the treatment required and the prognosis of the tooth. Fibre-optic light transillumination is recommended to visualize and identify cracks. This should be used pre-operatively during examination and after all restorations have been removed from the tooth. It is important to remove all restorations, caries and cracks for thorough investigation of a tooth.<sup>22</sup> This allows full assessment of the tooth for pulp involvement, the amount of tooth structure remaining, whether the tooth can be restored again and its long-term prognosis.

After investigation of the teeth in this study, the pulp was treated with a sedative lining. The lining of choice was Ledermix cement which contains triamcinolone (0.67 per cent), calcium hydroxide (33.4 per cent), and zinc oxide-eugenol. Triamcinolone is a corticosteroid agent, which acts as an anti-inflammatory agent. Hume and Kenney<sup>23</sup> showed that 70 per cent of this agent is released from Ledermix cement within the first 24 hours of application to dentine and the remainder is released by the end of three days. The resolution of pain symptoms in the teeth in this study was consistent with the findings of Hume and Kenney's study<sup>23</sup> and demonstrates the value of using this material for the management of reversible pulpitis. The return to clinically normal pulp status for all but two teeth (one with continued pulpitis, one with uncertain status), as evidenced by the three-month review and pulp testing, plus the longer term follow-up of 46 teeth also indicates that there are no long-term detrimental effects from this material as believed by many practitioners in the past. This belief was centred around the presence of the corticosteroid but, as shown by Hume and Kenney's *in vitro* study,<sup>23</sup> this drug is only present for up to three days. It is likely that the *in vivo* time of effect is even

less due to the dynamics of fluid flow through the pulp clearing the drug at a faster rate in a patient's tooth.

After all the triamcinolone has been released, the remaining components in the Ledermix cement can continue to exert their therapeutic effects on the pulp. The calcium hydroxide in Ledermix cement has well known and well researched effects on the dental pulp<sup>24-27</sup> whilst eugenol can be both anti-inflammatory and anti-bacterial,<sup>28-30</sup> depending on the concentration reaching the pulp following its release from the cement by the progressive hydrolysis that occurs at the cavity floor.<sup>28</sup> Brännström<sup>31</sup> has also shown that zinc oxide-eugenol prevents bacterial entry into cavities which helps to reduce and/or avoid pulp inflammation.

The symptoms of pulpitis continued in one tooth following the initial conservative management. This may have been a result of the subjective findings of the examination being incorrectly interpreted or it may be a result of further trauma (and thus more inflammation) to the pulp as a result of the operative procedure used to investigate and temporarily restore the tooth. The latter also likely applies to the two teeth where the pulps initially returned to a clinically normal state after the conservative treatment but then they developed signs suggestive of pulpitis again once the core restoration had been placed some time later. There was one tooth where the symptoms resolved but it was subsequently diagnosed as having pulp necrosis. This is also suggestive of further trauma as a result of the operative procedure but in such a situation the necrosis may have occurred immediately or very soon after the initial treatment. Once pulp necrosis occurs, the pulp symptoms typically resolve and no further pain is experienced until acute apical periodontitis occurs following infection of the root canal system.

The importance of removing all restorations, caries and cracks for further investigation is demonstrated by this study. Results show that of all the teeth referred for endodontic treatment, only 15 per cent actually required endodontic treatment, whilst 85 per cent were treated conservatively. Furthermore, there were dramatic differences in the number of missing cusps pre-operatively and postoperatively which translates to major differences in potential treatment options for these teeth.

The teeth managed conservatively were restored with interim restorations using traditional chemical-set glass ionomer cements since they do not shrink as a result of not containing any resin, which is particularly advantageous for large cavities. Furthermore, these materials do not require light curing which cannot be carried out through SS bands. Ketac Silver was used where aesthetics were not a concern because the colour contrast with the tooth structure helps the operator to remove this material and conserve more tooth structure. Ketac Silver is also less brittle and has adequate

strength to withstand access cavity preparation if endodontic treatment becomes necessary later.<sup>32</sup> Ketac Fil was used if an aesthetic restoration was required, as in upper and lower anterior teeth and some premolar teeth.

In this study, 76 per cent of the teeth had SS bands placed as part of the interim restorations in order to help retain them, and not to splint cracks or cusps together. Bands will not prevent splitting of the tooth if a vertical crack is present and it has not been removed. In addition, bands will not prevent bacterial penetration,<sup>33</sup> thus if the crack is not removed, then pulp irritation may continue and the root canal system may become infected. The bands may also help with endodontic treatment if it becomes necessary during the follow-up period by providing a stable interim restoration, a stable reference point for measuring canal lengths and by facilitating rubber dam placement.<sup>32</sup>

None of the teeth in this study required extraction and only four teeth required endodontic treatment after the initial investigation appointment. In contrast, Roh and Lee<sup>21</sup> analysed 154 cases of teeth with cracks and they reported that 43 per cent required crowns without root canal filling (RCF), 43 per cent required crowns with RCF and 14 per cent were extracted. Roh and Lee also concluded that there is a high possibility of a crack where intact teeth are sensitive to thermal changes and to the bite test (although they did not mention what type of bite test was done). These symptoms and signs are evidence of an inflamed pulp but this report did not give any details about the pulp diagnosis or the periradicular status so their results are difficult to compare with other studies as it was not clear whether they limited their study to teeth with reversible pulpitis or not.

Krell and Rivera<sup>34</sup> reported a six-year evaluation of 127 cracked teeth diagnosed with reversible pulpitis. This is the most similar study to the current study in terms of the cases selected for analysis. However, these investigators used a different treatment approach as they recommended crowning the teeth and then reviewing them to determine whether the pulpitis resolved. If the symptoms continued or if the pulp became necrotic, then endodontic treatment was done via an access cavity cut through the crown. They reported that 21 per cent of the sample converted to irreversible pulpitis within two months or had pulp necrosis within five months. They concluded that if endodontic treatment is not required within six months, then it is unlikely to be required later (unless another initiating event occurs). In comparison, none of the teeth in the current study required endodontic treatment after crowns were placed and only 4 per cent required endodontic treatment before crowning. The approach taken by Krell and Rivera was to manage the crack as a mechanical problem with an attempt to splint the crack together with the crown whereas the

management protocol utilized in the current study was based on the crack being the cause of the pulp inflammation. By placing crowns immediately, Krell and Rivera did not directly manage the inflamed pulp and therefore a considerable number of the pulps had further progression of their disease to irreversible pulpitis or pulp necrosis. It is possible that the further trauma to the pulp associated with the crown preparation and placement may have contributed to the progression of the pulp disease although this would have been less likely if the pulpitis had been managed and had resolved prior to the crown procedures being done. It is also possible that many of the 79 per cent of teeth whose pulps healed had their cracks removed as part of the crown preparation process and this may explain why the symptoms resolved in these teeth. However, it is impossible to determine this from their report.

The diagnosis of reversible pulpitis must always be considered as a provisional diagnosis which needs to be confirmed and this can only be done when the pulp recovers – this requires at least 6–8 weeks, but three months provides a longer time period to enable the operator to distinguish between pulp necrosis and a clinically normal pulp – both of which are symptomless.

## CONCLUSIONS

Provided there has been an accurate diagnosis of the pulp status and its cause, teeth with reversible pulpitis due to cracks can be treated conservatively without endodontic treatment in about 80 per cent of cases. Endodontic treatment may be required in some cases for “mechanical” or restorative dental reasons or if the pulp is exposed and this can usually be determined at the initial appointment by removing any restorations and cracks from the tooth. This study supports the concept that a crack is a cause of pulp disease rather than being a disease itself or a syndrome.

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