Cracked Teeth: A Review of the Literature

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ABSTRACT
Although cracked teeth are a common problem for patients and dentists, there is a dearth of evidence-based guidelines on how to prevent, diagnose, and treat cracks in teeth. The purpose of this article is to review the literature to establish what evidence exists regarding the risk factors for cracked teeth and their prevention, diagnosis, and treatment.

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INTRODUCTION

Tooth fractures are encountered by dentists daily (Figure 1). The severity and consequences of the fracture can range from minor, needing no treatment at all, to severe, resulting in root canal therapy (RCT), or even tooth loss. One form of tooth fracture, cracked tooth syndrome (CTS), often presents a diagnostic conundrum to the dentist and a painful, frustrating event to the patient. Cracked tooth syndrome is a term applied to a presumptive diagnosis of incomplete tooth fracture that typically presents with consistent symptoms of pain to biting and temperature stimuli, especially cold. Unfortunately, by the time the incomplete tooth fracture becomes symptomatic, the tooth may already be destined for RCT or extraction. Routine clinical examinations often uncover visible fracture lines in asymptomatic teeth. A patient survey of over 14,000 molars by the Practice-based Research in Oral Health network from the Oregon Health and Science University revealed the virtually ubiquitous presence of cracks in these teeth.[1]

Since the outcomes for teeth with an incomplete tooth fracture can be so consequential, resulting in the need for major restoration, RCT, or extraction, the development of a crack poses a significant problem to patients and dentists. A recent study revealed that 44% of crowns performed by a group of general dentists in North Carolina were done to prevent tooth fracture.[2] The study then went on to show that, when groups of dentists examined the same patients, there was little consensus about which teeth should be crowned due to risk of fracture. There is a current need for an evidence-based set of guidelines as to how to prevent, diagnose, and treat cracks in teeth. The purpose of this article was to review the literature to establish

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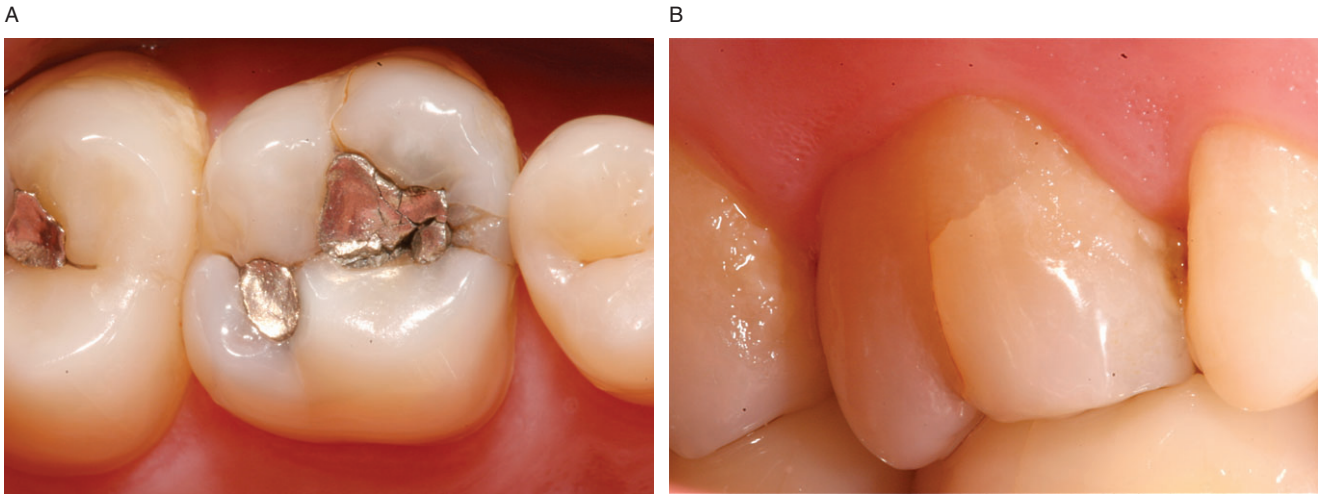

Figure 1. A, *Occlusal view of tooth #3 with vertical fractures extending from a defective amalgam restoration over the mesial marginal ridge and down the mid-facial surface.* B, *Facial aspect of the same tooth demonstrating incomplete tooth fracture extending vertically from the occlusal surface approximately 2/3 the distance to the cementoenamel junction before proceeding in a mesial direction.*

what evidence exists regarding the risk factors for cracked teeth and their prevention, diagnosis, and treatment.

LITERATURE SEARCH PARAMETERS

No specific criteria were applied a priori as to what articles would be accepted into this review. Rather, the intent was to be as comprehensive as possible. Pubmed and Ovid databases were searched for any articles that met the criteria of containing "cracked tooth," "cracked tooth syndrome," "cracked tooth diagnosis," "cracked tooth treatment," "cracked tooth risk factors," and "tooth fracture." No date limits were applied. An initial screening of returned abstracts was accomplished, and relevant full-length articles from peer-reviewed periodicals were obtained. Pertinent citations contained in the full-length articles were used as sources for additional review.

CLASSIFICATION/DEFINITIONS OF TOOTH FRACTURE

Historically, there have been a number of terms used to describe cracked teeth as well as a number of different classification schemes. Incompletely fractured teeth were described by Gibbs in 1954 and by Ritchey and colleagues in 1957.[3,4] Cameron coined the term "cracked tooth syndrome" in 1964 and defined it as an incomplete fracture of a vital posterior tooth that may or may not involve the pulp.[5]

The American Association of Endodontists (AAE) has identified five types of cracks in teeth.[6] Whereas it is important as a clinician to be familiar with all crack forms as an aide in diagnosis, it is often difficult to distinguish clinically among the various types of cracks. The first fracture and the most benign is a craze line. *Craze lines* are visible fractures that only involve enamel. However, it is not always possible to determine that a visible fracture is limited to enamel. *Fractured cusps* originate in the crown of the tooth, extend into dentin, and the fracture terminates in the cervical region. They are usually associated with large restorations causing unsupported cuspal enamel. A *cracked tooth* is defined by the AAE as a crack

extending from the occlusal surface of the tooth apically without separation of the two segments. A *split tooth* is a crack that extends through both marginal ridges usually in a mesiodistal direction, splitting the tooth completely into two separate segments. *Vertical root fractures* originate in the root, and are generally complete, although they may be incomplete. A problem common to all the classification systems is that they fail to connect the descriptions to the clinical consequences or treatment recommendations.

Silvestri and Singh (1978) characterized tooth fracture into two major categories: *completely fractured teeth* and *incompletely fractured teeth*.[7] The *complete fracture* was then subdivided into *obliquely directed* and *vertically directed* complete fractures. The complete oblique fracture was suggested by the authors to occur most frequently as a consequence of an extensive restoration undermining a cusp. The undermined cusp then is completely sheared off under the forces of mastication or parafunctional habits. A vertically directed complete fracture is demonstrated clinically as two independently mobile segments of the tooth and root in relation to one another. *Incomplete tooth fractures* were also divided into two categories: *oblique* and *vertical*. An oblique crack will originate in enamel on the occlusal surface, involve one or more cusps, run into dentin in an oblique direction under cusps, and terminate gingivally in enamel or cementum. There is no complete shearing of tooth segments. Vertical incomplete fractures originate in enamel and extend into the dentin, and, in some cases, extend into the root. The crack may run in a mesiodistal direction over one or both marginal ridges or buccolingually between the cusps with no complete separation of segments.

Talim and Gohil (1974) developed a more detailed classification scheme:[8]

Class I. Fracture involving enamel
- a. Horizontal or oblique
- b. Vertical
  1. Complete
  2. Incomplete

Class II. Fracture involving enamel and dentin without involving pulp
- a. Horizontal or oblique
- b. Vertical
  1. Complete
  2. Incomplete

Class III. Fracture of enamel and dentin involving the pulp
- a. Horizontal
- b. Vertical
  1. Complete
  2. Incomplete

Class IV. Fracture of the roots
- a. Vertical or oblique
  1. Involving the pulp
  2. Not involving the pulp
- b. Horizontal
  1. Cervical third
  2. Middle third
  3. Apical third

PREVALENCE/INCIDENCE RATE

Most of the studies reporting on the incidence and prevalence of incomplete tooth fractures agreed that cracked teeth were significantly associated with intracoronal restorations and were most prevalent in mandibular molars.[5,9–11] The highest prevalence rates appeared in patients over 40 years old,[5,9,10,12] women being more affected than men,[5,9] although one study showed an almost equal distribution between gender groups.[12]

Bader and colleagues (1995) reported on the overall incidence rates of complete tooth fractures.[13] The complete fracture rates were 5.0 teeth per 100 adults per year for all teeth and 4.4 teeth per 100 adults per year for posterior teeth, with 15% of fractures resulting in pulpal involvement or extraction. The corresponding rates for molars and premolars were 3.1 and 1.3 teeth per 100 adults, respectively, from the total number of fractures seen in posterior teeth.

Recent research has shown that cracks in teeth with no restorations, as well as fractures in the maxillary molars, appear more frequently than once thought.[12] Table 1 summarizes the data on the

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TABLE 1. PROPORTION OF CRACKED TEETH BY TOOTH TYPE FROM 12 CLINICAL STUDIES.

Study author	Tooth type	Incidence rate (%)	Total teeth	% unrestored	Average age
Abou-Rass, 1983[18]	Mandibular molars	45.8	120	15.8	
	Maxillary molars	20.8			
	Mand. premolars	0			
	Max. premolars	19.2			
	Other	14.2			
Bader et al., 2001[14]	Mandibular molars	36.3	377		
	Maxillary molars	22			
	Mand. premolars	6.9			
	Max. premolars	20.4			
	Other	14.3			
Brynjulfsen et al., 2002[64]	Mandibular molars	28.3	46		
	Maxillary molars	39.1			
	Mand. premolars	4.3			
	Max. premolars	28.3			
	Other	0			
Cavel et al., 1985[15]	Mandibular molars	44.9	118	4.2	
	Maxillary molars	25.4			
	Mand. premolars	5.1			
	Max. premolars	24.6			
	Other	0			
Cameron, 1964[5]	Mandibular molars	54	50		
	Maxillary molars	28			
	Mand. premolars	2			
	Max. premolars	16			
	Other	0			
Cameron, 1976[9]	Mandibular molars	66.7	102		
	Maxillary molars	23.5			
	Mand. premolars	0			
	Max. premolars	9.8			
	Other	0			
Eakle et al., 1986[10]	Mandibular molars	43.2	206	8.7	37.6
	Maxillary molars	25.73			
	Mand. premolars	25.24			
	Max. premolars	5.83			
	Other	0			
Hiatt, 1973[29]	Mandibular molars	70	100	35	40–49
	Maxillary molars	19			
	Mand. premolars	10			
	Max. premolars	1			
	Other	0			
Krell and Rivera, 2007[49]	Mandibular molars	59.6	796		
	Maxillary molars	29.9			
	Mand. premolars	1.6			
	Max. premolars	8.9			
	Other	0			
Lagouvardos et al., 1989[65]	Mandibular molars	46.5	200		25–48
	Maxillary molars	20			
	Mand. premolars	5			
	Max. premolars	28.5			
	Other	0			
Roh et al., 2006[12]	Mandibular molars	36.4	154		40–49
	Maxillary molars	57.1			
	Mand. premolars	1.9			
	Max. premolars	4.6			
	Other	0			
Talim and Gohil, 1974[8]	Mandibular molars	45			
	Maxillary molars	22.5			
	Mand. premolars	7.5			
	Max. premolars	25			
	Other	0			

proportion of cracked teeth by tooth type reported from 12 studies. The table shows the percentages of maxillary and mandibular molars and premolars with cracks as well as the total number of teeth in the study with cracks and/or fractures. If the restorative status of the fractured teeth was reported in the study, this is also included as well as the average age of the patient. Bader and colleagues (2001)[14] and Cavel and colleagues (1985)[15] reported on complete cusp fracture. Eakle and colleagues (1986) reported on combined results, and 19.9% of the fractures noted in the study were incomplete.[10] Averaging the results of the 12 studies shows that once a tooth is found to have a crack, 48% of cracked teeth are mandibular molars, 28% are maxillary molars, 16% are maxillary premolars, 6% are mandibular premolars, and about 2% are other teeth.

ETIOLOGY

Perhaps the best way to prevent tooth fractures is to understand the factors that predispose a tooth to crack. A review of the studies reporting on the risks for cracked teeth draws attention to the multifactorial aspect of the cracked teeth etiology, with two primary factors predisposing teeth to cracks: natural predisposing features (lingual inclination of the lingual cusps of mandibular molars and steep cusp/fossa of maxillary premolars, bruxism, clenching, extensive attrition, and abrasion) and iatrogenic causes (use of rotary instruments, cavity preparation, and the width and depth of the cavity).[16,17]

Many different factors can cause changes in the structural strength of teeth, including the structural design of cavity preparations. An example of this is large mesio-occlusal-distal (MOD) preparations, which may jeopardize the integrity of the tooth by decreasing the amount of sound tooth structure remaining, especially when the tooth is subjected to excessive occlusal stresses.[18] The excessive depth of an MOD cavity preparation, in combination with lateral masticatory forces, creates internal shearing and tensile stresses that invite complete or incomplete vertical root fracture.[19] Anytime a tooth is treated with a restoration, the possibility of fracture increases because of reduced supporting tooth structure.[7,9,10,19–26] The more surfaces restored and/or the wider the isthmus, the greater the chance of cuspal fracture.[15] Bader and colleagues (2004) studied risk indicators for fracture among teeth with existing restorations and demonstrated increasing RVP (relative volume proportion-size of restoration, i.e., a measure that accounts for the depth and area of the restoration relative to the size of the tooth) as a strong risk factor for complete cusp fracture.[27] Trauma from parafunctional forces, excursive interferences, injury of the face or mouth, restorative procedures, and thermal expansion and contraction of restorative materials have all been associated with coronal fractures.[18,23-25,28] Combinations of variables such as interferences coupled with a restoration also increase the chance of a crack being present.[24] Clinical observation suggests that fractured cusps and fractured teeth occur more frequently among bruxers than nonbruxers.[28] The role of occlusion is often cited in the development of CTS and coronal fractures. The wedging effect of the cusp–fossa relationship has been attributed to being a primary factor in cuspal fractures.[15,18,29–31] It appears that cuspal anatomy can contribute to fracture potential in that nonfunctional cusps appear to fracture with a higher frequency. Nonfunctional cusps have been shown to differ from functional cusps in anatomic form, which may lead to the higher fracture potential.[32] The functional cusps of the maxillary molars in this in vitro study and all of the mandibular posterior teeth were significantly wider than the nonfunctional cusps. Also, the functional cusps had a greater angular inclination than the nonfunctional cusps. Age is also a contributing factor to tooth fracture. It has been shown that the fatigue crack growth resistance of human

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dentin decreases with both age and dehydration.[33] Recent findings with current social implications have shown that oral piercings can cause tooth fractures.[34–36]

DIAGNOSIS

CTS has been described in the literature as a difficult diagnostic and treatment problem.[5] The diagnosis of CTS has been based in the past exclusively on tooth symptomatology: localized pain during chewing or biting, unexplained sensitivity to cold, and pain on release of pressure.[5,17,24,25,31,37–42] Besides the symptomatology described by the patient, the diagnosis of CTS can be verified through a succession of procedures or tests performed by the clinician. The most commonly used tools in the diagnosis of CTS are vision enhancers, symptom reproducers, and radiographs.[43] Transillumination with a fiber optic light and use of magnification will aid in the visualization of a crack.[9,18,23,41,43,44] The tooth should be clean and the light source placed directly on the tooth. A crack that penetrates the dentin of the tooth will cause a disruption in the light transmission under these circumstances. Many authors suggest removing existing restorations and stains once the tooth has been localized to further aid in the visualization of the crack.[18,23,41,43–45] Percussion, biting, and thermal pulp tests are used to reproduce the patient's symptoms.[17,31,39,41,45] To perform the bite test, a small rubber disk, burlew wheel, or a plastic wedge is placed over each occlusal cusp. The patient's pain is evaluated upon closing and opening, with pain upon release usually indicative of a cracked tooth.[18,25,45] Radiographs can aid in the evaluation of the pulpal and periodontal health of the tooth, but it is rare to see a crack on a radiograph.[18,23,31,42,43,45] Ultrasound is also capable of imaging cracks in simulated tooth structure and could pose an important diagnostic aid in the future.[46] All of these diagnostic procedures have been described in the literature, yet none of them have been tested in a controlled clinical trial. Thus, CTS remains difficult to diagnose and a source of frustration for both the dentist and patient.

TREATMENT

Conventional treatments for CTS reported in the literature involve some form of protective cuspal coverage restoration. The specific treatment protocol suggested is to remove any existing restoration, evaluate the health of the pulp and remaining coronal tooth structure, and if indicated, restore with a full crown. Any tooth with irreversible pulpitis or a necrotic pulp should have RCT prior to crown placement.[4,8,9,18,47] Cast gold partial or complete tooth coverage, porcelain fused to metal full coverage, and all porcelain full coverage have all been used.[7,20,38,42,43] Some authors advocate removing the existing restoration, placing a sedative filling (for example IRM, a zinc oxide eugenol restorative material), and cementing an orthodontic band for stabilization. Once symptoms have resolved and the tooth has been deemed restorable, a buildup and full coverage restoration is placed.[23,48] Other authors advocate occlusal adjustment in addition to crown placement.[30] Aside from some isolated presentations of case reports, only one clinical trial conducted to support the use of extracoronal restorations in the treatment of cracked teeth was found in this review of the literature. The study by Krell and Rivera (2007) reported the outcomes of symptomatic cracked teeth that were initially diagnosed with reversible pulpitis and treated with full coverage restorations.[49] The outcomes of this study suggest that, if a crack is identified early in cases with a diagnosis of reversible pulpitis and a crown is placed, root canal treatment will be necessary in about 20% of the cases. One hundred and twenty seven teeth were followed after crown placement for 6 years. From a restorative standpoint, the full coverage treatment was successful for all 127 teeth because symptoms resolved (with or without RCT) and the teeth were retained. This study did not compare success rates of crowns versus other

restorative treatments so it is impossible to interpret the results to say that full coverage is the best treatment for CTS. In reality, practitioners are placing crowns in prevention of CTS. Despite the fact that there is a lack of consensus among practitioners as to when a tooth is at risk for a fracture, one study demonstrated that 42% of crowns placed were done to avoid fracture.[2]

More conservative bonded restorations have also been advocated to treat symptomatic cracked teeth as opposed to a full crown restoration. Both types of amalgam restorations (bonded or nonbonded) and bonded resin composite restorations have been discussed in the literature.[16,41,43,50–54] The majority of the studies done on tooth fracture involve in vitro load tests. Teeth are prepared and restored with various materials, or not restored, and subject to mechanical loading until the tooth fractures.[22,23,53,55–62] These studies produced mixed results when comparing the strength of teeth restored with either bonded or nonbonded restorations. The studies in favor of bonded restorations increasing the strength of a prepared tooth suggested that a stabilization of the prepared tooth structure may occur by means of an adhesive restoration in the form of internal splinting.[55,59,60] The authors of these studies also suggest that teeth restored with bonded amalgam are significantly more resistant to fracture than teeth with nonbonded amalgam and that bonded amalgam appears to be as effective as bonded composite.[53,62] Conversely, Joynt and colleagues[22,58] also performed in vitro load tests that produced contradicting results. Both of these studies showed that there was no significant difference among restorative systems: bonded composite, bonded amalgam, and conventional amalgam.[22,58] These studies showed that preparing teeth significantly reduced the tooth's resistance to fracture, but once restored with composite or amalgam, there was no significant difference in fracture resistance between the two materials. However, most in vitro studies rarely take into account the fatigue and aging factors that undoubtedly contribute to crack formation and propagation in the mouth, and so must be interpreted with caution.

More clinically relevant and far less prevalent are the in vivo controlled clinical studies. Davis and Overton (2000) followed 40 teeth diagnosed with CTS.[41] The teeth were restored with either bonded complex amalgam restorations or complex amalgam restorations with mechanical retention. The patients were followed for 12 months. Both groups were successful at resolving chewing sensitivity over the course of the study.

Opdam and colleagues (2008) followed 40 patients diagnosed with reversible pulpitis and CTS and treated with direct composite restorations for 7 years.[51] The patients were divided into two groups and the restorations placed were either direct composite intracoronal restorations or direct composite cuspal overlay. After 7 years, no teeth were extracted due to restorative failures; therefore, all treatments were considered successful. However, three patients needed RCT, 50% of all restored teeth were still symptomatic after 6 months, and 25% were still symptomatic after 7 years. There were no restorative failures for the group with cuspal coverage, but the intracoronal group did have a mean annual failure rate of 6.0%. This difference was significant. The authors suggested that bonded composite can be an effective treatment for painful cracked teeth, resulting in more than 90% of the teeth maintaining pulp vitality. Signore and colleagues (2007) performed a retrospective evaluation of the clinical performance of bonded indirect resin composite onlays for the treatment of painful cracked teeth.[54] Over the 6-year observation period, 93.02% were symptom free and a restorative success. Wahl and colleagues (2004) found in a retrospective clinical survey that there was no significant difference in the prevalence of cusp fracture rates

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in amalgam-restored teeth versus composite-restored teeth for younger patients (age 18–54 years), but a higher rate of cusp fractures adjacent to composite restorations compared to amalgam restorations in older patients (age 55–96 years).[63]

There are also cases in which the only treatment option is extraction. In these cases, the crack has split the tooth in two. Extraction is usually the only option when the crack is complete, deep to bone, involves the furcation, and when pieces are mobile.[7,23,31,47]

CONCLUSION

The purpose of this article was to review the literature to establish what evidence exists regarding the risk factors for cracked teeth and their prevention, diagnosis, and treatment. The following conclusions may be drawn from this review:

1. Cracks in teeth are a common clinical finding.
2. Almost all cracks are found in posterior teeth; prevalence studies have found that mandibular molars were the most likely to have a fracture, and this occurrence was nearly twice as great as that for maxillary molars, the next most commonly fractured teeth.
3. Complete tooth fracture incidence has been reported at five fractured teeth per 100 adults per year.
4. The risk factors for a cracked tooth are multifactorial, and can be grouped into two general categories: natural causes (i.e., tooth form, age, and wear patterns) or iatrogenic causes (i.e., tooth preparation).
5. CTS is a difficult diagnosis and is based primarily on symptomatology: localized pain during chewing or biting, unexplained sensitivity to cold, and general pain during chewing or biting.
6. There is very little consensus among practitioners as to which cracked teeth are in need of protective restoration, what this restoration should be, or when intervention is appropriate. Despite the fact that many practitioners prescribe restorative treatment for asymptomatic teeth with visible crack lines in order to prevent CTS or complete tooth fracture, there is no evidence in the literature to support this practice.
7. Limited clinical studies show that once a tooth is diagnosed with CTS and reversible pulpitis, the tooth may successfully be treated with a full crown, a complex amalgam, or a bonded composite overlay.
8. More controlled clinical studies are needed to determine which treatment modalities are best suited for specific clinical situations. There is no current evidence demonstrating which treatment option has the greatest success rate both from a restorative perspective and from a pulpal health standpoint.

Little in the way of concrete evidence exists regarding the etiology, diagnosis, and treatment of cracked teeth. In vitro research is needed to elucidate the mechanisms by which cracks initiate and propagate in teeth. More clinical research is needed so that practitioners may attempt to prevent tooth fracture, diagnose CTS with confidence, and treat diagnosed teeth with the most conservative yet appropriate restoration. A clinical study has been initiated in Northwest Practice-based Research Collaborative in Evidence-based DENTistry (NW PRECEDENT), one of the National Institute of Dental and Craniofacial Research (NIDCR)-funded dental Practice-based Research Networks in an attempt to answer some of these questions. A prospective cohort study will follow both symptomatic and asymptomatic cracked teeth, some of which will receive treatment and some of which will not. It is hoped that the data obtained will allow correlation of diagnostic criteria to clinical crack features, the identification of crack characteristics that are predictive of progression, and assessment of the effectiveness of different treatment regimens.

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