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Cracked Tooth Syndrome: A Review of the Literature

Abstract: Cracked tooth syndrome (CTS) is a term used to describe a type of incomplete fracture of posterior teeth. CTS is a common clinical finding, so dentists are likely to encounter patients experiencing CTS. However, diagnosis is not straightforward and may be difficult because its signs and symptoms may resemble those arising from other dental conditions. Nevertheless, early detection of CTS is critical to the success of its management. Crack propagation can be hindered when it is at an early stage before reaching the pulp, thereby potentially leading to an improved prognosis. This article provides an overview of CTS, and sheds light on its clinical examination, diagnosis, management, and approaches for prevention. This knowledge will enable dentists to recognize CTS early and manage it appropriately.

CPD/Clinical Relevance: Dentists must be well prepared to identify CTS early and provide patients with the most appropriate treatment.
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Cracked tooth syndrome (CTS) is a term used to describe a type of incomplete fracture of posterior teeth. CTS is also known as incomplete tooth crack.^{1,2} The crack usually involves the enamel and dentine and occasionally extends into the pulp.^{3–7} The crack begins at the crown and continues apically and mesiodistally to affect one or both of the marginal ridges and the proximal surfaces.⁸ CTS can affect filled and endodontically treated teeth as well as sound unfilled teeth.⁷ CTS affects females more than males, with the most affected individuals aged 30–50 years. CTS can affect any posterior tooth; however, the mandibular molars and maxillary premolars are the most afflicted. Nevertheless, mandibular premolars are the least affected teeth.^{7,9–11}

Two different crack patterns have been described. The first pattern occurs when the crack is centrally located in the affected tooth. The crack may spread to the pulp,

causing reversible pulpitis in the early stages and irreversible pulpitis and pulp necrosis or tooth fracture later on.¹² The second pattern occurs when the crack is peripherally located and can spread, leading to complete fracture of the affected cusp.⁶

CTS has a multifactorial aetiology as numerous independent or interrelated factors induce the crack. These factors generate significant internal stress in a tooth resulting in the development and propagation of the crack.^{1,9}

CTS symptoms, like discomfort and pain during biting or tooth hypersensitivity to cold, encourage the patient to seek dental treatment. Therefore, the dentist should be able to diagnose CTS, though the diagnosis may not be straightforward.^{1,13} This article aims to overview CTS, its causes, and management options. This knowledge will assist the reader in diagnosing and managing CTS.

Literature review

All relevant textbooks, bibliographies of major publications, and PubMed (Medline) data sources were searched, chosen, and used in this paper. Articles were also acquired from Google Scholar without regard to time constraints. The reference list includes the papers that were chosen.

Classification

It is essential to clarify that CTS is a type of longitudinal tooth fracture. The longitudinal tooth fracture is categorized into five subclasses: craze lines (Figure 1), fractured cusp, cracked tooth (CT), split tooth, and vertical root fracture.⁸ All types of longitudinal tooth fracture, except craze lines, are typically found in posterior teeth.^{1,8} However, fractured cusp, CT, and split tooth begin on the occlusal surface and advance apically, affecting the enamel, dentine, and possibly the pulp. Vertical root fractures develop deep into the root.

These types of longitudinal fractures have been recognized and classified to establish global definitions to reduce misunderstandings caused by the lack

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Crack type	Description
Craze lines	They are apparent cracks in the enamel noticed in both anterior and posterior teeth
A fractured cusp	Craze lines are common in posterior teeth and can cross the marginal ridges and extend down the buccal and lingual surfaces. Long vertical craze lines are more common in anterior teeth (Figure 1)
A cracked tooth	It begins at the crown of the tooth, extending into the dentine, and the fracture ends in the cervical region of the tooth. It is usually seen in heavily restored teeth due to fracture of the unsupported enamel
A split tooth	It is described as a crack that extends apically from the occlusal surface of the tooth without separating the two parts. The crack is usually seen in the centre of the tooth, mesiodistally, and may involve one or both marginal ridges (Figure 2)
Vertical root fractures	It arises when a crack propagates and splits the tooth into two separate fragments. It occurs as a result of crack propagation and is typically positioned in the centre of the tooth. It is caused by a crack growing in a mesiodistal orientation and crossing both marginal ridges and spreads in the apical direction. It may be a result of CTS (Figure 3)

Table 1. Classifications and descriptions of longitudinal fractures as presented by the American Association of Endodontists.⁸



Figure 3. A split tooth is indicated by separated tooth segments of the upper first right molar. Generalized tooth surface loss (TSL) affecting the first and second premolar and first molar is obvious.



Figure 1. A stained craze line (red arrow) on the labial surface of the upper central incisors and an incisal edge notch (green arrow) induced by snacking on dried sunflower seeds.

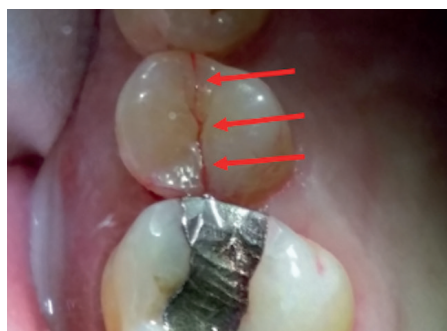


Figure 2. A clinical image of a maxillary second premolar and first molar. The maxillary second premolar with a mesio-distal crack involving the occlusal surface and the mesial and distal marginal ridges. A dye is used to assist in the detection of the crack. The mesial region of the amalgam appears brighter than the distal portion, indicating that occlusion may have an influence on the development of the crack

of a uniform standard for categorization. Many classifications, each with distinct characteristics, can be found in the literature.¹⁴ Table 1 describes the various longitudinal tooth fractures.⁸

CTS-related discomfort/pain

Cracks in CTS should be considered in terms of their extension and time.¹⁵ As a result, the diagnosis and treatment of CTS are different and linked to the time it takes for the crack to form and propagate. A patient with CTS, for example, may complain of discomfort when chewing; however, if the crack is not addressed, the crack will progress towards the pulp. The symptoms worsen as the crack moves closer to the pulp, resulting in bony dehiscence, a narrow and deep periodontal pocket, and/or extensive peri-apical bone resorption.¹ The most noticeable symptom of CTS is discomfort/pain in biting or tooth hypersensitivity induced with cold stimuli.^{1,6}

Hypotheses have been suggested to explain the pain. For instance, the hydrodynamic theory was first presented to explain the widely observed dentine hypersensitivity when dentine is exposed;¹ however, it is also applied to explain the pain associated with CTS.^{17,18} According to this hypothesis, abrupt movements of dentinal tube fluid stimulate odontoblasts in the pulp, resulting in pain as myelinated A-type fibres inside the dental pulp are

activated.^{17,18} In CTS, the abrupt movements of dentinal tube fluid occur when the cracked fragments move independently and induce pain.¹⁷

It has been suggested that the perception of hypersensitivity to cold may occur in patients with CTS due to noxious irritants leaking through the crack. This leads to the release of neuropeptides, which cause a concomitant decrease in the pain threshold of unmyelinated C-type fibres within the dental pulp.¹⁸

Another explanation for the pain is that crack fragment movements stretch and compress the odontoblastic processes in the crack, generating pain.¹⁸

Aetiology

Regardless of the exact reasons or causes that may interact to create cracks and CTS, various elements have been documented to have a role in the onset and propagation of such cracks.^{1,6,9} Hence, any factor that causes excessive internal stress within the tooth might trigger the development and advancement of cracks in CTS.⁶ As a result, it is not unreasonable to suggest that CTS is a multifactorial condition since the crack is induced by a number of factors that operate independently or simultaneously.^{1,9} For instance, excessive occlusal forces exerted by parafunctional activity, such as bruxism on a normal healthy tooth, or normal physiological occlusal forces applied to an extensively filled tooth would result

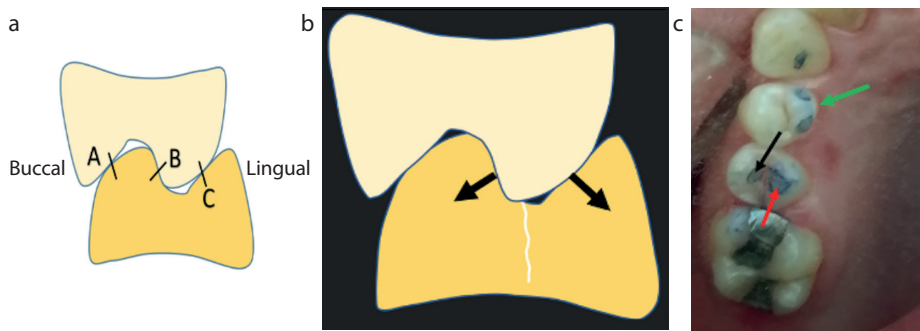


Figure 4. (a) Representations of occlusal contact at the intercuspal position (ICP): A, B, and C. (b) The clinical image of these occlusal contacts on the first and second maxillary premolars.

in one or more types of longitudinal tooth fractures, including CTS, as defined by the American Association of Endodontists.⁸

Lynch and McConnell classified CTS aetiology broadly into four categories: restorative procedures; occlusal factors; developmental elements; and other miscellaneous factors.⁶ CTS can thus be caused by excessive amalgam condensation pressures, or a mismatch in the coefficients of thermal expansion of the filling material and the tooth structure.⁶ Inserting retentive pins and applying a bulk composite filling without taking polymerization shrinkage into account may result in crack propagation. Furthermore, cementing a tight-fitting inlay creates hydraulic pressure, which can cause cracks to generate and spread, leading to CTS.^{6,19,20}

Occlusal forces on the posterior teeth are significantly higher than those on the anterior teeth. This is because the mandible acts as a type III lever, which means that the closer a tooth is to the fulcrum, the temporomandibular joint (TMJ), the more stress it receives.^{6,7} Furthermore, the occlusal morphology of the posterior teeth favours the generation of cracks/fractures due to the opposing cusp's wedging action.⁸ It has been proposed that the lingual cusps of maxillary molars act as plungers, creating structural fatigue in the lower antagonists.^{5,7} Cusp-fossae occlusal relationships can result in significant occlusal stresses generating cracks. Figure 4 displays representations of occlusal contact at the intercuspal position (ICP), and wedging effects of such occlusal contacts.

Additionally, teeth with steep cusps or deep developmental grooves may be more prone to cracking. Furthermore, a tooth or teeth may drift or over-erupt due to a cavitated carious lesion or an opposing tooth/teeth extraction. Consequently, occlusal interferences may be formed.

These interferences expose tooth/teeth to significant horizontal occlusal forces during mandibular excursion movements, leading to crack development.

It is debatable whether restored and decayed teeth are more vulnerable to CTS than sound intact teeth. The previous research³ found that heavily restored teeth were more susceptible to cracking and were more negatively impacted by CTS.^{3,22} On the other hand, a recent study found that cracks occur more frequently in unrestored sound teeth, which was linked to weakening the tooth structure.^{7,23–25} However, parafunctional habits also play a role.^{5,6,26} As parafunctional activities, such as bruxism, which affects up to 31% of the population, may induce crack development and propagation.^{32,33}

Dental history and clinical manifestations of CTS

It is essential to be aware of the presence of CTS to establish an appropriate diagnosis.^{13,27,28} The diagnosis is not simple and may be difficult because the discomfort and pain arising from CTS may resemble those arising from other sources such as sinusitis or temporomandibular joint (TMJ) disorders.¹³ However, dentists appear to be more competent in recognizing and diagnosing CTS than in earlier years.⁷ Lee and associates⁷ observed a reduction in the incidence of endodontic therapy for CTS in comparative research conducted at two different dates. The decrease was attributed to the early identification of cracked teeth due to better knowledge and awareness of cracked tooth features and a more precise diagnosis.⁷ CTS manifests a range of clinical signs and symptoms based on the location and extent of the crack and the degree of pulp inflammation when the pulp is involved.^{7,13,14,20,28}

Early detection of CTS is critical to the management success as the crack propagation can be stopped by restorative intervention before it reaches the pulp, which would lead to a poor prognosis.^{13,14}

The chief complaint and the history of the chief complaint are essential for diagnosing and managing CTS. Pain induced when chewing or putting hard objects between the teeth, such as a pipe, provides important diagnostic information.^{1,29–31} Occlusal pressure on a particular cusp can induce severe pain, which serves as the foundation for the so-called 'bite test', which is essential for diagnosis. The test involves the patient biting down on an item such as a toothpick, a wood stick, or Fractfinder (Denbur, Oak Brook, IL, USA) or Tooth Slooth II (Professional Results Inc, Laguna Niguel, CA, USA) during the test.^{1,6,7,13} The use of the Fractfinder or Tooth Slooth is highly beneficial as they allow for selective pressure on one cusp at a time. As a result, locating the affected cusp is possible.

Pain may be mild and goes away quickly, but it gets worse as the occlusal force increases. Furthermore, pain on biting that intensifies when the mouth is opened is a key symptom that may suggest the existence of CTS.¹

A history of several months of discomfort and acute pain while biting or consuming cold food/drinks or sugary meals likely indicate a CTS symptom.¹ However, if a cusp is fractured, but no dentine exposure, the patient may not experience symptoms.³¹

A thorough dental history may reveal a history of extensive dental treatment, occlusal interferences, high spot filling, or repeated cementation failure of an intra-coronal restoration

It is critical to distinguish pain caused by CTS from pain caused by recently placed restorations, a restoration fracture, or pain caused by orofacial or psychological issues. It is necessary to obtain a detailed medical history.^{1,6,33}

Cracks involving the pulpal tissue can cause pulpal and periodontal problems.^{16,34} Pulp inflammation may arise as a result of microleakage-induced irritation.^{7,28} A cracked tooth with a deep periodontal pocket is more likely to require root canal treatment.^{7,25} A probing pocket depth of more than 6 mm was found to be a significant predictive factor for the survival of cracked teeth treated with root canal treatment.²⁵ However, the prognosis may

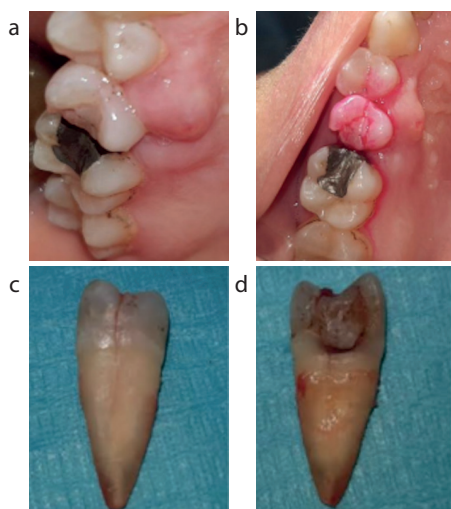


Figure 5. Clinical images of the upper right quadrant. **(a)** a lateral periodontal abscess between the first and second premolars. **(b)** On the second premolar, a stained mesial fracture and occluso-distal (OD) composite resin restoration with poor marginal integrity and signs of microleakage. **(c)** the extracted second premolar's mesial view shows a crack extending from the mesial ridge to the cemento-enamel junction and the root. **(d)** the extracted premolar with the composite filling and a crack extending from the cavity floor down to the root

be questionable. Figure 5 illustrates CTS associated with a lateral abscess.

The apical area of the cracked teeth must be carefully examined because cracked teeth with apical lesions had a lower success rate than cracked teeth without apical lesions.

To prevent misdiagnosis, make every effort to distinguish between pain produced by CTS and pain caused by pulpal, periodontal, or peri-apical periodontitis.²⁶

Examination and diagnosis

It is worth mentioning that the patient is unlikely to recognize the tooth causing the discomfort/pain, which obscures and complicates diagnosis. The diagnosis is also affected by factors such as the position and extent of the crack.¹³ Furthermore, the cracked tooth is challenging to identify clinically because crack lines are sometimes difficult to locate, and cracked teeth have complicated and wide-ranging symptoms.^{7,13}

Like any other condition, CTS is diagnosed based on the chief complaint, dental and medical history, and clinical examination. It may be required to clean and polish the questionable tooth/teeth

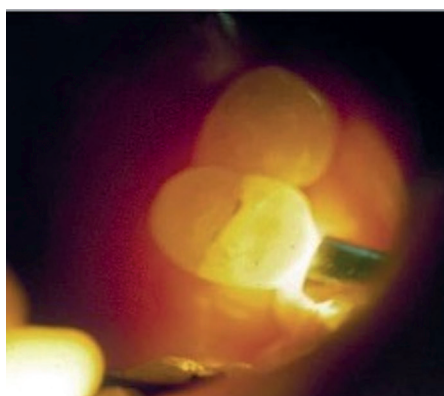


Figure 6. Transillumination (crack line visualization). As light does not pass through the crack, the tooth side closest to the light source seems bright, while the side further away from the light appears darker.

to remove stains that obstruct visual examination. Several factors that influence clinical detection of CTS include the crack's length, the type of illumination (dental light or fibre-optic transillumination), the operator's working distance and use of dyes such as methylene blue and iodine, and the presence of a restoration.^{1,35,36}

A visual inspection aided with magnifying loupes and fibre-optic transillumination (Figure 6) or other light sources and dye colouring the crack is used to detect the crack and diagnose CTS.^{6,7,37}

To detect and trace a crack, caries and restoration must be removed.¹³ The restoration's edge and the marginal ridge must be checked. Furthermore, the occlusion should be examined to determine that it is not a contributing factor in the development of CTS (Figure 2).

Transillumination is an effective tool for diagnosing CTS.¹ Figure 6 shows a clinical picture of a tooth being tested for a crack in a patient complaining of pain on biting. As light does not pass through the crack, the tooth side closest to the light source seems bright, while the side further away from the light appears darker. When transillumination is used with magnification, visualization of the crack is improved.¹ However, these procedures have limitations that must be acknowledged to obtain an accurate diagnosis. Transillumination may be poor at identifying cracks from craze lines.¹

Special dyes (Figure 2), such as methylene blue, are frequently used.⁷ However, when using dye to identify cracks, it may take 2–5 days for the dye to stain the cracks sufficiently to make them apparent. The delicate colour in the crack may go unidentified.¹

A tooth with a crack is usually not sensitive to axially directed percussion, and the vitality/ sensibility tests are generally positive.^{1,13} Yet, due to the pulpal inflammation, the affected tooth may occasionally exhibit hypersensitivity to cold thermal stimuli, leading to confusion.

An orthodontic band or a temporary (provisional) crown may be used to clarify the diagnosis.^{13,38} The band can be cemented to the tooth and left there for a few days to determine whether CTS is present. The diagnosis of CTS is verified if the discomfort/pain disappears once the band is cemented because it prevents separation of the crack during function.¹³ The band or the provisional crown may be left cemented for 2–4 weeks. The absence of pain indicates a correct CTS diagnosis.¹³

Composite resin can be used as a temporary splint when it is placed over the occlusal surface and extended over the axial walls without etching or bonding.¹⁸ The patient can bite down on it with an intervening bite test. If a crack is present, pain and discomfort disappear because the crack no longer opens on biting and clenching, possibly confirming the diagnosis of CTS.¹⁸

Cracks that extend into pulpal or periodontal tissue can cause pulpal and periodontal complications.^{1,13,34,36} A localized periodontal pocket or lateral periodontal abscess may be caused by a crack that spreads subgingivally (Figure 5). As a result, the periodontal examination should be regarded as an integral component of clinical evaluation.

It is important to highlight that a tooth that is non vital for no apparent reason might be caused by an unseen longitudinal crack spreading from the occlusal surface into the pulp, known as fracture necrosis.³⁹ Owing to the risk of extensive periodontal and/or peri-apical bone loss, these teeth may have a poor prognosis following endodontic therapy, and extraction may be the only treatment choice.³⁹

If a crack/fracture is suspected, a wedging test can be used to determine segment movement and distinguish a cracked tooth from a broken cusp or split tooth.⁸ A fractured cusp may fall off at mild wedging tension. The pieces move apart when wedging stresses are applied, indicating a split tooth.⁸ On the other hand, a cracked tooth is most likely to be present if there is no mobility.

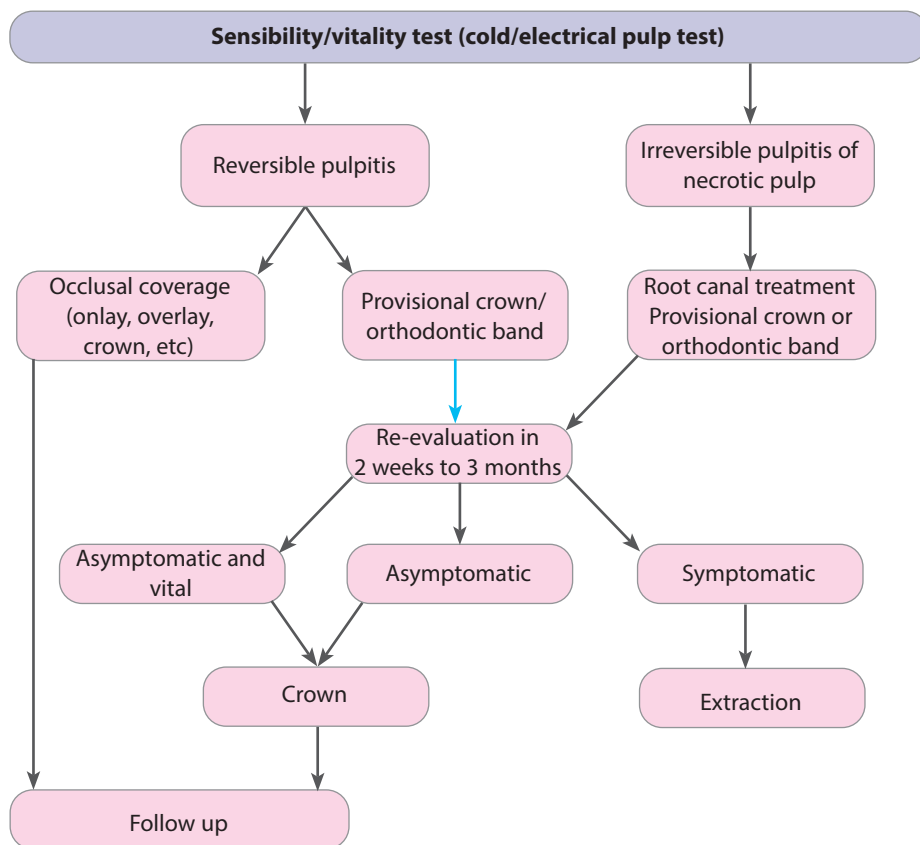


Figure 7. A flow chart of possible management options. Modified from Lee *et al.*⁷

Prognosis	Characteristics of the causative crack
Excellent	<ul style="list-style-type: none"> ■ Cuspal fractures within the dentin that angle from the facio-pulpal or linguo-pulpal line angle of a cusp to the cemento-enamel junction or slightly below. ■ Horizontal fracture of a cusp that does not involve the pulp.
Good	<ul style="list-style-type: none"> ■ A coronal vertical fracture that goes mesiodistally into the dentin but not into the pulp.
Poor	<ul style="list-style-type: none"> ■ A coronal vertical fracture that goes mesiodistally into the dentin and pulp but is restricted to the crown
Hopeless	<ul style="list-style-type: none"> ■ A coronal vertical fracture that runs mesiodistally through the pulp and extends into the root.

Table 2. The prognosis of CTS as suggested by Clark and Caughman.⁴⁶

Radiograph and ultrasound

Radiography is usually inconclusive when the crack runs in a mesiodistal direction parallel to the plane of the film.^{1,6,13,20} However, radiography is more conclusive when the crack runs in the buccolingual direction. Radiographs must be taken to rule out any other pathological changes associated with the affected tooth, such as peri-apical radiolucency, bone loss, and internal or external resorption.^{1,6} Condensing osteitis, which is related to low-grade pulpal irritation, has also been observed in the peri-apical area of teeth with a split root.³⁵

Ultrasound was tested to detect cracks and differentiate between areas with and without a 'simulated' crack.⁴⁰ This positive outcome might lead to its application in the diagnosis of CTS. Furthermore, using a clinical microscope gives an optimal magnification level for assessing enamel cracks.^{12,13} Therefore, it may be recommended for use whenever possible.

Several methods for detecting cracks have recently been tested, including contrast-enhanced micro-computed tomography,⁴³ dental optical coherence tomography,^{7,44} and cone beam computed tomography (CBCT).^{2,45}

However, more research and continual review are necessary to cover all potential benefits and drawbacks of these methods.

Differential diagnosis

Diagnosis of CTS may be difficult, and as a result, is often misdiagnosed. However, several conditions should be considered when CTS is being diagnosed. These conditions include reversible and irreversible pulpitis, acute apical periodontitis, dentine hypersensitivity, fractured restorations, galvanic pain, postoperative sensitivity associated with recently placed composite resin restorations, occlusal interferences, high spot filling, pain due to parafunctional habits (i.e. bruxism), orofacial pain, and atypical facial pain.¹³

Management of CTS

Many options are available for CTS management depending on several factors. The treatment strategy is influenced by the crack pattern (peripheral or central), size, and amount of remaining tooth structure.^{1,41} For instance, if the fracture is small, the affected area can be smoothed. When a significant portion of a tooth is lost, but the pulp is not involved, it can be restored with a composite resin restoration or bonded amalgam, a partial-coverage restoration, such as an onlay or overlay, or a full-coverage restoration. Teeth with reversible pulpitis due to CTS can be treated conservatively if diagnosed early, and no endodontic treatment is required.⁴²

When reversible pulpitis associated with CTS is suspected, an orthodontic band or provisional (temporary) crown, as well as occlusal adjustment, may be performed.^{1,18} This treatment is frequently performed on a short-term basis to rule out other possible causes of the patient's complaint as it inhibits the movements of crack fragments which induce pain.

Root canal treatment may be considered when there are signs and symptoms of irreversible pulpitis or necrotic pulp, and a temporary crown can be used as a splint.⁷ The tooth must be monitored, and the appropriate treatment strategy must be decided based on the results.³⁸ The temporary crown is then removed and replaced with a permanent crown when the symptoms have subsided.³⁰ Extraction may be inevitable if the signs and symptoms continue or if

a crack grows into the pulp or below the alveolar bone.⁷

However, root resection, bicuspidization, or hemisection options may be used in some cases. Lee *et al*⁷ presented a treatment protocol for CTS, and Figure 7 shows a modified version.

The prognosis of CTS treatment is challenging to predict because there is no definitive method for accurately estimating the crack extension.⁷ Clark and Caughman⁴⁶ suggested a classification for the prognosis of CTS. The classification consists of four categories displayed in Table 2.

It is not unreasonable to suggest that late detection of CTS results in pulp involvement and necrosis, necessitating root canal therapy, which may reduce success rates compared to cracked teeth that are diagnosed in their early stage and do not require root canal treatment.

Prevention

To decrease internal stress inside the tooth, tooth preparation for an intra-coronal restoration must satisfy several parameters, whether direct or indirect. For instance, internal line angles in the prepared cavity should be rounded to reduce stress concentration on the tooth structure. Composite resin fillings should be placed in increments to reduce composite bulk and lower the configuration factor (C-factor) impact. In some circumstances, such as MOD cavities, cuspal coverage restorations, such as an onlays, overlays or crowns, should be considered, especially if the buccolingual cavity is wide.³⁰ For example, Reeh and colleagues⁴⁷ observed that tooth stiffness was linked to the integrity of the marginal ridge. They concluded that losing one or both marginal ridges reduces tooth stiffness by 40% and 60%, respectively. Therefore, maintain the marginal ridge integrity wherever feasible while planning a filling.⁴⁷ The intra-coronal restoration should fit passively to reduce hydraulic pressure during cementation. The occlusion should be thoroughly examined and interference corrected. In a patient with a history of parafunctional habit, the use of an occlusal splint is strongly recommended.

Conclusions

CTS is a real clinical problem that the dentist may have to deal with. It is important to distinguish between CTS induced pain and pain caused by other stimuli. Because CTS signs and symptoms

are similar to those associated with other dental diseases, a thorough evaluation of the chief complaint, past dental history, and medical history and a comprehensive clinical examination is required to arrive at a reliable diagnosis. Once a diagnosis has been determined, a number of treatment options are available. These options are based on several factors, such as the crack's location and extent, the pulp's state, the presence of peri-apical pathosis, and the periodontal pocket depth. These factors affect the symptoms, management, and long-term success rate.^{7,14,42}

Compliance with Ethical Standards

Conflict of Interest: The author declares that he has no conflict of interest.

Informed Consent: Informed consent was obtained from all individual participants included in the article.

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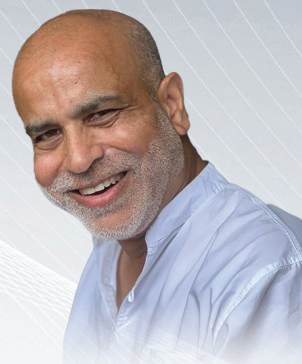


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