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CRACKED TOOTH SYNDROME

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Resumen

Introducción: El síndrome del diente fisurado (SDF) se define como una fractura incompleta de un diente posterior vital que involucra la dentina y ocasionalmente se extiende hacia la pulpa. Los dientes más comúnmente afectados son los molares mandibulares, seguidos de los premolares y molares superiores. En la práctica clínica, el diagnóstico de SDF puede ser difícil y desafiante para muchos dentistas debido a la variedad de síntomas y al hecho de que es difícil de reconocer. Sin embargo, entre los síntomas más frecuentes en los pacientes con SDF se encuentran el dolor agudo al morder y la sensibilidad térmica. El SDF tiene una etiología multifactorial, algunas de las más frecuentes son: traumatismo masticatorio o accidental y mordida involuntaria con fuerza masticatoria fisiológica o con un objeto muy duro. **Objetivos:** El objetivo de este estudio es comparar y evaluar las diferentes herramientas diagnósticas y determinar la herramienta ideal en caso de síndrome de diente fisurado, establecer los principales factores etiológicos, determinar el manejo óptimo y estudiar el pronóstico. **Metodología:** La presente investigación se realizó a partir de una extensa revisión bibliográfica utilizando Medline, Pubmed y la biblioteca en línea de la Universidad Europea. **Conclusión:** El síndrome del diente fisurado puede tener múltiples causas y etiologías, por lo que es importante implementar diversas herramientas de diagnóstico para poder descartar otras posibles patologías y obtener el diagnóstico definitivo. La prueba de mordida y la transiluminación son dos de los métodos de diagnóstico que han demostrado ser muy comunes para la detección de SDF, utilizándose una combinación de los dos. Además, un diagnóstico precoz se ha asociado con un tratamiento restaurador y un pronóstico con más éxito.

Palabras clave: Síndrome del diente fisurado, diagnóstico, manejo, etiología, diente fisurado y tratamiento, signos y síntomas del síndrome del diente fisurado.

Abstract

Introduction: Cracked tooth syndrome (CTS) is defined as an incomplete fracture of a vital posterior tooth that involves the dentine and occasionally extends into the pulp. The most commonly affected teeth are mandibular molars, followed by maxillary premolars and maxillary molars. The diagnosis of CTS can be difficult and challenging for many dentists in clinical practice due to the variety of symptoms and the fact that it is hard to recognise. However, among the most frequent symptoms in patients with CTS is a sharp pain on biting and thermal sensitivity. CTS has a multifactorial aetiology, some of the most frequently seen being masticatory or accidental trauma, and unintentional biting with either physiologic masticatory force or on a very hard object. **Objectives**: This study aimed to compare and evaluate the different diagnostic tools and to determine the ideal tool in case of cracked tooth syndrome, establish the main aetiological factors, determine the optimal management and study the prognosis. **Methodology**: The present research was carried out based on an extensive bibliographical review using Medline, Pubmed and the online library of Universidad Europea. **Conclusion**: Crack tooth syndrome can have multiple causes and aetiologies; therefore, it is important to implement a variety of diagnostic tools to be able to dismiss other possible pathologies and achieve the definitive diagnosis. Bite test and transillumination are two of the diagnostic methods that proved to be widely common for the detection of CTS but used as a combination of the two. Moreover, an early diagnosis has been associated with more successful restorative management and prognosis. **Keywords**: Cracked tooth syndrome, diagnosis, management, aetiology, cracked tooth and treatment, signs and symptoms of cracked tooth syndrome.

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Introduction

Cracked tooth syndrome (CTS) is defined as an incomplete fracture of a vital posterior tooth that involves the dentine and occasionally extends into the pulp [1]. Cameron [2] was the first to introduce the term cracked tooth syndrome in March 1964, when he described a direct relationship between restoration size and the appearance of CTS. The studies of Cameron referred to a higher incidence of CTS among women, [2] however new research shows that both sexes are equally affected [3]. The most commonly affected teeth are mandibular molars, followed by maxillary premolars and maxillary molars. On the other hand, mandibular premolars appear to be the least affected [3]. The crack typically seems to have a mesiodistal orientation in the majority of the teeth, and in the mandibular molars, it may have a buccolingual direction [1]. The diagnosis of CTS can be difficult and challenging for many dentists in clinical practice due to the variety of symptoms and the fact that it is hard to recognise [4]. Among the most frequent symptoms in patients with CTS is a sharp pain on biting and thermal sensitivity, especially to cold food and drinks [4,5]. The article written by Tanumihardja M.[6] mentioned the following as the most common causes of CTS: masticatory or accidental trauma and unintentional biting with either physiologic masticatory force or a very hard object that may suddenly generate an excessive load, causing the tooth to split[6]. The discovery of a cracked tooth should be as early as possible, consisting of multiple diagnostic tests for the dentist to firstly, correctly diagnose the tooth and secondly, to achieve the best treatment plan and prognosis [7].

History and Classification

Historically, there have been several terms used to describe cracked teeth. In 1954 Gibbs was the first to describe incompletely fractured posterior teeth and a few years later Ritchey and colleagues in 1957 discussed pulpitis due to an incomplete fractured tooth [8]. Shortly after that, Cameron invented 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 [9]. Furthermore, many other terms have been used such as split-root syndrome, hairline fracture, hairline tooth fracture, enamel infraction, crown craze, craze lines and crack [8]. The study by Hasan S. et al. [8] explained a research called "cracking the cracked tooth code" that was written by the American Association of Endodontics where five types of cracked teeth have been identified.

Craze lines are visible fractures that only involve the enamel. Long vertical craze lines are most commonly seen in anterior teeth (Figure 1a). *Fractured cusps* originate in the crown of the tooth, extend into the dentin, and it terminates in the cervical part of the tooth. They are frequently seen in teeth with large restorations, causing unsupported cuspal enamel (Figure 1b). A *cracked tooth* is defined as a crack extending from the occlusal surface of the tooth apically without the separation of the segments. A crack is often seen at the centre of the tooth in a mesiodistal direction including one or both marginal ridges (Figure 1c). A *split tooth* is a typical crack that extends through both marginal ridges usually in a mesiodistal direction splitting the tooth completely into two segments (Figure 1d). *Vertical root fractures* arise at the root in a buccolingual direction. The crack may be complete or incomplete and may include the whole root or only a part (Figure 1e) [8,9].

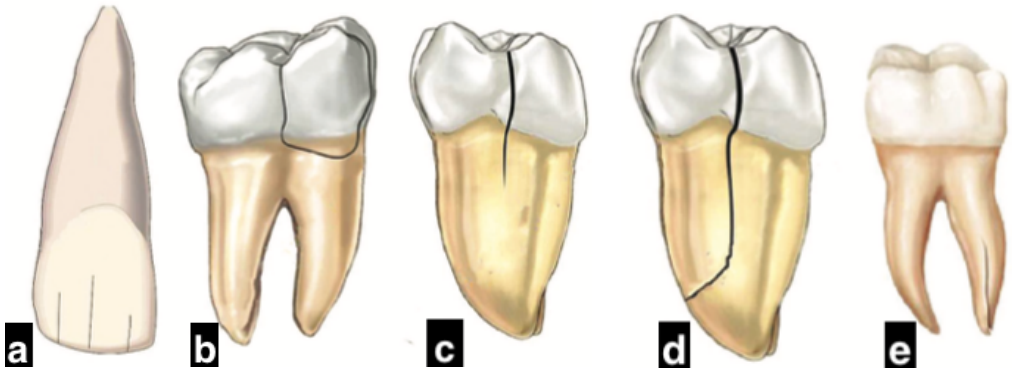

Figure 1: Schematic drawing of the different types of cracked teeth. (a) craze line, (b) fractured cusp, (c) cracked tooth, (d) split tooth, (e) vertical root fracture [8].

Epidemiology and Aetiology

More recent studies state that CTS is one of the most frequent problems among patients and has led to the third major causing factor in the loss of posterior teeth in adults. Cameron´s study presented that 80% of the cases of CTS appeared in patients above 40 years old. However, nowadays, more cases are proven to happen in much younger patient [10]. It is found to be more common among patients within the age range between 30-60 years. The appearance of CTS is unknown, but an incidence rate of 34-74% has been registered. Nevertheless, it is highly probable that the incidence of CTS will increase as people maintain their teeth into an older age today. As mentioned before, mandibular molars show to be the most frequently affected teeth. One of the reasons for this may be the eruption sequence. Mandibular first molars are the first permanent teeth to erupt into the dental arch, therefore they are more susceptible to dental caries and likely have more restorative treatments done. This leads to a higher risk of fracture. The "wedging effect" in the lower first molar teeth caused by the prominent mesio-palatal cusp of the maxillary first molar teeth may be another cause of the mandibular molar teeth being the most affected [3, 8].

CTS has a multifactorial aetiology that can be divided into two primary predisposing factors: natural predisposing features and iatrogenic causes [9].

Natural predisposing features include *morphological factors* such as steep cusp/fossas of maxillary premolars and lingual inclination of the lingual cusps of mandibular molars, which are considered to be the most probable to suffer complete loss by fracture of both lingual cusps. CTS due to *occlusion* is another important aetiology, which includes masticatory accidents such as biting on a hard object or food with excessive force. Some authors claim that this is the most common cause of CTS. The presence of occlusal interferences and/or loss of anterior guidance may contribute to harmful eccentric forces leading to a crack or worse, a fracture. Nowadays, a lot more people maintain their natural teeth much longer than before, the *ageing dentition* being at a higher risk to suffer cracks, as dental hard tissue becomes more rigid and less elastic with age and the forces applied may be greater than the elastic limits of the dentine. Lastly, regarding natural predisposing factors, *parafunctional habits* such as bruxism -centric and eccentric-, extensive attrition and abrasion are also important aetiological factors [3, 9].

Iatrogenic factors include the use of *rotatory instruments*, *cavity preparation* and the *width* and *depth of the cavity*. Excessive removal of tooth tissue during a cavity preparation has proved to significantly reduce the intrinsic strength of the tooth, causing it to be at a higher risk to crack. Logically the deeper and bigger the cavity, the higher the risk of cracks and fractures because of reduced supporting tooth structure [3, 9].

Signs and symptoms

Cracked tooth syndrome has a variety of signs and symptoms and it is not always easy to diagnose. However, the main signs and symptoms that all authors mention are masticatory pain and sensitivity to cold and sweet food; and these vary depending on the location, direction and size of the crack [(11)]. Other factors like pulp involvement can lead to signs and symptoms of irreversible pulpitis or necrosis. If the crack reaches the root surface, it may present an isolated periodontal pocket.

Therefore, the definitive diagnosis of a crack can only be made once there are a variety of the aforementioned symptoms present, and once all other presumptive diagnoses have been excluded. Removal of any existing restoration can also improve the visibility of a possible crack, which can help to confirm the diagnosis, and is therefore recommended [(6)].

Diagnosis and Management

As it is known the CTS can be challenging to diagnose due to the diverse signs and symptoms. However, an early diagnosis with the help of multiple diagnostic tools like the patient´s history, periodontal state, radiographs, vitality tests and microscopic detection has shown to have a direct relation with a successful treatment and better prognosis. Also, the diagnosis and treatment of CTS will depend on the location, periodontal probing depth and the direction of the crack line [(11)].

Three other important diagnostic tools that have been shown to be important for the diagnosis of CTS:

Bite test: Nowadays, there are many options for how to perform the bite test. It can be performed using a wooden toothpick, as Cameron used in 1964; or by using other tools, such as a cotton roll, orange wooden stick, rubber abrasive wheels such as Berlew wheel, or the head

of number 10 round bur in a handle of cellophane tape. Other commercial methods such as Fractfinder (Denbur, Oak Brook, IL, USA) and Tooth Slooth (Professional Results) have been described and supported by Ehrman et al. as methods that present high levels of sensitivity when compared to the use of wooden sticks and cotton rolls [4, 8].

Transillumination: Transillumination has been explained by different authors as one of the most used diagnostic tools for CTS. Transillumination is a light source that is placed directly on the tooth surface and in combination with a fibre optic light and magnification, it will improve the visualization of the crack [4, 9].

Optical coherence tomography: Optical coherence tomography (OCT) is an image tool based on interferometry**,** which uses light at a wavelength near-infrared to produce cross-sectional images of biological structures at a high resolution, without exposure to harmful electromagnetic radiation (X-ray). Future improvement of the OCT has led to; SS-OCT (swept-source OCT), which provides live cross-sectional images of the internal biological structures such as dental tissues, with microscopic level resolution [12,13].

Additional tests such as ultrasound, dye test, quantitative light-induced fluorescence technology, Cone-Beam Computed Tomography image (CBCT) with meglumine diatrizoate and iodine laser have been described as useful methods in the diagnosis of CTS [4,14,15,16].

Depending on the diagnosis and the severity of the crack line the treatment can vary from a simple restoration to endodontic treatment or as a last resort, extraction. Related to the restorative treatment options, depending on the severity of the crack, the restorative treatment has been divided into; Immediate treatment, Direct restoration with and/or without cuspal coverage and Indirect restoration with and/or without cuspal coverage [5, 17, 18].

Prognosis

Similar to aetiology, the prognosis of teeth with CTS also depends on multiple factors. Two main factors are the location and the degree of the crack. Cracks that do not involve the dental pulp, run horizontal, involve only one marginal ridge and do not run more than 2-3 mm below the periodontal attachment have an excellent prognosis according to S. Banerji et al. [(3)]. If the dental pulp, more than one marginal ridge, and a more vertical fracture are involved, the prognosis is worse. The anatomy of the tooth and roots, the history of previous restations of the tooth and functional and parafunctional forces are other factors that may have an effect on the prognosis. This also shows why it is so important to diagnose early [(3)].

Objectives

Primary Objectives:

- To compare and evaluate the different diagnostic tools and to determine the ideal method in case of cracked tooth syndrome.

Secondary objectives:

- To establish the main aetiological factors of cracked tooth syndrome.
- To determine the optimal management, in cases of cracked tooth syndrome.
- To study the prognosis of teeth affected by cracked tooth syndrome

Methodology

This study was carried out exclusively based on a thorough bibliographic review of the literature on cracked tooth syndrome. The online library of Universidad Europea de Madrid (UEM) was used as the main source of information; providing access to Medline and Pubmed, which were then used to search for and access various articles. Additionally, Google scholar was consulted to find additional articles on the various aspects of the topic presented in this research. Initially, a publication date limit was set in the search for articles, thereby excluding all articles published prior to 2010. However, the range limit of 10 years was later discarded, due to the significance and relevance of certain information found in articles published prior to that date.

In the search engine, some keywords were used either alone or in combinations such as: cracked tooth syndrome, diagnosis, management, aetiology, cracked tooth and treatment, signs and symptoms of cracked tooth syndrome. Through the online research, 40 articles were initially found; and 28 of those articles met the inclusion criteria, listed below, allowing them to be used in this study.

The following inclusion/exclusion criteria were considered:

Inclusion criteria:

- English or Norwegian language articles or books
- Articles relevant to the objectives of the study
- Recent studies, preferably from the last 10 years
- Articles are written in journals of dentistry of impact

Exclusion criteria:

- Articles or books not written in English or Norwegian
- Articles irrelevant to the objectives of the study

Discussion

Different diagnostic tools

The diagnosis of cracked tooth syndrome is often complex and confusing due to its variable and unpredictable symptoms which have shown to be challenging for dentists in clinical practice [7]. Due to the variable symptoms of CTS, it may be easily misdiagnosed because of similar features to other dental conditions. Such conditions include: acute periodontal disease, reversible pulpitis, dental hypersensitivity, galvanic pain associated with silver amalgam restorations, sensitivity resulting from micro-leakage from recently placed composite resin restorations, post-restoration high occlusion, occlusal trauma as a result of parafunctional habits, orofacial pain originating from conditions such as trigeminal neuralgia and psychiatric disorders such as atypical facial pain [3, 8].

Therefore, to achieve a successful diagnosis of CTS, it is important to perform a good dental history of the patient as early as possible. In fact, the patient can provide information that may give a more precise and closer diagnosis to detect CTS, for example, pain while biting. The patient may complain of pain while eating specific hard food or pain while biting on any hard objects [1, 4, 10]. Following the information from the patient, a good clinical examination is equally important. In a tooth where the crack continues subgingivally, a localized periodontal defect may be detected through periodontal probing, however, this may also indicate a split tooth that has a worse prognosis than a cracked tooth [1, 4]. The use of radiographs during clinical examination can be useful in excluding any other dental pathologies. However, the reliability of the radiograph as a diagnostic tool for CTS depends on the direction of the crack: while cracks that run in a buccolingual direction are often easily detected, cracks that proceed in a mesiodistal direction, which are parallel to the plane of the film, are not [1, 4, 8].

The diagnosis of CTS can be easily achieved with certainty if the clinician can detect the crack through a visual diagnosis. The crack is observed as a crack line located at the tooth surface [19]. However, this does not occur in the majority of the cases due to the small size of the crack, therefore further additional clinical examinations are important to include in the daily practice to determine the extension and localization of the crack line and to establish the best treatment plan possible [7, 20].

As stated by Erinne B. et al. [9] the most commonly used tools to detect cracked tooth syndrome are; vision enhancers, symptom reproducers, radiographs, transillumination with a fibre optic light and the use of magnification that will enhance the visualization of the crack. If a restoration is present many authors advise eliminating it to archive a better visualization of the crack [7, 9, 19].

When cracked tooth syndrome was first described by Cameron in 1964[2], the most common symptoms mentioned by patients were pain upon biting and an unexplained sensitivity to cold. To this day, these symptoms remain the most common in cracked tooth syndrome patients, as confirmed by a general consensus of the scientific community, for example by the Journal of the Canadian dental association in 2002[1], the British Dental Journal in 2010[3], and a case report by M. Fawzy et al. in 2020[21]. Therefore, this finding of biting /chewing pain can serve as an early diagnosis of CTS with the help of a bite test and a vitality test at the suspected teeth. While the vitality of these teeth usually remains positive, with no signs of pulp affectation, there are cases where they could present hypersensitivity to cold stimuli, indicating inflammation of the pulp [5, 8].

Bite test

The first bite test was performed in 1964 using a wooden toothpick. The bite test is used as a symptom reproducer aid, assisting in the diagnosis of a cracked tooth [10].

A study was done by Yang Y. et al. [10] compared the use of wet cotton rolls and Tooth Slooth, which help in the early diagnosis of cracked tooth syndrome (Figure 2a and 2b). A Tooth Slooth is composed of a small plastic bite block shaped like a pyramid (20 x 10 mm) attached to a handle. The tip of the pyramid can be placed on each individual cusp of the tooth suspected of presenting a crack. The patient is asked to bite, thereby putting selective pressure on one cusp [6, 10]. Pain while biting or after the release of biting pressure is the most probable pathognomic sign of a cracked tooth syndrome [6, 10, 22].

46 patients were enrolled in this study, 91.3% of these patients presented pain when they bit on the Tooth Slooth and 63.0% were only uncomfortable when biting the wet cotton rolls. This study verified that the relative ratio of biting pain using the Tooth Slooth was considerably higher than the use of wet cotton rolls in the aid of early diagnosis of CTS [10].

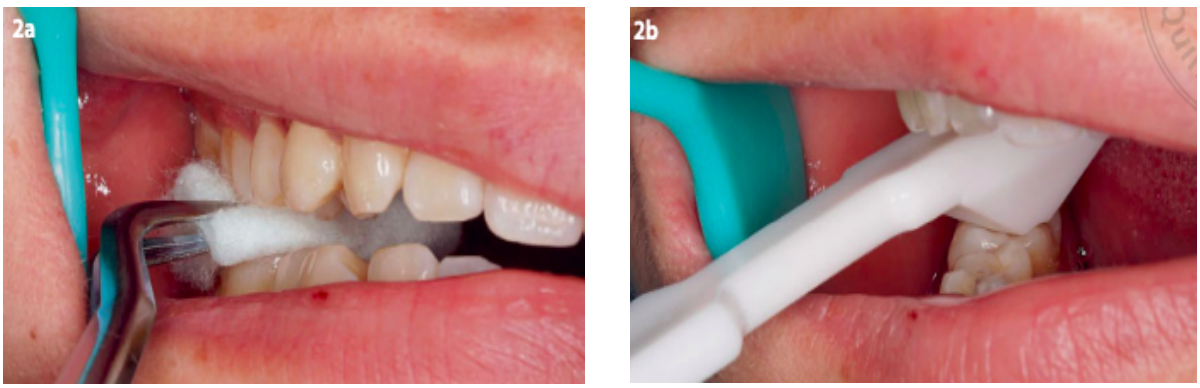

Figure 2: 2a Bite test with a wet cotton roll, 2b Bite test using a Tooth Slooth [10].

The study by Yang Y. et al. [10] attributed the differences in sensitivity of the tests to the surface area covered. While the cotton rolls put pressure on the whole or majority of the tooth surface, thereby locating the tooth with biting pain, the Tooth Slooth, on the other hand, can identify the exact cusp involved as it localizes the pressure to that area.

Trans-illumination

A study done by Erinne B. et al. [9] where they reviewed the literature of cracked teeth and another study by Kadandale S. et al. [23] where they studied three different cases presenting cracked tooth syndrome, they referred to transillumination with fibre optic light source and a magnifier as the most common method to diagnose CTS. Mathew et al. [4] and Hasan S. et al.[8] described that transillumination can be used to diagnose both incomplete cracks found in CTS and incomplete vertical tooth fractures.

Before carrying out the transillumination test it is important to first clean and dry the tooth followed by the placement of the light source directly on the involved tooth. In a tooth that does not present any cracks or may only present craze lines the light transmitted will go through the crown, whilst a tooth presenting a crack will block the light transmitted. Due to the crack, dark and light areas are formed and separated making the crack visible [4, 8, 22].

Fitha Prabantari Angela and Anggraini Margonno [7] highlighted the success of using transillumination together with povidone-iodine in the detection of a fracture line, extending mesiodistally on the occlusal surface towards both marginal ridges. Another study, conducted by Wright et al. [7], confirmed these findings, underlining the success of using transillumination in combination with a stain, in this case, methylene blue, to be the best diagnostic test for cracks.

However, the transillumination technique presents two main disadvantages. It has been proven that transillumination worsens the results of the diagnosis by dramatizing the cracks of the tooth. As a consequence, the lines will appear also at the level of structural cracks, meaning that the cracks seen may belong to the natural features of the tooth**.** The second main disadvantage is that transillumination is not able to distinguish and doesn´t have the sensitivity to distinguish the slight change of colours thereby it does not provide information of the depth of the crack [4, 8, 16]. However, these disadvantages have been overcome by using the

transillumination with a fibre-optic light together with magnification which then will provide better visualization of a crack, improving the quality and the treatment outcome. In fact, transillumination is one of the most used diagnostic tools especially in early detection [4, 7, 22, 23].

Optical coherence tomography (OCT)

Because of the disadvantage of the transillumination test, new methods like OCT have been studied to improve the diagnosis of cracks. In a study by Y. Shimada et al. [13] they compared SS-OCT imaging with transillumination to diagnose cracks (Figure 3a and 3b) [13].

In a healthy tooth, the complete thickness of the enamel can be seen through SS-OCT because of the dentin-enamel junction (DEJ). The DEJ appears as a dark border and due to the different biological components, the enamel and dentin can be differentiated (Figure 3b). Nonetheless, if a crack presents deeper into the dentine, it´s harder to diagnose them using optical coherence tomography. Furthermore, factors like the surface inclination and roughness of the tooth are highly prone to affect the penetration depth of the SS-OCT. Therefore, a tooth presenting a smooth surface will achieve a more favourable penetration depth for SS-OCT [12].

Throughout the study of Yasushi Shimada et al. [12] and another study by M.S. Segarra et al. [13], they explained the appearance of the crack on the SS-OCT as a bright line because of the high backscattered waves, which makes it possible to detect very small cracks [12, 13]. However, the backscattering effect of the optical coherence tomography has been explained as an important disadvantage by Roma M. et al. [22] therefore they did not recommend it [22].

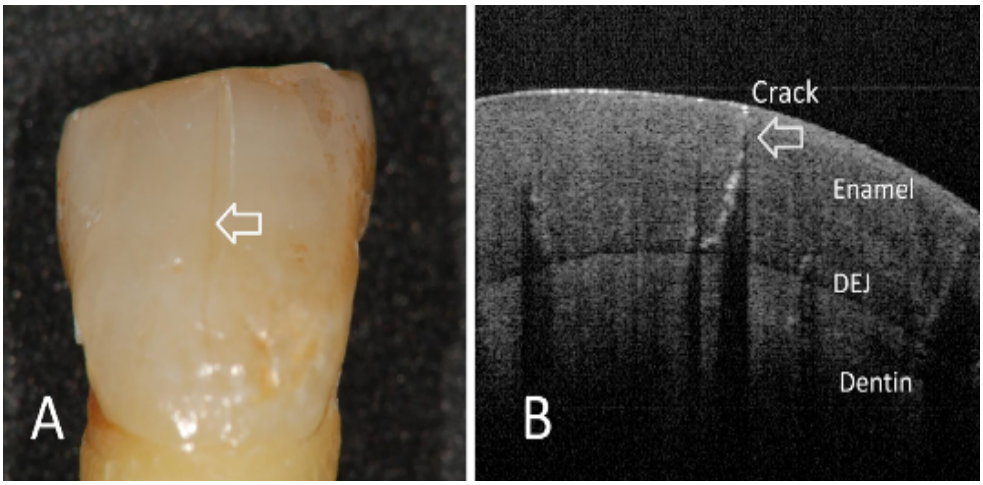

Figure 3: a; Hairline enamel crack through transillumination and b; crack from enamel to DEJ through SS-OCT [12].

Another study done by Sang-Hee Lee et al. [20] proposed the use of optical coherence tomography as a diagnostic tool for cracked tooth syndrome. Sang-Hee Lee et al. [20], proved the accuracy of SS-OCT (Figure 4c) by comparing the findings of crack lines with other conventional tools such as visual inspection (Figure 4a), transillumination (Figure 4b) and Micro-CT (Figure 4d) [20]. Throughout their study, 61 teeth and 109 surfaces were examined. This study established that the mean number of detected crack lines per surface (MNDCps) was higher in SS-OCT than in the three other conventional methods. However, they reported 8 cases where the number of observed crack lines using transillumination was superior to SS-OCT. With this, they concluded that the SS-OCT sensitivity and specificity were as high as for transillumination and found to be an acceptable diagnostic tool for cracked tooth syndrome [20].

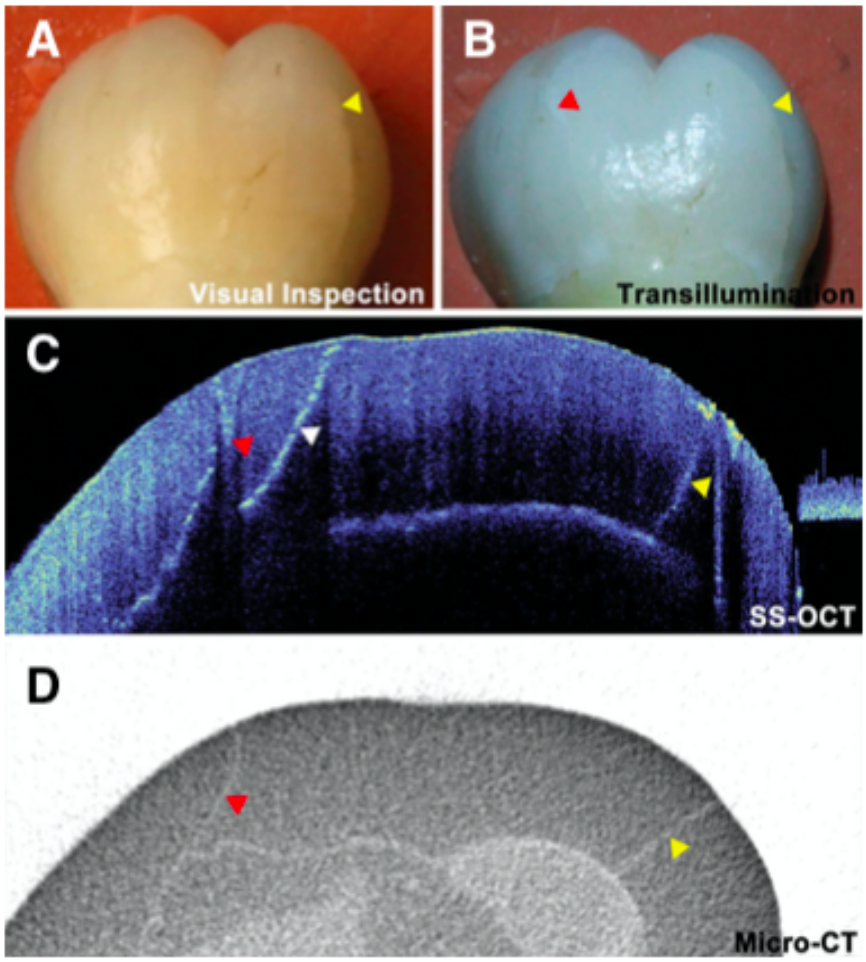

Figure 4: The crack lines detected in the four different detection tools [20].

Despite the backscattering effect described by Roma M. et al. [22], the SS-OCT has some important advantages, such as it uses light thereby has no risk of radiation exposure, can be safely used in infants and pregnant women and can be used not only to diagnose cracks but also carries and micro-gaps at the site of restoration [12, 13].

In addition to the study by Roma M. et al. [22] the three other studies by Yasushi Shimada et al. [12], M.S. Segarra [13] and study by Sang-Hee Lee et al. [20] provided more detailed information regarding the use of SS-OCT to diagnose CTS and approved it as a successful diagnostic tool, especially in early diagnosis.

Others

Another method that is used to diagnose CTS, mentioned in the introduction, is *quantitative light-induced fluorescence technology* (QLF). This method was studied by Jun et al. [14] where they examined 96 extracted human teeth. They found a correlation with transillumination as both used light and therefore share the same advantages regarding the safe use in children, pregnant women and other people that are sensitive to radiation. Their results proved a successful use of the QLF technique not only in detecting the crack but also the depth. However, this is the first study using QLF technology for the diagnosis of CTS therefore future studies are needed [12, 14].

The Australian Endodontic Journal in 2020[16] did a study using a *diode laser* to diagnose symptomatic cracks in teeth with a cracked tooth. This study was done over 4 years and twelve patients were included. Throughout their study ten of the twelve patients had a positive response to the laser scan. Therefore, the authors A. Sapra et al. [16] concluded that the use of diode laser could be used as a diagnosing method in symptomatic cracks in patients having CTS. However, as this study had a small sample size it is important to carry out future studies with a bigger sample size to confirm the diode laser as a preferred approach. Additionally, this method has a disadvantage as it is unclear if it can be used in pregnant and breastfeeding patients [16].

A study was done by Yuan et al. [15] used *Meglumine Diatrizoate* (MD) which is an iodine contrast to increase the quality of diagnosing a cracked tooth with *Cone-Beam Computer Tomography image* (CBCT). This study demonstrated the successful use of MD as a contrast medium to detect crack lines. However, it presents many disadvantages such as; it can disappear in contact with saliva, very small size cracks might not be detected and movement and

restriction of muscles make it hard to perform in the clinic. Therefore, additional studies are needed for using MD as an iodine contrast in the future [15].

As mentioned in the introduction *dye test* could be used as an additional tool for diagnosing CTS. In three different studies written by S. Banerji et al. [3], Mathew et al. [4], and Hasan S. et al. [8], they describe the use of gentian violet or methylene blue stains used to emphasize the crack. Although 2-5 days is needed for it to be successful, thereby a provisional restoration may be needed. However, a provisional restoration may aggravate the crack leading to a worse condition of the tooth and more invasive treatment.

Lastly the study by Mathew et al. [4] and a later study by Hasan S. et al. [8] mention *ultrasound* and its ability of imaging cracks in simulated tooth structure which could be a successful diagnosing tool in the future.

Aetiology

As mentioned in the introduction cracked tooth syndrome has a multifactorial aetiology. Lubisich et al. [9] and Qian et al. [24] divided the aetiological factors into two primary predisposing factors: natural predisposing factors and iatrogenic cause. Related to the natural predisposing factors, masticatory accidents such as biting on a hard object or food were described by S. Banerji et al. [3] as the most common cause of CTS. Moreover, iatrogenic factors like cavity preparations have proven to significantly increase the chance of cracked tooth. Lubisich et al. [9] referred to an earlier study where they found a direct correlation regarding the size of cavity preparation with a crack and fractured tooth [3, 9].

Lynch CD. et al. in 2002[1] described the different aetiological factors of CTS dividing it into four categories: `restorative procedures`, occlusal factors`, `developmental conditions` and `miscellaneous factors` (Table 1). This classification has been well accepted as it has been

used in later studies done by the British Dental Journal in 2010[3] and in the International Journal of Applied and Basic Medical Research [8] in 2015.

Classification	Factors	Examples
Restorative procedures	Inadequate design features	Over-preparation of cavities Insufficient cuspal protection in inlay/onlay design Deep cusp–fossa relationship
	Stress concentration	Pin placement Hydraulic pressure during seating of tightly fitting cast restorations Physical forces during placement of restoration, e.g., amalgam or soft gold inlays (historical) Non-incremental placement of composite restorations (tensile stress on cavity walls) Torque on abutments of long-span bridges
Occlusal	Masticatory accident	Sudden and excessive biting force on a piece of bone
	Damaging horizontal forces	Eccentric contacts and interferences (especially mandibular second molars)
	Functional forces	Large untreated carious lesions Cyclic forces
	Parafunction	Bruxism
Developmental	Incomplete fusion of areas of calcification	Occurrence of cracked tooth syndrome in unrestored teeth
Miscellaneous	Thermal cycling	Enamel cracks
	Foreign body	Lingual barbell
	Dental instruments	Cracking and crazing associated with high-speed handpieces

Table 1: Classification of the aetiological factors of cracked tooth syndrome [1, 3, 8].

Although the authors use different methods to classify the different aetiological factors the majority of the causes are the same, just divided into different categories.

Two other factors that have been discussed by other authors include the sex of the person affected and the tooth involved. The study by Hasan S. et al. [8] has shown that females appear to be more susceptible to getting CTS. Most other articles, however, have shown that both sexes are equally susceptible to CTS. On the other hand, many studies unanimously agree that mandibular molars are the most susceptible tooth to experience cracked tooth syndrome. These studies were mentioned in the paper by Lubisich et al. [9], where 10 out of the 12 studies listed agreed that mandibular molars were most prone [3, 6, 8, 9].

Management

The British Dental Journal has described several methods for managing CTS. However, it lacks clinical studies to confirm the most favourable technique to use [5]. The different managing method for CTS based on the study by S. Banerji et al. in 2010 and another study by the same authors done in 2017 the treatments should be effective, efficient, economic, predictable and biologically conservative based on the mentioned factors [5, 18]. Another important factor explained by other authors which are important to take into account when choosing the best treatment option is the extension of the crack and if it involves the pulp or not [1, 6, 22].

As explained in the introduction the different restorative management of CTS is divided into: Immediate treatment, Direct restoration with and/or without cuspal coverage and Indirect restoration with and/or without cuspal coverage [5, 17, 18].

Immediate treatment

The Journal of the Canadian Dental Association [1] describes that immediate treatment depends on the amount of tooth involved. If the amount is very small, just the removal of the crack part and restoring it with a composite can be achieved. However, if the crack involved is huge or affecting the pulp the tooth involved is highly recommended by several authors to be immobilised. To immobilise the segment different methods have been explained, such as copper ring, orthodontic band, temporary crown and direct composite splint. Different studies have agreed to use a stainless-steel orthodontic band as the most favourable method due to the effective modelling and minor irritating of the gingiva (Figure 5a). The orthodontic bands have been advised to be used in combination with an occlusal adjustment which has been proven to alleviate correlated symptoms and reduced stress to the involved tooth [1, 18, 23, 25].

Furthermore, a more detailed study done by S. Banerji et al. in 2014[17] proved that direct placement of bonded composite resin over the tooth surface to splint the fracture and immobilise the segment has been successfully used as a minimally invasive method for diagnosing and management of symptoms of CTS (Figure 5b). This method is now called a `direct composite splint` (DCS) by multiple authors. However, this method has been reported only to be successful for the management of CTS in a short to medium period of time. Moreover, as mentioned before the different methods need future studies to approve the best option in clinical practice [5, 17, 18].

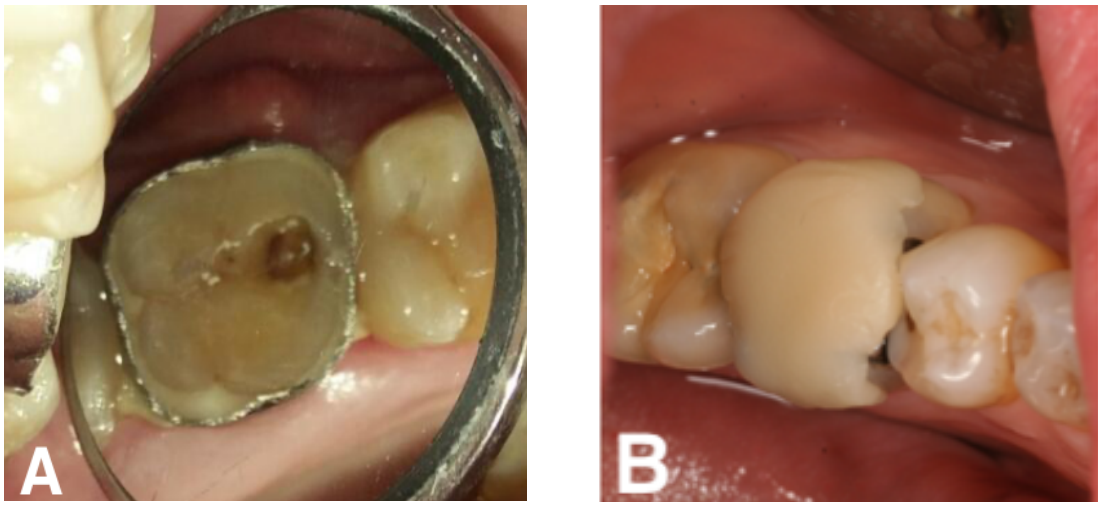

Figure 5: 5a crack tooth stabilised with orthodontic band and 5b crack tooth splinted with DCS [7, 17].

Direct restoration

Reports from different studies show that direct restoration with or without cusp coverage in the management of CTS has been a successful treatment option. As mention earlier, the extension of the crack influences the choice to restore with or without cusp coverage. Opdam et al. [18] studied two different groups, one group was treated with direct composite intra-coronal resin restoration (without cusp coverage) and the other group with direct bonded resin overlay

restoration (cusp coverage). This study proved that a direct restoration treatment with cusp coverage had a higher success rate because of the possibility of the continuous breakdown of the inter-coronal material due to cyclical functional loading that could lead to future cracks. Therefore, important factors like parafunctional habits like tooth clenching or grinding have been discussed as an important factor to take into consideration when choosing the treatment option [5]. More studies have discussed that to achieve long-term management of CTS and best prognosis the direct restoration with cusp coverage is the treatment of choice. In the study by S. Banerji et al. [18] they had a success rate of 72.7% of teeth treated with direct composite resin inlays or onlays with 11 years follow-up period. [5, 7, 18].

Nevertheless, this approach has been described to be cost-effective, efficient and aesthetic. Also, in comparison with indirect restoration, direct restoration seems to be less problematic in the concern to maintain the pulp. However, direct restoration requires abundant operator skills and it's not clear the survival of direct restoration especially among bruxists patient [5, 7, 18].

Indirect restoration

As mentioned for the direct restoration, the indirect restoration can also be done with or without cusp coverage. As described by the British Dental Journal in 2017[5] the materials used in indirect restoration have the ability to provide much better mechanical properties in the oral environment and easier to work with. The different materials for indirect restoration have been discussed in different studies. Signore et al. [26] studied the use of indirect bonded resin composite onlays to treat CTS (Figure 6a). This study showed a 93.02% survival rate with a six-year follow-up period in a sample of 43 teeth, demonstrating the success of this material in teeth presenting CTS [5, 18, 26]. Moreover, indirect composite onlays have manifested to be

beneficial compared to porcelain due to their great ability to absorb compressing load. In fact, it decreases the shock received by the underlying tooth structure [18].

The use of ceramic onlays versus composite onlays has been explained by S. Banerji et al. [18]. They have proved the advantages of using composite as opposed to ceramic. The fragility and the low elastic modulus of ceramics make the material a less favourable option, as they infer a limited ability of plastic deformation when bearing a masticatory load, leading to a higher possibility of fractures. This is especially significant when comparing ceramics to composite materials, which have a higher elastic modulus and are therefore able to bear more load [5, 18]. As for the type of restoration, the majority of authors state that a full-coverage crown is the best treatment for the management of CTS. This is argued due to the efficient spread of the occlusal load over the entire tooth and a better retention, increasing immobilisation [5, 6, 18]. An example of this is shown in Figure 6b, which presents a fractured tooth treated with a full coverage porcelain-fused-to-metal crown [7].

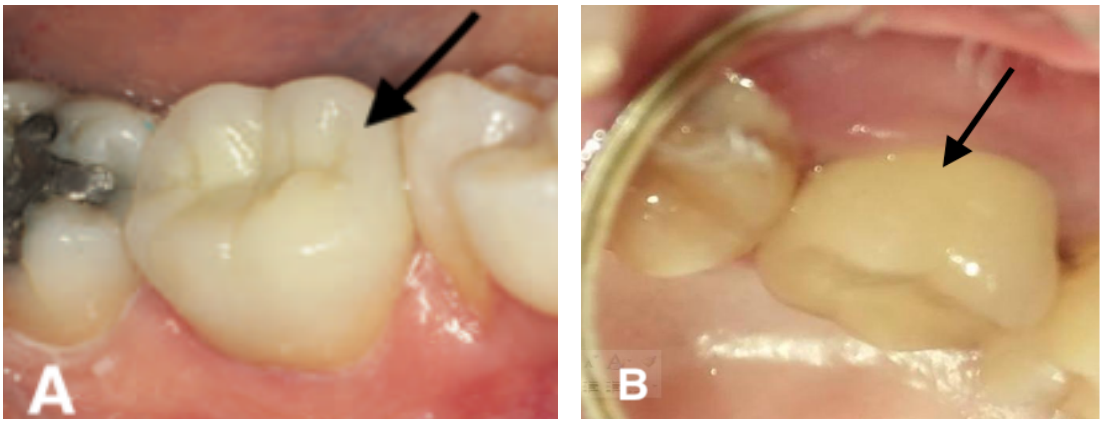

Figure 6: (a) A tooth treated with an indirect resin composite onlay, which previously presented a mesial fracture. (b) A tooth-, previously presenting a fracture in the occlusal surface, treated with a full coverage porcelain-fused-to-metal crown [7, 18].

A more recent study by the Iranian Endodontic Journal [11] proposed the use of the CAD-CAM system in the treatment of cracked teeth (Figure 7). Through this technique they provided a faster approach as the treatment could be done in one visit, hence no temporary crown is

needed. Furthermore, this study had a 100% survival rate over 5 years of all the three different cases (3 samples) they presented, therefore demonstrated the use of CAD-CAM as a potential treatment for CTS [11].

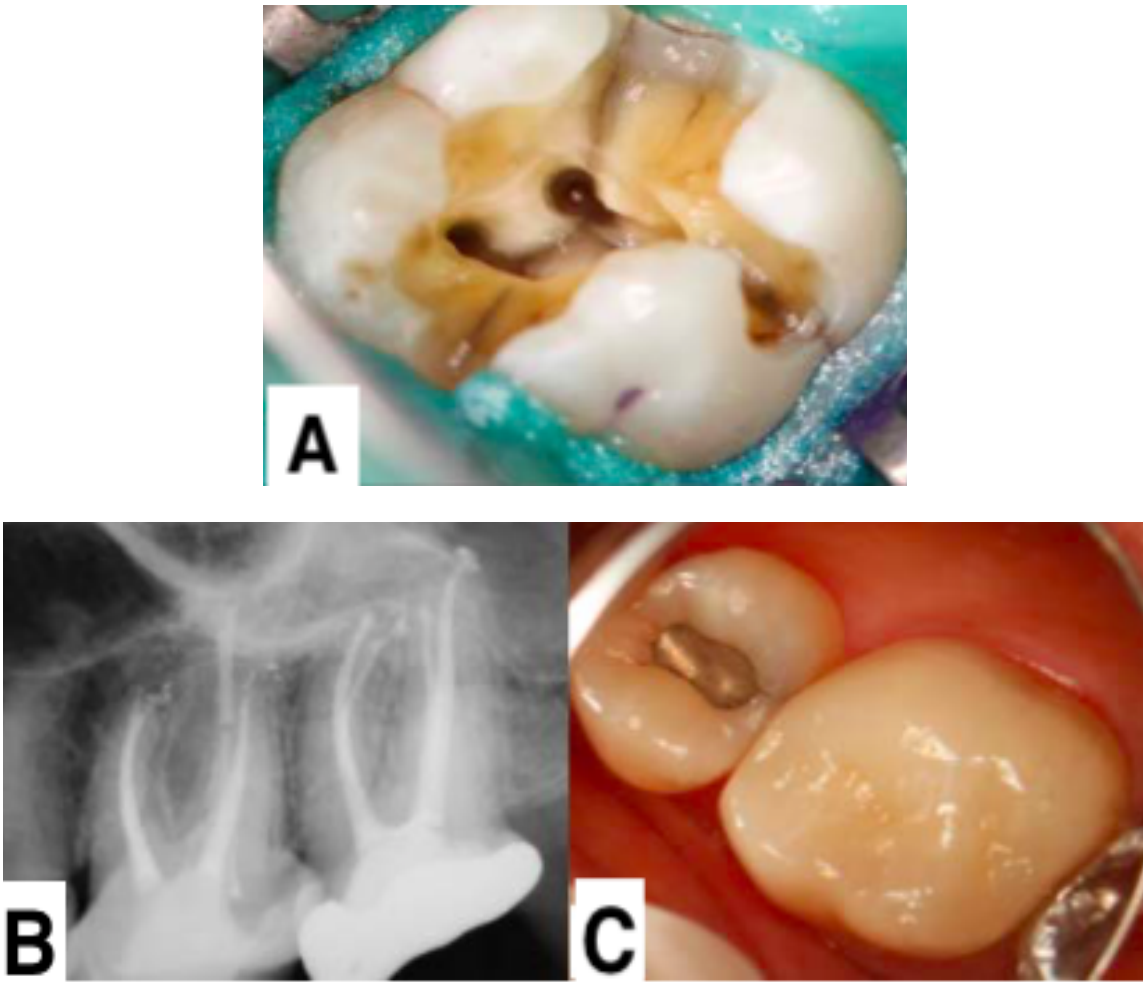

Figure 7: (a) Presents tooth 26 with the crack lines, (b) shows the final endodontic treatment performed and (c) present the tooth at the end with the full coverage crown made by the CAD-CAM system [11].

Nevertheless, as explained in multiple articles the condition of the pulp and the periapical areas influences the treatment plan. If the pulp is vital it may proceed directly to the restorative treatment, however, if it has any symptoms of irreversible pulpitis or a necrotic pulp

an endodontic treatment is needed before the restorative treatment [7, 19, 22, 23]. This was presented in the study by Sadasiva Kadandale et al. [23] where they studied 3 different cases including three patients where each of them had one tooth presenting cracked tooth syndrome. With help of two pulp test and no responses to any of them, a root canal treatment was required in all the 3 cases. Following the root canal treatment, a composite core to splint the fracture was used, later to terminate a full-coverage metal-ceramic crown was used. With regular check-up, this tooth presented a successful treatment [23].

As mentioned in the previous paragraph, the study by the Iranian Endodontic Journal[11] also studied 3 different cases presenting crack tooth syndrome. In case 2 it was diagnosed irreversible pulpitis and in case 3 pulp necrosis was in both cases due to the deep extension of the crack line. Therefore, in the two cases, they needed to perform endodontic treatment, latterly they completed the treatment with a full-coverage crown done through the CAD-CAM system. One of their cases is presented in figure 7 a, b and c. Nevertheless, in comparison to the study by Sadasiva kadandale et al. [23], this study by the Iranian Endodontic Journal [11] presents a better follow-up with a survival rate of 100% as mentioned before. However, future studies and cases are needed with a higher number of individuals involved [11, 23].

Prognosis

The prognosis of a tooth presenting CTS will depend on multiple factors. Furthermore, the localization and the degree of the crack as S. Banerji et al. [3] explained in their study are two important factors for the prognosis of CTS [3]. Nevertheless, different authors as for example Fitha Prabantari A. et al. [7] and Hasan S. et al. [8] stated the importance of an early diagnosis thereby early management leading to a favourable prognosis [3, 22]. Moreover, the early detection of a crack can avoid further deterioration and can prevent the crack from extending into the pulp chamber or sub-gingivally [3]. An example of this is presented in one of the cases by Kadandale Sadasiva et al. [23] where they detected a tooth presenting a fracture extending mesio-distally and vertically towards the floor of the pulp chamber. The final treatment for this tooth was an extraction, after which they discovered a fracture involving both the entire crown and root [23]. This highlights the importance of early detection: if the patient had visited the dentist sooner, the fracture may have been detected earlier, increasing the likelihood of the tooth being saved.

Additionally, the involvement of the pulp has also proved to be highly important for the prognosis explained by S. Banerji et al. [3]. If the crack extends into the pulp an endodontic treatment is needed which have been proved to have an increased failure rate of 14.5% after a follow-up period of 2 years [3].

However, two different studies done by Sim et al. [27] and Kang et al. [28] were based on the survival of a tooth presenting a crack after treated with a root canal treatment. The study by Sim et al. [27] presented a survival rate of 81.8% in 84 teeth presenting cracks after a 5-year follow-up. Furthermore, Kang et al. [28] presented a survival rate of 90.0% in 88 teeth incorporated after 2 years of the follow-up period. This shows that with a good endodontic treatment the survival and the prognosis of the tooth increases [7, 27, 28].

Conclusions

1. Crack tooth syndrome can have multiple causes and aetiologies, thereby it presents different symptomology which can make it challenging to diagnose.

2. It is important to implement multiple diagnosing tools to be able to dismiss other possible pathologies and archive the definitive diagnosis. However, the bite test and the transillumination are two of the diagnosing methods which are proved to be widely common for detection of CTS, but used as a combination of the two, and also with other materials.

3. The aetiology of CTS is also multifactorial and can be divided into: restorative procedures, occlusal factors, developmental conditions and miscellaneous factors.

4. The management of CTS depends on the severity, extension, and localization of the crack. Thereby there are multiple methods of how to manage it. However, it has been proven that a full-coverage crown is the best treatment options for CTS, although future studies are needed.

5. The prognosis of CTS depends on multiple factors as in all the other cases. However, early diagnosis has been associated with more successful restorative management and prognosis. Furthermore, the improvement of clinical skills has proved a higher survival rate and prognosis. In the cases of a tooth presenting a crack with damage to the pulp, root canal treatment is needed prior to crown placement.

Responsibility

The present research is looking into different ways to diagnose and manage Cracked Tooth Syndrome. Many ways on how to diagnose this pathology have been explained, one of the most common tools being the bite test. This can be done with only a cotton roll or a Tooth Slooth which are inexpensive both for the clinic and for the patient.

Furthermore, an early diagnosis of the syndrome can allow for an early treatment intervention, which can be significantly cheaper for the patient, as well as less risky for their health. This will benefit the entire population, but especially the part of the population with a lower income. Therefore, it is important that all clinicians are familiar with how to diagnose CTS and what is the best possible way to treat it. This means that more research is necessary since the improvement of diagnostic tools could lead to more affordable treatments and therefore increased accessibility to dental health care.

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Annexes

Article 1:

The Cracked Tooth Syndrome

• Christopher D. Lynch, BDS, MFDRCSI •
• Robert J. McConnell, BDS, PhD, FFDRCSI •

Abstract

The purpose of this article is to review the clinical features, diagnosis and management of the cracked tooth syndrome (CTS). The condition refers to an incomplete fracture of a vital posterior tooth that occasionally extends into the pulp. A lack of awareness of the condition coupled with its varied clinical features can make diagnosis of CTS difficult. Common symptoms include an uncomfortable sensation or pain from a tooth that occurs while chewing hard foods and which ceases when the pressure is withdrawn. The patient is often unable to identify the offending tooth or quadrant involved, and may report a history of numerous dental procedures with unsatisfactory results. Successful diagnosis and management requires an awareness of the existence of CTS and the appropriate diagnostic tests. Management options depend on the nature of the symptoms and extent of the lesion. These options include routine monitoring, occlusal adjustments, placement of a cast restoration and endodontic treatment. A decision flowchart indicating the treatment options available to the dental practitioner is presented.

MeSH Key Words: *cracked tooth syndrome/diagnosis; cracked tooth syndrome/therapy; dental restoration, permanent*

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This article has been peer reviewed.

The term cracked tooth syndrome (CTS) refers to an incomplete fracture of a vital posterior tooth that involves the dentine and occasionally extends into the pulp.[1-3] The term was first introduced by Cameron[1] in 1964, who noted a correlation between restoration size and the occurrence of CTS. Mention is made in the earlier literature of pulpal pain resulting from incomplete tooth fractures,[4,5] and also of "greenstick fractures" of the crown.[6] A more recent attempt to define the nature of this condition describes it as "a fracture plane of unknown depth and direction passing through tooth structure that, if not already involving, may progress to communicate with the pulp and/or periodontal ligament."[7]

The condition presents mainly in patients aged between 30 years and 50 years.[8-10] Men and women are equally affected.[11] Mandibular second molars, followed by mandibular first molars and maxillary premolars, are the most commonly affected teeth.[2,12] While the crack tends to have a mesiodistal orientation in most teeth, it may run buccolingually in mandibular molars.[11]

Two classic patterns of crack formation exist.[1] The first occurs when the crack is centrally located, and following the dentinal tubules may extend to the pulp; the second is where the crack is more peripherally directed and may result in cuspal fracture. Pressure applied to the crown of a cracked tooth leads to separation of the tooth components along the line of the crack. Such separation in dentine results in the movement of fluid in the dentinal tubules, stimulating odontoblasts in the pulp as well as the stretching and rupturing odontoblastic processes lying in the tubules,[3] thus stimulating pulpal nociceptors. Ingress of saliva along the crack line may further increase the sensitivity of dentine.[13] Direct stimulation of pulpal tissues occurs if the crack extends into the pulp.

Symptoms and Diagnosis

Successful diagnosis of CTS requires awareness of its existence and of the appropriate diagnostic tests. The history elicited from the patient can give certain distinct clues. Pain on biting that ceases after the pressure has been withdrawn is a classical sign.[1,3] Incidences usually occur while eating, or where objects such as a pencil or a pipe are placed between the teeth.[3] The patient may have difficulty in identifying the affected tooth[4] (there are no proprioceptive fibres in the pulp chamber). Vitality testing usually gives a positive response,[1,2] and the tooth is not normally tender to percussion in an axial direction.[4] Significantly, symptoms can be elicited when pressure is applied to an individual cusp.[3,4,14] This is the

Article 2:

A ten-year study was made of the cracked tooth syndrome, in which 102 posterior teeth with cracks were investigated. Early diagnosis and treatment can prevent further cracking into the pulp and fracture of the tooth.

The cracked tooth syndrome: additional findings

Caryl E. Cameron, DDS, MS, Chicago

In an earlier report in March 1964, 50 instances of the cracked tooth syndrome were described.[1] That paper called attention to the syndrome to make the dentist aware of the problem so he could make the correct diagnosis. Once the diagnosis is made, further cracking into the pulp and fracture of the tooth can be prevented.

Another 102 teeth have been studied: only posterior teeth were involved, anterior teeth were not included.

▪ *Diagnosis:* Discomfort in chewing is the most frequent symptom of a cracked tooth, but unexplained sensitivity to cold is often experienced by the patient. The patient complains that it hurts to bite on one side of the mouth, but he may not know which tooth is involved or whether the pain is in the mandible or maxilla. However, a crack should be suspected when the patient experiences pain when chewing on that side of the mouth, especially when chewing tough foods.

The dentist should be suspicious that the tooth is cracked if no caries or sensitive cementum is found and the tooth structures appear normal in the radiograph. These cracks occur most frequently in the mandibular second molars. They are easy to diagnose if they can be seen. Food and bacteria may stain the plaque in the crack when the crack extends over the distal marginal ridge and onto the distal surface. A typical crack

Fig 1 ▪ Typical crack in distal surface of mandibular second molar.

is shown in Figure 1; there is no restoration on the distal surface of the tooth and the third molar is missing.

Unfortunately, most posterior teeth that crack have been restored, thus obscuring the crack and necessitating the use of other diagnostic procedures. Diagnostic methods previously described were tapping the various cusps in different directions, wedging along a margin of the restoration with a sharp instrument, having the patient bite on a wooden toothpick, and staining.

An additional diagnostic aid to locating the

Article 3:

Cracked tooth syndrome. Part 1: aetiology and diagnosis

S. Banerji,[1] S. B. Mehta[2] and B. J. Millar[3]

VERIFIABLE CPD PAPER

PRACTICE

IN BRIEF

- Updates and clarifies the definition of the term 'cracked tooth syndrome', including an overview of the typically associated signs and symptoms of this syndrome complex.
- Provides an account of the epidemiology, aetiology and diagnosis of the condition, including a description of available special clinical tests to form a positive diagnosis.
- Details the factors which may influence the prognosis of affected teeth.

Symptomatic, incompletely fractured posterior teeth can be a great source of anxiety for both the dental patient and dental operator. For the latter, challenges associated with deriving an accurate diagnosis together with the efficient and time effective management of cases of cracked tooth syndrome are largely accountable for the aforementioned problem. The aim of this series of two articles is to provide the reader with an in-depth insight into this condition, through the undertaking of a comprehensive literature review of contemporarily available data. The first article will provide details relating to the background of cracked tooth syndrome including the epidemiology, patho-physiology, aetiology and diagnosis of the syndrome, together with a consideration of factors which may influence the prognostic outcome of teeth affected by incomplete, symptomatic fractures. The second article will focus on the immediate and intermediate management of cracked teeth, and also provide a detailed account of the application of both direct and indirect restorations and restorative techniques used respectively in the management of teeth affected by this complex syndrome.

INTRODUCTION

The term 'cuspal fracture odontalgia' was first used by Gibbs in 1954,[1] to describe a condition which is better now known as 'cracked tooth syndrome' or 'cracked cusp syndrome'. The latter concept was coined by Cameron in 1964,[2] who proceeded to define the condition as 'an incomplete fracture of a vital posterior tooth that involves the dentine and occasionally extends to the pulp'. In more recent times the definition has been amended to include, 'a fracture plane of unknown depth and direction passing through tooth structure that, if not already involving, may progress to communicate with the pulp and or periodontal ligament'.[3]

The term 'incomplete fracture of posterior teeth' is often used interchangeably with that of cracked tooth syndrome,[4] while the terms 'green-stick fracture' or 'split tooth syndrome' have also been used synonymously.[5]

Patients suffering from cracked tooth syndrome (CTS) classically present with a history of sharp pain when biting, or when consuming cold food/beverages.[6] It has been suggested that the symptom of pain on biting increases as the applied occlusal force is raised.[7] A detailed assessment of the symptoms may reveal a history of discomfort that may have been present for several months previously. Other symptoms may include pain on release of pressure when fibrous foods are eaten, 'rebound pain'.[8] Pain may also be elicited by the consumption of sugar containing substances[5] and also by the act of tooth grinding or during the undertaking of excursive mandibular movements.[9] While some patients are able to specify the precise tooth from which the symptoms may be arising, the latter is not a consistent feature. The absence of heat induced sensitivity may also be a feature.

Where the fracture line may eventually propagate into the pulp chamber ('complete fracture'), symptoms of irreversible pulpitis or apical periodontitis may ensue, while fractures which progress further towards the root may be associated with areas of localised periodontal breakdown or at worst culminate in vertical tooth fracture[5]

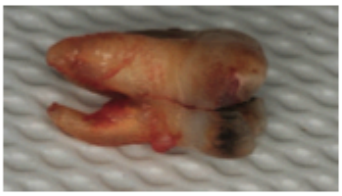

Fig. 1 Shows an example of a tooth with a vertical root fracture, where the patient initially presented with symptoms of cracked tooth syndrome. Any delays in instituting therapy may result in such an outcome, which may happen where there is doubt over the diagnosis of the condition

as shown by Figure 1. Table 1 provides a summary of the commonly associated signs and symptoms associated with CTS.

The physiological basis of pain on chewing has been hypothesised by Brannstrom *et al.*[10] to be accounted for by the sudden movement of fluid present in dentinal tubules which occurs when the fractured portions of the tooth move independently of one another. It is thought that the latter results in the activation of myelinated A-type fibres within the dental pulp, thereby accounting for the acute nature of the pain. It has also been suggested that the perception of hypersensitivity to cold may occur as a result of the seepage of noxious irritants through the crack, which results

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Article 4:

Dental Science - Review Article

Diagnosis of cracked tooth syndrome

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ABSTRACT

The incidences of cracks in teeth seem to have increased during the past decade. Dental practitioners need to be aware of cracked tooth syndrome (CTS) in order to be successful at diagnosing CTS. Early diagnosis has been linked with successful restorative management and predictably good prognosis. The purpose of this article is to highlight factors that contribute to detecting cracked teeth.

KEY WORDS: Bite test, cracked tooth syndrome, transillumination

Cracked tooth is defined as an incomplete fracture of the dentine in a vital posterior tooth that involves the dentine and occasionally extends into the pulp. The term "cracked tooth syndrome" (CTS) was first introduced by Cameron in 1964.[1]

The diagnosis of CTS is often problematic and has been known to challenge even the most experienced dental operators, accountable largely by the fact that the associated symptoms tend to be very variable and at times bizarre.[2] The aim of this article is to provide an overview of the diagnosis of CTS.

Diagnosis

Diagnosing CTS has been a challenge to dental practitioners and is a source of frustration for both the dentist and the patient. Identification can be difficult because the discomfort or pain can mimic that arising from other pathologies, such as sinusitis, temperomandibular joint disorders, headaches, ear pain, or atypical orofacial pain. Thus, diagnosis can be time consuming and represents a clinical challenge.[3] Early diagnosis is paramount as restorative intervention can limit propagation of the fracture, subsequent microleakage, and involvement of the pulpal or periodontal tissues, or catastrophic failure of the cusp.[4]

The ease of diagnosis varies according to the position and extent of the fracture. Mandibular second molars, followed by mandibular first molars and maxillary premolars are the most commonly affected teeth. The tooth often has an extensive intracoronal restoration. The pain may sometimes occur following dental treatments, such as cementation of an inlay, which may be erroneously diagnosed as interferences or high spots on the new restoration. Recurrent debonding of cemented intracoronal restorations such as inlays may indicate the presence of underlying cracks.

Dental History

When eliciting the history from the patient, certain distinct clues can be obtained.[5] There may be a history of a course of extensive dental treatment involving repeated occlusal

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Article 5:

The management of cracked tooth syndrome in dental practice

S. Banerji,[1] S. B. Mehta*[2] and B. J. Millar[3]

In brief

Explains the features of cracked tooth.	Describes diagnostic techniques and outlines treatment options.	Introduces a novel diagnostic and immediate management technique.

Cracked tooth syndrome is a commonly encountered condition in dental practice which frequently causes diagnostic and management challenges. This paper provides an overview of the diagnosis of this condition and goes on to discuss current short and long-term management strategies applicable to dental practitioners. This paper also covers the diagnosis and management of this common condition and aims to inform clinicians of the current thinking, as well as to provide an overview of the techniques commonly used in managing cracked tooth syndrome.

Introduction

Cracks in teeth are exceedingly common. Some may be become problematic and can lead to symptoms, cracked tooth syndrome and tooth loss.

A 'crack' may be defined as a 'line on the surface of something along which it has split without breaking apart', while a 'fracture' may be considered to be 'the cracking or breaking of a hard object or material' (www.oxforddictionaries.com).[1] Cracks on teeth may range from innocuous craze lines limited to the enamel layer, to a split tooth to one that may display the presence of a vertical root fracture. The term 'incomplete fracture' is used to describe a fracture plane of unknown depth and direction passing through tooth structure that may, if not already doing so, progress to communicate with the pulp or periodontal ligament'.[2] Where the fracture plane may progress to the external surface of the tooth (either the clinical crown or root) or to the pulp chamber (culminating in apical periodontitis), a diagnosis of a *complete fracture* may apply. Complete and incomplete fractures may be subdivided into those that take a vertical or oblique direction.[3]

Incomplete fractures of posterior teeth are commonly (but not always) associated with the condition of cracked tooth syndrome, frequently abbreviated to CTS. Patients presenting with CTS often complain of symptoms of sharp pain on biting and thermal sensitivity particularly during the consumption of cold foods and beverages.[4] The intensity of the perceived pain on biting is often proportional to the magnitude of the applied force.[5] Additional symptoms that are less frequently reported include: the perception of pain on release particularly when fibrous foods are eaten, (a phenomenon termed 'rebound pain'), pain elicited by the act of tooth clenching or grinding or by consuming sugary substrates and less commonly by heat stimuli. Sometimes, patients suffering from CTS are also able to accurately locate the affected tooth. The precise cause of the symptoms associated with CTS is unknown.[6,7]

The aim of this article is to provide an overview of the condition of CTS as well as to appraise traditional management strategies including the description of a recently described technique to assist with the diagnosis, immediate management and subsequent treatment of CTS.

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CTS

Epidemiology and aetiology

Cracked tooth syndrome appears to typically affect adult patients that are past their third decade, often affecting teeth that have previously received restorative intervention, although not exclusively.[8] A possible reason includes older teeth having more restorations and may thus experience increased lateral occlusal load due to the possible loss of anterior guidance over time.

Mandibular molar teeth seem to be most commonly involved, followed by maxillary premolars, maxillary molars and mandibular premolars. In a recent clinical audit, mandibular first molar teeth were most commonly affected by CTS possibly due to the wedging effect of the opposing prominent maxillary mesio-palatal cusp onto the mandibular molar central fissure.[9]

The aetiology of CTS is multifactorial. Causative factors include: previous restorative procedures, occlusal factors, developmental conditions/anatomical considerations, trauma and miscellaneous factors (such as an ageing

Article 6:

6

Cracked tooth syndrome

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ABSTRAK

Cracked tooth syndrome sering ditemukan dalam praktek sehari-hari. Tingkat kejadian gigi yang mengalami retakan cenderung meningkat. Hal ini terjadi karena usia manusia yang bertambah panjang dan gigi dapat bertahan lebih lama. Sebagai akibatnya, manusia memiliki gigi dengan perawatan saluran akar dan restorasi yang lebih kompleks, sehingga gigi lebih rentan terhadap retakan. Disamping itu, hidup yang penuh tekanan dapat memicu kebiasaan tanpa sadar seperti *clenching* dan bruksisma yang dapat merangsang retakan gigi. Akan tetapi, banyak gigi retak yang dapat diselamatkan bila tanda dan gejala khas dari sindroma retakan gigi dapat diketahui lebih awal.

Kata kunci: *cracked tooth syndrome*, diagnosis, penanganan

ABSTRACT

Cracked tooth syndrome is usually found in daily dental practice. The incidence of cracks teeth tends to increasing. People are living longer and keeping their teeth longer. As a consequence, people have more complex restoration and endodontic treatment, leaving teeth more prone to cracks. In addition, stressful lives may provoke unconscious habits such as clenching and bruxism which can induce cracks in teeth. However, many cracks teeth can be saved nowadays when the characteristic signs and symptoms of cracked tooth syndrome can be diagnosed earlier in its development.

Key word: *cracked tooth syndrome, diagnose, management*

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INTRODUCTION

Cracked tooth syndrome is defined as an incomplete fracture of the dentine in a vital posterior tooth that may involve the dental pulp.[1]

Cameron in 1964 (cited from Ehrmann & Tyas, and Mittal et al) was the first to describe the term 'cracked tooth syndrome' although the similar condition has been mentioned earlier by Gibbs which used the term 'cuspal fracture odontalgia.' Other terms such as 'hairline fracture', incomplete crown root fracture, split root syndrome, enamel infraction, crown craze, craze lines, and tooth structure cracks have been reported.[1,2]

The symptoms will depend on the location and depth of the cracks, and the time between commencement of symptoms and diagnosis.

The most common cause of cracked tooth syndrome are masticatory or accidental trauma, unintentional biting with physiologic masticatory force or a small and very hard object may suddenly generate an excessive load that may

Article 7:

Diagnosis and Management of Maxillary Left Second Molar with Cracked Tooth Syndrome: A Case Report

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Abstract

Cracked tooth syndrome is known as a major diagnostic challenge in clinical practice. Successful diagnosis and management of this condition requires an awareness of its existence and appropriate diagnostic tests. The aim of this article is to report a clinical case of a cracked tooth syndrome appeared in maxillary left second molar and emphasize on its diagnosis and management. A 45-year-old female patient reported with pain on her maxillary left second molar for the past two months, which increased when biting or chewing. The tooth was tender on palpation and fistula was seen on the gingival region. Radiograph examination revealed a radiolucent area on the apical region. A fracture line running mesio-distally on the occlusal surface was visible using a staining technique. The tooth was diagnosed with chronic periapical abscess et causa necrotic pulp. An orthodontic band was cemented onto this tooth prior to root canal treatment and full-crown was cemented as post-endodontic restoration. The absence of pathological sign and symptoms, and healing of the periapical lesion which can be seen in radiograph examination after 1 month follow-up showing a successful treatment of this case.

Case report (J Int Dent Med Res 2017; 10: (1), pp. 169-175)

Keywords: Cracked tooth, molar, diagnosis, management.

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Introduction

The term cracked tooth syndrome was initially introduced by Cameron in 1964. It defined as an incomplete fracture of a vital posterior tooth that involves the dentin and occasionally extends into the pulp.[1] The American Association of Endodontics identified and classified five types of cracks in teeth, from least to most severe: craze lines; fractured cusp; cracked tooth; split tooth; vertical root fractured.[2]

Cracked tooth itself was defined as a condition of an incomplete longitudinal fracture which usually directed mesiodistally and may extend through either or both of the marginal ridges and through the proximal surface of the tooth. The fracture line may be located in the crown only or may extend for varying distance to the proximal root.[2] The condition Cracked tooth may be caused by excessive forces from occlusion or mastication, either because of large forces that being applied on the tooth or normal forces on a weakened tooth caused by complex restoration or endodontic treatments.[3]

Cracked tooth is most commonly occurred in patients over 40 years old, affected women more than men, although there are studies that revealed an almost equal distribution between gender group.[1,4] Most of the studies agreed that cracked teeth were most prevalent in mandibular molars, followed by maxillary premolars and maxillary molar teeth – while mandibular premolar teeth was reported to be the least affected.[1,4,5] Another study by Roh and Lee reported that cracked teeth were found most frequently in the maxillary molars (33.8% in first molar, 23.4% in second molar) than in the mandibular molars (20.1% in first molar, 16.2% in second molar).[4] The prevalence of cracked tooth which running mesiodistally was 81.1%.[5] Cracked tooth was also commonly associated with intracoronal restoration, though it also may occur in healthy and sound tooth.[3]

The diagnosis of cracked tooth can be challenging for dentist in clinical practice.[6] The

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Article 8:

Educational Forum

Cracked tooth syndrome: Overview of literature

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Abstract

Pain is defined as an "unpleasant sensory and emotional feeling which is associated with actual or potential injury of tissue or expressed in terms of such injury." Tooth pain usually refers to pain around the teeth or jaws mainly as a result of a dental condition. Mostly, toothaches are caused by a carious cavity, a broken tooth, an exposed tooth root or gum disease. The toothache may sometimes be the result of radiating pain from structures in the vicinity of tooth and jaws (cardiac pain, ear, nose, throat pain, and sinusitis). Therefore, evaluation by both dentists and physicians are sometimes necessary to diagnose medical illnesses causing "toothache." Cracked tooth syndrome is a major diagnostic challenge in clinical practice. Accurate diagnosis and appropriate treatment are complicated due to lack of awareness of this condition and its bizarre clinical features. Early diagnosis has been linked with successful restorative management and good prognosis. This article provides a detailed literature on the causes, classification, signs and symptoms, diagnosis, and treatment planning of cracked tooth syndrome.

Key words: Cracked tooth syndrome, diagnosis, tooth pain

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Introduction

Cracked tooth syndrome may be defined as a fracture plane of unknown depth, which originate from the crown, passes through the tooth structure and extends subgingivally, and may progress to connect with the pulp space and/or periodontal ligament.[1,2]

Gibbs in 1954, was the first to describe the clinical symptoms of incomplete fracture of posterior teeth involving the cusp and termed it as "cuspal fracture odontalgia."[3] Cases of incomplete fracture with subsequent pulpitis were reported by Ritchey *et al.* in 1957.[4] Cameron in 1964 coined the term "cracked tooth syndrome." Here, the signs and symptoms were not apparent, and the teeth showed painful response to cold or pressure applications and became necrotic, however, the pulp and periodontium were apparently healthy.[5]

Ellis defined, incomplete tooth fracture as a "fracture plane of unknown depth and direction passing through tooth structure, and may advance to connect with the pulp and/or periodontal ligament."[6,7]

In the late 1970s, Maxwell and Braly advocated the use of the term incomplete tooth fracture.[8] According to Luebke, fractures are either complete or incomplete, although, other terms such as split-root syndrome, hairline fracture, hairline tooth fracture, enamel infraction, crown craze, craze lines, and tooth structure cracks are also known.[9]

Classification

Several classifications have been proposed based on: (a) The type or site of the crack, (b) the direction and degree of the crack, (c) the risk of symptoms, (d) pathological processes.

The American Association of Endodontists,[10] in a document titled "cracking the cracked tooth code" identified five types of cracked teeth [Table 1].

Craze lines are visible fractures and contained within the enamel. In posterior teeth, craze lines are usually seen to

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Article 9:

Cracked Teeth: A Review of the Literature

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THOMAS J. HILTON, DMD, MS†
JACK FERRACANE, PhD‡
ON BEHALF OF NORTHWEST PRECEDENT

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.

(*J Esthet Restor Dent* 22:158–167, 2010)

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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Article 10:

GENERAL DENTISTRY

Biting pain reproduced by the Tooth Slooth: an aid for early diagnosis of cracked tooth

Yaping Yang, PhD*/Gongpei Chen, BSc*/Fang Hua, PhD/Qing Yu, PhD/Weidong Yang, PhD

Objective: The purpose of this study was to find a reliable method to reproduce biting pain to facilitate an early diagnosis of cracked tooth and to verify the feasibility of the Tooth Slooth in diagnosing a cracked tooth. **Method and materials:** In this study, 46 intact teeth diagnosed as cracked teeth were selected. Patients were asked to bite wet cotton rolls and the Tooth Slooth, and clinical findings were recorded. The difference in the relevance ratio between these two bite test methods was determined. **Results:** The relevance ratio of biting pain by the Tooth Slooth and wet cotton rolls was 91.3% and 32.6%, respectively. There was a statistically significant difference between these two bite tests ($P < .001$). **Conclusions:** Within the limitations of this study, the relevance ratio of biting pain by the Tooth Slooth was significantly higher than that of the wet cotton rolls. The Tooth Slooth was a reliable method to reproduce biting pain and was useful for early diagnosis of cracked teeth. *(Quintessence Int 2019;50:82–87; doi: 10.3290/j.qi.a41498)*

Key words: bite test, cracked tooth, early diagnosis, Tooth Slooth

Cracked tooth syndrome is one of the most common problems that patients suffer, and has become the third major factor in posterior tooth loss in adults.[1] In 1964, up to 80% of cracked teeth were reported to occur in patients over 40 years of age,[2] whereas the age of patients with cracked tooth syndrome tends to be much younger.[3]

The clinical symptoms and signs include pain to biting, pain to cold, and spontaneous pain, and can present alone or in combination and vary greatly from tooth to tooth and from patient to patient.[4-6] The diagnosis of cracked tooth syndrome can be challenging because of its variable and unpredictable symptoms. Some cracked teeth can be missed or misdiagnosed when they present an obscure craze line or in the absence of pain history, resulting in progression of the cracks as time passes, which may finally lead to a split tooth or even tooth extraction. On the other hand, some dental conditions may present similar symptoms and can be misdiagnosed as cracked tooth syndrome, thus complicating the diagnosis and possibly leading to an inappropriate treatment plan. Accurate early diagnosis is important because it is associated with early management and a better prognosis.[1,7]

It has been acknowledged that symptoms vary according to the depth and orientation of the crack, but there are common trends throughout the process.[7,8] Generally, as the crack first occurs and then slowly progresses deep into the pulp, a patient with cracked tooth may experience a similar progression of symptoms: first, pain to biting, especially on hard or tough food, followed by sensitivity to cold and then spontaneous pain. If not well controlled, swelling of the gingiva or tooth splitting may occur at the late stage[9]. It is generally accepted that early management of a cracked tooth at the stage when biting pain occurs is appropriate because at a later stage, the dental pulp could become involved; at that point, root canal treatment must be performed, resulting in a pulpless tooth.[10,11]

An accurate early diagnosis plays a decisive role of the prognosis of a cracked tooth. In general, the diagnosis of cracked tooth mainly depends on the patients' complaint, medical history, and clinical examination. When the cracks are relatively clear, the diagnosis is straightforward. However, in many cases when the cracks are obscure and the symptoms are atypical, the diagnosis becomes difficult. More clinical examinations are

Article 11:

IEJ Iranian Endodontic Journal

Optimization of Results for Cracked Teeth Using CAD-CAM System: A Case Series

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ABSTRACT

Different restorative techniques have been proposed for the treatment of posterior teeth affected by cracked tooth syndrome (CTS). However, the literature is scarce in protocols of how to solve CTS using ceramic restorations made by computer aided design–computer aided manufacturing (CAD-CAM) system. CAD-CAM provides a fast and efficient restorative treatment usually in a single visit, reducing the risk of contamination and micro-infiltration of the cracked line. The objective of this work was to describe 3 clinical cases of cracked teeth, which presented vertical fracture lines in different directions and extension through the pulp, restored by CAD-CAM system, with 5-year follow-up. Patients with short-term spontaneous masticatory pain, cold sensibility and restored teeth without cuspal coverage were selected. Digital radiographs (DR) were taken to confirm the pulp and periapical status. Periodontal probing depth, sensitivity, percussion, and occlusion tests were performed. The fracture lines with their direction and extension were identified under dental optical microscope (DOM). The treatment plan was performed in two stages: immediate treatment to stabilize the tooth and minimize pain, and final restorative treatment by CAD-CAM system to stabilize the crack. Patients were between the ages of 37 and 45 years. Most of the studied teeth presented extensive restorations without cuspal coverage. The presence of occlusal interference, in lateral movement, was a constant finding. Endodontic treatment was performed in cases of irreversible pulpitis or pulpal necrosis. In all three cases, cavity preparation was performed for full coverage restorations, as the fracture lines extended in several directions, requiring a re-enforcement of the cervical region of the teeth in question. The survival rate of the reported cases was 100% with 5-year clinical and radiographic follow-up, suggesting that CAD-CAM system may be a promising alternative treatment in the management of CTS, improving tooth longevity.

Keywords: CAD-CAM; Cracked Teeth; Cracked Tooth Syndrome; Incomplete Fracture; Prognosis

Introduction

According to the classification of cracks described by the American Association of Endodontists, there are 5 types of cracks: graze lines, fractured cusp, cracked tooth, split tooth and vertical root fracture [1].

Cracked tooth syndrome (CTS) also known as incomplete fracture is defined as a flat fracture that breaks the continuity of the enamel and dentine usually mesiodistally but where the segments do not completely separate, being held together by a portion of the structure. This fracture as it represents unknown depth and direction can extend to the pulp. CTS correspond to an intermediate stage of fracture, which if not diagnosed early, may progress to a complete fracture [2, 3]. All reviews state that the main signs and symptoms for CTS are chewing pain, sensitivity to cold and sweet food [3-6]. These symptoms may vary according to the position and extent of each cracked line. Some patients can precisely specify the tooth from which the symptoms may be arising, while others cannot [3-6]. The etiology of CTS is multifactorial, being described as "excessive

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Review Article

Evaluation of dental caries, tooth crack, and age-related changes in tooth structure using optical coherence tomography

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ABSTRACT

Optical coherence tomography (OCT) is an imaging technique that can visualize the internal biological structure without X-ray exposure. Swept-source OCT (SS-OCT) is one of the latest version of OCT, wherein the light source is a tunable laser that sweeps near-infrared wavelength light to achieve real-time imaging. The imaging depth of OCT is highly influenced by the translucency of the medium. The medium that does not transmit light and the deeper structure beyond the range of light penetration depth are not relevant for OCT imaging. In OCT, sound enamel is almost transparent at the OCT wavelength range, and enamel and dentin can be distinguished from each other as the dentin–enamel junction (DEJ) appears as a dark border. Demineralized enamel and dentin are imaged as bright zones because of the formation of numerous micro-porosities where the backscatter of OCT signal is increased. In cavitated caries at interproximal or occlusal hidden zone, the upper margin of the cavity reflects the signal showing a distinct bright border in the SS-OCT image. SS-OCT is capable of determining crack penetration depth even when the cracks extended beyond the DEJ. SS-OCT has a high degree of sensitivity and specificity for the detection of dental caries and tooth cracks. SS-OCT is also capable of detecting non-carious cervical lesions and occlusal tooth wear in cross-sectional views to estimate the amount of tooth structure loss.

1. Introduction

Optical coherence tomography (OCT) is an interferometric technique that can create cross-sectional images of biological structures without X-ray exposure [1]. The imaging mechanism is analogous to ultrasonography [2]. Ultrasonography uses sound to measure the echo and time delay from the deep structures to generate the images, while OCT uses light and measures the backscattered signals from the deep structures [2]. Since the velocity of light is too high to measure the time delay, OCT employs an interferometer to measure the pathway difference of the light and construct the depth profile [1,2]. To create fringe responses of the light, OCT uses coherent light of near-infrared wavelength, where light has its maximum depth of penetration in the biological structures (near-infrared window) [2]. The first *in vitro* and *in vivo* images of dental hard and soft tissue with OCT were acquired by Colston et al. [3].

OCT is a non-invasive imaging method that uses light and eliminates the risk of radiation exposure. Thus, OCT is a safe diagnostic method for dental diseases and can be used in pregnant woman and young children. The early OCT systems were based on time-domain (TD) detection in which echo time delays of light were identified by measuring the interference signal as a function of time, while scanning the optical path length of the reference arm [2]. Advances in OCT technology have enabled dramatic increases in image resolution and speed of imaging. Fourier-domain (FD) techniques provide distinct increase in sensitivity as compared to the traditional TD-OCT [2,4]. Swept-source (SS-)OCT is one of the implements of FD-OCT and employs an interferometer with a narrow-linewidth, frequency-sweep laser, and detectors to measure interference versus time (Fig. 1) [2,5]. Recent SS-OCT systems offer cross-sectional images of the internal biological structures in real time with microscopic level resolution (Fig. 2).

The imaging depth of OCT is highly influenced by the translucency of the medium [2]. OCT imaging is favorable for an object

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Three-Dimensional Analysis of Enamel Crack Behavior Using Optical Coherence Tomography

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Abstract

The aim of this study was to nondestructively analyze enamel crack behavior on different areas of teeth using 3D swept source-optical coherence tomography (SS-OCT). Ten freshly extracted human teeth of each type on each arch (n = 80 teeth) were inspected for enamel crack patterns on functional, contact and nonfunctional, or noncontact areas using 3D SS-OCT. The predominant crack pattern for each location on each specimen was noted and analyzed. The OCT observations were validated by direct observations of sectioned specimens under confocal laser scanning microscopy (CLSM). Cracks appeared as bright lines with SS-OCT, with 3 crack patterns identified: Type I – superficial horizontal cracks; Type II – vertically (occluso-gingival) oriented cracks; and Type III – hybrid or complicated cracks, a combination of a Type I and Type III cracks, which may or may not be confluent with each other. Type II cracks were predominant on noncontacting surfaces of incisors and canines and nonfunctional cusps of posterior teeth. Type I and III cracks were predominant on the contacting surfaces of incisors, cusps of canines, and functional cusps of posterior teeth. Cracks originating from the dental-enamel junction and enamel tufts, crack deflections, and the initiation of new cracks within the enamel (internal cracks) were observed as bright areas. CLSM observations corroborated the SS-OCT findings. We found that crack pattern, tooth type, and the location of the crack on the tooth exhibited a strong correlation. We show that the use of 3D SS-OCT permits for the nondestructive 3D imaging and analysis of enamel crack behavior in whole human teeth in vitro. 3D SS-OCT possesses potential for use in clinical studies for the analysis of enamel crack behavior.

Keywords: imaging, lasers, oral diagnosis, monitoring, tooth location, fracture

Introduction

Enamel is the hardest substance in the human body. Despite its high hardness values (3 to 6 GPa), enamel has a very low elastic modulus (70 to 110 GPa), almost like glass (Cuy et al. 2002). These characteristics make enamel brittle and prone to cracking, which may sometimes lead to fracture.

Enamel, as the outermost covering of the tooth, is a contact tissue where most fractures start (Lucas and van Casteren 2015). In recent years, the micro-mechanical properties of enamel and its crack growth behavior have been the subject of much research. Previous studies classify fracture modes in enamel and brittle materials as conventional outer cone cracks, which form outside the maximum contact; inner cone cracks, which form immediately under the contact; and median radial cracking or far-field, flexure-induced cracks (Zhang et al. 2005; Lawn et al. 2009). A thorough understanding of the microstructure and micromechanical properties of enamel and its crack growth behavior under loading can have several applications: (1) As a basis for the development of synthetic enamel replacements (biomaterials and biomimicry) (Chai et al. 2009; Lucas et al. 2009); (2) As evidence of the force that produced the crack (Constantino et al. 2010); and (3) As a way to monitor, prognose, and prevent further damage to teeth. Indeed, through early intervention, most coronal cracks can be managed successfully and conservatively with direct restorative materials (Bader et al. 2004).

Studies on enamel crack behavior consistently show the remarkable resilience of enamel under loading, and cite its complex microstructure as the primary reason for its "damage-tolerant" behavior (Bajaj et al. 2008; Chai et al. 2009; Yahyazadehfar et al. 2013). However, these studies induced loading on the extracted teeth, and such artificially produced cracks might not have been representative of those that occur

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Article 14:

Basic Research—Technology

Detection and Analysis of Enamel Cracks by Quantitative Light-induced Fluorescence Technology

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Abstract

Introduction: The ability to accurately detect tooth cracks and quantify their depth would allow the prediction of crack progression and treatment success. The aim of this *in vitro* study was to determine the capabilities of quantitative light-induced fluorescence (QLF) technology in the detection of enamel cracks. **Methods:** Ninety-six extracted human teeth were selected for examining naturally existing or suspected cracked teeth surfaces using a photocuring unit. QLF performed with a digital camera (QLF-D) images were used to assess the ability to detect enamel cracks based on the maximum fluorescence loss value (ΔF_{max}, %), which was then analyzed using the QLF-D software. A histologic evaluation was then performed in which the samples were sectioned and observed with the aid of a polarized light microscope. The relationship between ΔF_{max} and the histology findings was assessed based on the Spearman rank correlation. The sensitivity and specificity were calculated to evaluate the validity of using QLF-D to analyze enamel inner-half cracks and cracks extending to the dentin-enamel junction. **Results:** There was a strong correlation between the results of histologic evaluations of enamel cracks and the ΔF_{max} value, with a correlation coefficient of 0.84. The diagnostic accuracy of QLF-D had a sensitivity of 0.87 and a specificity of 0.98 for enamel inner-half cracks and a sensitivity of 0.90 and a specificity of 1.0 for cracks extending to the dentin-enamel junction. **Conclusions:** These results indicate that QLF technology would be a useful clinical tool for diagnosing enamel cracks, especially given that this is a nondestructive method. *(J Endod 2016;42:500–504)*

Key Words

Diagnosis, enamel crack, quantitative light-induced fluorescence

People need to maintain their teeth in good condition for a longer period of time because of the increasing average life span. This situation has resulted in an increased occurrence of cracked teeth (1), usually in adults (2). The frequency of cracks in natural teeth is reportedly 4%–5% in every 100 adults, with molars constituting over 75% of cases and premolars constituting the rest (3). Most studies have found that cracks mainly occur in restored teeth, with unrestored teeth constituting 35% of cracked teeth (4). According to these reports, the frequency of diagnosing tooth cracks is increasing, and the location of occurrence also seems to be diversifying, which indicates the importance of acquiring a greater understanding of tooth cracks.

According to the American Association of Endodontists, longitudinal tooth fractures are divided into 5 types: craze line, fractured cusp, cracked tooth, split tooth, and vertical root fracture (1). An asymptomatic crack in the tooth enamel may progress along with dentin cracks (5, 6). The causative factors of a tooth crack vary. Masticatory function is the most common factor related to vertical tooth fracture (7). Diagnosing a tooth crack is very difficult, and it can also be difficult to determine the appropriate treatment because of the difficulty of visualizing such cracks and the symptoms varying depending on the direction and rate of progression of the cracks (8, 9).

The main symptoms of tooth crack are momentary pain associated with sensitivity to cold, hot, sweet, and/or bitter foods (7, 10). However, crack lines at an early stage may not be visible or even dyeable and also may not cause any reaction to cold and hot stimuli (11, 12). In addition, the successful restoration and prognosis are important to ensuring that patients do not continue to experience discomfort after treatment (13). Prompted by the previously mentioned observations, we are developing an early detection technology that can objectively and accurately diagnose the direction and depth of tooth cracks.

Several different methods have been used for diagnosing tooth cracks, such as methylene blue dye, microscopic examination, transillumination, the bite test, radiography, removal of tooth fillings, cone-beam computed tomographic (CBCT) imaging, and optical coherence tomographic imaging (2, 14–18). The transillumination method can reveal whether or not cracks exist but has difficulties in determining the depth of cracks. Difficulties are also associated with the use of dyes such as methylene blue dye depending on the direction and position of cracks.

CBCT imaging can be more useful for detecting vertical fractures and cracks than periapical dental radiography. However, the risk of radiation from CBCT imaging remains a problem (19). Swept-source optical coherence tomographic (SS-OCT) imaging based on irradiation at near-infrared wavelengths can be used to detect vertical root fracture (20). Strong correlations were found between the depth of enamel cracks as evident in cross-sectional SS-OCT images and the results of histologic evaluations (16).

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Using Meglumine Diatrizoate to improve the accuracy of diagnosis of cracked teeth on Cone-beam CT images

M. Yuan[1], A. T. Gao[1], T. M. Wang[1], J. H. Liang[1], G. B. Aihemati[1], Y. Cao[1], X. Xie[2], L. Y. Miao[3] & Z. T. Lin[1]

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Abstract

Yuan M, Gao AT, Wang TM, Liang JH, Aihemati GB, Cao Y, Xie X, Miao LY, Lin ZT. Using Meglumine Diatrizoate to improve the accuracy of diagnosis of cracked teeth on Cone-beam CT images. *International Endodontic Journal*, **53**, 709–714, 2020.

Aim To explore in a laboratory setting the feasibility of using Meglumine Diatrizoate (MD) to improve the accuracy of diagnosis of cracked teeth on cone-beam CT (CBCT) images.

Methodology Twenty-four teeth were cracked artificially by soaking them cyclically in liquid nitrogen and hot water. The number and position of crack lines were evaluated with a dental operating microscope and used as the gold standard. The artificially cracked teeth were then examined using routine scanning (RS) and enhanced scanning (ES) modes, respectively. For the ES mode, MD was painted on the surface of the crack lines, and then, CBCT scanning with the same parameters was performed after 10 min. A radiological graduate student and an experienced radiologist evaluated the presence or absence of crack lines, respectively. The differences between the RS and ES modes were determined and assessed using McNemar's test. Inter-examiner agreement and intra-examiner agreement were assessed using kappa analysis.

Results Fifty-seven crack lines were found in the 24 cracked teeth. In the RS mode, the accuracy of detection of crack lines was 23% (radiological graduate student) and 32% (experienced radiologist), whereas in the ES mode, the accuracy was 61% (radiological graduate student) and 65% (experienced radiologist). The inter-examiner agreement was 0.693 in RS mode and 0.849 in ES mode. The intra-examiner agreement was 0.872 and 0.949 for the radiological graduate student in RS and ES mode respectively; and one for the experienced radiologist both in RS and ES mode.

Conclusions Compared with routine scanning mode, more crack lines could be detected in enhanced scanning mode using Meglumine Diatrizoate as a contrast medium. MD could be a potential contrast medium to improve the accuracy of detection of crack lines on CBCT images.

Keywords: cone-beam CT, cracked tooth, diagnosis, meglumine diatrizoate.

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Introduction

Cracks in teeth may occur in both horizontal and vertical directions involving the crown and/or root (Kahler 2008). Many authors have proposed various terminologies, definitions and classifications for cracks in teeth and have reported different characteristics of this condition (Seo *et al.* 2012). The American

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ORIGINAL RESEARCH

Laser-assisted diagnosis of symptomatic cracks in teeth with cracked tooth: A 4-year in-vivo follow-up study

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Keywords
cracked tooth, diode laser, endodontics, laser diagnosis, vitality test.

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Abstract

The purpose of this study was to determine whether a near-infrared diode laser could be used as an adjunct to help identify and localise symptomatic cracks in patients with cracked tooth. An 810-nm diode laser at 1 W continuous wave energy with a 200 micro-fibre tip was used to scan the offending tooth. Crack identified during the laser scan was removed, restored and reviewed after four weeks and after 4 years. The laser was able to significantly ($P = 0.0001$) identify suspected cracked teeth from non-cracked control teeth. Of the twelve patients examined, ten participants experienced discomfort as the laser passed over a crack line. At 4-week and 4-year recall, a majority of the ten treated patients responded positively to the management of crack. This study showed that diode laser could be an adjunctive tool for early detection and management of symptomatic cracks with the possibility of improving long-term survival.

Introduction

Cracked tooth can be a difficult disorder to diagnose and manage (1,2). In an ageing population where people are retaining teeth for many decades, the prevalence of cracked tooth is likely to increase (3).

Failure to diagnose the condition early could result in eventual crack progression, pulpal necrosis and potential tooth loss (4). Tooth splits or fractures are the third most common reason for tooth loss in developed countries (5). With time, the prognosis of the tooth worsens and the cost of treatment increases (6). Early diagnosis may result in treatment with a simple restoration. However, if it progresses to communicate with the pulp, root canal treatment and cuspal coverage restoration are often necessary (7,8).

Currently, diagnosis of cracked tooth is largely dependent on the patients' signs and symptoms (e.g. thermal sensitivity and pain on bite and release) (7,9). However, these symptoms can mimic an array of other pathologies. The 'bite test', an important diagnostic tool for assessment of teeth with cracked tooth, can potentially propagate the crack further (10,11). Trans-illumination, an adjunct diagnostic technique used in diagnosis of cracked tooth, is reliant on the correct interpretation of visible crack lines (1). Fracture lines diffract the light in such a way that the fractured segments are illuminated differentially; however, subtle changes in contrast of the trans-illuminated crack line can make interpretation difficult; craze lines can be incorrectly visualised as structural cracks (1). Furthermore, it may be very difficult to determine the location and direction of the crack/s responsible for patient symptoms (1,9).

The purpose of this study was to determine whether a near-infrared 810-nm diode laser could be used as novel and adjunct method to help identify and localise symptomatic cracks in patients with cracked tooth.

Materials and method

The Griffith University Expedited Ethical Review committee approved this study (Protocol Number DOH/03/13/HREC). Patients who attended Griffith University Undergraduate Dental Clinic, identified with symptoms of cracked tooth, were invited to participate in the study. All patient referrals had to meet the inclusion and exclusion criteria. As the risk of laser is uncertain in pregnant and breastfeeding patients, this group of patients was excluded. Also, patients with dental caries, defective restorations, endodontic treatment on tooth in question,

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A multi-centred clinical audit to describe the efficacy of direct supra-coronal splinting – A minimally invasive approach to the management of cracked tooth syndrome

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ABSTRACT

Objectives: This audit looked at the use of direct composite splinting to manage cracked tooth syndrome (CTS).
Methods: Patients who had been assessed as having CTS were offered the treatment of a directly bonded, composite overlay restoration placed in supra-occlusion. Cases were reviewed up to 3 months later.
Results: In all, 151 restorations were followed up in the audit of which 131 were successful at 3 months. The remaining 20 restorations failed due to pulp complications (11), failure of the composite (5) or intolerance to the high restoration (4). Of the 131, patients described transient problems with chewing (94), composite breakage (13), TMD (1), phonetics (1), increased mobility (1) and tender to chewing (1).
Conclusions: This is a successful non-invasive method of managing CTS in the short term for patients willing to accept transient effects.

Clinical significance

The use of a minimally invasive directly bonded composite flat occlusal splint for the symptomatic management and concomitant protection of teeth diagnosed with cracked tooth syndrome was described previously. This audit assesses its efficacy amongst 151 cases. In all, 131 were successful and reported a reduction in symptoms before proceeding to further treatment.

1. Introduction

Incomplete fractures of posterior teeth are typically associated with the symptoms of sharp pain during biting and thermal hypersensitivity, usually to cold stimuli. The condition is usually referred to as 'cracked tooth syndrome' (CTS).[1] The aetiology of CTS is often multi-factorial.[2]

The presenting symptoms of this condition can however display considerable variance, thereby sometimes leading to

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Article 18:

Cracked tooth syndrome. Part 2: restorative options for the management of cracked tooth syndrome

S. Banerji,[1] S. B. Mehta[2] and B. J. Millar[3]

PRACTICE

IN BRIEF

- Includes a consideration of means available to provide acute care for a patient suffering from cracked tooth syndrome.
- Provides a comprehensive review of the available literature of both direct and indirect restorations/restorative materials to manage an incompletely fractured posterior tooth.
- Introduces the concept of the direct coronal splint as a novel approach for the management of this distressing condition.

VERIFIABLE CPD PAPER

The second of this two part series on 'cracked tooth syndrome' will focus on the available methods for the immediate, intermediate and definitive management of patients affected by this condition. Included in this article is a comprehensive account of the relative merits/drawbacks of various restorative materials and their respective techniques of application for the treatment of symptomatic, incompletely fractured posterior teeth.

PRINCIPLES FOR THE MANAGEMENT OF CRACKED TOOTH SYNDROME

It is apparent from the first article of this series that the diagnosis of cracked tooth syndrome can pose a major challenge to the dental operator. It would also be fair to state that the management of the condition is by no means always a simple straightforward matter.

While it would appear that there is no universally accepted restorative protocol, it is generally agreed that the aim of restorative therapy is to immobilise the segments of the tooth that move on loading. The latter may be achieved in a limited number of cases simply by the removal of the affected cusp and restoring the defect with an appropriate material, or in the majority of cases by the placement of a restoration that prevents independent movement of the tooth segments on either side of the crack, thereby 'splinting' the tooth together.[1]

The process of splinting should minimise flexure of the compromised cusp, therefore not only aiming to alleviate the symptoms of pain on biting but also prevent further propagation of the crack and reduce the ingress of bacterial microorganisms into the dental pulp.[2]

Historically a plethora of different 'forms' of dental restorations have been advocated to 'splint teeth' affected by incomplete fractures. This paper will divide these into four broad categories. Hence:

- Immediate
- Direct restorations placed intracoronally without cuspal coverage
- Direct restorations, which provide cuspal coverage
- Indirect restorations placed intracoronally without any cuspal support and indirect restorations which provide cuspal coverage (onlays and full coverage restorations).

The aim of this article is to review the available literature on the above restorations when used to treat cases of cracked cusp syndrome, with emphasis placed on the efficacy, efficiency, economic viability and biological cost of each of the above.

IMMEDIATE THERAPY OF CTS

It is generally accepted that the more rapidly a tooth with a crack is treated, the easier it will be to avoid irreversible damage. Table 1 provides a list of the possible immediate treatment options. As an 'immediate' or remedial approach a number of authors have advocated the undertaking of occlusal adjustments upon affected teeth, to reduce the stress on the tooth, so as to not only prevent further crack propagation but also relieve the associated symptoms.[3]

Table 1 Immediate treatment options for CTS

Occlusal adjustment – destructive, short term	
Remove segment – highly destructive	
Immobilisation of segment:	
Copper ring	difficult and periodontally damaging
Orthodontic band	time consuming, possibly not available
Temporary crown	highly destructive, time consuming
Direct composite splint	quick, low cost, readily available and non-invasive

However, it has been argued that simply grinding the tooth out of occlusion is likely to be only of limited benefit as the tooth may still be critically stressed by a food bolus to such an extent that the process of flexure will still continue on loading.[4] Furthermore, occlusal adjustment may not only involve the removal of healthy sound tooth tissue, but when undertaken without analysing the effects on the residual dentition may also lead to unwanted occlusal interferences elsewhere in the dental arch.

Fox *et al.*[5] have recommended that following a positive diagnosis of a cracked tooth where a pre-existing restoration is present, it should be removed to assess the full extent of the fracture. Often during this process the affected cusp may 'splinter off' and the remaining defect managed accordingly.

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Cracked tooth diagnosis and treatment: An alternative paradigm

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Abstract

This article reviews the diagnosis and treatment of cracked teeth, and explores common clinical examples of cracked teeth, such as cusp fractures, fractures into tooth furcations, and root fractures. This article provides alternative definitions of terms such as cracked teeth, complete and incomplete fractures and crack lines, and explores the scientific rationale for dental terminology commonly used to describe cracked teeth, such as cracked tooth syndrome, structural versus nonstructural cracks, and vertical, horizontal, and oblique fractures. The article explains the advantages of high magnification loupes (×6–8 or greater), or the surgical operating microscope, combined with co-axial or head-mounted illumination, when observing teeth for microscopic crack lines or enamel craze lines. The article explores what biomechanical factors help to facilitate the development of cracks in teeth, and under what circumstances a full coverage crown may be indicated for preventing further propagation of a fracture plane. Articles on cracked tooth phenomena were located via a PubMed search using a variety of keywords, and via selective hand-searching of citations contained within located articles.

Keywords: Crack propagation, cracked tooth syndrome, microscopes, tooth fractures

INTRODUCTION

A cracked tooth is a tooth in which there exists a partial[1] or complete fracture of a stress plane that commonly occurs in that tooth. A tooth stress plane results from occlusal forces that are commonly imposed on that tooth that may cause, during a masticatory cycle, an instance of higher energy to occur within the stress plane. This instance of higher energy may result in fracture of some of the chemical bonds of the natural tooth structure that traverses the stress plane. With many masticatory cycles, a clinically significant fracture plane may develop on the stress plane. As the fracture plane expands, the rate of fracture of the stress plane theoretically accelerates, due to proportionately increased stress being put on the remaining nonfractured area of the stress plane. With enough fracture area expansion, occlusal forces may become capable of causing the tooth structure around the fractured area to flex, which may result in sensitivity, if the stress plane is contiguous with the periodontal ligament or the pulp chamber, or perhaps if such flexure causes fluid movement within odontogenic processes.[2] Eventually, the stress plane fractures

Article 20:

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ORIGINAL ARTICLE

Dental optical coherence tomography: new potential diagnostic system for cracked-tooth syndrome

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Abstract
Purpose The aim of the present study was to determine the reliability of optical coherence tomography (OCT) in detecting cracked teeth and its relative clinical effectiveness by comparing it with other diagnostic methods including conventional visual inspection, trans-illumination, and micro-computed tomography (micro-CT).
Methods The reliability of swept source OCT (SS-OCT) was verified by comparing the number of detected crack lines on 109 surfaces of 61 teeth with those detected with other conventional methods.
Results One to one comparison revealed that crack lines that were invisible with naked eyes could be found in SS-OCT images. The detection ability of SS-OCT was superior or similar to those of micro-CT (100.0 %) and trans-illumination.
Conclusions Crack lines shown in the SS-OCT images had distinct characteristics, and structural crack lines and craze lines could be distinguished in SS-OCT images. Thus, the detection ability of SS-OCT renders it an acceptable diagnostic device for cracked-tooth syndrome.

Keywords Optical coherence tomography (OCT) · Swept source OCT (SS-OCT) · Cracked-tooth syndrome · Trans-illumination · Micro-computed tomography (micro-CT)

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Introduction

Cracked-tooth syndrome is a common dental problem in which the patients experience an instantaneous, sharp, shooting pain when the affected tooth comes in contact with its corresponding tooth during mastication. The severity of this problem can range from minor, needing no treatment at all, to severe, resulting in the necessity for root-canal therapy or even extraction [14, 15, 17, 23]. Since cracks on involved teeth are usually tiny and invisible to the naked eye, effective diagnostic tools are necessary not only for patients but also for their dentists to determine the location and extent of the crack line.

Trans-illumination is known to aid in the detection of tooth cracks but this diagnostic instrument has its limitations because it detects all cracks ranging from craze lines to even complete vertical root fracture simply as structural cracks and cannot differentiate between them [12, 17]. Micro-computed tomography (micro-CT) is also helpful in this regard, since it provides data regarding the internal structure of a tooth crack due to relative differences in x-ray attenuation; however, the resolution of micro-CT is limited to 40 μm and the image contrast is too low to detect particularly small cracks [10]. Thus, the current diagnostic recommendation for cracked-tooth syndrome is clinical observation of the patient's symptom after tooth preparation and provisional crown setting over 2–3 weeks [15].

Considering the mechanical and physiological functions of enamel and dentin, tooth preparation as an irreversible intervention should be implemented minimally. As a major prosthodontic principle, tooth preparation should provide sufficient space for a crown prosthesis that will support occlusal force, but also retain the sound portion of the tooth. However, insufficient partial preparation of the cracked area can lead to further progress of cracking via a

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CASE REPORT

Clinical Case Reports WILEY

Management of cracked tooth using simvastatin as intracanal medicament

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Abstract

Cracked tooth syndrome is presented as pain associated with biting and sensitivity. Intracanal medication with simvastatin stimulates hard tissue formation at crack line, and the tooth was functioning on the follow-ups.

KEYWORDS

cracked tooth, intracanal medicament, simvastatin

1 | INTRODUCTION

Cracked tooth syndrome is a common well-documented condition that may occur due to morphologic, physical, and iatrogenic factors. Epidemiologic data revealed that splits or fractures are the third most common cause of tooth loss, indicating a high clinical significance of this syndrome.[1]

Diagnosis of cracked tooth is challenging, and the treatment has been controversial. Stainless steel bands were often used as a diagnostic tool and a temporary before a full coverage restoration.[1] Root canal treatment (RCT), followed by a crown, is recommended if the pulp becomes irreversibly inflamed.[2] One study reported successful treatment with a bonded composite restoration after 6 months, with no differences between restorations with or without cusp coverage.[3] The prognosis of the relevant tooth depends on the extent of the crack and whether the crack has extended through enamel, dentin, pulp, and/or the pulp chamber floor. Cracks that extended to the pulpal floor or beyond alveolar bone have been deemed hopeless.[2]

Simvastatin is a drug used primarily to treat hyperlipidaemia and protect against cardiovascular diseases. It has been shown to possess pleiotropic effects such as antimicrobial, anti-inflammatory, immunomodulatory, antioxidant, and bone-forming properties. Statins also exert an effect on dentin and pulp regeneration.[4] A recent systematic reviews and meta-analysis studies[5,6] indicated that adjunctive use of locally delivered statins to mechanical periodontal treatment is beneficial to increasing bone fill percentage and improved intrabony defects.

Data involving management of a cracked teeth are rare in the literature, which makes clinical decisions more difficult, and additional information regarding cracked teeth would provide a better perspective on the clinical management and outcome of these teeth. In this case report, we introduce a description for the treatment of a cracked maxillary central incisor using simvastatin as intracanal medicament.

2 | MATERIALS AND METHODS

A 23-year-old male dental student was referred to the Department of Endodontics, Faculty of Dentistry, Tanta University. The patient had no significant medical history. His chief complaint was pain associated with biting in the maxillary right central incisor. There was a Class III composite

Article 22:

Criteria For Management of Cracked Tooth Syndrome: A Review

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Abstract

A cracked tooth is a confusing and difficult clinical entity in the dentistry. This clinical scenario poses a diagnostic challenge to the clinician. The cracks in the teeth may propagate coronally or from radicular portion of the teeth. Cracked teeth can occur both in healthy and endodontically treated teeth. Cracked tooth syndrome requires appropriate diagnosis and treatment planning as the signs and symptoms can be vague and misleading. Initial diagnosis of cracked teeth have proven to give a successful prognosis and the treatment can be kept as conservative as possible. This article highlights a detailed overview of etiology, signs, symptoms, classification and diagnosis and treatment modality of cracked teeth.

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Keywords: Cracks, Cracked tooth, Craze line, Fractured cusp.

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Introduction

Craze line or incomplete fractures of the teeth which appear asymptomatic can become symptomatic. The clinical signs may be bizarre ranging from sensitivity to varying degrees of pain. The localization of this condition is vague and annoying. The cracks may develop in enamel and underlying dentin in the initial cases but in severe cases, it may affect the pulp and the periodontal supporting structures. The range of pain may vary from slight sensitivity to severe gnawing pain which cannot be tolerated.

Cracked tooth or split tooth is described as complete or incomplete tooth fracture that involves dentin and in some instances affects the pulp (1- 4). Cracked tooth was first noticed as an incomplete cuspal fracture of a posterior tooth and was termed as "cuspal fracture odontolagia" by Gibbs in 1954 (5). The terminology cracked tooth syndrome was first coined by Cameron in 1964 (2). In this scenario, the symptoms were not clear but the teeth exhibited a painful response to pulp sensibility tests, and the tooth was rendered necrotic, whilst the pulp and periodontium were healthy (2,6).

Ellis in his literature exhibited the incomplete fracture of the teeth as a fracture line of varying direction extending through tooth structure to an unknown depth and may advance to connect with the pulp and/or periodontal ligament (6-9).

Teeth affected with cracks may present themselves in vertical or horizontal fracture involving crown and root (10). The causative factors for the cracks is generally the combination of occlusal load and the treatment procedures (11). Crown and Crown root fractures are considered as incomplete fractures in the crown aspect of the posterior teeth extending in a mesiodistal direction involving the marginal ridge.

The crack initiates in the coronal aspect of the tooth and may end at the cementoenamel junction or extend into the radicular portion of the tooth (2, 10, 12, 13). Vertical root fractures are complete straight-line fractures extending from the root to the periodontium (14). The various etiological factors are mentioned in table 1.

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Article 23:

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Cracked tooth syndrome: A report of three cases

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Abstract

Cracked tooth syndrome (CTS), the term was coined by Cameron in 1964, which refers to an incomplete fracture of a vital posterior tooth extending to the dentin and occasionally into the pulp. CTS has always been a nightmare to the patient because of its unpredictable symptoms and a diagnostic dilemma for the dental practitioner due to its variable, bizarre clinical presentation. The treatment planning and management of CTS has also given problems and challenges the dentist as there is no specific treatment option. The management of CTS varies from one case to another or from one tooth to another in the same individual based on the severity of the symptoms and depth of tooth structure involved. After all, the prognosis of such tooth is still questionable and requires continuous evaluation. This article aims at presenting a series three cases of CTS with an overview on the clinical presentation, diagnosis and the different treatment options that varies from one case to another.

KEY WORDS: Green stick fracture, hairline fracture, incomplete fracture, split tooth syndrome

In 1964, Cameron introduced a new terminology to the field of dentistry known as "cracked tooth syndrome (CTS)." He used the term to describe a clinical condition which is characterized by an incomplete fracture of a vital posterior tooth extending to the dentin and occasionally into the pulp.[1] The diagnosis of CTS has been embarrassing to a dental practitioner as the condition presents an incomplete history, nonspecific symptom, and unidentifiable sign during clinical examination and routine radiographic projections.[2] Although a fracture line may run in mesiodistal direction on the occlusal surface of the tooth, the depth of the fracture plane and its orientation through the tooth structure is not evident.[3] The fracture may continue to involve the pulp, root dentin and cementum

Article 24:

Dental Traumatology

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Correlation between cuspal inclination and tooth cracked syndrome: a three-dimensional reconstruction measurement and finite element analysis

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Key words: cuspal inclination; cracked tooth syndrome; three-dimensional reconstruction; three-dimensional finite element analysis

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Abstract – *Background/Aim*: This paper explored the correlation between cuspal inclination and tooth cracked syndrome by measuring and reconstructing the cuspal inclinations of cracked maxillary first molars through three-dimensional (3D) finite element analysis (FEA). *Material and methods*: The cuspal inclinations of 11 maxillary left first molars with cracked tooth syndrome and 22 intact controls were measured by 3D reconstruction. The mean values of each group were used to construct two 3D finite element models of maxillary first molar for comparing stress distribution under the loads of 200N at 0°, 45°, and 90°, respectively, to the tooth axis. *Results*: There was statistically significant difference in the cuspal inclination between the incompletely fractured group and the intact control group ($P < 0.001$), which was 5.5–6.7 degrees steeper. The model from the mean cuspal inclinations of the incompletely fractured molars showed the maximum tensile stress of 5.83, 10.87, and 25.32 MPa, respectively, in comparison with 5.40, 8.49, and 22.76 MPa for the model of the control group. Besides, the tensile stress was mainly at the center groove and cervical region of the molar model. *Conclusions*: Steeper cuspal inclinations resulted in an increment in tensile stress that was mainly at the center groove and cervical region of the molar model under equivalent loads. Higher unfavorable tensile stress was generated with the increasing horizontal component load on the cuspal incline. This indicates an effective reduction of cuspal inclination to the compromised teeth for dentists.

Introduction

The term of cracked tooth syndrome (CTS) was first coined by Cameron (1) in 1964. It has been defined as an incomplete fracture of the dentine in a vital posterior tooth that involves the dentine and occasionally extends into the pulp and must be distinguished from a split tooth (1–6). The condition was associated with the teeth of older age groups, mainly in patients aged between 40 and 60 years (7). Its prevalence was similar in men and women.

It is well known that cracked teeth occur most frequently in the mandibular molars with large or poor restorations (1–9). However, cracks in teeth with no restoration appear more frequently in dental clinics these days, and the location of cracked teeth in the mouth seems to vary. Recent researches have shown that the prevalence of cracked tooth was the highest in the intact teeth with no restoration, in maxillary first molars (10, 11). As has been reported by Roh and Lee (10), cracked teeth were found more frequently in the maxillary molars (33.8% in first molar, 23.4% in second molar) than in the mandibular molars (20.1% in first molar, 16.2% in second molar) of 154 cracked teeth. Qing et al. (11) reported that intact maxillary first molars (45.7%) were the most commonly affected teeth by CTS of 258 cracked teeth without restorations.

It is difficult for dentists to identify CTS from other dental diseases with similar symptoms, as the CTS

Article 25:

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8 August, 2000

PRESERVATION OF THE ROOTS -

MANAGEMENT AND PREVENTION PROTOCOLS

FOR

CRACKED TOOTH SYNDROME

By

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Article 26:

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A 4- to 6-year retrospective clinical study of cracked teeth restored with bonded indirect resin composite onlays

Signore A, Benedicenti S, Covani, Ravera G
Int J Prosthodont. 2007;20:609-16

Purpose

The purpose of this study was to retrospectively evaluate the clinical performance of bonded indirect resin composite onlays for the treatment of painful, cracked teeth over a 6-year period.

Materials and Methods

Forty-three posterior teeth diagnosed as having a crack were selected in the restorative department of the University of Genoa. Inclusion criteria were sensitivity to biting and cold and a clinically visible crack. Direct composite buildup after removal of the existing restoration was performed before definitive cavity preparation. All composite onlay restorations were cemented with an adhesive technique using a 3-step total etch system and a dual-cure composite cement. Patients were interviewed and clinically examined at 1 week, 4 weeks, and every 6 months.

Results

The effectiveness of bonded onlay restorations was evaluated for a mean observation time of 4.78 years. At 1 week, 38 (88.37%) restored teeth were free of pain, 3 (6.98%) still had sensitivity to cold, and 2 (4.65%) still had sensitivity to cold and chewing. At 4 weeks, 40 (93.02%) teeth were free of pain, 2 (4.65%) still had sensitivity to cold and chewing, and 1 (2.32%) needed endodontic treatment. Two other teeth (4.65%) also needed endodontic treatment, the first after 2 months and the second after 5 months. During the evaluation period, 3 restorations (6.98%) failed, and upon clinical examination, 40 (93.02%) teeth were free of symptoms with a 6-year survival rate of 93.02% (life table analysis).

Conclusions

Bonded indirect resin composite onlays can be successful in treating painful, cracked teeth. From the findings of this study, it appears that cuspal protection should be incorporated into the design of coronal restorations.

Abstract

Root surface and coronal caries in adults with type 2 diabetes mellitus

Hintao J, Teanpaisan R, Chongsuvivatwong V, Dahlen G, Rattarasarn C
Community Dent Oral Epidemiol. 2007;35:302-9.

Objectives

To determine the effect of type 2 diabetes mellitus (DM) on coronal and root surface caries and to investigate some factors suspected of being related to or interacting with DM, that may be associated with coronal and root surface caries.

Methods

A stratified cross-sectional study was conducted in 105 type 2 diabetic patients and 103 non-diabetic subjects of the same age and gender. Coronal and root surface caries, exposed root surfaces, periodontal status, stimulated salivary functions, oral hygiene status, oral health behaviors, and counts of mutans streptococci and lactobacilli were measured.

Results

Type 2 diabetic patients compared with non-diabetic subjects had a higher prevalence of root surface caries (40.0% versus 18.5%; $P = 0.001$), a higher number of decayed/filled root surfaces (1.2 +/- 0.2 versus 0.5 +/- 0.1; $P < 0.01$) and a higher percentage of generalized periodontitis (98.1% versus 87.4%; $P < 0.01$); but the prevalence and decayed/filled surface of coronal caries was not significantly different (83.8% versus 72.8% and 8.0 +/- 9.4 versus 6.3 +/- 7.5 respectively). The factors associated with root surface caries included type 2 DM, a low saliva buffer capacity, more missing teeth, and existing coronal caries; whereas wearing removable dentures, more missing teeth, a high number of lactobacilli, and a low saliva buffer capacity were associated with coronal caries.

Conclusion

Type 2 DM is a significant risk factor for root surface, but not for coronal caries. Periodontal disease should be treated early in type 2 diabetic subjects to reduce the risk of subsequent root surface caries.

Abstract

Article 27:

Decision Making for Retention of Endodontically Treated Posterior Cracked Teeth: A 5-year Follow-up Study

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Abstract

Introduction: The study aimed to investigate the 5-year survival of root-filled posterior cracked teeth and its related factors. **Methods:** Two hundred patients who had root canal–treated posterior cracked teeth at the National Dental Centre were recalled for a 5-year review. Eighty-four patients who met the inclusion criteria were included in this study. The cases were managed following the treatment protocol for cracked teeth at the center. The data for analyses were obtained from the patients' clinical records. Statistical analyses were performed using SPSS 21.0 (SPSS Inc, Chicago, IL). The outcome measure was the presence of tooth at the time of the review. **Results:** At 5 years, 77 teeth "survived" (92%), and 7 teeth (8 %) were extracted. Patient demographics, tooth type and location, existing restoration, number and location of cracks, presence of pretreatment signs and symptoms, and initial pulpal and periapical diagnosis did not significantly affect the survival of the teeth. Univariate analysis showed that teeth with extension of the cracks onto the pulpal floor were more often extracted (odds ratio = 4.5, $P = .07$). Multivariable analyses found that extension of cracks onto the pulpal floor independently increased the odds of tooth loss by 11-fold (odds ratio = 11, $P = .033$), with other factors being held constant. The 5-year survival estimate in the absence and presence of crack extension onto the pulpal floor was 99% and 88%, respectively. **Conclusions:** Coronal cracks may be predictably treated, whereas radicular cracks increased the odds of the tooth being extracted. *(J Endod 2016;42:225–229)*

Key Words

Cracked tooth, endodontic, failure rate, long-term survival

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According to the American Association of Endodontists classification (1997, 2008), a cracked tooth is defined as an incomplete fracture initiated from the crown and extending subgingivally, usually directed mesiodistally. The fracture may extend through either or both of the marginal ridges and through the proximal surfaces. The fracture is located in the crown portion of the tooth only or may extend from the crown to the proximal root (1, 2). A cracked tooth occurs commonly in mandibular molars followed by maxillary premolars (3, 4).

The condition presents both diagnostic and restorative challenges to the dentist. A cracked tooth may present with variable signs and symptoms (5–8) depending on the location and extent of the crack, which are often difficult to determine (9). For teeth diagnosed with reversible pulpitis, a cemented stainless steel orthodontic band on the involved tooth serves both as a temporary and diagnostic procedure before a full crown is placed (10). Root canal treatment followed by full coronal restoration is recommended if the pulp becomes irreversibly inflamed (2, 5, 10).

The prognosis of a cracked tooth depends on the extent of the crack into the enamel, dentin, or pulp and whether it penetrates the external root surface (11). Cracks that communicate through the pulpal floor or beyond the alveolar bone level are deemed hopeless (12). Long-term clinical studies on the survival of cracked teeth are scarce. Tan et al (13) found that the 2-year survival rate of cracked teeth was 85.5%. To date, there is no known study that has looked into the long-term outcome of cracked teeth (ie, the progression of cracks over time). The availability of such information will provide a better perspective on the clinical management and treatment outcome of these teeth, thereby providing evidence-based treatment options and advice to the patient.

The aim of this retrospective cohort study was to examine the 5-year survival rate of teeth with cracks and to determine which factors influenced the outcome.

Methods and Materials

Two hundred patients with root canal–treated cracked teeth at the National Dental Centre from June 2000 to June 2002 were recalled for a 5-year review. Eighty-six (86) patients responded to the invitation, giving a recall rate of 43%. The inclusion criteria were all patients who had root canal therapy on posterior cracked teeth. Exclusion criteria were patients with root canal–treated anterior cracked teeth and patients with incomplete clinical and radiographic records.

Eighty-four patients who had root canal–treated posterior cracked teeth were included in this study. Two patients were excluded because their root canal–treated teeth were incisors. These cracked teeth had been managed following the treatment protocol for cracked teeth at the National Dental Centre (Fig. 1). Root canal treatment was performed by 4 endodontists at the center. After rubber dam isolation, standard access cavity preparation and instrumentation were performed using 1% sodium hypochlorite solution as an irrigant. The root canals were obturated with gutta-percha and Roth's 801 sealer (Roth International, Chicago, IL).

The number, location, and extent of cracks (coronal or radicular) were charted by the endodontists upon access opening preparation. Radicular cracks were cracks that had extended to the pulpal floor and beyond the root canal orifices. Coronal cracks were those that were confined within the walls of the pulp chamber. The extent of the

Article 28:

Cracked Teeth: Distribution, Characteristics, and Survival after Root Canal Treatment

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Abstract

Introduction: The aims of this study were to analyze the distribution and characteristic features of cracked teeth and to evaluate the outcome of root canal treatments (RCTs) for cracked teeth. The prognostic factors for tooth survival were investigated. **Methods:** Over the 5-year study period, 175 teeth were identified as having cracks. Data were collected regarding the patients' age, sex, tooth type, location and direction of cracks, probing depth, pulp vitality, type of restoration, cavity classification, opposing teeth, and previous endodontic treatment history. Cracked teeth were managed via various treatment methods, and the 2-year survival rate after RCT was analyzed using the Kaplan-Meier method in which significance was identified using the log-rank test. Possible prognostic factors were investigated using Cox multivariate proportional hazards modeling. **Results:** One hundred seventy-five teeth were diagnosed with cracks. Most of the patients were aged 50–60 years (32.0%) or over 60 (32.6%). The lower second molar was the most frequently (25.1%) affected tooth. Intact teeth (34.3%) or teeth with class I cavity restorations (32.0%) exhibited a higher incidence of cracks. The 2-year survival rate of 88 cracked teeth after RCT was 90.0%. A probing depth of more than 6 mm was a significant prognostic factor for the survival of cracked teeth restored via RCT. The survival rate of root-filled cracked teeth with a probing depth of more than 6 mm was 74.1%, which is significantly lower than that of teeth with probing depths of less than 6 mm (96.8%) (P = .003). **Conclusions:** Cracks were commonly found in lower second molars and intact teeth. RCT was a reliable treatment for cracked teeth with a 2-year survival rate of 90.0%. Deep probing depths were found to be a significant clinical factor for the survival of cracked teeth treated with RCT. *(J Endod 2016;42:557–562)*

Key Words

Cracked teeth, Korean population, probing depth, root canal treatment, tooth survival

Cracked teeth may be described as teeth with crack lines present in the vertical plane (1, 2). Many terminologies and classifications have been proposed to describe the characteristics and conditions of cracked teeth (3–5). The American Association of Endodontists (AAE) categorizes cracks into 5 types: craze lines, fractured cusp, cracked tooth, split tooth, and vertical root fracture (VRF) (6). Cracked teeth may result in sharp pain upon biting, unexplained cold sensitivity, pain on release of pressure, or deep probing depths associated with the crack (7–9). The diagnosis of cracked teeth is not straightforward because the symptoms are diverse, and crack lines may be difficult to locate; dye staining, transillumination, or microscopy may be necessary to identify cracks (2, 10). The determination of the severity of a crack is often a prediction rather than an accurate diagnosis, and there are no accurate methods to predict the prognosis of a cracked tooth based on clinical examinations (11).

Cracked teeth represent a restorative dilemma and a source of frustration for both clinicians and patients because of their complicated and vague symptoms and unpredictable prognosis. Treatment plans for cracked teeth depend on the extent and location of the cracks and the severity of the symptoms (12). If the size of the involved portion of the tooth is relatively small and the crack avoids the pulp, the tooth could be restored conventionally using resins, inlays, or crowns (13). If the crack is extensive with prolonged symptoms, thermal hypersensitivity, and pulpal and periapical pathology, root canal treatment (RCT) is required before crown placement. There are some cases in which the crack extends into the pulpal floor, deep down to the bone, or symptoms persist even after RCT; in such situations, extraction is usually the only viable option (13, 14). RCT is among the most important treatment options to salvage symptomatic cracked teeth diagnosed with irreversible pulpitis or pulp necrosis. However, there is a lack of information regarding the endodontic prognosis of cracked teeth; only in 1 study did the authors apply survival analysis to evaluate the outcome of RCT in cracked teeth at a tertiary institute, and the sample size was small (15). The aims of this study were to analyze the distribution and characteristic features of cracked teeth, to evaluate the survival rate of cracked teeth after RCT, and to investigate prognostic factors for tooth survival.

Materials and Methods

This study was approved by the ethics committee of the Ewha Womans University Hospital, Seoul, Korea. Patients who visited the Department of Conservative Dentistry at Ewha Womans University Dental Hospital between 2009 and 2014 and were suspected of having cracked teeth were examined thoroughly by 2 examiners. Examinations by the naked eye, with staining using methylene blue dye, and through the use of microscopy were performed to detect cracks. There were 1977 teeth examined during a 5-year period. Cracks were observed in 175 teeth, and the patients' age, sex, tooth number, location and direction of cracks, crack type, probing depth, pulp vitality, results of

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