Universidad Europea

GRADUATION PROJECT

Degree in Dentistry

CRACKED TOOTH SYNDROME

Madrid, academic year 2024/2025

Identification number: **90**

RESUMEN

Introducción: El síndrome del diente fisurado (SDF) es un desafío diagnóstico en odontología debido a su presentación clínica compleja y la dificultad de detectar microfracturas mediante métodos convencionales. El diagnóstico temprano y preciso es crítico para prevenir mayor daño estructural y determinar el tratamiento más apropiado. **Objetivos**: Este estudio busca evaluar la efectividad y confiabilidad de los métodos de diagnóstico actuales para identificar el SDF, evaluar los factores etiológicos que contribuyen a la condición y proponer opciones de tratamiento alineadas con el tipo y severidad de las grietas. **Materiales y métodos**: Se realizó una revisión sistemática de 30 artículos revisados por pares, a través de las bases de datos Medline Plus, Pubmed y Google Scholar, accedidos a través de la biblioteca CRAI de la UEM. Se analizaron diversas herramientas de diagnóstico como la transiluminación, pruebas de mordida, imágenes radiográficas y otros métodos avanzados. La revisión también examinó los factores predisponentes relacionados con los hábitos parafuncionales, los procedimientos restauradores, así como los enfoques de tratamiento: adhesión, cobertura cuspídea e intervenciones endodónticas. **Resultados**: Los hallazgos sugieren que, si bien las técnicas de diagnóstico tradicionales siguen siendo ampliamente utilizadas, las modalidades más nuevas, como la tomografía de coherencia óptica (OCT) y la micro-CT, ofrecen mejores tasas de detección. El bruxismo, las restauraciones extensas y el envejecimiento de la dentición se identificaron como factores de riesgo clave. Las estrategias de tratamiento varían según la gravedad de la fisura; las restauraciones mínimamente invasivas resultan eficaces para las fisuras en fase inicial, mientras que las coronas de cobertura completa o la endodoncia son necesarias para los casos avanzados. **Conclusiones**: A pesar de los avances en la tecnología diagnóstica, ningún método garantiza por sí solo una precisión completa en la detección del SDF. Un enfoque multimodal que combina pruebas clínicas y técnicas de imagen mejora la precisión diagnóstica. Las medidas preventivas, como los ajustes oclusales y la educación del paciente, siguen siendo esenciales para reducir la prevalencia del SDF y garantizar la preservación dental a largo plazo. Se necesita más investigación para optimizar los protocolos de diagnóstico y la eficacia del tratamiento.

PALABRAS CLAVE

Odontología, síndrome del diente fisurado, fisura, diagnóstico, tratamiento, pronóstico

ABSTRACT

Introduction: Cracked Tooth Syndrome (CTS) is a diagnostic challenge in dentistry due to its complex clinical presentation and the difficulty of detecting microfractures using conventional methods. Early and accurate diagnosis is critical for preventing further structural damage and determining the most appropriate treatment. **Objectives**: This study aims to evaluate the effectiveness and reliability of current diagnostic methods in identifying CTS, assess the etiological factors contributing to the condition, and propose treatment options aligned with the type and severity of cracks. **Materials and Methods**: A systematic review of 30 peer-reviewed articles was conducted, through Medline Plus, Pubmed databases and Google Scholar, accessed via UEM CRAI library. Various diagnostic tools were analyzed such as transillumination, bite tests, radiographic imaging and other advanced methods. The review also examined predisposing factors concerning parafunctional habits, restorative procedures, as well as treatment approaches: bonding, cuspal coverage and endodontic interventions. **Results**: The findings suggest that while traditional diagnostic techniques remain widely used, newer modalities such as optical coherence tomography (OCT) and micro-CT provide improved detection rates. Bruxism, extensive restorations and aging dentition were identified as key risk factors. Treatment strategies vary depending on crack severity, with minimally invasive restorations proving effective for early-stage cracks, whereas full-coverage crowns or root canal therapy are required for advanced cases. **Conclusions**: Despite advancements in diagnostic technology, no single method ensures complete accuracy in detecting CTS. A multimodal approach combining clinical tests and imaging techniques enhances diagnostic precision. Preventive measures, such as occlusal adjustments and patient education, remain essential in reducing CTS prevalence and ensuring long-term tooth preservation. Further research is necessary to optimize diagnostic protocols and treatment efficacy.

KEYWORDS

Dentistry, cracked tooth syndrome, fissure, diagnosis, treatment, prognosis

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1. INTRODUCTION

1.1. Historical context

Cracked Tooth Syndrome (CTS), first introduced by Caryl E. Cameron in 1964 **[1]**, is a condition characterized by cracks or incomplete fractures in teeth that are often not readily visible, yet can lead to significant pain and discomfort. These cracks are commonly observed in clinical practice, presenting challenges in both diagnosis and management. Initially termed “cuspal fracture odontalgia” **[1]** by Gibbs in 1954, Cameron expanded the understanding of this phenomenon, recognizing a range of symptoms that patients experience, and thereby establishing it as a “syndrome”. The condition can manifest with varying symptoms, sometimes being symptomatic or asymptomatic, often resulting in conflicting pulpal and periodontal diagnoses that may lead to misdiagnosis by dentists.

In 2015, John S. Mamoun and D. Napoletano **[2]** emphasized the inconsistent nature of symptoms associated with cracked teeth, suggesting that these fractures could be precursors to both pulpal and periodontal diseases. This has been supported by clinical observations where patients experienced relief after a cusp broke off **[1,2]**, therefore suggesting pre-existing cracks. They raised questions about the appropriateness of classifying cracked teeth as a distinct “syndrome.” The definitions provided in the 2012 *Glossary of Endodontic Terms*, the 2008 publication “*Cracking the Cracked Tooth Code*”, and by the *International Association of Dental Traumatology* were also not consistent with one another. Despite this debate, the term has gained acceptance within the dental community over time.

1.2. Epidemiology

In a study realized by *Ferracane et al*., they analyzed a practice-based research **[3]** performed by *Hilton et al*. **[4]** and found that nearly 70% of patients at general dental practices had at least one cracked posterior tooth, with 45% of those being symptomatic **[5]**. Reports indicate that fissures occur in 4% to 5% **[6]** of adults, with molars accounting for over 75% of cases and premolars making up the remainder. Most studies suggest that fissures are most commonly found in teeth that have undergone untreated root canal therapy, which constitutes 35% of cases. The average age of patient with cracked teeth is 54 years old with a range from 19 to 85 years, suggesting that CTS affects a wide part of the population, focusing more on middle-aged patients **[3]**. The first upper molar is identified as the most frequently affected tooth, mainly due to its role in primary contact point in occlusion, followed by first lower molar and second lower molar. Additionally, during the COVID-19 epidemic, there has been a noticeable rise in instances **[6]**.

1.3. Diagnosis

1.3.1. Classification of cracks

Understanding biomechanical properties of teeth is essential for identifying the causes of cracks. During chewing or night-time grinding, tooth tissue absorbs these occlusal forces **[5]**. The distinct structures and properties of enamel, dentin, and cementum result in varying levels of force absorption. Additionally, these mechanical properties can change with age, potentially leading to reduced elasticity and a diminished capacity to absorb occlusal forces effectively **[7]**. Molars and premolars are particularly susceptible to cracks, often splitting into buccal and lingual fragments **[1,7]**. Protective overlays or full veneer crowns should be used to stop deeper fissures, particularly in teeth that have been damaged by caries or root canal therapy **[6,8]**. Neglecting this preventive measure is considered inadequate dental care.

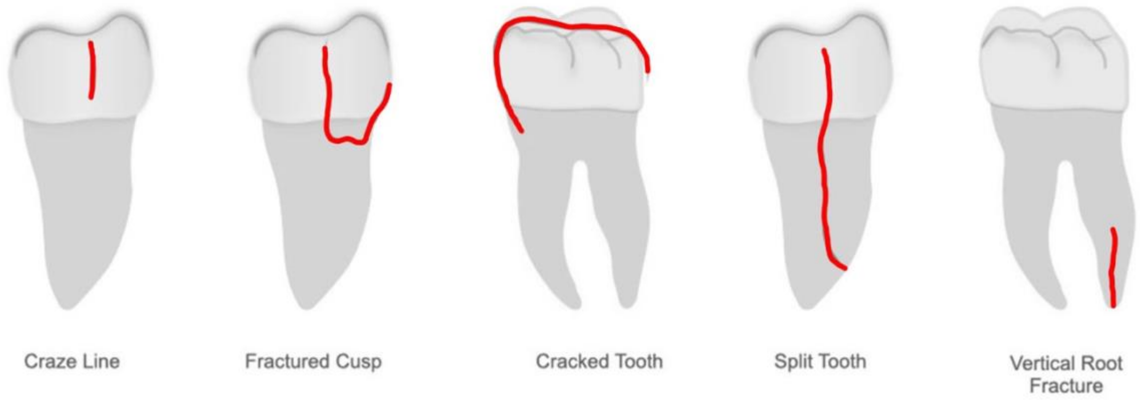

***Figure 1**: Classification of CTS according to the American Association of Endodontists (AAE).*

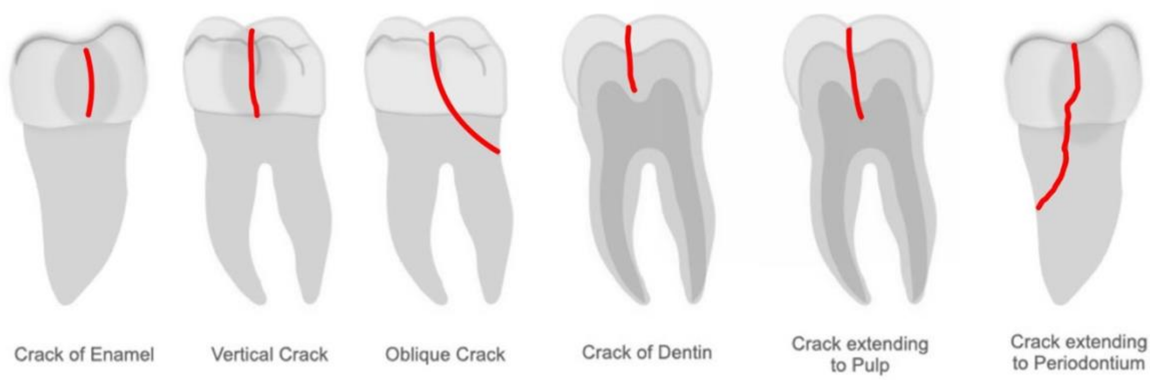

***Figure 2**: Classification of CTS according to the FDI.*

The American Association of Endodontists (AAE) classifies CTS into five main types (**Figure 1**) based on where the crack originates, its direction, associated symptoms, the condition of the tooth pulp, and the likely endodontic prognosis **[9]**. The World Dental Federation (FDI) chose a broader approach **[9]** (**Figure 2**) of CTS, addressing both complete and incomplete cracks, in order for general dentists to assess adequately CTS, recommending early intervention and prevention. For the purpose of this study, we will focus on the **AAE classification** of CTS with visual clinical presentation showed in **Figure 3**.

- **Craze Line**

Cracks that initiate in the tooth's crown and may extend in various directions. They do not cause symptoms and typically do not affect the pulp, which remains vital. The prognosis for craze lines is excellent, as they are minor and often don't require any treatment.

- **Fractured Cusp**

Cracks that also begin in the crown but usually run in a mesiodistal or buccal-lingual direction. Patients may experience mild pain, particularly when biting down or when the tooth is exposed to cold. The pulp is usually unaffected and remains vital, with a good overall prognosis.

- **Cracked Tooth**

Fractures may begin in the crown and sometimes extend into the root, generally following a mesiodistal direction and often centered on the tooth. These cracks can cause acute pain on biting and may occasionally lead to sharp pain in response to cold stimuli. The pulp condition may differ based on the crack's depth. The prognosis is often uncertain and depends on the depth and extent of the crack.

- **Split Tooth**

Fractures extend from the crown down into the root in a mesiodistal direction. This type of crack typically causes marked pain when chewing, and root canal treatment is often necessary. The prognosis is generally poor unless the crack stops just below the gum line.

- **Vertical Root Fracture**

Originates in the root of the tooth and runs buccal-lingually. Patients with this type of fracture may experience vague pain that resembles symptoms of periodontal disease. Root canal treatment is often needed, and the prognosis is poor. In cases where the tooth has multiple roots, root resection may be required.

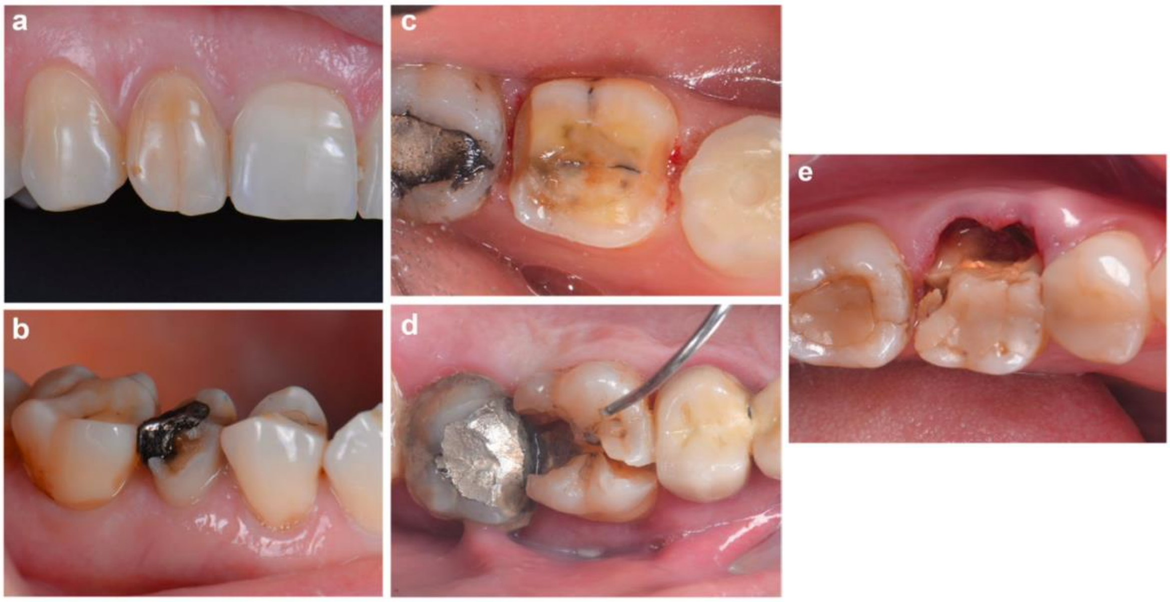

Figure 3*: Examples of the AAE classification. a) Craze line b) Fractured cusp c) Cracked tooth d) Split tooth e) Vertical root fracture* ***[9]****.*

1.3.2. Signs and symptoms

The diagnosis of CTS primarily relies on tooth-specific symptoms, including localized pain during chewing or biting, unexplained cold sensitivity, and discomfort upon pressure release. Patients often struggle to identify the exact source of pain, as it can radiate to surrounding areas. While occlusal forces are the primary cause of CTS, several factors can influence a tooth's vulnerability and prognosis. Untreated cracked teeth are generally stable in terms of pulp symptoms, but also, it has been observed that in many cases, there was a reduction of pain over time **[3]**. The following **Table 1 [1,10]** and **Table 2** will help us to understand more in depth the diagnosis of CTS upon the basis provided by the AAE classification.

AAE Classification	Signs	Symptoms
Craze lines	▪ Fine superficial lines visible with naked eye. ▪ No structural compromise of the tooth.	▪ No pain or sensitivity
Fractured cusp	▪ Visible partial separation of cusp. ▪ Positive bite test. ▪ No pulp involvement.	▪ Sharp, localized pain when biting, especially when releasing pressure. ▪ Sensitive to temperature change or sweet food.
Cracked tooth	▪ Sharp pain on biting and release. ▪ Tooth sensitive to hot and cold. ▪ Difficulty localizing the pain.	▪ Crack visible under magnification or transillumination. ▪ Positive bite test. ▪ No deep probing, unless the crack extends sub gingivally.
Split tooth	▪ Visible complete fracture separating tooth in distinct segments. ▪ Individual movements of tooth segments. ▪ Loss of structure integrity.	▪ Severe pain. ▪ Awareness of tooth segments moving separately. ▪ Sensitivity to chewing or pressure.
Vertical root fracture	▪ Deep narrow periodontal pockets adjacent to fracture. ▪ Radiographic evidence of bone loss.	▪ Mild pain, often asymptomatic in early stages. ▪ Gum swelling in case of infection, leading to endo-periodontal lesion.

***Table 1**: Signs and symptoms associated to CTS according to AAE classification.*

<table>
<tr><td rowspan="6">Pulpal disease</td><td>Normal pulp</td><td colspan="2">The pulp is asymptomatic with normal pulp testing.</td></tr>
<tr><td>Reversible pulpitis</td><td colspan="2">Clinical diagnosis based on subjective and objective findings, suggesting mild inflammation of the pulp. Thermal testing elicits a quick, transient response that subsides once the stimulus is removed. No spontaneous pain, but sharp discomfort typically occurs in response to cold stimuli.</td></tr>
<tr><td rowspan="2">Irreversible pulpitis</td><td>Symptomatic</td><td>Condition where the pulp is severely inflamed and cannot heal on its own, characterized by persistent, spontaneous or lingering pain often triggered by cold or hot stimuli.</td></tr>
<tr><td>Asymptomatic</td><td>A condition where the pulp is irreversibly damaged but does not cause noticeable symptoms, often detected during routine examinations or imaging.</td></tr>
<tr><td>Pulp necrosis</td><td colspan="2">A clinical diagnosis confirming pulp necrosis, characterized by the absence of response to pulp testing.</td></tr>
<tr><td>Previously treated/initiated therapy</td><td colspan="2">Tooth already treated by a partial or complete endodontic treatment. Similar characteristics with pulp necrosis.</td></tr>
<tr><td rowspan="5">Periapical disease</td><td>Normal apical tissues</td><td colspan="2">Apical tissues remain asymptomatic and exhibit a normal response to percussion and palpation tests.</td></tr>
<tr><td>Symptomatic apical periodontitis</td><td colspan="2">Inflammation of the apical periodontium, characterized by pain in response to biting, percussion or palpation. X-ray: findings include at least a widened periodontal ligament space, with or without the presence of periapical radiolucency.</td></tr>
<tr><td>Asymptomatic apical periodontitis</td><td colspan="2">The tooth typically shows no response to pulp testing, with an observable apical radiolucency. No sensitivity to biting pressure.</td></tr>
<tr><td>Acute apical abscess</td><td colspan="2">Acute inflammatory reaction caused by pulp infection and necrosis, presenting with sudden onset, tenderness under pressure, pus formation and swelling of the surrounding tissues.</td></tr>
<tr><td>Chronic apical abscess</td><td colspan="2">Slow-developing inflammatory response to pulp infection and necrosis, typically presenting with little to no discomfort and periodic pus drainage through a fistula.</td></tr>
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Table 2: *Review of pulpal and periapical diagnosis.*

1.3.3. Differential diagnosis for CTS

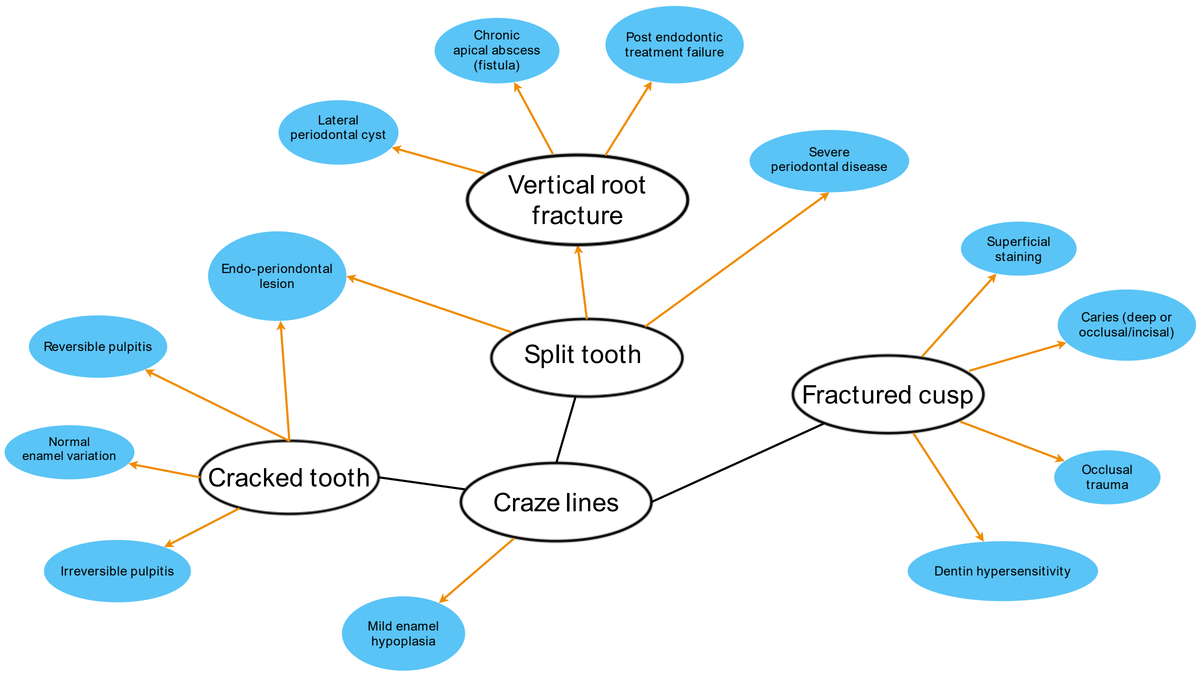

Figure 4*: Differential diagnosis for CTS: visual approach.*

Craze lines, confined to the enamel, are often benign and asymptomatic. However, under repetitive thermal and mechanical stresses, they can weaken the tooth structure and predispose it to more significant fractures, such as a fractured cusp. If untreated, it may allow dentin exposure, initiating dentin hypersensitivity or reversible pulpitis.

The cracked tooth classification represents a critical transition, where incomplete fractures extend through the crown and may involve the pulp. These cracks expose dentinal tubules, increasing the risk of bacterial infiltration, irreversible pulpitis, and eventual necrosis if left untreated.

In advanced stages, a split tooth or vertical root fracture signifies the culmination of untreated CTS. These conditions are often characterized by mobility of tooth segments and severe, persistent pain. They may lead to secondary complications, such as endo-periodontal lesions, chronic apical abscesses, or severe periodontal disease, due to bacterial invasion through the fracture site. These advanced classifications are typically associated with a poor prognosis, often requiring extraction or extensive restorative efforts.

This structured approach emphasizes the importance of diagnosing and managing each stage early, as delaying intervention can escalate the condition and limit treatment options.

1.3.4. Pathophysiology of pain in cracks

Tooth cracks, regardless of their location, direction or size, were consistently found to be colonized by bacterial biofilms. These cracks are exposed to saliva and are challenging, almost impossible, to clean effectively with current oral hygiene techniques **[11]**. The pain experienced in CTS is mainly explained by the hydrodynamic theory, describing the movement of fluid within dentinal tubules. When cracks expose dentinal tubules, variable parameters such as thermal, mechanical or even osmotic stimuli will engender a change of pressure in the tubules, generating shearing forces that will activate A-delta fibers **[12]**. As a consequence, a sharp, transient pain will be produced when biting or exposure to cold.

1.3.5. Current diagnostic techniques

Accurate and early diagnosis is critical for ensuring successful treatment and improving prognosis. This process involves a combination of traditional and advanced diagnostic methods.

Traditional tools include the occlusion or bite test, periodontal probing, methylene blue dye staining, vitality tests, transillumination **[13]**, as well as newer techniques like quantitative light fluorescence (QLF) **[13,14]**. These methods aid in detecting cracks through visual and symptomatic cues.

Recent advancements in diagnostic tools, primarily imaging-based, have enhanced accuracy. Cone-beam computed tomography (CBCT), X-rays, ultrasound (US), and optical coherence tomography (OCT) **[13,15]** are increasingly used to visualize crack lines and structural abnormalities. Moreover, artificial intelligence (AI)-based **[16]** diagnostic systems are emerging as promising tools, assisting dentists in identifying CTS and effectively communicating the diagnosis to patients.

Ultimately, a comprehensive approach that considers the patient's history, periodontal health, radiographic findings, vitality testing, and microscopic detection, as well as the crack's location, depth, and orientation, is essential for accurate diagnosis and tailored treatment of CTS.

- **Bite test**

The bite test is a diagnostic method used to reproduce biting pain and is essential for diagnosing cracks that are not able to be detected easily **[17]**. Currently, we have two methods to perform a bite test. The first one is by using a wet folded gauze placed on the occlusal portion of the tooth in question, then asking the patient to bite. The second one, with an instrument called Tooth slooth, placing it on one cusp of the suspected tooth at a time. Then, we record the response which could be normal, uncomfortable or painful. In **Figure 5**, we can see a visual representation of the bite test.

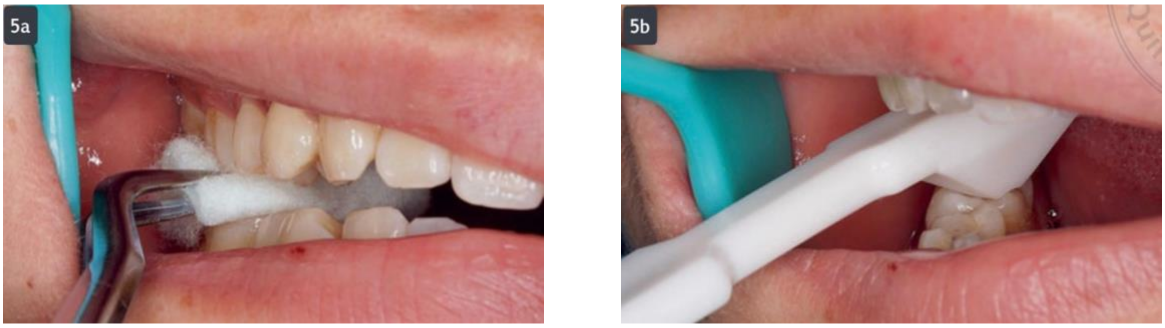

***Figure 5**: 5a: Bite test performed with a gauze; 5b: Bite test performed with a tooth slooth **[17]**.*

- **Transillumination**

Transillumination is a widely used diagnostic technique to detect variations in tooth anatomy based on light properties. The traditional form of this technique is called Fiber-optic Transillumination (FOTI) and the most advanced one, Digital Imaging Fiber-optic Transillumination (DI-FOTI) **[13,16]**. While FOTI being more cost-effective and extensively used, DI-FOTI gives us a greater accuracy and seems to be the preferred option in dental practices, in spite of its price **[10]**.

- **Optical coherence tomography**

Optical coherence tomography (OCT) is a high resolution imaging technique that can detect enamel cracks up to 3mm of depth **[18]**. This technique uses near infrared light to produce accurate cross-sectional images of vital structures by combining low coherence interferometry, white light interferometry and confocal microscopy **[15]**. Recent ameliorations brought us to the Swept-source OCT (SS-OCT), particularly effective in diagnosing structural cracks, from craze lines to CTS, and even invisible to naked eye cracks.

- **Methylene blue dye and optic microscopy**

Methylene blue dye can be helpful in in detecting coronal cracks **[13]** based on the aggregation property of the dye. It has the ability to flow into the cracks and be visible under magnification. However, the use of dye is not appropriate to assess depth of cracks **[18]** and could lead to misdiagnosis of surface imperfections as cracks. This is why methylene blue can be used in combination with radiographic techniques like cone-beam computed tomography (CBCT) to enhance sensitivity and specificity **[18]**.

1.4. Treatment and prognosis

When it comes to treatment options for CTS, as stated by *Alkhalifah et al.*, we may not treat the tooth and monitor in case of minimal crack and asymptomatic state **[19]**. This attitude is quite accepted in cases of craze lines. Direct restorations may be involved as option when the crack does not extend deeply and do not involve pulp symptoms; we will try to stop de propagation of the crack. Crowning those cracked teeth is advised when the cracks extend deeply, in order to redistribute the biomechanical forces. If the patient experiences pulp symptoms we may perform a root canal treatment along the crowning. Eventually, the cracks may extend sub gingivally, restricting in a drastic way our options to save a tooth, letting us we no other option than extraction **[3,9]**.

The prognosis of CTS depends on multiple factors, among others, the location and the degree of extension of cracks. According to *Ferracane et al.*, only about 3% of teeth with cracks experienced fractures and only 12% showed crack progression over three years **[3]**.

1.5. Justification

Cracked tooth syndrome being a complex dental condition, yet remaining misunderstood and challenging to be diagnosed, poses major issues related to patient care. Despite the advancements in dentistry since 1964, we still struggle to manage CTS due to its variety of presentation depending on the extent of the cracks. This is why this study is aiming at assessing the effectiveness and reliability of the current diagnostic methods of CTS, providing a base on linking the best diagnostic method to a presentation of crack.

It is important to remember that the causes of CTS remain multifactorial, somewhat elusive. To understand the complexity of the condition, we will have to explore the contributing factors, trying to determine if one factor can be overrepresented over others in guiding to CTS. An accurate diagnosis allows for thorough etiologic treatment, ranging from minor restorative treatment to tooth extraction. Thus, reviewing and analyzing treatment options will be the foundation for a customized approach of patient's needs, by aligning treatment with specificities of CTS.

2. OBJECTIVES

Primary objective

- To evaluate the effectiveness and reliability of current diagnostic methods in patients affected by cracked tooth syndrome.

Secondary objectives

- To assess the possible causes leading to cracked tooth syndrome.
- To establish treatment options in adequation with the type of cracks previously diagnosed.

3. MATERIAL AND METHODS

In this graduation project on Cracked Tooth Syndrome (CTS), a comprehensive literature review was conducted to identify and synthesize relevant research findings. The primary sources of literature were peer-reviewed journal articles, published mostly within the past 10 years to ensure the inclusion of the most recent advancements in the field. A comprehensive search yielded an initial set of 30 articles, which were narrowed down to 18 for final inclusion based on specific criteria to ensure relevance.

To retrieve these articles, electronic databases accessible through the UEM CRAI Library were used, with a particular focus on the Medline Plus, PubMed databases and Google Scholar. These platforms provided access to a broad array of peer-reviewed literature, helping to ensure that the articles reviewed were credible and pertinent to the research topic.

To maintain a high standard of relevance in the review process, specific inclusion and exclusion criteria were applied during the article selection process:

- **Inclusion criteria**
  - Studies published within the last 10 years (2014–2024) to ensure relevance to current clinical practices and diagnostic advancements.
  - Peer-reviewed articles that focus on clinical, diagnostic, and treatment approaches to CTS.
  - Studies that present data on risk factors, symptoms, prevalence, and outcomes associated with CTS in various populations.
  - Articles available in full text to allow for a comprehensive analysis of methodology, findings, and limitations.
  - Publications in English or French, to ensure accurate understanding and interpretation of findings.

- **Exclusion criteria**
  - Studies that did not specifically address cracked tooth syndrome or that addressed it only partially, such as those focused on broader dental fractures or trauma without direct reference to CTS.
  - Literature reviews and editorials that lacked original data or analysis, to maintain a focus on primary research studies.
  - Articles published more than 10 years ago, unless cited as foundational studies providing essential background or historical context for CTS.

4. RESULTS

4.2. Data extraction and analysis

Following the selection of articles, key data were extracted, including study objectives, sample size, methodology, key findings, and limitations. This data extraction process enabled a systematic comparison of findings across studies, facilitating the identification of common themes, trends, and gaps in the existing literature on CTS. The synthesis of these findings provides the foundation for the analysis and discussion presented in this graduation project.

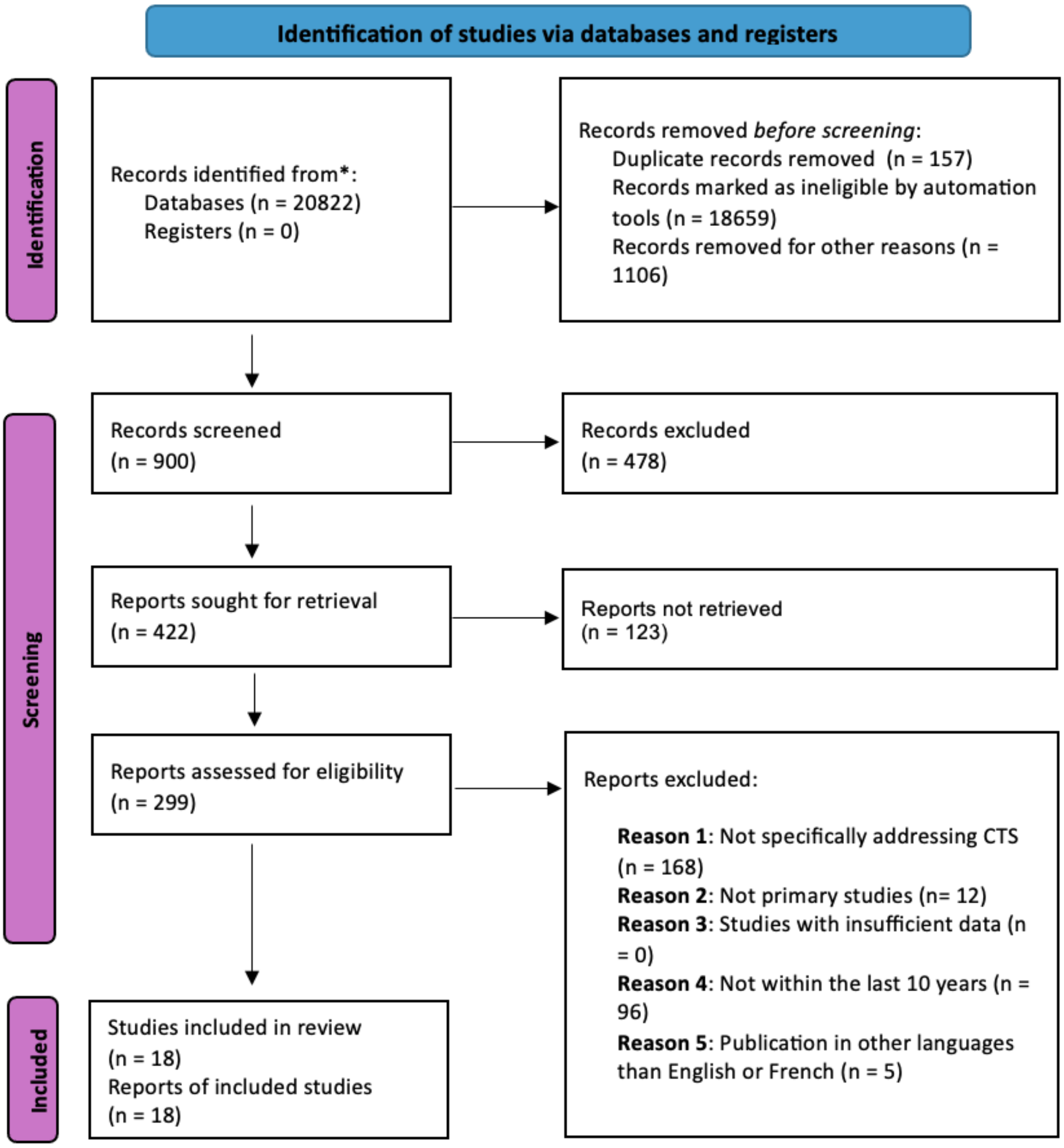

***Figure 6**: PRISMA 2000 Flow diagram.*

Authors	Year	Title	Type of study	Sample	Country
Alaugaily & Azim	2022	*CBCT Patterns of Bone Loss and Clinical Predictors for the Diagnosis of Cracked Teeth and Teeth with Vertical Root Fracture*	Cross-sectional study	CBCT scans of cracked teeth	USA
Alkhalifah et al.	2017	*Treatment of Cracked Teeth*	Cross-sectional study	100+ dentists	Saudi Arabia
Cameron	1964	*Cracked Tooth Syndrome*	Case series	Multiple cases	UK
Chen et al.	2021	*Clinical Features and Risk Factors of Cracked Teeth*	Cross-sectional study	200+ patients	China
Davis & Shariff	2019	*The Effect of Occlusal Adjustment on Cracked Teeth*	Cohort study	50 patients	USA
Ferracane et al.	2023	*Lessons Learned from the Cracked Tooth Registry – a Three-year Clinical Study*	Prospective cohort study	3,000 patients	USA
Fong et al.	2023	*Diagnostic and Treatment Preferences for Cracked Posterior Teeth*	Cross-sectional study (dentists)	200+ dentists	Australia
Hilton et al.	2017	*Correlation Between Symptoms and External Characteristics of Cracked Teeth*	Observational study (practice-based research)	2,975 cracked teeth	USA
Jun et al.	2016	*Detection and Analysis of Enamel Cracks by Quantitative Light-induced Fluorescence Technology*	Experimental study (In vitro)	96 extracted teeth	South Korea
Krell & Caplan	2018	*12-month Success of Cracked Teeth Treated with Orthograde Root Canal Treatment*	Retrospective cohort study	2,086 cracked teeth	USA
Nuamwisudhi & Jearanaiphaisarn	2021	*Oral Functional Behaviors and Tooth Factors Associated with Cracked Teeth in Asymptomatic Patients*	Cross-sectional study	56 patients	Thailand
Ricucci et al.	2015	*The Cracked Tooth: Histopathologic and Histobacteriologic Aspects*	Experimental study (In vitro)	12 cracked teeth	Italy
Sh et al.	2016	*Dental Optical Coherence Tomography: New Potential Diagnostic System for Cracked-Tooth Syndrome*	Experimental study (imaging)	61 teeth	South Korea
Shi et al.	2022	*Stress Distribution and Fracture Resistance of Repairing Cracked Teeth with Fiber-reinforced Composites and Onlay*	Experimental study (In vitro)	3D modeling of cracked teeth	China
Yang et al.	2019	*Biting Pain Reproduced by the Tooth Slooth: An Aid for Early Diagnosis of Cracked Tooth*	Prospective clinical study	46 cracked teeth	China
Yuan et al.	2020	*Using Meglumine Diatrizoate to Improve the Accuracy of Diagnosis of Cracked Teeth on Cone-beam CT Images*	Experimental study (In vitro)	24 cracked teeth	China
Zhao et al.	2024	*Occlusal Veneer Restoration Treatment Outcomes of Cracked Tooth Syndrome: A 22.4-month Follow-up Study*	Prospective clinical study (follow-up)	27 cracked teeth	China
Zhou et al.	2022	*New Technique for Detecting Cracked Teeth and Evaluating the Crack Depth by Contrast-enhanced CBCT*	Experimental study (In vitro)	31 cracked teeth	China

Table 3: *Data extraction from selected reports after PRISMA (n = 18).*

4.3. Results tables

Article	Methodology	Results	Conclusion
Caryl E. Cameron [1] - *Case series*	▪ 50 cracked teeth, with patient history evaluations and microscopic examination. ▪ Sectioning and staining techniques were used to assess crack depth and extent.	▪ Cracks were most common in mandibular second molars. ▪ Higher prevalence over 35 years old. ▪ Most frequent symptom: pain on chewing pressure, thermal sensitivity. ▪ Cracks often linked to large restorations (amalgam fillings).	▪ Importance of early diagnosis of CTS. ▪ Symptoms like chewing discomfort and thermal sensitivity can indicate underlying fractures. ▪ Preventive full-coverage restorations (crowns), can help protect vulnerable teeth from further damage.
Hilton et al. [4] – *Observational study (practice-based research)*	▪ 2,975 cracked teeth collected. ▪ The study included data at patient, tooth, and crack level to identify characteristics featured in cracked teeth symptomatology. ▪ Statistical analyses (associations between variables).	▪ Cracked teeth were more likely to be symptomatic in patients with clenching or grinding (OR: 1.30). ▪ Cracks that blocked transilluminated light were also associated with symptoms (OR: 1.31), while stained cracks were negatively associated with symptoms (OR: 0.68).	▪ High frequency of symptoms in molars with distal crack that blocked transilluminated light (patients with clenching/grinding habits). ▪ Stained cracks were less likely to be symptomatic.

***Table 4:** Results table 1 out of 9.*

Article	Methodology	Results	Conclusion
Ferracane et al. [3] - *Prospective cohort study*	▪ 2,858 patients with cracked teeth. ▪ Assessment of symptoms, crack progression, and treatment outcomes.	▪ Found that only 3% of cracked teeth fractured, and 12% showed crack progression. ▪ Most symptomatic teeth improved over time, and treatment was mostly done with crowns. ▪ Only 14% of treated teeth required retreatment.	▪ Concluded that clinicians are generally good at determining which teeth need treatment. ▪ Conservative approach is often warranted, with full crowns being the most effective treatment for long-term survival.
Ricucci et al. [11] - *Experimental study (in vitro)*	▪ 20 extracted teeth (12 with cracks, 8 with severe attrition) using histopathology and histobacteriology. ▪ Light microscopy and bacterial staining to assess dentin and pulp conditions.	▪ Found that all cracks were colonized by bacterial biofilms, with bacterial invasion of dentinal tubules leading to pulp inflammation and necrosis. ▪ Crack location and direction influenced the severity of pulp reactions.	▪ Concluded that bacterial infiltration plays a key role in pulp pathology of cracked teeth.

Table 5*: Results table 2 out of 9.*

Article	Methodology	Results	Conclusion
Jun et al. [14] **–** *Experimental study (in vitro)*	▪ Quantitative light-induced fluorescence (QLF) to detect enamel cracks in 96 extracted human teeth. ▪ Analyzed cracks using fluorescence imaging and histologic evaluation.	▪ Strong correlation between QLF fluorescence loss and enamel crack depth (CC = 0.84). ▪ QLF-D demonstrated high sensitivity (0.87–0.90) and specificity (0.98–1.00) in detecting enamel cracks.	▪ Concluded that QLF-D is a reliable, non-destructive method for diagnosing enamel cracks. ▪ Early crack detection using fluorescence technology could help prevent tooth fractures and improve treatment outcomes.
Sh et al. [15] **-** *Experimental study*	▪ Investigated the reliability of optical coherence tomography (OCT) for detecting cracked teeth. ▪ Compared OCT with visual inspection, transillumination, and micro-computed tomography in 61 extracted teeth.	▪ Found that OCT detected 65.1% of crack lines, compared to 52.3% with transillumination and 47.4% with visual inspection. ▪ OCT was more sensitive in detecting structural cracks and differentiating them from craze lines.	▪ Concluded that OCT is a highly effective, non-invasive diagnostic tool for detecting CTS. ▪ Suggested that OCT can improve early diagnosis and guide treatment planning, potentially reducing unnecessary interventions.

***Table 6**: Results table 3 out of 9.*

Article	Methodology	Results	Conclusion
Yang et al. [17] – *Prospective clinical study*	▪ Effectiveness of the Tooth Slooth in 46 patients with cracked teeth. ▪ Patients performed bite tests using wet cotton rolls and the Tooth Slooth. ▪ Pain responses were recorded and analyzed.	▪ The relevance ratio of biting pain with the Tooth Slooth was 91.3%, significantly higher than with wet cotton rolls (32.6%).	▪ Concluded that the Tooth Slooth is a more effective tool for reproducing biting pain and diagnosing CTS compared to wet cotton rolls. ▪ Recommended its use for early detection to prevent crack progression and avoid misdiagnosis.
Zhou et al. [18] - *Experimental study (In vitro)*	▪ Developed an artificial cracked tooth model (n=31) and compared the effectiveness of pre-experimental CBCT, contrast-enhanced CBCT, and micro-CT for detecting cracks and assessing crack depth + statistical analyses.	▪ Sensitivity of contrast-enhanced CBCT (67.7%) was higher than pre-CBCT (48.4%). ▪ The ICC between contrast-enhanced CBCT and micro-CT was 0.753, indicating good consistency.	▪ Concluded that contrast-enhanced CBCT improves crack detection but is not reliable for measuring crack depth. ▪ Recommended further refinement of CBCT imaging techniques to enhance clinical applicability.

***Table 7**: Results table 4 out of 9.*

Article	Methodology	Results	Conclusion
Alkhalifah et al. [19] – *Cross-sectional study*	▪ Survey of 95 dental practitioners in Kuwait. ▪ Evaluation of 5 different cracked tooth scenarios and selected their preferred treatment approaches. ▪ Statistical analysis was performed to compare decision-making patterns.	▪ Found large variations in treatment choices. ▪ Endodontists were significantly more likely to recommend crowning asymptomatic cracked teeth than general practitioners ($p = 0.032$). ▪ Extraction was preferred by general practitioners in severe cases ($p = 0.048$).	▪ Concluded that despite suggested guidelines, treatment decisions vary widely among practitioners. ▪ Highlighted the need for evidence-based guidelines and further research on the long-term prognosis of different treatment approaches.
David et Shariff [20] – *Cohort study*	▪ 70 cracked teeth with radicular extensions treated with RCT and full-coverage restorations. ▪ Evaluated survival and success over a 2- to 4-year period.	▪ Found a 100% survival rate in the first 2 years and 96.6% survival up to 4 years. ▪ Success rate was 90.6%, with no significant impact from pocketing, crack depth, or marginal ridge involvement.	▪ It was determined that cracked teeth with radicular extensions have a more favorable prognosis than previously believed.

***Table 8**: Results table 5 out of 9.*

Article	Methodology	Results	Conclusion
Alaugaily & Azim [21] - *Cross-sectional study*	▪ 95 patients with cracked teeth or vertical root fractures (VRF) using clinical and radiographic data. ▪ Statistical tests (Chi-square, Fisher's exact test).	▪ CBCT had 4.4 times higher odds of detecting bony defects compared to PA radiographs. ▪ Cracked teeth were linked to shallow probing (<6 mm), direct restorations, and angular defects on CBCT. ▪ VRFs were associated with deep probing (>6 mm), indirect restorations, J-shaped defects on CBCT, and cortical plate loss.	▪ Concluded that CBCT imaging patterns can differentiate cracked teeth from VRFs. ▪ Recommended CBCT as a diagnostic tool for preclinical detection, with angular defects suggesting cracked teeth and J-shaped defects indicating VRFs.
Chen et al. [22] – *Cross-sectional study*	▪ 62 cracked teeth (with endodontic treatment). ▪ Evaluated clinical symptoms, radiographic findings, and restoration type. ▪ Statistical analysis: chi-square and Fisher's exact tests.	▪ Overall success rate was 75.8% at a mean follow-up of 23.3 months. ▪ Teeth with full-coverage restorations had a 93.6% success rate, while those without proper restoration had only 20% success.	▪ Concluded that full-coverage restorations are crucial for long-term success in endo treated cracked teeth. ▪ Recommended avoiding posts when possible and emphasized early intervention to prevent progression and failure.

***Table 9**: Results table 6 out of 9.*

Article	Methodology	Results	Conclusion
Fong et al. [23] – *Cross-sectional study*	▪ Survey among Australian dentists to assess their diagnostic methods and treatment preferences for cracked posterior teeth. ▪ Statistical tests: Chi-square, Fisher's exact test	▪ 56.8% preferred indirect cuspal-coverage restorations for asymptomatic cracked teeth. ▪ 64.9% favored direct composite restorations for cold-sensitive teeth, while 36.8% used orthodontic bands for teeth with biting pain. ▪ 46.8% recommended extraction if root canal-treated teeth had a 5 mm probing depth.	▪ Concluded that Australian dentists varied significantly in diagnosing and treating cracked teeth. ▪ Need for standardized guidelines and further clinical research into crack progression, biomechanics, and optimal treatment strategies.
Krell et Caplan [24] – *Retrospective cohort study*	▪ 2086 cracked teeth. ▪ Assessed 12-month success of root canal-treated cracked teeth and developed a prognostic index. ▪ Used multivariable regression analysis.	▪ Among the 363 teeth analyzed, 82% were successful after 1 year. ▪ The most significant risk factors for failure were probing depths ≥5 mm, distal marginal ridge cracks, and severe periapical diagnosis.	▪ Concluded that cracked teeth treated with RCT can have a higher success rate than previously reported. ▪ Introduced the Iowa Staging Index as a prognostic tool for treatment planning and patient counseling.

Table 10: *Results table 7 out of 9.*

Article	Methodology	Results	Conclusion
Nuamwisudhi & Jearanaiphaisarn [25] – *Cross-sectional study*	▪ 56 patients with 135 cracked teeth. ▪ Questionnaires to assess oral functional behaviors. ▪ Microscopic examination: methylene blue staining to detect cracks and analyzed intraoral parameters. ▪ Statistical analysis: linear and binary logistic regression.	▪ Eating hard food was significantly correlated with posterior cracked teeth ($p < 0.05$). ▪ Molars with occlusal restorations and steep cuspal inclinations were more likely to develop cracks. ▪ Distolingual cusp inclination was a significant predictor for molar cracks, and lingual cusp inclination for premolars.	▪ Concluded that dietary habits, steep cuspal inclinations, and occlusal restorations are risk factors for cracked teeth. ▪ Recommended modifying occlusal surfaces and considering restorations that preserve tooth structure to reduce crack formation.
Shi et al. [26] - *Experimental study (In vitro)*	▪ Finite element analysis (FEA) and fracture failure test on maxillary first premolars. ▪ Tested different restorations: crowns, onlays, fiber-reinforced composites (FRCs), and combinations.	▪ The annular ribbond + crown group: higher fracture resistance than crown-only group. ▪ The annular ribbond + onlay group: more favorable fracture than crown group.	▪ Concluded that fiber-reinforced composites and onlays improve fracture resistance in cracked teeth compared to traditional crown restorations. ▪ Recommended combining fiber-reinforced materials with onlays or crowns to enhance tooth survival.

Table 11: *Results table 8 out of 9.*

Article	Methodology	Results	Conclusion
Yuan et al. [27] – *Experimental study (In vitro)*	▪ 24 artificially cracked teeth. ▪ Comparing routine CBCT (RS) and contrast-enhanced CBCT (ES) with Meglumine Diatrizoate (MD) as a contrast agent. ▪ Evaluated crack detection accuracy with two observers (student/professional). ▪ Statistical analysis: McNemar's test and kappa analysis.	▪ Accuracy of crack detection improved from 23% (RS) to 61% (ES) for the student and 32% (RS) to 65% (ES) for the radiologist.	▪ Concluded that MD-enhanced CBCT significantly improves crack detection compared to routine scanning. ▪ Suggested that contrast agents could be a valuable addition to CBCT imaging for diagnosing cracked teeth in clinical settings.
Zhao et al. [8] – *Prospective clinical study (follow-up study)*	▪ 27 cracked teeth from 24 patients with cold and/or biting pain. ▪ Restored teeth with lithium disilicate occlusal veneers and followed up for an average of 22.4 months. ▪ Assessed pain relief, masticatory ability, survival rates. Kaplan-Meier analysis.	▪ The 12-month pulp survival rate was 92.6%, and the tooth survival rate was 100%. ▪ Pain completely disappeared in all cases except two that developed pulpitis.	▪ Concluded that occlusal veneer restorations are a minimally invasive and effective option for treating cracked teeth, offering high survival and success rates. ▪ Recommended for cases where cracks involve enamel and dentin but not the pulp.

Table 12*: Results table 9 out of 9.*

5. DISCUSSION

5.1. Outline

Since Cameron's establishment of the "Cracked tooth syndrome" (CTS) in 1964, many researchers and practitioners have made breakthroughs to better understand this quite unfamiliar condition. CTS remain a significant challenge nowadays due to the difficulty of diagnosis of cracks and the variability of patients' symptoms. Mastering our knowledge about CTS is crucial in a way that it can enhance our therapeutic decision when facing a patient with cracked teeth.

This study aimed to critically evaluate effectiveness and reliability current diagnostic methods in patients affected by CTS, to assess the possible causes leading to CTS and establish treatment options in adequation with the type of cracks previously diagnosed.

The results obtained through this study brought primary evidence to evaluate diagnostic tools used, multifactorial etiology of this condition and the importance of the therapeutic decision on the long-term outcome.

5.2. Evaluation of diagnostic methods for cracked tooth syndrome

5.2.1. Traditional diagnostic methods and their limits

Traditional diagnostic methods to assess cracks are a range of techniques and tools such as visual examination and under optic microscopy (with or without methylene blue dye), bite tests or transillumination. These techniques are quite common and of simple use to confirm the presence of cracks but become quickly inadequate when it comes to assess their extension and depth.

5.2.1.1. Tooth Slooth®

Roma et al. (2020) stated that bite tests were useful in identifying CTS, especially when pain was experienced upon pressure release considering it as a pathognomonic feature of CTS **[28]**. *Yang et al. (2019)* described the use of the Tooth Slooth® (**Figure 5b**) which can reproduce pain upon releasing pressure **[17]**. In their study, they concluded that the Tooth Slooth® was more effective than wet cotton rolls in cracks detection (**Table 7**). However, according to *Roma et al.*, while being effective in identifying symptomatic teeth, it does not give us any information about the crack depth and direction **[28]**.

5.2.1.2. Transillumination

According to *Olivieri et al. (2020)* and *Roma et al. (2020)*, fiber optic transillumination (FOTI) enhances the visibility of the crack, however, most of them being craze lines (not requiring intervention), they can lead to potential misdiagnosis **[28,29]**. In addition, FOTI enhances the visibility of cracks but is unable to differentiate craze lines form deeper structural cracks **[2]**.

5.2.1.3. Methylene blue staining and optic microscopy

According to *Zhou et al. (2022)*, methylene blue dye staining is an undeniable aid in crack visualization, although their main concern was the false positives that may be generated **[18]**. By combining methylene blue dye and an optic microscope we can reduce the potential false positives generated, as magnification allows us to better analyze cracks characteristics **[27]**. Ultimately, *Li et al. (2021)* suggested that the use of operating microscope with a magnification of 14x to 18x was the most reliable approach for early stage crack detection and helping to differentiate superficial cracks from structural cracks **[13]**.

5.2.2. Imaging techniques

5.2.2.1. Cone-beam computed tomography (CBCT)

Radiographic tests are essential in assessing and visualizing cracks with cone-beam computed tomography (CBCT) being, nowadays, the most used tool. CBCT provides a three-dimensional image giving us a more accurate idea of deep cracks, particularly for vertical root fracture and periapical lesions **[16]**. Nonetheless, the resolution of CBCT is limited in detecting fine enamel cracks **[18]**, by extension, failing in detecting early stages of CTS (**Table 7**). The studies from *Yuan et al. (2020)* revealed that using meglumine diatrizoate (MD), a radiopaque contrast agent, more cracks were detected by CBCT compared to routine CBCT (**Table 12**), also giving more accurate information on depth and direction of cracks **[27]**. According to *Gonzalez-Guajardo et al. (2021)*, CBCT was unreliable in case of appearance of artefacts, such as motion, or human interpretation errors, that could compromise the diagnostic accuracy **[6]**.

5.2.2.2. Micro-computed tomography (Micro-CT)

Micro-computed tomography offers a significantly higher resolution than CBCT and is considered as the gold standard for microcracks detection **[18]**. According to *Guo et al. (2022)*, its clinical application is limited due to high radiation exposure to the patient and high cost **[16]**.

5.2.2.3. Optical coherence tomography (OCT)

Optical coherence tomography is a non-invasive technique used in CTS diagnosis. This technique consists in Its main feature is that technique allows us to detect subsurface cracks up to 3mm deep, making it a good alternative to detect early-stage cracks **[15]**. Indeed, *Sh et al. (2016)* have found that OCT detected 65.1% of crack lines, compared to 52.3% with transillumination and 47.4% with visual inspection (**Table 6**).

5.2.2.4. Quantitative laser-induced fluorescence (QLF)

QLF employs a non-invasive approach by utilizing the autofluorescence of teeth under visible blue-light irradiation (405 nm), which can identify and quantify enamel cracks through the analysis of fluorescence loss **[14]**. In **Table 6**, the results obtain by *Jun et al.* show that QLF is surpassing traditional methods such as transillumination, methylene blue staining, and CBCT imaging, when focusing on fine enamel cracks. Furthermore, QLF provides objective quantification of crack severity, potentially aiding clinicians in treatment decisions. However, QLF's clinical implementation remains limited, largely due to potential interferences caused by composite restorations, staining, or dental plaque, which can alter fluorescence readings and compromise accuracy **[14,18]**.

5.2.3. Artificial intelligence and emerging technologies

Artificial intelligence (AI) is an emerging powerful regarding dental diagnosis and probably will be a key feature in CTS. As we have seen before, the complexity of CTS remains in the difficulty of early detection, the ambivalent symptomatology and the boundaries of traditional methods **[2,12,16]**. According to *Guo et al.*, recent studies emphasize on AI-driven diagnostic imaging, particularly on convolutional neural networks (CNNs), the ultimate goal being to have the highest sensitivity and specificity achievable when applied to CBCT or OCT **[16]**. AI does not only improve detection of cracks but also accurately assess depth and direction of cracks which is a critical feature in determining tooth prognosis and by extension, the adequate treatment **[6,16,23]**. Thanks to AI, we will probably manage to enhance our clinical decision-making, minimizing unnecessary tooth loss and being able to tackle CTS at its core.

5.3. Causes and risk factors for cracked tooth syndrome

5.3.1. Occlusal and mechanical factors

Excessive occlusal loads, commonly generated by parafunctional habits such as bruxism, clenching, and other repetitive stresses, significantly contribute to cumulative microdamage within dental structures **[1]**. These microfractures may progressively extend, resulting in clinically detectable cracks **[2,9]**. Molars and premolars, located proximally to the temporomandibular joint, experience particularly intense occlusal forces, further increasing their susceptibility to fractures. The repeated nature of parafunctional activities, especially teeth grinding, exacerbates microstructural deterioration and enhances fracture propagation **[5,10]**.

5.3.2. Restorative and endodontic influences

Significant restorative interventions, including large amalgam or composite fillings **[1]** and full-crown restorations, critically weaken tooth integrity by disrupting natural stress distribution patterns, which predisposes teeth to structural failure **[7,26]**. Teeth undergoing endodontic treatments are particularly at risk due to extensive dentin removal, canal enlargement, and subsequent post-placement **[24]**. These procedures substantially alter the biomechanical properties of dentin, particularly decreasing its elasticity and moisture content, thus increasing fracture susceptibility under functional loads **[24,30]**. Krell and Caplan established the Iowa Staging Index as a tool to assess prognosis of such cases (**Table 10**).

5.3.3. Age-related and anatomical factors

Age significantly affects the risk of CTS, predominantly impacting individuals between the ages of 40 and 60 **[13]**. Aging-related structural modifications of dental tissues, particularly increased brittleness and reduced dentinal resilience, facilitate crack initiation and propagation even under normal functional stresses **[8,13]**. Anatomically, mandibular molars exhibit an increased predisposition to fractures, given their unique position, complex occlusal morphology, and high exposure to chewing forces. Maxillary premolars and molars similarly demonstrate an elevated risk profile, attributable to the intricacy of their occlusal surfaces and directional occlusal forces experienced during mastication **[2,28]**.

5.3.4. Iatrogenic contributions

Aggressive cavity preparations, inappropriate restorative techniques, improper handling of endodontic instruments, and unsuitable material selections are primary contributors to structural weakening of the tooth. These procedural errors frequently create stress concentrations and exacerbate existing microfractures within the dental structure. Hence, meticulous attention to operative techniques, along with judicious selection and application of restorative materials, are essential preventive strategies to minimize iatrogenic damage and subsequent crack propagation **[3,5,26,30]**.

5.3.5. Thermal and environmental stressors

Repeated exposure to temperature extremes, characteristic of certain dietary habits involving hot and cold substances, induces cyclic expansion and contraction of enamel and dentin. This thermal cycling generates stress concentrations and initiates microcracking processes within the tooth structure. Experimental findings support the hypothesis that thermal cycling notably accelerates the formation and propagation of dental cracks, highlighting the importance of managing environmental stressors in preventive dentistry **[12,18]**.

5.3.6. Challenges and advances in diagnosis

Accurately diagnosing cracked tooth syndrome remains challenging due to its subtle and varied clinical presentation. Initial cracks may manifest inconsistently and transiently, complicating early detection through conventional examination methods including visual inspection, palpation, and traditional radiography **[14,17]**. Recent advancements in imaging modalities, such as optical coherence tomography (OCT), quantitative laser-induced fluorescence (QLF), and contrast-enhanced cone-beam computed tomography (CBCT), offer enhanced diagnostic precision. These technologies significantly improve the clinician’s ability to detect subtle fractures, determine their extent, and effectively plan subsequent management strategies **[15,18,27]**.

5.4. Treatment alternatives for different types of cracks

5.4.1. Conservative approach

For craze lines and superficial enamel cracks, no active treatment is usually required. These cracks are commonly asymptomatic and do not extend into the dentin or pulp **[13]**. However, periodic monitoring is necessary, particularly in patients with parafunctional habits such as bruxism **[25]**. In some cases, occlusal adjustments may help prevent further crack propagation **[8]**.

Resin infiltration and adhesive sealants have been explored as potential treatment options for superficial cracks. These materials provide a mechanical barrier against bacterial penetration and reduce crack progression **[2]**. However, their long-term effectiveness remains questionable, and more clinical studies are required to validate their success.

5.4.2. Direct restorations

When cracks extend beyond the enamel into the dentin but remain confined to the crown, direct composite restorations or bonded amalgam fillings are commonly used. Studies show that resin-based composites can reduce stress concentration at the crack site and improve fracture resistance **[26]**.

Fiber-reinforced composites (FRCs) have emerged as a promising treatment option. *Shi et al.* demonstrated that fiber-reinforced composites combined with onlay restorations (**Table 11**) significantly improved fracture resistance and reduced the risk of crack propagation **[26]**.

However, direct restorations may not be effective in cases with deep dentin involvement. A meta-analysis published by *Olivieri et al.* showed that endodontically treated cracked teeth restored with direct fillings had a higher failure rate than those treated with crowns **[29]**.

5.4.3. Indirect restorations

5.4.3.1 <u>Onlays and occlusal veneers</u>

For moderate cracks extending into the dentin but without pulpal involvement, onlays and occlusal veneers are preferred over full crowns to preserve tooth structure **[8]**. The clinical study by *Zhao et al.* consisted in a 22.4-month follow-up and showed more than 90% success rate for occlusal veneers in treating cracked teeth (**Table 12**).

5.4.3.2 Full crowns

For extensive cracks with high risk of propagation, full-coverage crowns remain the gold standard. Crowns distribute occlusal forces more evenly and provide a hoop reinforcement effect, reducing the risk of further crack progression **[5]**. A study by *Roma et al*., showed that teeth restored with full crowns had a significantly lower incidence of fracture propagation compared to those with direct restorations **[28]**. However, excessive tooth preparation for full crowns may lead to additional weakening of the remaining tooth structure .

5.4.4. Prognosis

According to *Li et al.,* superficial cracks generally have an excellent prognosis and require minimal intervention **[13]**. Cracks confined to the dentin have a moderate prognosis, with survival rates improving significantly when reinforced with bonded restorations **[26]**. Cracks extending into the pulp or root have a poor prognosis, particularly if periodontal pocketing is present **[11]**.

Vital cracked teeth treated with crowns or onlays have high survival rates, exceeding 80-90% at five years **[8]**. Endodontically treated cracked teeth have lower survival rates; a success rate of 82% at one year, decreasing with time **[29]**. According to *Son et al.*, cracked teeth with pulpal necrosis requiring RCT are at higher risk of vertical fracture and extraction **[5]**.

Cracks associated with localized periodontal pocketing (>6 mm) are a strong predictor of poor prognosis. However, if periodontal status is stable, survival rates are comparable to non-cracked teeth **[5,20]**.

6. CONCLUSIONS

- The main goal of this study was to evaluate the effectiveness and reliability of current diagnostic methods for Cracked Tooth Syndrome (CTS). Traditional approaches such as visual inspection, transillumination, and bite tests remain useful but lack precision in detecting microcracks and assessing crack depth. CBCT and contrast-enhanced CBCT improve subgingival crack detection but have resolution limitations in superficial cracks detections, while optical coherence tomography (OCT) shows potential but is not widely available. As a result, no single technique seemed to be enough to diagnose with accuracy CTS, but rather a multimodal approach combining clinical examination, functional tests, and advanced imaging provides the best diagnostic accuracy. However, early detection is key to preventing crack progression (location, depth and extension) allowing to plan effective treatment.

- In accordance with our secondary objective, this study identified occlusal forces, parafunctional habits, and restorative procedures as key contributors to CTS. Factors such as bruxism, heavy mastication, high cuspal inclination and thermal cycling increase crack formation, while large or non-bonded restorations weaken tooth structure, making them more susceptible to fractures. Since CTS is multifactorial, early identification of high-risk patients through occlusal analysis and preventive strategies (including adjustments, splints, and conservative restorations) is crucial for minimizing crack progression and improving long-term tooth survival.

- Eventually, this study showed treatment options adapted to different types of cracks in CTS, emphasizing a case-specific approach based on crack severity, location, and depth (pulpal involvement). Superficial enamel cracks require only monitoring or minimal intervention, while dentin-level cracks benefit from fiber-reinforced composites, onlays, or occlusal veneers to prevent propagation. Extensive cracks reaching the pulp often necessitate root canal therapy followed by full-coverage crowns, whereas radicular cracks with periodontal involvement have a poor prognosis, often requiring extraction. A combined diagnostic approach is fundamental for selecting the most appropriate treatment, improving long-term outcomes, and preserving tooth structure whenever possible.

7. SUSTAINABILITY

The sustainability of this study about Cracked Tooth Syndrome (CTS) is directly linked to economic, environmental, and social factors in modern dental practice.

Economically, early diagnosis and minimally invasive treatment reduce the financial burden on patients by preventing extensive procedures such as root canal treatment or extractions. Investing in preventive care, occlusal adjustments, and conservative restorations promotes cost-effective, long-term oral health solutions.

From an environmental perspective, the integration of advanced diagnostic tools (e.g., optical coherence tomography, contrast-enhanced CBCT) can minimize unnecessary radiation exposure and material waste associated with over-treatment. Moreover, biocompatible and recyclable dental materials, such as fiber-reinforced composites, contribute to reducing the environmental footprint of dental restorations.

Socially, improving diagnostic accuracy and access to preventive care can enhance oral health equity, particularly in underprivileged populations. Raising awareness of occlusal health and parafunctional habits can lead to better long-term oral health, reducing the need for complex treatments. Ethical and evidence-based approaches to CTS management align with sustainability principles, ensuring that dental care remains accessible, efficient, and environmentally responsible.

8. REFERENCES

[1] Cameron CE. CRACKED-TOOTH SYNDROME. J Am Dent Assoc 1939 1964;68:405–11. https://doi.org/10.14219/jada.archive.1964.0108.

[2] Mamoun JS, Napoletano D. Cracked tooth diagnosis and treatment: An alternative paradigm. Eur J Dent 2015;9:293–303. https://doi.org/10.4103/1305-7456.156840.

[3] Ferracane JL, Hilton TJ, Funkhouser E, National Dental Practice–Based Research Network Collaborative Group. Lessons learned from the Cracked Tooth Registry: A 3-year clinical study in the Nation's Network. J Am Dent Assoc 1939 2023;154:235–44. https://doi.org/10.1016/j.adaj.2022.11.020.

[4] Hilton TJ, Funkhouser E, Ferracane JL, Gilbert GH, Baltuck C, Benjamin P, et al. Correlation between symptoms and external characteristics of cracked teeth: Findings from The National Dental Practice-Based Research Network. J Am Dent Assoc 2017;148:246-256.e1. https://doi.org/10.1016/j.adaj.2016.12.023.

[5] Son M, Quintela L, Pryles RL, Blicher B. Saving Cracked Teeth: The Current State of Evidence. Compend Contin Educ Dent Jamesburg NJ 1995 2024;45:306–10.

[6] Gonzalez-Guajardo DI, Ramirez-Herrera GM, Mas-Enriquez A, Capetillo-Hernandez GR, Tiburcio-Morteo L, Cabral-Romero C, et al. Cracked tooth syndrome, an update. Int J Appl Dent Sci 2021;7:314–7. https://doi.org/10.22271/oral.2021.v7.i2e.1226.

[7] Kang SH, Kim BS, Kim Y. Cracked Teeth: Distribution, Characteristics, and Survival after Root Canal Treatment. J Endod 2016;42:557–62. https://doi.org/10.1016/j.joen.2016.01.014.

[8] Zhao W, Luo J, Zhang S, Zhang Z, Su Z, Fu B, et al. Occlusal veneer restoration treatment outcomes of cracked tooth syndrome: A 22.4-month follow-up study. Clin Oral Investig 2024;28:368. https://doi.org/10.1007/s00784-024-05735-x.

[9] Korkut B, Bayraktar ET, Tağtekin D, Çolak H, Özcan M. Cracked Tooth Syndrome and Strategies for Restoring. Curr Oral Health Rep 2023;10:212–22. https://doi.org/10.1007/s40496-023-00352-1.

[10] Keith V. Krell. Cracked Teeth and Vertical Root Fractures: A New Look at a Growing Problem. Am Assoc Endodontists 2022. https://www.aae.org/specialty/newsletter/22938/.

[11] Ricucci D, Siqueira JF, Loghin S, Berman LH. The cracked tooth: histopathologic and histobacteriologic aspects. J Endod 2015;41:343–52. https://doi.org/10.1016/j.joen.2014.09.021.

[12] Longridge NN, Youngson CC. Dental Pain: Dentine Sensitivity, Hypersensitivity and Cracked Tooth Syndrome. Prim Dent J 2019;8:44–51. https://doi.org/10.1177/205016841900800101.

[13] Li F, Diao Y, Wang J, Hou X, Qiao S, Kong J, et al. Review of Cracked Tooth Syndrome: Etiology, Diagnosis, Management, and Prevention. Pain Res Manag 2021;2021:3788660. https://doi.org/10.1155/2021/3788660.

[14] Jun M-K, Ku H-M, Kim E, Kim H-E, Kwon H-K, Kim B-I. Detection and Analysis of Enamel Cracks by Quantitative Light-induced Fluorescence Technology. J Endod 2016;42:500–4. https://doi.org/10.1016/j.joen.2015.12.008.

[15] Sh L, Jj L, Hj C, Jt P, Hj K. Dental optical coherence tomography: new potential diagnostic system for cracked-tooth syndrome. Surg Radiol Anat SRA 2016;38. https://doi.org/10.1007/s00276-015-1514-8.

[16] Guo J, Wu Y, Chen L, Long S, Chen D, Ouyang H, et al. A perspective on the diagnosis of cracked tooth: imaging modalities evolve to AI-based analysis. Biomed Eng Online 2022;21:36. https://doi.org/10.1186/s12938-022-01008-4.

[17] Yang Y, Chen G, Hua F, Yu Q, Yang W. Biting pain reproduced by the Tooth Slooth: an aid for early diagnosis of cracked tooth. Quintessence Int Berl Ger 1985 2019;50:82–7. https://doi.org/10.3290/j.qi.a41498.

[18] Zhou J, Fu J, Xiao M, Qiao F, Fu T, Lv Y, et al. New technique for detecting cracked teeth and evaluating the crack depth by contrast-enhanced cone beam computed tomography: an in vitro study. BMC Oral Health 2022;22:48. https://doi.org/10.1186/s12903-022-02085-6.

[19] Alkhalifah S, Alkandari H, Sharma PN, Moule AJ. Treatment of Cracked Teeth. J Endod 2017;43:1579–86. https://doi.org/10.1016/j.joen.2017.03.029.
[20] Davis MC, Shariff SS. Success and Survival of Endodontically Treated Cracked Teeth with Radicular Extensions: A 2- to 4-year Prospective Cohort. J Endod 2019;45:848–55. https://doi.org/10.1016/j.joen.2019.03.015.
[21] Alaugaily I, Azim AA. CBCT Patterns of Bone Loss and Clinical Predictors for the Diagnosis of Cracked Teeth and Teeth with Vertical Root Fracture. J Endod 2022;48:1100–6. https://doi.org/10.1016/j.joen.2022.06.004.
[22] Chen Y-T, Hsu T-Y, Liu H, Chogle S. Factors Related to the Outcomes of Cracked Teeth after Endodontic Treatment. J Endod 2021;47:215–20. https://doi.org/10.1016/j.joen.2020.11.024.
[23] Fong J, Tan A, Ha A, Krishnan U. Diagnostic and treatment preferences for cracked posterior teeth. Aust Dent J 2023;68:135–43. https://doi.org/10.1111/adj.12959.
[24] Krell KV, Caplan DJ. 12-month Success of Cracked Teeth Treated with Orthograde Root Canal Treatment. J Endod 2018;44:543–8. https://doi.org/10.1016/j.joen.2017.12.025.
[25] Nuamwisudhi P, Jearanaiphaisarn T. Oral Functional Behaviors and Tooth Factors Associated with Cracked Teeth in Asymptomatic Patients. J Endod 2021;47:1383–90. https://doi.org/10.1016/j.joen.2021.05.012.
[26] Shi R, Meng X, Feng R, Hong S, Hu C, Yang M, et al. Stress Distribution and Fracture Resistance of repairing Cracked Tooth with Fiber-reinforced Composites and Onlay. Aust Endod J J Aust Soc Endodontology Inc 2022;48:458–64. https://doi.org/10.1111/aej.12578.
[27] Yuan M, Gao AT, Wang TM, Liang JH, Aihemati GB, Cao Y, et al. Using Meglumine Diatrizoate to improve the accuracy of diagnosis of cracked teeth on Cone-beam CT images. Int Endod J 2020;53:709–14. https://doi.org/10.1111/iej.13270.
[28] Roma M, Hegde S, Mallya PL, Chitra. Criteria For Management of Cracked Tooth Syndrome: A Review. J Int Dent Med Res 2020;13:1198–203.
[29] Olivieri JG, Elmsmari F, Miró Q, Ruiz X-F, Krell KV, García-Font M, et al. Outcome and Survival of Endodontically Treated Cracked Posterior Permanent Teeth: A Systematic Review and Meta-analysis. J Endod 2020;46:455–63. https://doi.org/10.1016/j.joen.2020.01.006.
[30] Leong DJX, de Souza NN, Sultana R, Yap AU. Outcomes of endodontically treated cracked teeth: a systematic review and meta-analysis. Clin Oral Investig 2020;24:465–73. https://doi.org/10.1007/s00784-019-03139-w.

9. ANNEXES

Figure 6: PRISMA 2000 Flow diagram - Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n7.

The PRISMA 2020 statement: an updated guideline for reporting systematic reviews

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The Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement, published in 2009, was designed to help systematic reviewers transparently report why the review was done, what the authors did, and what they found. Over the past decade, advances in systematic review methodology and terminology have necessitated an update to the guideline. The PRISMA 2020 statement replaces the 2009 statement and includes new reporting guidance that reflects advances in methods to identify, select, appraise, and synthesise studies. The structure and presentation of the items have been modified to facilitate implementation. In this article, we present the PRISMA 2020 27-item checklist, an expanded checklist that details reporting recommendations for each item, the PRISMA 2020 abstract checklist, and the revised flow diagrams for original and updated reviews.

SUMMARY POINTS

To ensure a systematic review is valuable to users, authors should prepare a transparent, complete, and accurate account of why the review was done, what they did, and what they found

The PRISMA 2020 statement provides updated reporting guidance for systematic reviews that reflects advances in methods to identify, select, appraise, and synthesise studies

The PRISMA 2020 statement consists of a 27-item checklist, an expanded checklist that details reporting recommendations for each item, the PRISMA 2020 abstract checklist, and revised flow diagrams for original and updated reviews

We anticipate that the PRISMA 2020 statement will benefit authors, editors, and peer reviewers of systematic reviews, and different users of reviews, including guideline developers, policy makers, healthcare providers, patients, and other stakeholders

Systematic reviews serve many critical roles. They can provide syntheses of the state of knowledge in a field, from which future research priorities can be identified; they can address questions that otherwise could not be answered by individual studies; they can identify problems in primary research that should be rectified in future studies; and they can generate or evaluate theories about how or why phenomena occur. Systematic reviews therefore generate various types of knowledge for different users of reviews (such as patients, healthcare providers, researchers, and policy makers).[1 2] To ensure a systematic review is valuable to users, authors should prepare a transparent, complete, and accurate account of why the review was done, what they did (such as how studies were identified and selected) and what they found (such as characteristics of contributing studies and results of meta-analyses). Up-to-date reporting guidance facilitates authors achieving this.[3]

The Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement published in 2009 (hereafter referred to as PRISMA 2009)[4-10] is a reporting guideline designed to address poor reporting of systematic reviews.[11] The PRISMA 2009 statement comprised a checklist of 27 items recommended for reporting in systematic reviews and an "explanation and elaboration" paper[12-16] providing additional reporting guidance for each item, along with exemplars of reporting. The recommendations have been widely endorsed and adopted, as evidenced by its co-publication in multiple journals, citation in over 60 000 reports (Scopus, August 2020), endorsement from almost 200 journals and systematic review organisations, and adoption in various disciplines. Evidence from observational studies suggests that use of the PRISMA 2009 statement is associated with more complete reporting of systematic reviews,[17-20] although more could be done to improve adherence to the guideline.[21]

Many innovations in the conduct of systematic reviews have occurred since publication of the PRISMA 2009 statement. For example, technological advances have enabled the use of natural language processing and machine learning to identify relevant evidence,[22-24] methods have been proposed to