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Cracked Tooth Syndrome and Strategies for Restoring

Bora Korkut[1] · **Ezgi Tüter Bayraktar**[1] · **Dilek Tağtekin**[1] · **Hakan Çolak**[2] · **Mutlu Özcan**[3]

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Abstract

Purpose of Review The restorative management of cracked tooth syndrome (CTS) is very complex and depends on the pre-restorative diagnosis and decisions. This review discusses the strategies for restoring teeth with CTS and suggests a related clinical decision tree.

Recent Findings CTS is the incomplete fracture of the natural tooth crown. Preparation type and direct/indirect restorative protocol choices are the important factors effecting the prognosis of the tooth while multi-factorial etiology, complexity in diagnosis, and subjective decisions about the preparation make the clinical management very difficult. Therefore, the clinical management of CTS should be carried out by the guidance of an informative decision tree. This decision tree should focus on (1) the rational retention of tooth structure, (2) the preparation optimization, and (3) the restorative implications and choices.

Summary The restorative management of CTS is a complex issue which should be carried out systematically. The guidance of an informative, universal decision tree might be useful in daily clinical practice.

Keywords Crack · Fracture · Cracked tooth syndrome · Restoration

Introduction

The teeth including horizontal or vertical fractures, limited in dental crown and/or extending to root structure, are generally defined as the cracked teeth [1••]. The fracture lines may include one or both marginal ridges, extend to the subgingival levels of unknown depths, and sometimes may even communicate with the pulp tissue and/or periodontium (Fig. 1) [2, 3]. Pain and eventual pulp necrosis might be expected due to the bacterial toxin penetration into the pulp chamber [1••]. The etiology may be due to some parafunctional factors such as grinding and clenching, tooth wear patterns such as attrition and abrasion, deep fissures, remarkable alterations in intra-oral temperature, and dietary habits [1••]. Moreover, some iatrogenic factors such as poor cavity design, steep cusp inclination, mis-selection of restorative materials, and misuse of endodontic instruments may have a role [1••, 2, 4].

The term "cracked tooth syndrome" (CTS) was first mentioned by Cameron in 1964, as the incomplete fracture of the natural tooth crown [3], while some other researchers used different definitions for this kind of incomplete dental fractures such as greenstick fractures, hairline fractures, cracked cusp syndrome, incomplete vertical tooth fractures, and cracked tooth conundrum [5]. CTS usually evolves from a cracked tooth and patients usually suffer from several signs and symptoms of different levels of severity [5]. However, it does not always provide a related sensitivity. If presented, the sensitivity is usually worsened by a greater bite pressure and especially by cold [2]. Although some researchers have indicated that CTS is limited to vital teeth, it may also be observed in non-vital teeth. It is most frequently observed in lower second molars, followed by lower first molars, and then by upper premolars and second molars [2]. However, CTS is also very common in incisors following orthodontic debonding procedures and for the patients with bruxism (Fig. 2).

The incidence of CTS is popular in male, 40- to 50-year-old patients. CTS may be observed in both intact teeth and teeth with direct/indirect restorations [6]. The crack lines usually run in mesiodistal direction vertically (Fig. 3) and

✉ Bora Korkut
bora.korkut@marmara.edu.tr

1 Department of Restorative Dentistry, Faculty of Dentistry, Marmara University, Istanbul, Turkey

2 Kocaeli, Turkey

3 Clinic for Chewing Function Disturbances and Dental Biomaterials, Center of Dental Medicine, Dental University of Zurich, Zurich, Switzerland

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Fig. 1 Cracked upper molar and premolar teeth

Fig. 2 Central incisors including many crack lines under transillumination, of a patient with heavy bruxism

Fig. 3 Crack line in mesiodistal direction

extend to the root, whereas horizontal and horizontal-vertical crack lines were reported rarely [7, 8].

Although several researchers report on the etiology, incidence, clinical features, restorative strategies, and outcomes of the cracked teeth, because of the unpredictable nature, further investigation is still needed [1••, 8]. In terms of the CTS, in some specific conditions, the minimally invasive

Fig. 4 Vertical and transverse crack lines in maxillary first molar under transillumination

dentistry protocols may lead to the total loss of the tooth. Accordingly, early diagnosis and proper treatment of the cracked teeth is important [8]. However, crack lines usually may not be detected radiographically and even not apparent on visual inspection [1••]. Therefore, clinical examination and experience play key roles in the prognosis and the treatment planning. Clinical examination with magnification such as dental operating microscope or dental loupes may be useful to detect the borders of the crack lines. Moreover, transillumination (Fig. 4) and staining of the dental tissues following the removal of existing restorations may aid in the identification [1••].

The clinicians should define the location, depth, and extension of the crack correctly in order to select and perform a proper restorative protocol. Thereby, by an effective restorative treatment, fracture propagation as well as possible associated pulpal diseases may be limited [1••]. Accordingly, the classification of American Association of Endodontists (AAE) for the cracked teeth provides a useful and universal definition for various clinical scenarios [9]. The prognosis is determined based on the involvement of marginal ridges, dental pulp, and pulpal floor (Table 1; Fig. 5). The teeth with complete mesiodistal vertical fractures or the fractures in depth that cannot be reached and restored by the guide of gingivoplasty or alveoplasty are generally considered hopeless [1••].

Besides the classification of the American Association of Endodontists, the World Dental Federation (FDI) has also announced an alternative and more detailed classification for the CTS aiming to provide a simpler guidance for the dentists (Fig. 6) [10]. Clinical presentations of different types of cracks are shown in Fig. 7. The classification of FDI has provided 6 subdivisions instead of 5, including definitions related to the dental tissues such as enamel, dentin, pulp, and periodontium compared to the classification of AAE.

This review is mainly focused on the restorative interventions for the teeth with CTS that may vary depending on the location and depth of the crack. Other than the

Table 1 American Association of Endodontists classification of CTS [9]

Classification	Originate	Direction	Symptoms	Pulp status	Prognosis
Craze line	Crown	Variable	None	Vital	Excellent
Fractured cusp	Crown	Mesiodistal and/or buccal-lingual	Mild and generally, only to biting and cold	Usually vital	Good
Cracked tooth	Crown with/without root	Mesiodistal often central	Acute pain on biting Occasionally sharp pain to cold	Variable	Questionable: dependent on depth and extent of the crack
Split tooth	Crown with root	Mesiodistal	Marked pain on chewing	Often root-canal treatment needed	Poor unless crack terminates just subgingivally
Vertical root fracture	Roots	Buccal-lingual	Vague pain similar to periodontal disease	Mainly root-canal treatment needed	Poor: root resection indicated in multi-rooted teeth

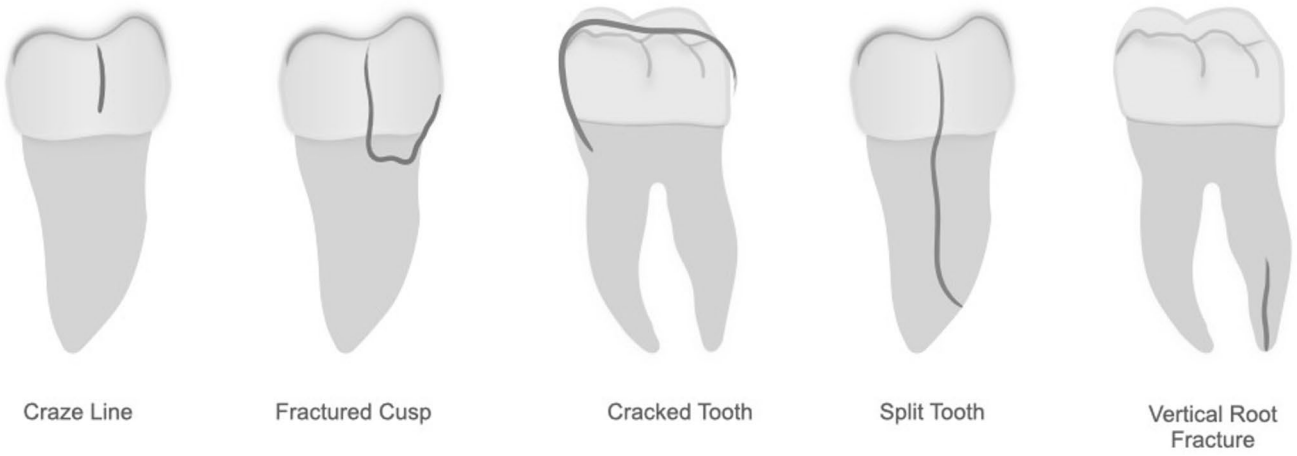

Fig. 5 The classification of CTS according to the AAE [9]

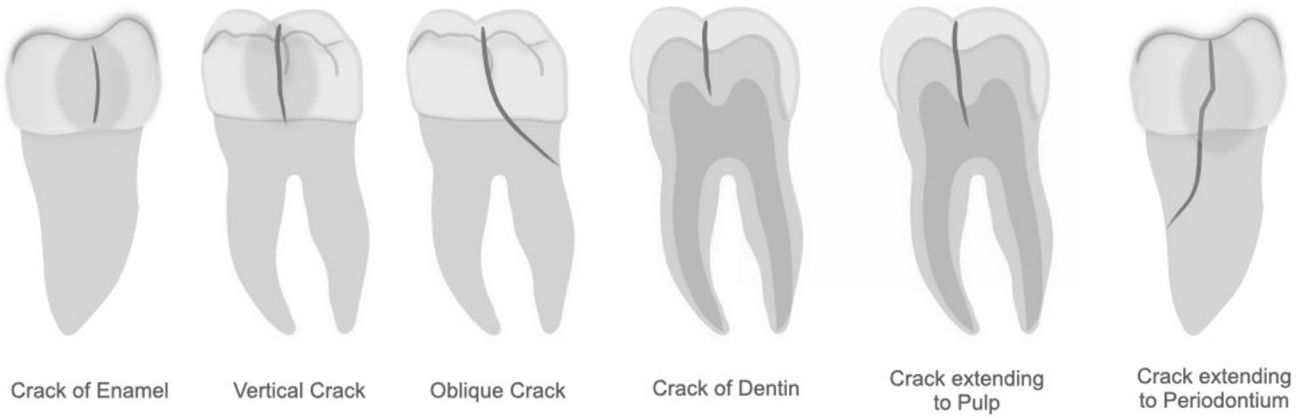

Fig. 6 The classification of CTS according to FDI [10]

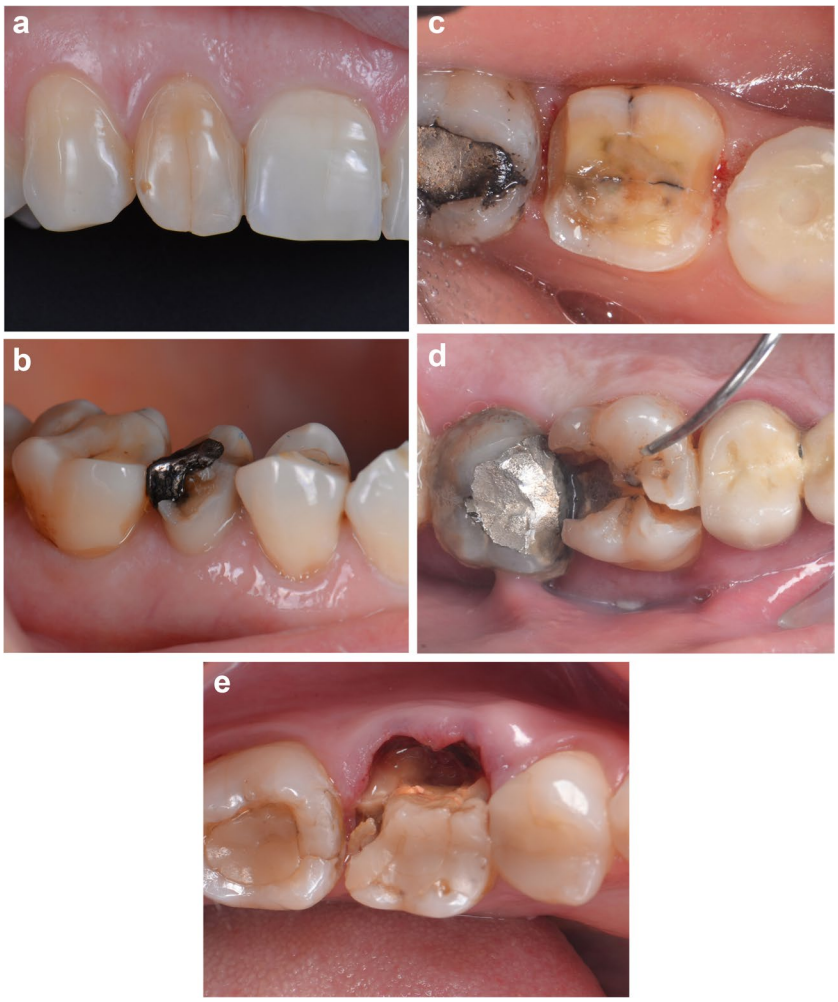

Fig. 7 **a** Craze line. **b** Fractured cusp. **c** Cracked tooth. **d** Split tooth. **e** Vertical root fracture

existing factors related to the crack (tooth morphology, previous cavity preparation, restorative material compaction, cervical hard tissue loss, occlusal load, parafunctions, and trauma), the following direct or indirect restorative protocol choice and the relevant preparation type also determine the prognosis of the tooth [10]. Moreover, the restorative procedures include not only the application technique but also the selection of the restorative material type.

Restorative Management of CTS

A decision tree was previously presented for the restorative management of CTS, which might be very useful for the clinical treatment planning. The decision tree includes (1) rational retention of tooth structure, (2) preparation optimization, and (3) restorative implications and choices [11••].

Rational Retention of Tooth Structure

Regarding the retention of tooth structure, firstly the restorative status of the tooth should be classified. If a remaining restoration has the potential to put the tooth at an increased risk of fracture, it should be classified as "*heavily restored*" tooth, whereas the rest should be classified as "*minimally restored*" tooth [11••]. However, this decision might be very complex, multi-factorial, and subjective, clinically. The real situation actually appears following the preparation including the total removal of the remaining restoration and the enamel tissues lacking dentin support. The diagnosis of a symptomatic crack is relatively easy, whereas several parameters should be considered in the presence of asymptomatic cracks such as residual cusp number and dimensions, configuration and depth of the cavity preparation, type, quality, and characteristics of restorative material, restorative technique, position of the tooth, functional and potential parafunctional loads, and remaining periodontal support [11••, 12].

Moreover, many more dentist and patient-related factors should be taken into consideration.

Other than the restorative status of the tooth, the retention or removal of the cracks should be determined. Dental cracks usually have the potential to propagate, and when reaching the oral environment, microbial dental plaque accumulation is inevitable, which might lead to periodontal and/or pulpal pathologies. Therefore, including the cracks in the preparation is a common clinical strategy. However, this strategy is rarely useful, especially when the crack is oriented vertically or the tooth is minimally or unrestored [11••]. In addition, when there is no visible terminal, it is generally impossible to know if a crack was completely removed or not, and the micro auxiliary cracks can barely be seen (Fig. 8) [13]. Unnecessary dental tissue loss might especially in biomechanically important cervical area might worsen the prognosis [11••, 14]. Also, considering the long-term quality of adhesion, enamel tissue is more preferrable than dentin, in terms of the location of restorative margin. The need for removing the crack should be evaluated accordingly [15].

Finally, the provision of cusp coverage should be evaluated. It is a well-known fact that full coverage of the affected cusp/cups provides more resistance to fractures by altering the occlusal load direction (primarily tensile stress to more supportive compressive stress) [16]. Accordingly, the needed space for restoration can be gained either by increasing the occlusal depth of preparation or by intruding the tooth [11••].

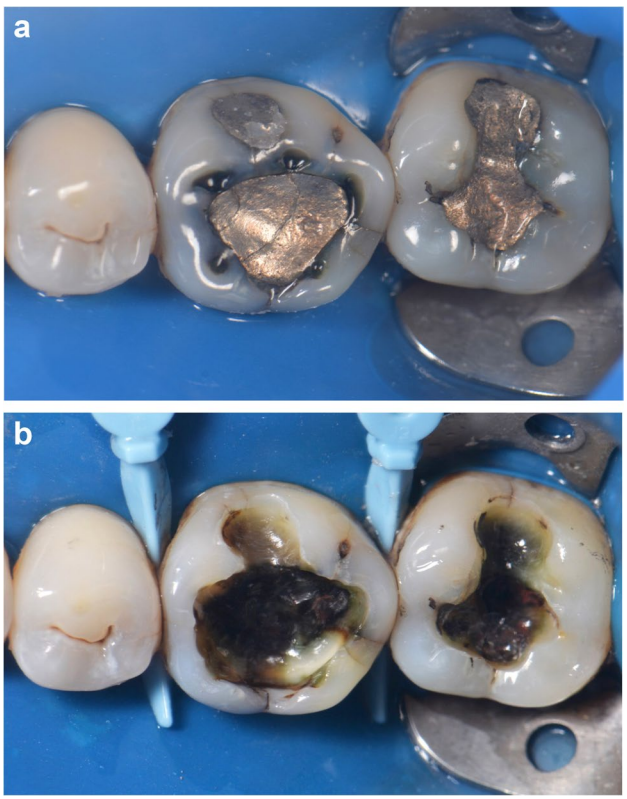

Fig. 8 **a**, **b** Determination of crack existence during the preparation

Optimization of Preparation

In terms of clinical longevity, the retention of enamel tissue is always better than the dentin tissue [1••]. However, regarding the CTS cases, it is usually better to remember the idea of "preparation for prevention" rather than the undisputed idea of "minimally invasive preparation." No cusp reduction is needed for the "minimally restored" teeth including affected cups and intact marginal ridges supporting by dentin [11••]. However, the cusps flex more with higher tensile stress in function for the "heavily restored" teeth and probably get fractured in the long term (Fig. 9) [16]. Therefore, the remaining affected cusps of the "heavily restored" teeth should be reduced and fully covered after an appropriate preparation. Generally, thin cusp tips are broken down during the cusp reduction procedure. The enamel tissues without dentin support and even the crack underlying enamel tissues with dentin support should be included in the preparation [11••]. On the other hand, in such cases the operator should be very careful with the preparation depth and the increase in restorative material thickness balance [17]. Although defining the risk of fracture of a cusp has multiple factors as previously discussed, it might be suggested to remove the contacts on retaining cusps in both dynamic and static occlusions, at least to move the eventual failure mode from tooth to restoration. In order to provide optimum balance between the force distribution and maintaining tooth structure, the suggested amount of cusp reduction ranges from 1.5 to 2 mm [11••]. The reduction should always include the crack and extent till the dentin support is provided. For removing the crack, fissure, diamond burs (small round,

Fig. 9 Heavily restored left mandibular molars. Split tooth in tooth #36

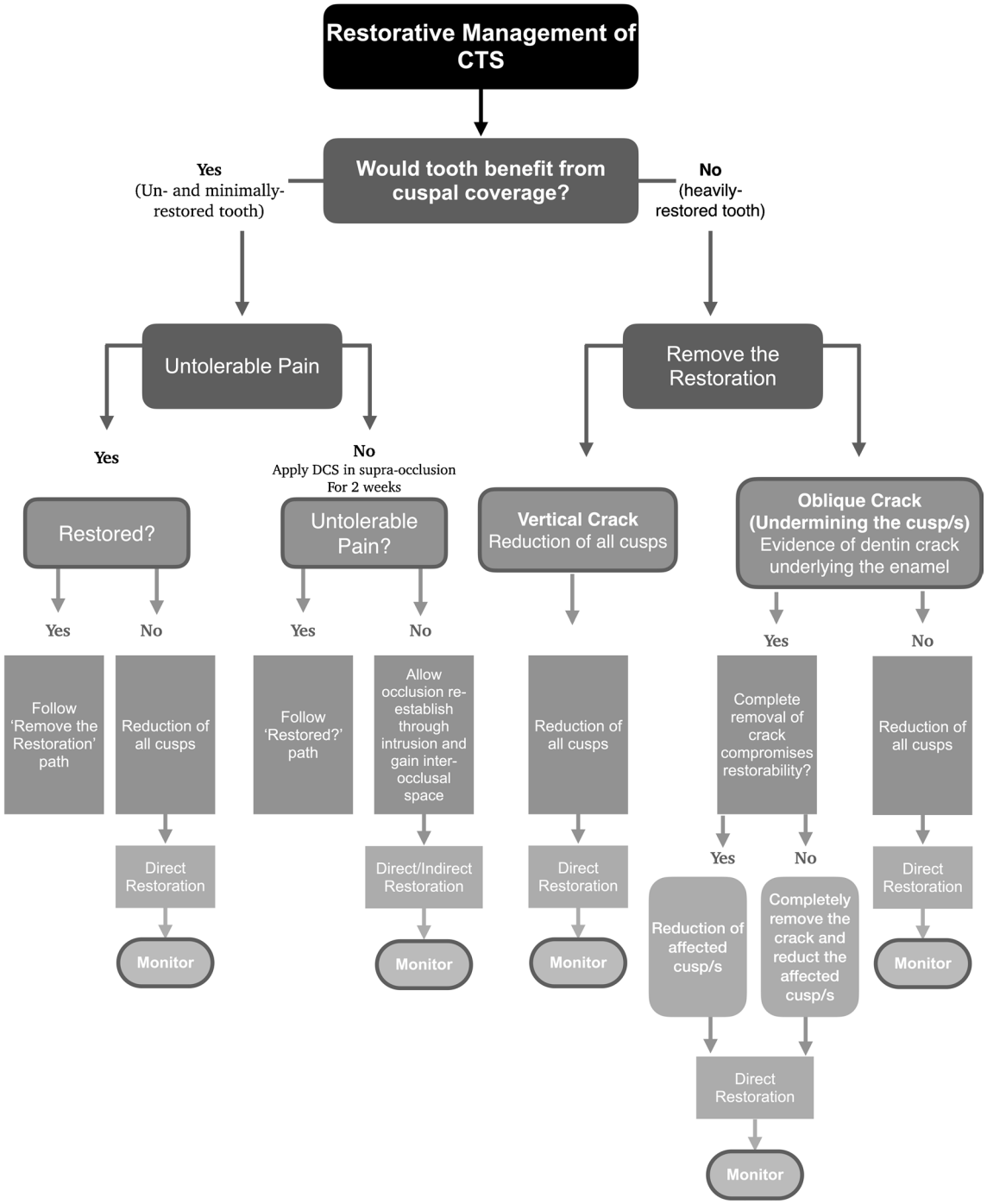

Fig. 10 Modified decision tree for the management of CTS [11••]

medium round, or tapered fine) can be used under water cooling. The presence of residual crack can be checked by using methylene blue dye [18]. Owing to the flocculent character and ponding tendency, it can be beneficial for determining the extent of crack [19]. Crack can be checked under a great magnification by using an operating microscope (6–8 magnification or greater) or loupes (2.5 magnification or greater) [20]. In addition, these two techniques can be used together, staining with methylene blue dye can be evaluated under the magnification.

The needed dentin support is another subjective decision, whereas it was previously suggested that at least 1.5–2 mm cusp thickness should be gained for a better restorative stability [21•, 22]. Only if the preparation

compromises the restorability of the tooth, further reduction should be canceled.

Following the cusp reduction, preparation of dentin by air abrasion (27 μ aluminum oxide particles) was considered a safer and more effective method compared to preparation by bur. Fatigue resistance of dentin reduces by preparation and deeper dentin tissue is more susceptible to fractures [11••]. The surface following air abrasion is free from crack remnants and considered more beneficial to compromised dentin by aiding the bonding agent [23].

Selection of Restorative Material and Technique

Various protocols have been presented in literature for the management of CTS. Each of them has their own limitations and opportunities. Clinicians can select the convenient protocol for themselves, according to the conservative level, effectiveness, and efficiency [24, 25•]. As mentioned above, some researchers support removing of the affected cusp completely so that the treatment protocol is planned through subtractive occlusal adjustments or restoration of the residual cavity [26]. The consensus about the incomplete cracks for the teeth is splinting of the tooth [24]. Splinting can prevent the unwilling devastating movements during the occlusal loading; hence, it can prevent progression of the fracture.

Immediate Management of CTS

After the diagnosis of CTS (particularly the CTS on mandibular lingual cusps), the primary aim is the relieving of the symptoms and minimalizing the occlusal loading on the tooth by adjusting the occlusal contacts [27]. Without a proper treatment, the cracked tooth will gradually worsen and eventually may lead to tooth loss, according to the advice sheet of FDI [10].

Stainless steel band and copper rings (extra-coronal circumferential splints) can be used for the diagnosis and immediate treatment of CTS. These materials act as a splint and can prevent the potential future effects of the wrong diagnosis. Following the use of the band/ring, if the pain did not relieve, then the diagnosis changes and endodontic treatment and/or crown restoration can be performed [28, 29]. A temporary full-coverage crown can stabilize the crack and divert the occlusal forces; hence, the occlusal pressure is minimized. On the other hand, producing of temporary crown is generally considered time-consuming and exhaustive [27].

Direct composite splint (DCS) is another immediate management procedure of CTS based on the "Dahl" phenomenon, first introduced by Banerji et al. in 2010 [29–32]. The Dahl concept is relevant with tooth wear localized in anterior region and has aimed to create an intra-occlusal space without reduction of the tooth structure. Mechanism of DCS is creating space by

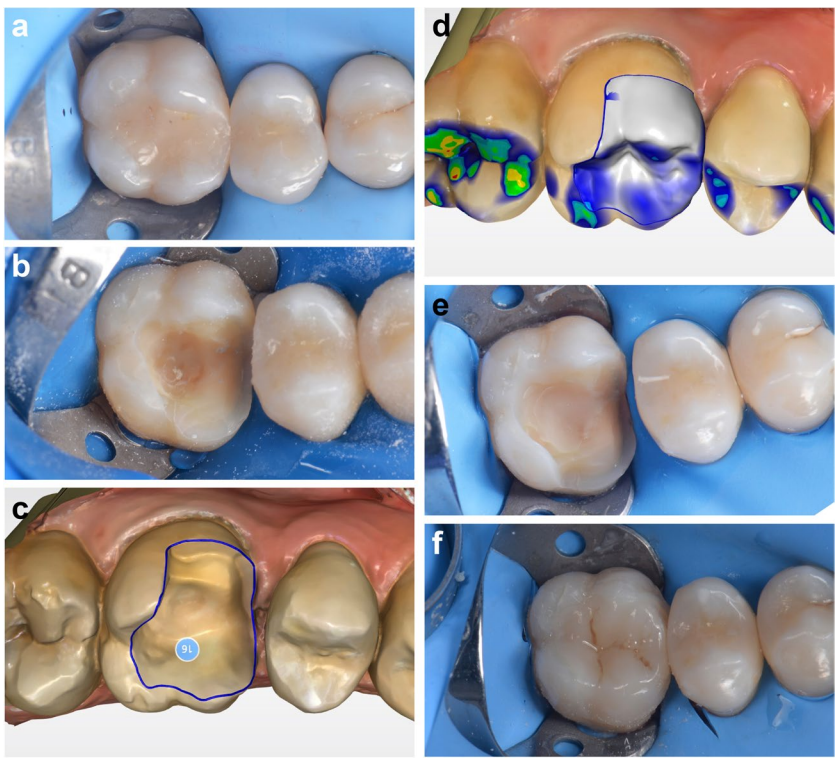

Fig. 11 **a** Old composite restoration on #26. **b** Onlay preparation including the mesiopalatal cusp with crack. **c** Digital impression. **d** Digital onlay design. **e** Adhesion protocol for cementation. **f** Indirect cementation of resin-ceramic cad/cam block

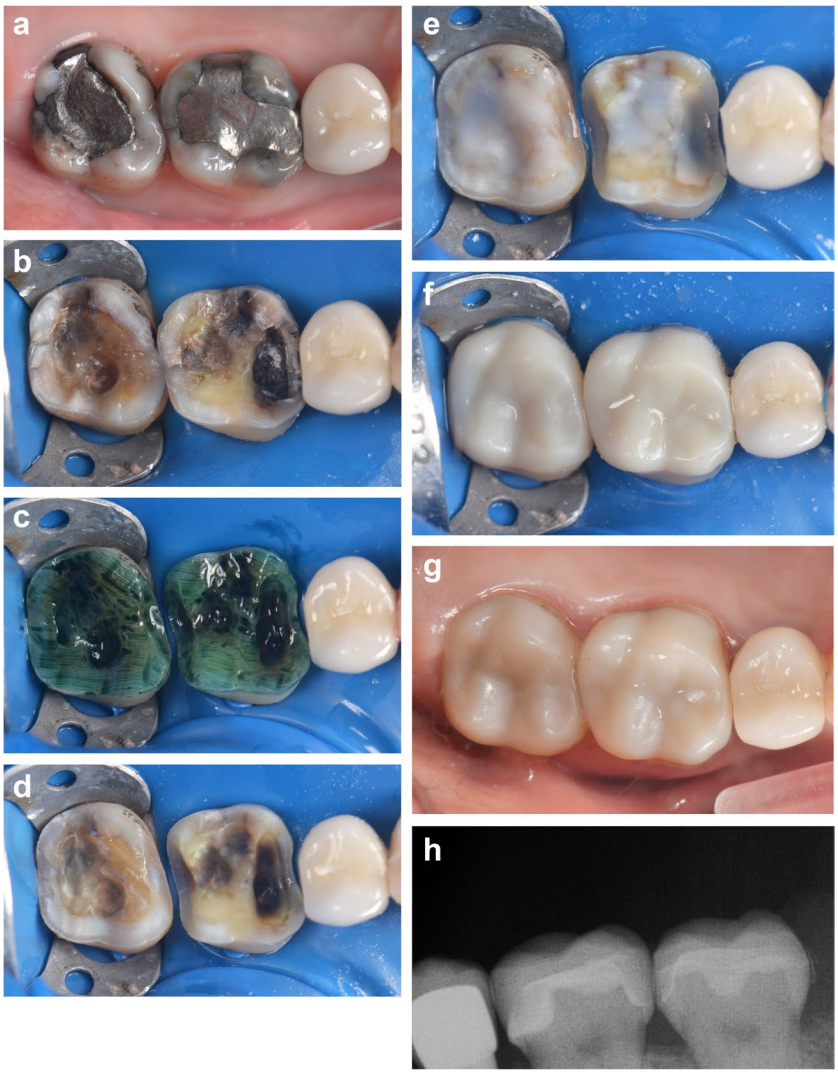

Fig. 12 **a** Old amalgam restorations. **b** Overlay preparation. **c** Caries and crack detection. **d** Crack detection of a vertical crack on tooth #27 and enamel cracks on teeth #26 and #27. **e** Immediate dentin sealing (IDS). **f** Indirect cementation of ceramic cad/cam overlays. g One month follow-up. **h** X-ray

re-establishing the interocclusal tooth contacts with axial movement, for the permanent restoration. Banerji et al. have reported that the treatment of incompletely fractured tooth with properly placement of DCS is promising. They reported 86.7% success rate within the three months of follow-up reports. Following the planning, direct resin composite is applied to the occlusal surface to connect the crack segments, thereby splinting the tooth [30]. A flat splint created in the supra-occlusal position of the related tooth and the thickness of the splint should be ~ 1.0–1.5 mm over the occlusal surface [25•]. This technique can be used both with and without the preparation. Some authors perform minimal reduction on the functional cusps, whereas it is generally used in a non-invasive way [29]. The next appointment is generally planned in two-week time. The sim of this immediate treatment is the intrusion of the tooth and reconstitution of the occlusal contacts. According to the restorative management of CTS, in case of untolerable pain, the presence of the former restoration is the key for the decision on the treatment plan. If the cracked tooth was previously restored, then "Remove the restoration path" should be followed (Fig. 10). On the contrary, if there is no restoration on the cracked tooth, all cusps should be reducted and then direct restoration can be performed and monitored (Fig. 10). In case of no untolerable pain, DCS should be performed and followed. If untolerable pain occurs in the following two-week period, "Restored" path should be followed (Fig. 10), whereas if untolerable pain does not occur, then the clinician should allow the occlusion to re-establish through the intrusion of the tooth and to gain inter-occlusal space. Afterwards, the DCS should be removed, and direct/indirect restorations can be performed and monitored (Fig. 10) [21•].

Direct Restorations

Generally, resin-based composite materials have been recommended for the CTS and they can be performed through both direct and indirect techniques. The direct restoration indications for CTS are indicated in Graphic 1. In case of no untolerable pain, if there is no restoration on the cracked tooth, then the "Reduction of all cusps" procedure should be followed, and direct restoration can be performed (Fig. 10). After the application of DCS, in case of no untolerable pain for the following two-week period, direct restoration is indicated (Fig. 10). Additionally, in case of an oblique crack and/or vertical crack, direct restoration is indicated. Therefore, the adhesive restorations are more favorable in such cases [33]. Performing direct the restoration with resin-based composites can provide the "shock absorption"; besides, it diverts the occlusal loads through the axial walls which is safer for survival of the tooth [21•]. Cracked tooth is protected either by direct or indirect restorations; however, when the load is over 1000 N, then the direct restorations have a higher survival incidence [34].

In literature, both paste-type and flowable composites have been used for the treatment of CTS previously [35]. In some cases, paste-type composites can be used to bond the affected cusps, for the cusp reinforcement and relieving the discomfort during the mastication [36]. Flowable composites are also used in CTS cases by injecting the composite into the crack space; however, this technique should be used in areas exposed to low occlusal forces [37].

Indirect Restorations

Indirect technique provides the use of materials that have superior mechanical properties compared to the direct resin-based materials and this technique demands less operator skills as well [27]. Indirect restorations for CTS consist of inlay, onlay, and full crown restorations (Figs. 11 and 12). They can present a high corrosion resistance, superior marginal adaptation, and optimal wear characteristics. A study demonstrated that indirect MOD (mesial-occlusal-distal) resin-bonded composite and ceramic inlays with adhesive cementation can provide a high fracture strength similar to the natural tooth [38]. Regarding the comparison of ceramic and composite onlays, ceramics are considered more brittle materials rather than the composites, hence providing limited ability of plastic deformation. Also, the "shock absorbing" potential of the ceramics under occlusal loads can be considered as another superior property [24, 25•, 29]. Resin composites for the indirect applications display higher elastic modulus in comparison to the ceramics; therefore, they absorb more compressive loads by 57% against ceramic materials [39]. On the other hand, there are many studies advocating to the use of ceramic materials for the CTS treatment [40]. According to the majority of the previous research, the ceramic onlays can be preferred for their superior wear resistance and friction, preserving the remaining tooth structure. In case of "crack tooth" situations, full crown restoration can increase biomechanical stability of the tooth (Table 1) [41••]. Particularly after endodontic treatment of cracked teeth, full coverage crowns showed significantly higher survival rate and the risk of complications is relatively reduced. Consistent with that statement, the FDI reported that the crown placement on a cracked tooth provides maximum support and protection, while mentioning success is not guaranteed in all cases [10]. However, it is a well-known fact that the full coverage crowns do not offer a biologically conservative treatment [42–44].

Regarding the type of the indirect material selection, feldspathic porcelain, glass-ceramic, glass-infused alumina, or zirconia can be used for the treatment of CTS [45]. The elasticity modulus values are ranged from 50 (for glass-ceramic and feldspathic porcelain) to 250 GPa (for glass-infused zirconia and alumina) [35, 45]. According to the previous reports, lithium disilicate-based ceramics present a higher residual flexural fatigue strength than glass-rich ceramics and indirect resin composites [46]. Additionally, lithium disilicate-based ceramics present a lower fatigue degradation under occlusal loads, thereby providing a long clinical service [8, 46].

Conclusions

Along with the diagnosis and classification, the preparation type, direct or indirect restorative protocol selection may affect the prognosis of the tooth with CTS. However, the multi-factorial etiology, complexity in diagnosis, and subjective decisions especially regarding the preparation type make the restorative management clinically very difficult and cause further damage to the teeth with CTS. Therefore, clinical management of CTS should be carried out through the guidance of an informative and universal decision tree. The decision tree should include the rational retention of tooth structure, preparation optimization, restorative implications, and material choices.

Declarations

The Section Editors for the topical collection Dental Restorative Materials are Mutlu Özcan and Paulo Francisco Cesar. Please note that Section Editor Mutlu Özcan was not involved in the editorial process of this article as she is a co-author.

Conflict of Interest The authors declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent No animal or human subjects by the authors were used in this study.

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