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Original Article

Location of crack lines associated with the prognosis of a cracked tooth restored by occlusal veneer

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Abstract *Background/purpose:* Crack lines (CLs) in cracked teeth (CTs) are challenging to detect. Since restoring CT by occlusal veneer showed favorable clinical outcomes, we found that CLs could be identified more clearly after tooth preparation during the treatment. Herein, we reevaluated and recorded the location of CLs and analyzed their associations with the prognosis.
Materials and methods: Eighty CTs with normal or reversible pulpitis were assessed and restored by occlusal veneer. Before and after preparation, CLs were identified and divided into type I: CLs without mesial-distal or buccal-lingual direction across the marginal ridge and type II: CLs with mesial-distal or/and buccal-lingual direction across the marginal ridge. Patients were followed up for 1 week, 1, 2, 3, 6, and 12 months after treatment to examine the relief of thermal/biting sensitivity and pulp complications.
Results: The groups underwent significant changes before and after tooth preparation. The classification before tooth preparation was not related to probing depth and the prognosis

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of CT; however, after tooth preparation, CTs in type II were correlated with probing depth >6 mm (r = 0.271, $P = 0.015$), while teeth in type I experienced a short time relief (≤1 month) in thermal sensitivity compared to those in type II ($P = 0.013$). There was also a significant difference between type I and type II in the survival rate of pulp vitality ($P = 0.029$). *Conclusion:* CLs could be identified accurately after tooth preparation, impacting the relief time of symptoms and pulp survival rate in CTs.

Introduction

A cracked tooth (CT) is defined as a thin surface disruption of enamel, dentin, and possibly cementum of unknown depth or extension. It is a common disease of dental hard tissue and a standard presentation in general dental practice, affecting about 5 % of all adults yearly.[1,2] In the USA, the incidence of CT has increased significantly over the last decade.[3] As there is no accurate way to know to what extent the crack has advanced, it is difficult to estimate the prognosis of CT. The consequences of CT range from minor, needing no treatment at all, to severe, requiring root canal therapy (RCT) or even tooth extraction.[4—7]

Establishing an early CT diagnosis and understanding the characteristics of crack lines (CLs) are essential to prevent unwanted complications.[2,6] Since most patients are asymptomatic at an early stage, an initial inapparent CL is difficult to detect by the naked eye.[6,8,9] CL can be concealed beneath developmental grooves or restorations and covered by pigments.[10] Many authors suggested the removal of the existing restorations and stains to further aid in the visualization of the crack.[11,12] Various methods, such as magnified vision, dyes, transillumination, and fluorescence, have been proposed to enhance the early identification of CLs.[8,9] Nevertheless, all these methods have certain limitations.[9] Also, CL-related details, including the number, location, direction, and extension, might still be challenging to determine, leading to a false record or analysis.

CLs can run in different directions but are usually directed mesiodistally.[11] They can involve 1 or more marginal ridges and extend apically. Some characteristics of the CLs, like CL on the distal margin, have been associated with increased odds of the tooth being symptomatic and treatment failure.[11,13] On the contrary, another clinical research found that the number and direction of CLs were unrelated to tooth loss.[14] Thus, the correlation between CLs and prognosis needs to be further explored.

In previous studies, CTs restored by occlusal veneer showed favorable clinical outcomes.[15,16] In the present study, we found that it could be easier to identify CLs after tooth preparation of CT for an occlusal veneer. The detailed characteristics of CL and the multi-directions could be recorded more accurately, unlike those observed before tooth preparation. The complexity of CLs may be the product of biting habits (biting force, eating hard food, bruxism, etc.) and weak teeth structure (steep cusps, weakened developmental grooves, etc.). Also, multi-directions of CLs after tooth preparation may indicate further extension of the CLs. Therefore, we hypothesized that the types of CL are associated with symptoms and pulp complications after being restored by occlusal veneer.

Materials and methods

Patients

Adult patients with CT were recruited between March 2021 and August 2023. The main inclusion criteria were: (1) patients with subjective symptoms of biting pain; (2) patients diagnosed with a CT via biting test; (3) at least one CL identified via visual examination or methylene blue dye or direct transillumination; (4) the tooth with normal pulp or reversible pulpitis; (5) patients accepted the treatment and agreed to regularly participate in follow-up. Patients were excluded if diagnosed with a fractured cusp tooth, split tooth, vertical tooth fracture, abnormal pulp viability, or periapical lesion or if clinical data were incomplete.

Two experienced endodontists (working as endodontists for more than 8 years) provided the diagnosis, treatment, and recall examination. Ethics approval for the study was obtained from the Research Ethics Committee. The study adhered to the STROBE guidelines. All patients signed an informed consent form.

Data collection

Data collection was performed before treatment, and the following data were collected: (1) demographic data (gender, age); (2) tooth number; (3) the result of cold test (normal, reversible pulpitis); (4) responses to biting tests and percussion; (5) periodontal probing depths; (6) periodontal ligament of the apical area; (7) location and direction of CLs.

Clinical examination

Biting test: a small cotton ball was placed on the occlusal surface of the cracked tooth from the front to the back, and the patient was instructed to "bite slightly, squeeze tightly, and open quickly." Also, Tooth Slooth (Professional Results, Laguna Niguel, CA, USA) was placed either between the cusps of a tooth or onto the cusp, and the patient was asked to bite. The biting test that generated the biting pain was in accordance with the patient's chief complaint.

Normal pulp and reversible pulpitis: all teeth were without a history of spontaneous pain and presented only mild sensitivity to cold or sweet stimuli.[17] Patients showed the same reaction with the counterpart a few seconds or immediately upon removal of the stimulus with a cold test. All teeth were negative to palpation. Radiographs showed no periapical lesions.

Percussion test: percussion was performed by tapping on the occlusal surfaces of the teeth with a blunt instrument vertical on the cusp (parallel to the axis of teeth) or on the inclined surface (lateral percussion). The strength of percussion was the same as that of percussing normal teeth, which did not generate pain. A "painful" reaction was considered when patients felt discomfort compared to normal teeth.

Cold test: first, small cotton with cold spray (Coltène/Whaledent, Langenau, Germany) was placed on the middle third of the buccal surface of the normal teeth, and the sensitivity was recorded. Next, the same was applied to the target tooth, and the sensitivity was recorded.

Periapical lesion: periapical radiography showed that the width of the radiolucency exceeded at least twice the width of the periodontal ligament space in the apical part of the root.[18]

Probing depth: buccal and lingual periodontal probing depth recorded in the mesial and distal interproximal spaces and furcas.

Detection of crack lines

Another two observers (working as endodontists for more than 8 years) detected and marked the CLs separately through high-definition photographs before and after tooth preparation. All intraoral pictures were acquired using a single lens reflex digital camera (Canon, Oita, Japan). Before tooth preparation, developmental grooves extending to the marginal ridge were considered as a CL. After tooth preparation, cracks on the finish line extending deeper were recorded. Different results between the two observers were discussed. The data was not recorded or analyzed until the results from the two inspections were identical.

Treatment protocol

Upon diagnosis, CT was prepared for an occlusal veneer (Ivoclar Vivadent, Schaan, Liechtenstein), a cuspal-coverage restoration. The detailed treatment procedure is reported in our previous study.[15,16] Clinical photographs were taken for each case before and after tooth preparation to illustrate the CLs. The visual inspection of the CL, including the number, location, and range, was detailed and documented.

After a temporary restoration, if no signs or symptoms of inflammation persisted and the pulp vitality test was positive, a definitive occlusal veneer was placed.

All teeth were examined at 1 week, 1, 2, 3, 6, and 12 months after treatment, and then every 6 months until the symptoms disappeared during the follow-up period. The biting/thermal sensitivity relief and pulp status were recorded and analyzed. The successful occlusal veneer was defined as the absence of biting or thermal sensitivity without pulp necrosis and progressive radiographic pathosis.

Statistical analysis

SPSS Version 27 was used for statistical analysis. The associations between classifications of CT and thermal/biting sensitivity were evaluated using cross tabs with Pearson Chi-square. The correlations between the classification of CT and probing depth were analyzed using Spearman Correlation Analysis. The pulp complication was analyzed using the Kaplan–Meier method, and significance was identified using the log-rank test. A P value < 0.05 represented statistical significance.

Results

Demographic and clinical features

Among a total of 86 CTs initially enrolled, 6 CTs were excluded due to incomplete clinical data, resulting in 80 CTs (72 patients) that were included in the final analysis. Five patients with 5 teeth did not return to the hospital; they reported no symptoms during a follow-up telephone call. All patients suffered from biting pain, whereas 44 % of the teeth were affected by sensitivity to cold or hot food (Table 1).

Table 1 Distribution and statistical analysis of demographic data of patients with cracked teeth.

Category/variable	Subgroup	N (%)
Age, years	≤35	43 (60 %)
	>35	29 (40 %)
Gender	Female	33 (46 %)
	Male	39 (54 %)
Location in the arch	Maxillary	62 (78 %)
	Mandible	18 (22 %)
Location of tooth	Maxillary first molar	31 (39 %)
	Maxillary second molar	26 (33 %)
	Maxillary second premolar	5 (6 %)
	Mandibular first molar	12 (15 %)
	Mandibular second molar	6 (8 %)
Thermal sensitivity	Yes	35 (44 %)
	No	45 (56 %)
Eating hard food	Yes	45 (63 %)
	None	27 (37 %)
Bruxism	Yes	7 (10 %)
	None	65 (90 %)
Clenching	Yes	7 (10 %)
	None	65 (90 %)
Cold test	Normal pulp	23 (29 %)
	Moderate cold sensitivity	44 (55 %)
	Severe cold sensitivity	13 (16 %)
Percussion test	Vertical—Normal	70 (88 %)
	Vertical—Painful	10 (13 %)
	Lateral—Normal	52 (65 %)
	Lateral—Painful	28 (35 %)
Probing depth	≤3 mm	24 (30 %)
	4–6 mm	50 (63 %)
	>6 mm	6 (8 %)

Clinical characteristics of cracked teeth

Most CTs were in the maxillary arch (78 %); 31 maxillary first molars and 26 maxillary second molars were involved. There were 23 patients who were diagnosed with normal pulp, while the remaining 71 % showed cold sensitivity during the cold test. Ten CTs were sensitive to pain based on the vertical percussion test, and the ratio increased to 35 % when tested from the lateral direction. Most CT (93 %) initially had a probing depth <6 mm.

Features of crack lines

CL was observed via photographs (Fig. 1). CL was recorded following the diagnosis for the first time. After tooth preparation, CL was re-evaluated.

According to the location and direction of CL, both before and after tooth preparation, CTs were divided into 2 distinct classifications (Fig. 1, Table 2): type I: CLs without mesial-distal or buccal-lingual direction across the marginal ridge; type II: CLs with mesial-distal or/and buccal-lingual direction across the marginal ridge. After tooth preparation, 6 CTs changed from type I to type II, while 18 changed from II to I. There was a significant difference in types of CLs after tooth preparation compared to before tooth preparation ($P = 0.001$, Table 2).

Table 2 Types of cracked teeth depending on the crack line features.

Items		After tooth preparation		Pearson chi-square
		Type I	Type II	
Before tooth preparation	Type I	20	6	0.001
	Type II	18	36	

Type I: No mesial-distal or buccal-lingual direction through the marginal ridge.
Type II: Mesial-distal or/and buccal-lingual direction through the marginal ridge.

The classifications of cracked teeth after tooth preparation were associated with probing depth

Probing depth was a key factor associated with the prognosis of CT. Therefore, we analyzed the correlation between the classification of CT and probing depth. Results

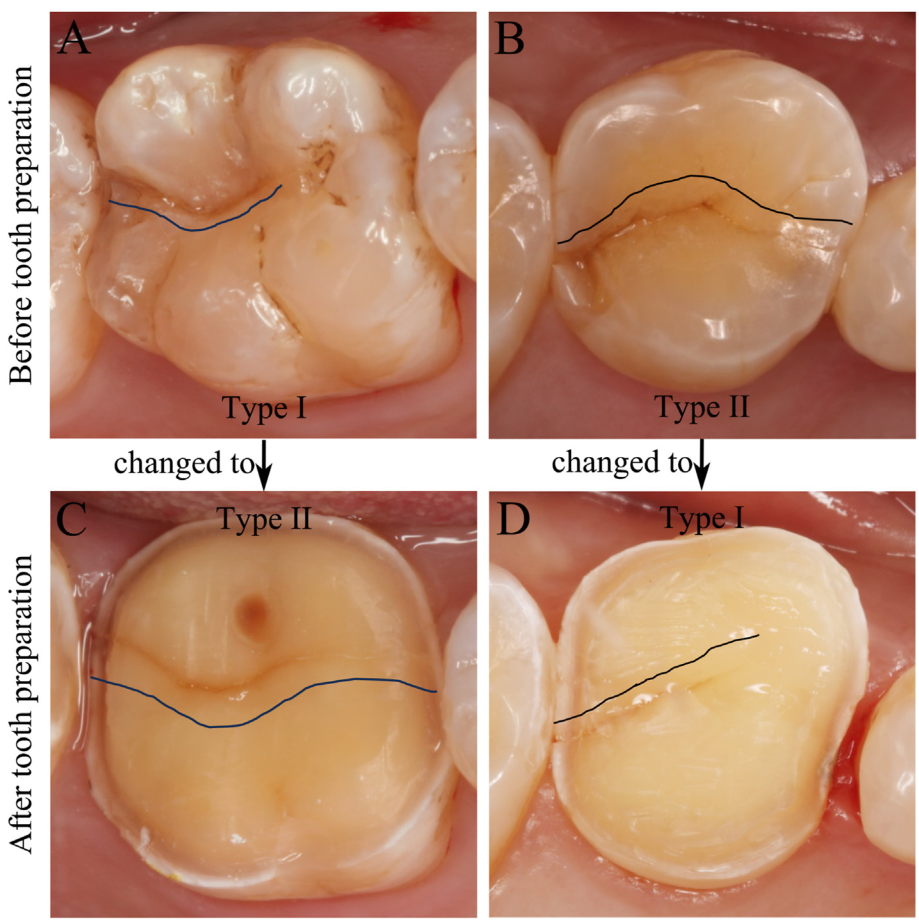

Figure 1 Crack line type changed before and after tooth preparation. (A–B) Before tooth preparation: (A) type I: crack lines without mesial-distal or buccal-lingual direction across the marginal ridge; (B) type II: crack lines with mesial-distal or/and buccal-lingual direction across the marginal ridge. **(C–D)** After tooth preparation: (C) type II; (D) type I.

Table 3 Correlation between classification of cracked teeth and probing depth.

Tooth	Types	Probing depth (n)			r	*P*
preparation		≤6 mm	>6 mm	All (n)		
Before	I	24	2	26	0.005	0.964
	II	50	4	54		
After	I	38	0	38	0.271	**0.015**
	II	36	6	42		

showed that type II after tooth preparation was associated with probing depth >6 mm (r = 0.271, $P = 0.015$, Table 3).

The classifications of cracked teeth after tooth preparation were associated with thermal sensitivity post-treatment

Seventy-five CTs maintained pulp healthy and were evaluated for the association between thermal sensitivity and the classification of CTs during the follow-up period. Before tooth preparation, no significant differences were found between different groups (all $P > 0.05$). However, when re-evaluating the thermal sensitivity after tooth preparation, type I CTs had a significant short-time relief (≤1 month) compared with type II CTs ($P = 0.013$, Table 4).

The classifications of cracked teeth after tooth preparation were associated with pulp complications post-treatment

During follow-up, it was found that 5 (6 %) CTs had pulp complications and required root canal therapy (RCT). We counted RCT as a failure event of the pulp vitality. Similarly, CL features after tooth preparation had a more significant impact on the result. Kaplan–Meier survival analysis showed a significant difference between Type I and Type II ($P = 0.029$, Fig. 2).

Discussion

In this study, we restored CTs with occlusal veneer, achieving favorable clinical outcomes.[15,19] During the treatment, CLs on the occlusal surface of CTs were recorded before and after tooth preparation. Our findings showed that removing the superficial layer of CT revealed the hidden CLs, erased the shallow ones, and highlighted the significant ones. To the best of our knowledge, this is the first study that provided a detailed description of CL after tooth preparation and

Table 4 Relationship between thermal/biting sensitivity and the classification of cracked teeth after tooth preparation[a].

Tooth preparation	Items	Types	The relief time of pain (n)			Pearson chi-square
			≤1 month	≥2 month	All (n)	
Before	Thermal sensitivity	I	20	3	23	0.747
		II	42	10	52	
	Biting sensitivity	I	17	6	23	0.438
		II	44	8	52	
After	Thermal sensitivity	I	36	2	38	**0.013**
		II	26	11	37	
	Biting sensitivity	I	32	6	38	0.725
		II	29	8	37	
	I	No mesial-distal or buccal-lingual direction through the marginal ridge				
	II	Mesial-distal or/and buccal-lingual direction through the marginal ridge				

[a] Five cracked teeth that underwent root canal therapy were excluded from this analysis.

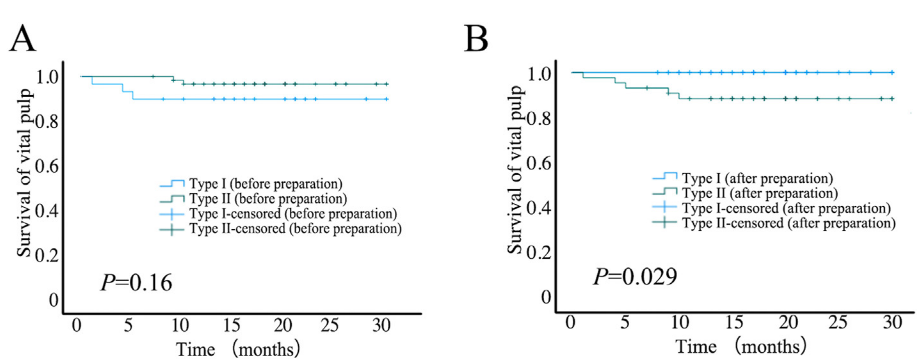

Figure 2 Vital pulp survival analysis of cracked teeth with type I and II crack lines before and after tooth preparation. (A) Crack line type had no relationship with pulp survival before tooth preparation. (B) Type II crack lines were associated with pulp complications after tooth preparation ($P = 0.029$).

pointed out a possible inaccurate assessment of the complexity of CL before tooth preparation.

In the present study, the CTs diagnosed with normal pulp or reversible pulpitis were included, and only 5 of 80 CTs required RCT during follow-up. The survival rates of vital pulp were higher than those reported in previous studies,[20,21] which might be due to the early diagnosis since the majority of patients were relatively young (60 % $\leq$ 35), and the existing symptoms lasted <12 months in two-thirds of patients.[21,22] The earlier the diagnosis, the better the prognosis.[23,24] In addition, occlusal veneer was applied in these cases to restore CT, reducing the pulp stimulation rather than a crown.[25]

Subsequently, CTs were divided into 2 types depending on whether CLs went through occlusal surface mesial-distally or/and buccal-lingually. Obviously, the depth of CLs impacted pulp tissue health and the prognosis of CTs.[5] However, in the existing literature, there is little evidence that could be used to help directly detect the depth of the CLs. An *in vitro* study somewhat supports our classification, demonstrating that the longer the crack on the occlusal surface, the longer the crack on the proximal surface.[26] Therefore, we hypothesized that once the CLs go through the occlusal surface mesial-distally or/and buccal-lingually, the CLs might extend to deeper tooth tissue, resulting in a poorer prognosis.

According to this hypothesis, we evaluated the effects of CL types. Our results showed that the types of CLs before preparation had no significant effect on the prognosis of CTs restored by occlusal veneer, which is consistent with a previous study, reporting that the directions of CLs had no relationship with the loss of CT.[14] However, after re-evaluating the CL types after tooth preparation, type II was found to have a poorer prognosis. Firstly, type II CLs were associated with deep probing depth (>6 mm). Probing depth was an indirect indicator predicting the extension of CLs. Many studies reported that probing depth is significantly correlated with pulp status and tooth survival rate in CTs.[11,21,27,28] Secondly, the type II CLs group had a longer relief time of thermal sensitivity. Thirdly, type II CLs affected pulp status and caused pulp complications, thus requiring RCT. We supposed these inconsistent results before and after tooth preparation were due to the difficulty in accurately identifying CL before tooth preparation. All the results supported the premise that CLs could be detected clearly after tooth preparation and predict the prognosis of CTs.

In conclusion, the present study proposed that the classification of CLs significantly differed before and after tooth preparation. After tooth preparation, type II CLs were associated with deep probing depth, delayed thermal sensitivity relief time, and low survival rates of the vital pulp in CTs. Factors influencing prognosis were likely to change at different stages as the CT developed, and the types of CLs impacted therapeutic effects in the relatively early stage. However, more cases and longer follow-ups are required to confirm the reported data.

Declaration of competing interest

The authors declare no potential conflicts of interest concerning the authorship and/or publication of this article.

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