

# Evaluate four different ways in diagnosing tooth cracks

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## Research article

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# Abstract

## Introduction

The aim of this study was to evaluate four different ways in diagnosing tooth cracks, which may provide certain theoretical bases for early diagnosis of cracks.

## Methods

123 freshly extracted human teeth were collected in the Stomatology Hospital of Guangzhou Medical University, Guangzhou, China. Three observers examined the cracks of the crowns with naked eye, microscope, methylene blue dye, and methylene blue dye with magnification microscopic examination methods independently. Two criteria (crack lines appeared in enamel and dentin) were used to diagnose teeth cracks, and statistical analysis was performed using the SPSS and MedCalc statistical software. Kendall's W was conducted to assess the agreement among the three observers in each detection method. Sensitivity, specificity, positive predictive value, negative predictive value, and the area under the curve (AUC) drawn in terms of sensitivity and (1-specificity) were calculated to evaluate the diagnostic value of four different methods.

## Results

3 teeth were excluded because of the visual fatigue of the observer, and there were 120 teeth left. The method of methylene blue plus microscope had the lowest value of Kendall's W in criterion 1 and 2. The overall AUC values were more than 0.7 in both the microscopic and methylene blue plus microscopic method according to criterion 1 and 2, and in the method of naked-eye according to criterion 2. The pairwise comparison between A, B and C had statistical difference in the method of naked-eye, microscope and methylene blue plus microscope in criterion 2 ( $P < 0.05$ ).

## Conclusions

Detecting tooth crack with the method of methylene blue plus microscope have a higher consistency among different experienced endodontists. Microscope and methylene blue dye with magnification microscopic examination were effective methods to diagnosis tooth crack. More cracks can be detected by experienced endodontists, and the difference persisted even with the use of microscopes or methylene blue dye.

## Background

Tooth cracks have become the third largest reason of tooth loss after dental caries and periodontitis (1, 2). Crack lines at an early stage in the enamel may not be visible and tooth may not have any symptoms. When the crack lines are extending to surficial dentin, the tooth may exhibit hypersensitivity to cold, sweet, or sour stimulation. Most teeth failed to be diagnosed at early stages until crack lines extended to

the deep layer of dentin or the pulp cavity, which may lead to pulpitis or periapical periodontitis(1, 2). So early diagnosis of tooth cracks is important for its survival(3).

Several methods have been used for diagnosing tooth cracks, such as methylene blue dye, microscopic examination, transillumination, the bite test, periapical radiography (PR), cone-beam computed tomographic (CBCT) imaging and magnetic resonance imaging(4, 5). PR cannot diagnose early tooth cracks, especially when the crack extends from mesial to distal, or the crack is parallel to the long axis of the tooth. CBCT imaging can be more useful for detecting vertical fractures and cracks than dental periapical radiography. However, early enamel cracks are too tiny to be diagnosed by CBCT(6).

The common techniques clinically for diagnosing early enamel crack are methylene blue dye and microscopic examination(7–9). Several authors have suggested the application of methylene blue dye and transillumination to detect cracks(10, 11). Henry et al compared the effectiveness of transillumination and different dyes methods in identifying cracks, and concluded that transilluminating the root end, whether alone or in combination with a dye, was the most accurate way of diagnosing root-end dentinal cracks. Regardless of rater, methylene blue plus transillumination was the best identifying techniques between cracked and non-cracked root-end dentin (12). The microscope has a magnifying function which facilitates the observation of tiny crack lines and was used as the gold standard for detecting cracks in most studies (13, 14). However, no study has been conducted to compare the effectiveness of methylene blue dye and microscope in detecting tooth cracks.

Since most of the cracks we can detect clinically are in the crown of the tooth and the depth of the cracks determines the treatment plans and prognosis of the tooth, the accuracy of the detection method plays a decisive role in the diagnosis of tooth cracks(15). The detection rate of early cracks is also different according to distinct clinical experience of endodontists.

Therefore, this study was conducted to identify the most accurate detection methods among four clinical detection methods (naked-eye, methylene blue dye, microscope, methylene blue plus microscope), and assess the differences in the rate of crack detection among endodontists with different clinical experience. This study may provide certain theoretical bases for early diagnosis of cracks.

## Methods

### *Sample preparation*

123 freshly human teeth extracted from patients aged 13 to 89 y old on the maxillary and mandibular arches were collected in the Stomatology Hospital of Guangzhou Medical University, Guangzhou, China. The exclusion criteria were the presence of restoration, root absorption, root fracture, severe abrasion and wedge-shaped defects. All patients provided permission for the use of their extracted teeth in this study. And all the reasons for these teeth extraction were irrelevant to this study. The use of teeth was approved by the Ethical Review Board in Stomatology Hospital of Guangzhou Medical University Ethics Review Committee.

The 123 teeth were collected and immediately sterilized in 1% solution of chloramine(16). Then they were stored in 4°C refrigerator to maintain tissue hydration during the study. Three observers, a senior endodontist who has worked for more than 10 years (we defined as A), an intermediate endodontist who has worked for 5 years (we defined as B), and a junior endodontist who has just graduated (we defined as C) examined the teeth cracks in the crown under naked eye, magnification microscopic examination, methylene blue dye with naked eye, and methylene blue dye with magnification microscopic examination independently.

In the group of naked eye, the teeth were viewed with naked eye under the light of the dental chair; in the group of microscopic examination, the teeth were viewed under the microscopic examination with ×10 magnification; in the group of the methylene blue dye, the teeth were viewed with 2% methylene blue dye with naked eye under the light of the dental chair; in the group of methylene blue dye plus microscope, the teeth were viewed with 2% methylene blue dye under the microscopic examination with ×10 magnification. The methylene blue dye was allowed to remain on the tooth crown surface for 30 seconds, and then were rinsed with tap water for 5 seconds.

### *Micro-CT scanning*

Micro-CT scanning were used in these 123 teeth to detect whether the crack extended to dentin. To obtain high-definition images of the anatomic configuration of each tooth, the specimens were scanned in an isotropic resolution of 10 μm using the micro-CT scanner (SkyScan 1172; Bruker-micro CT, Kontich, Belgium) with 70 kV and 114 mA. Flat-field correction was performed before the scanning procedures to correct for variations in the camera pixel sensitivity. Scanning was performed by 360° rotation around the vertical axis with a rotation step of 0.5° and a camera exposure time of 7000 ms, and frame averaging of the X-rays was performed with a 1-mm-thick aluminum filter. The images were reconstructed with NRecon 1.6.3 software (Bruker-micro CT) using 40% beam hardening correction and a ring artifact correction of 10, resulting in the acquisition of 700–800 transverse cross-sections per tooth in a bitmap format. Dataviewer software (SkyScan 1172; Bruker-micro CT, Kontich, Belgium) was used to evaluate the cross-sections of teeth.

### *Diagnostic Criteria*

According to the suggestion of American Association of Endodontists (AAE), cracks are classified into 5 types: craze lines, fractured cusp, cracked tooth, split tooth, and vertical root fracture(17). In this study, we used two criteria to diagnose teeth cracks.

Criterion 1 covered all the crack lines within the enamel of the crown, including craze lines, fractured cusp, cracked tooth and split tooth. Vertical root fracture was beyond the scope of this article. Criterion 2 covered all the crack lines extending to the dentin, including fractured cusp, cracked tooth and split tooth. The crack lines reached or exceeded the enamel-dentinal junction under micro-CT scanning were also included in this criterion (Figure 1).

All the samples were observed in the following order: naked eye, microscope, methylene blue dye and methylene blue dye plus microscopic examination in each criterion. We recorded “1” for the samples with crack lines, and “0” for the samples without crack lines in each detection methods among different observers (Figure 2).

### *Statistical Analysis*

Statistical analysis was performed using the SPSS software package (SPSS statistics 25.0; SPSS, Inc, Chicago, IL). We used Kendall’s  $W$  to calculate the agreement of the three observers among four detection methods, and the  $H_0$  means that each tooth receives the same diagnosis under the detection method.

In criterion 1, we chose the method which had the lowest value of Kendall’s  $W$  as the gold standard method. Based on the gold standard method, a tooth recorded “1” by three or two people was diagnosed as “truly cracked tooth”, while the remaining teeth were classified as “truly non-cracked tooth”. In criterion 2, we also chose the method which had the lowest Kendall’s  $W$  as the gold standard method. According to the gold standard method, a tooth recorded “1” by three or two people was diagnosed as “truly cracked tooth”. In addition, all three observers agreed that the teeth with the crack lines reaching or exceeding the enamel-dentinal junction under micro-CT scanning were also classified as “truly cracked tooth” and the remaining teeth were classified as “truly non-cracked tooth”.

Following outcome variables were calculated: sensitivity (Se), defined as the probability of a diagnostic criterion indicating that the tooth crown is cracked, given that crown is truly cracked; specificity (Sp), defined as the probability of a diagnostic criterion indicating that the crown is not cracked, given that the tooth is truly not cracked; the positive predictive value (PPV), indicated as the probability that the crown is truly cracked given that the diagnostic procedure indicated it is cracked; and the negative predictive value (NPV), indicated as the probability that the crown is truly not cracked, given that the diagnostic procedure indicates it is not cracked.

When sensitivity is plotted against (1-specificity), the resulting curve is called a receiver operating characteristic curve that has a slope of 1. The diagnostic data are quantitated by calculating the area under the curve (AUC). Random chance areas were between 0 to 0.5, to be useful methods, the AUC for diagnostic procedures should be between 0.7 and 1.0, the AUC values for each observer under each method independently were calculated along with their 95% confidence intervals (CIs) and  $P$  values. Finally, to determine whether one observer had significantly better ability to discriminate between cracked and non-cracked teeth within diagnostic procedures, pair-wise multiple comparisons of AUCs between observers within procedures were conducted by the MedCalc statistical software version 15.2.2 (MedCalc Software, Ostend, Belgium) (12) (18, 19).

## **Results**

Firstly, we excluded 3 teeth which were diagnosed by C as tooth crack according to criterion 2, but not criterion 1, and there were 120 teeth left.

According to table 1, the method of methylene blue plus microscope had the lowest value of Kendall's W, with the  $KW = 0.055$ ,  $P = 0.001$  and  $KW = 0.026$ ,  $P = 0.06$  in criterion 1 and 2 respectively. In this study, we chose the method of methylene blue plus microscope as the gold standard. In criterion 1, 114 teeth were classified as "truly cracked tooth", and 6 teeth were classified as "truly non-cracked tooth". In criterion 2, 20 teeth were classified as "truly cracked tooth", and 100 teeth were classified as "truly non-cracked tooth".

Table 2 and table 3 summarized the sensitivity, specificity, positive and negative predictive value, AUC and the 95% CIs and  $P$  value for the AUC of different detection methods among three observers with two criteria.

In table 2, the overall AUC value of the microscopic and methylene blue plus microscopic method was more than 0.7 with  $P < 0.05$ . AUC values and their 95% confidence intervals (CIs) were as follows respectively: microscope, A 0.833 (95% CI, 0.601–1.000), B 0.750 (95% CI, 0.490–1.000) and C 0.750 (95% CI, 0.524–0.976) independently; methylene blue plus microscope, A 0.908 (95% CI, 0.731–1.000), B 0.750 (95% CI, 0.490–1.000) and C 0.781 (95% CI, 0.553–1.000) independently. Pairwise comparison of A, B and C within the methods of naked eye and methylene blue dye showed no statistical difference.

In table 3, the overall AUC values great than 0.7 were as follows: methylene blue plus microscope, A 0.885 (95% CI, 0.779–0.991), B 0.740 (95% CI, 0.596–0.884) and C 0.715 (95% CI, 0.568–0.862); microscope, A 0.755 (95% CI, 0.668–0.882); methylene blue dye, B 0.740 (95% CI, 0.596–0.884); naked-eye, A 0.730 (95% CI, 0.595–0.865) and B 0.715 (95% CI, 0.568–0.862) independently. The AUC values between 0.5 to 0.7 were as follows: microscope, B 0.645 (95% CI, 0.494–0.796) and C 0.645 (95% CI, 0.496–0.794); methylene blue dye, A 0.655 (95% CI, 0.538–0.772) and C 0.670 (95% CI, 0.519–0.821); naked-eye, C 0.555 (95% CI, 0.409–0.701). All  $P < 0.05$  excepted for C with the naked-eye. The pairwise comparison between A and B, A and C had significant statistical difference in the method of methylene blue plus microscope ( $P < 0.01$ ) and in the method of microscope ( $P < 0.05$ ), also, the pairwise comparison between A and C, B and C had statistical difference ( $P < 0.05$ ) in the method of naked-eye.

Table 4 showed the results of each detection method based on the two criteria of diagnosis. The AUC values were more than 0.7 with  $P < 0.01$  except the naked-eye and methylene blue dye methods under criterion 1, with the  $P = 0.539$  and  $P = 1.000$  independently. Pairwise comparison of each method showed no statistical difference in criterion 2, also the method between microscope and methylene blue plus microscope in criterion 1.

## Discussion

In this study, two common clinical methods (methylene blue dye and microscope) were applied to detect teeth cracks, the effectiveness of four methods were compared to provide guidance for the early diagnosis of tooth crack, and two criteria were used to diagnose tooth crack. Simply stated, criterion 1 was used to detect crack lines appeared in enamel, while criterion 2 was used to detect dentin cracks.

When the crack of the tooth extends to the dentin layer, it will appear some uncomfortable symptoms after hot or cold stimulation. Criterion 2 is more consistent with the clinical diagnosis.

One of the difficulties in this study is the determination of the gold standard.

Firstly, we used Kendall's W to calculate the agreement of the three observers among four detection methods. According to criterion 1 and 2, methylene blue plus microscope had the lowest value of Kendall's W among the four methods, that's to say, A, B and C had the highest consistency under the method of methylene blue plus microscope. Due to microscope with the function of magnifying, and methylene blue dyeing function, it was reasonable that the combination of methylene blue and microscope had the highest accuracy among the four methods.

Secondly, according to the methylene blue plus microscope method, a tooth which diagnosed crack tooth by three or two people was diagnosed as "truly cracked tooth". Why don't we choose other methods as the gold standard? If we choose other methods as the diagnostic gold standard, the diagnosis of tooth crack will also be different among different people.

Thirdly, we used micro-CT to accurately detect cracks according to resolution, previous study has concluded that micro-CT was an ideal technology for the diagnosis of cracks(20, 21). Moisture content of dentine can influence the detection of micro-CT. So in this study, we performed dried condition to avoid the missing of some cracks(22). Also, in order to reduce the omission diagnostic rate of dentin cracks, we used micro-CT to detect tooth cracks which reached or exceeded the enamel-dentinal junction.

Theoretically, the tooth which were diagnosed as tooth crack based on criterion 2 should have the same diagnosis in criterion 1. So we excluded 3 teeth which were diagnosed by C as tooth crack in criterion 2, but not in criterion 1. This may be caused by the visual fatigue of the observer. In this study, 114 teeth were diagnosed as cracked teeth in criterion 1, and 20 teeth were diagnosed as dentin crack. 94 teeth (78.3%) were diagnosed as craze lines which referred to the crack within enamel, and light can't be blocked by transillumination in these teeth. The results were consistent with the AAE guideline which has reported a high incidence of craze lines among permanent teeth.

Also, some factors in this study made it challenging to diagnose cracked teeth, such as grooves of teeth and subjectivity of each observer. The grooves can cause a change in the reflection of light, creating the illusion of a crack, especially in the method of methylene blue dye and methylene blue plus microscope. Each observer's subjectivity can lead to false positives or false negatives.

In looking at the teeth which diagnosed in criterion 1, the AUC < 0.7 in both the method of naked-eye and methylene blue dye, with the  $P > 0.05$ , that's to say, the method of naked-eye and methylene blue dye were more random in diagnosis. In criterion 1, the sensitivity of A and B was greater than C in the method of naked-eye and methylene blue dye, but both with the lower specificity than C, which led to the lower AUC values in A and B. That means more teeth without cracks were misdiagnosed as teeth crack with the method of naked-eye and methylene blue dye in A and B. Maybe more grooves were mistaken for cracks.

However, the method of microscope and methylene blue plus microscope can reverse the result with the naked-eye and methylene blue dye, especially for A. The methods of microscope and methylene blue plus microscope both had the AUC values more than 0.7. That's to say, the diagnostic value of using microscope alone or the methylene blue plus microscope was high in criterion 1.

In looking at the teeth which diagnosed in criterion 2, A had the high sensitivity to the diagnosis of dentin cracks, but with a lowest specificity among the three observers, which implies that A was better at diagnosing dentin crack. While B and C had high specificity, which implies that B and C were better at disclosing which teeth did not have cracks. Only in the methylene blue plus microscope method, the AUC value of all three observers was more than 0.7. C's diagnosis of tooth crack was more random under the method of naked-eye. The pairwise comparison between A, B and C had statistical difference in the method of naked-eye, microscope and methylene blue plus microscope, which implies more cracks can be detected by experienced people, and the difference persisted even with the use of microscopes or methylene blue dye.

## Conclusion

Detecting tooth crack with the method of methylene blue plus microscope have a higher consistency among different experienced endodontists. Microscope and methylene blue dye with magnification microscopic examination were effective methods to diagnosis tooth crack. More cracks can be detected by experienced endodontists, and the difference persisted even with the use of microscopes or methylene blue dye.

## Abbreviations

*SPSS*: Statistical Product and Service Solutions

*AUC*: area under the curve

*PR*: periapical radiography

*CBCT*: cone-beam computed tomographic

*Micro-CT*: micro computed tomography

*AAE*: American Association of Endodontists

*Se*: sensitivity

*Sp*: specificity

*PPV*: positive predictive value

*NPV*: negative predictive value

*CI*: confidence intervals

*KW*: Kendall's W

## **Declarations**

### **Ethics approval and consent to participate**

The study was approved by the Ethical Review Board in Stomatology Hospital of Guangzhou Medical University Ethics Review Committee(NO.KY2019070). Written informed and oral consent was obtained from the study participants, and from a parent or guardian for participants under 16 years old.

### **Consent for publication**

Not applicable.

### **Availability of data and material**

The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

### **Competing interests**

The authors declare that they have no competing interests.

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### **Authors' contributions**

YH and QF are the main investigators of this research article, they performed study and literature research, QZ J, WJ Z and YH were the three observers in this study. YH was responsible for statistical analysis, diagrams and figures, and then wrote the main part of manuscript and revised the manuscript; QF was responsible for collection teeth and micro-CT scanning; XC Y was participate in manuscript revision; ZC and QZ J were supervisor and consultant for this study, they participated in drafting the manuscript and helped in the revision of the manuscript. All of the authors read and approved the final manuscript.

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# Tables

**Table 1 The agreement of the three observers.**

		Naked-eye	methylene blue dye	microscope	methylene blue plus microscope
Criterion 1	Kendall's W	0.301	0.118	0.144	0.055
	Pvalue	0.000	0.000	0.000	0.001
Criterion 2	Kendall's W	0.078	0.494	0.225	0.026
	Pvalue	0.000	0.000	0.000	0.060

**Table 2 Sensitivity (Se), specificity (Sp), positive predictive value (PPV), negative predictive-value (NPV), and AUC for each observer with different detection method among the diagnosis of criterion 1.**

Method	Se	Sp	PPV	NPV	AUC	95% CI for AUC	P value
naked-eye							
A							
B	0.956	0.167	0.956	0.167	0.561	0.305-0.817	0.613
C	0.991	0.000	0.950	0.000	0.496	0.260-0.732	0.971
	0.649	0.667	0.974	0.091	0.658	0.433-0.882	0.193
methylene blue dye							
A	0.991	0.000	0.950	0.000	0.496	0.260-0.732	0.971
B	1.000	0.000	0.950	0.000	0.500	0.262-0.738	1.000
C	0.877	0.333	0.962	0.125	0.605	0.349-0.862	0.386
microscope							
A	1.000	0.667	0.983	1.000	0.833	0.601-1.000	0.006
B	1.000	0.500	0.974	1.000	0.750	0.490-1.000	0.039
C	0.833	0.667	0.979	0.174	0.750	0.524-0.976	0.039
methylene blue plus microscope							
A	0.982	0.833	0.991	0.714	0.908	0.731-1.000	0.001
B	1.000	0.500	0.974	1.000	0.750	0.490-1.000	0.039
C	0.895	0.667	0.981	0.250	0.781	0.553-1.000	0.021

pairwise comparison of A, B and C under each method showed no statistical difference

**Table 3 Sensitivity (Se), specificity (Sp), positive predictive value (PPV), negative predictive-value (NPV), and AUC for each observer with each detection method among the diagnosis of criterion 2.**

Method	Se	Sp	PPV	NPV	AUC	95% CI for AUC	<i>P</i> value
7e	0.600	0.860	0.462	0.085	0.730 <sub>□</sub>	0.595-0.865	0.001
	0.450	0.980	0.818	0.101	0.715 <sub>□</sub>	0.568-0.862	0.002
	0.150	0.960	0.429	0.150	0.555 <sub>□□</sub>	0.409-0.701	0.439
one blue dye	0.900	0.410	0.234	0.047	0.655	0.538-0.772	0.029
	0.500	0.980	0.833	0.093	0.740	0.596-0.884	0.001
	0.350	0.990	0.875	0.116	0.670	0.519-0.821	0.017
cope	0.850	0.700	0.362	0.041	0.775 <sub>□□</sub>	0.668-0.882	0.000
	0.300	0.990	0.857	0.124	0.645 <sub>□</sub>	0.494-0.796	0.041
	0.350	0.940	0.538	0.121	0.645 <sub>□</sub>	0.496-0.794	0.041
one blue plus cope	0.800	0.970	0.842	0.040	0.885 <sub>▲▲</sub>	0.779-0.991	0.000
	0.500	0.980	0.833	0.093	0.740 <sub>▲</sub>	0.596-0.884	0.001
	0.450	0.980	0.818	0.101	0.715 <sub>△</sub>	0.568-0.862	0.002

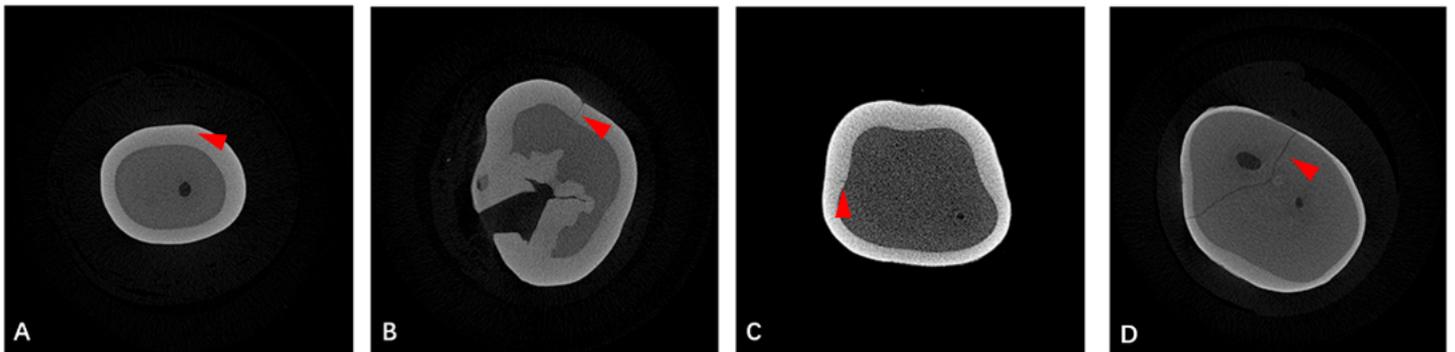
pairwise comparison of A, B and C under each method, ▲▲*P*< 0.01, □□*P*< 0.05.

**Table 4 Sensitivity (Se), specificity (Sp), positive predictive value (PPV), negative predictive-value (NPV), and AROC for each detection method among the diagnosis of the two criteria.**

Method	Se	Sp	PPV	NPV	AUC	95% CI for AUC	P value
Criterion 1 naked-eye	0.982	0.167	0.957	0.333	0.575 $\Delta$ $\square$	0.314 -0.835	0.539
methylene blue dye	1.000	0.000	0.950	0.000	0.500 $\blacktriangle$	0.262- 0.738	1.000
microscope	1.000	0.983	0.983	1.000	0.833 $\blacktriangle$ $\square$	0.601- 1.000	0.006
methylene blue plus microscope	1.000	1.000	1.000	1.000	1.000 $\Delta$	1.000 -1.000	0.000
Criterion 2 naked-eye	0.500	0.980	0.833	0.093	0.740	0.596 -0.884	0.001
methylene blue dye	0.700	0.970	0.824	0.058	0.835	0.711- 0.959	0.000
microscope	0.500	0.990	0.909	0.092	0.745	0.601 -0.889	0.001
methylene blue plus microscope	0.700	1.000	1.000	0.057	0.850	0.726- 0.974	0.000

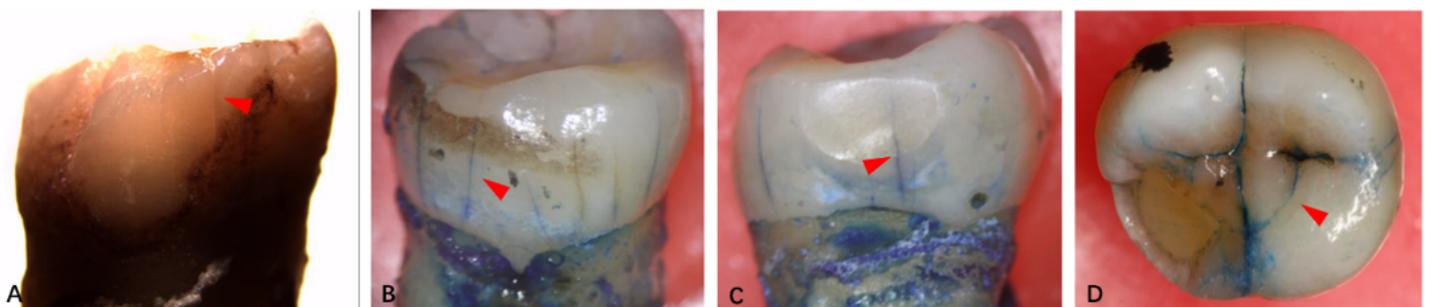
pairwise comparison of each method,  $\blacktriangle$  $\Delta$  $P < 0.01$ ,  $\square$  $P < 0.05$ .

## Figures



**Figure 1**

Depth of the cracked teeth scanned by micro-CT. (A) the crack line in the enamel. (B) the crack line reaches to the enamel-dentinal junction. (C, D) the crack line exceeds to the enamel-dentinal junction. The red arrow shows the crack line.



## Figure 2

Crack lines examination under microscope. (A) the crack line examination with naked-eye under microscope. (B) the crack line examination with methylene blue dye under microscope. (C) the cracked tooth diagnosed according to criterion 1. (D) the cracked tooth diagnosed according to criterion 2. The red arrow shows the crack line.