Review

Diagnostic accuracy of CBCT for tooth fractures: A meta-analysis

Hu Long, Yang Zhou, Niansong Ye, Lina Liao, Fan Jian, Yan Wang, Wenli Lai *

Department of Orthodontics, State Key Laboratory of Oral Diseases, West China Hospital of Stomatology, Sichuan University, Chengdu 610041, Sichuan, China

A R T I C L E   I N F O

Article history:
Received 17 July 2013
Received in revised form 26 November 2013
Accepted 30 November 2013
Available online xxx

A B S T R A C T

Objectives: The objective of this meta-analysis was to determine the diagnostic accuracy of cone-beam computed tomography (CBCT) for tooth fractures in vivo.

Methods: PubMed, Embase, Web of Science, ProQuest Dissertations & Theses, CNKI and SIGLE were searched from January 1990 to April 2013 for eligible studies. Quality Assessment of Diagnostic Accuracy Studies-2 (QUADAS-2) was employed to assess the quality of the included studies. Meta-analyses were performed in MetaDisc 1.4, Stata 12.1 and StatsDirect 2.7.9.

Results: Finally, 12 studies were included in this meta-analysis. The pooled sensitivity, specificity, positive likelihood ratio, negative likelihood ratio and summary receiver operating characteristic were 0.92 (95% CI = 0.89–0.94), 0.85 (95% CI = 0.75–0.92), 5.68 (95% CI = 3.42–9.45), 0.13 (95% CI = 0.09–0.18) and 0.94 (95% CI = 0.90–0.98), respectively. The pooled prevalence of tooth fractures in patients with clinically-suspected but periapical-radiography-undetected tooth fractures was 91% (95% CI = 83%-97%). Positive and negative predictive values were 0.98 and 0.43 (subgroup analysis: 0.98 and 0.28 for endodontically-treated teeth; 0.99 and 0.77 for non-endodontically-treated teeth).

Conclusion: We suggest that CBCT has a high diagnostic accuracy for tooth fractures and could be used in clinical settings. We can be very confident with positive test results but should be very cautious with negative test results, especially for endodontically treated teeth.

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1. Introduction

With the evolution and adaptation of animal species to diet, their teeth have evolved sophisticated microstructures to absorb considerably high occlusal forces and to protect their teeth from fractures, although their dental enamel is per se highly brittle. Despite these sophisticated microstructures, tooth fractures are still frequently encountered in dental practice. It has been well documented that the most common cause of tooth fractures in adults is high occlusal forces caused by biting on hard objects or abnormal contacts of opposing teeth. In addition, earlier endodontic therapy and malocclusions are implicated in the aetiology of tooth fractures. The
treatment of tooth fractures often requires an interdisciplinary approach, e.g., combined endodontic-orthodontic-prosthodontic treatments. Thus, tooth fracture is an issue discussed in almost all the dental specialties.

Unfortunately, the diagnosis of tooth fractures, especially root fractures, is sometimes difficult for dental practitioners due to their extremely variable clinical presentations and no pathognomonic signs. The most common diagnostic modality for tooth fractures—periapical radiography—has been revealed to have a low diagnostic accuracy and to leave many tooth fractures undetected. The introduction of cone-beam computed tomography (CBCT) in dentistry has allowed dental practitioners to acquire three-dimensional visualization of teeth with high spatial resolution and low radiation. Several studies have revealed the outstanding diagnostic accuracy of CBCT for tooth fractures, especially for those undetected through periapical radiography. However, these studies based on in vitro tooth fractures and the diagnostic performance of CBCT for tooth fractures in vivo has been poorly understood. Moreover, it has been reported that not all dental practitioners or dental students were aware of CBCT. Therefore, in order to help practitioners make correct diagnosis and subsequent prudent treatment decisions, we conducted this meta-analysis to critically appraise the currently available evidence and to determine the diagnostic accuracy of CBCT for tooth fractures in vivo.

2. Methods

2.1. Inclusion criteria for included studies

Studies should be those which examined the diagnostic accuracy of CBCT for tooth fractures in vivo. In vitro studies and case reports would be excluded. Participants in each study should be clinically suspected with tooth fractures and received CBCT examinations for the diagnosis of tooth fractures. The number of participants in each study should be at least 10. Furthermore, studies should have reference tests—surgical exploration or extractions—to establish the diagnosis of tooth fractures.

2.2. Search methods

We searched the electronic databases of PubMed, Embase, Web of Science, ProQuest Dissertations & Theses and CNKI. Moreover, the grey literature database of SIGLE was searched. The specific search strategy for each database is presented in Table 1. The electronic searching was from January 1990 to April 2013 with no language restriction. Two review authors (HL and YZ) conducted the electronic searching independently and in duplicate. Any disagreement was solved by discussion or referred to a third author.

2.3. Data extraction and analysis

2.3.1. Data extraction

Demographic data, reference test, true positive, false positive, false negative and true negative were extracted and recorded independently and in duplicate by two reviewer authors (HL and YZ).

2.3.2. Study outcomes

Study outcomes were sensitivity, specificity, positive likelihood ratio (LR), negative LR and summary receiver operating characteristic (SROC). Moreover, derivative outcomes (prevalence, positive predictive value (PPV) and negative predictive value (NPV)) were calculated from the study outcomes mentioned above.

2.3.3. Quality assessment

The quality of each included study was evaluated according to Quality Assessment of Studies of Diagnostic Accuracy-2 (QUADAS-2). Specifically, for each category (risk of bias and applicability concerns), studies with two or more domains of high risk would be designated as high risk; those with only one domain of high risk would be designated as medium risk; those with no domain of high risk would be designated as low risk. Assessments were conducted independently and in duplicate by two review authors.

2.3.4. Data analysis

Outcome data, i.e., sensitivity, specificity, positive LR, negative LR and SROC, would be statistically pooled. Moreover,
prevalences of tooth fractures, non-fractures, positive test results and negative test results were statistically pooled through Freeman–Tukey arcsine square root transformation for variance stabilization.\textsuperscript{20,21} PPV and NPV were calculated through Bayes’ theorem.\textsuperscript{22} Heterogeneity across studies was assessed through $I^2$ statistic. An $I^2$ statistic greater than 50% was considered substantial heterogeneity. If substantial heterogeneity existed, subgroup analysis or meta-regression would be conducted to explore the heterogeneity. Mantel–Haenszel fixed effect model would be used when a common effect size is shared among includes studies; otherwise, DerSimonian–Laird random effect model would be used.\textsuperscript{23} In addition, even if a common effect size is shared among all studies, a random effect model would be adopted when significant heterogeneity existed ($I^2 > 50\%$).\textsuperscript{23}

Sensitivity analysis was performed to assess the robustness of the pooled results in the meta-analyses. Moreover, publication bias was evaluated based on a regression test and funnel plot designed specifically for diagnostic systematic reviews.\textsuperscript{24} All the statistical analyses were performed in MetaDisc 1.4,\textsuperscript{25} Stata 12.1 (StataCorp, College Station, TX, USA) and StatsDirect 2.7.9 (StatsDirect Ltd., Cheshire, UK).

### 3. Results

#### 3.1. Description of included studies

Initially, we identified 154 articles from the database and excluded 137 irrelevant articles. The remaining 17 articles were further assessed for eligibility and 12\textsuperscript{8–10,26–34} were finally included in this meta-analysis. Specifically, the detailed procedures of electronic searching are shown in Fig. 1. Among the included studies, sample sizes ranged from 10 to 135 teeth. Fracture types included vertical, oblique and horizontal tooth fractures. Both non-endodontically and endodontically treated teeth were included. All studies verified tooth fractures through reference standards, i.e., surgical extraction or exploration. The detailed characteristics of each study are presented in Table 2.

#### 3.2. Quality assessment

According to QUADAS-2, the quality assessment comprised two categories: risk of bias and applicability concerns. In this meta-analysis, although risk of bias of included studies was medium to high, the applicability was of medium to low risk (Table 3).

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**Table 2 – Characteristics of included studies.**

<table>
<thead>
<tr>
<th>Study</th>
<th>Sample size (teeth)</th>
<th>Age (yrs)</th>
<th>Fracture type</th>
<th>Tooth status</th>
<th>CBCT</th>
<th>Reference test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Du (2010)</td>
<td>40</td>
<td>36.6</td>
<td>Vertical</td>
<td>Non-endodontic</td>
<td>NewTom 3 G; 110 kV, 6 mA, 9 s</td>
<td>Surgical extraction or exploration</td>
</tr>
<tr>
<td>Liu (2010)</td>
<td>40</td>
<td>57</td>
<td>Vertical and oblique</td>
<td>–</td>
<td>Planmeca ProMax 3D</td>
<td>Surgical extraction or exploration</td>
</tr>
<tr>
<td>Edlund (2011)</td>
<td>32</td>
<td>20–70</td>
<td>Vertical</td>
<td>Endodontic</td>
<td>iCAT or 3D Accuitomo 80; voxel: 80 or 125 μm</td>
<td>Surgical exploration</td>
</tr>
<tr>
<td>Ning (2011)</td>
<td>17</td>
<td>63</td>
<td>Vertical</td>
<td>Both</td>
<td>3DX multi-image micro-CT; 80 kV, 5 mA, 20 s; voxel: 125 μm</td>
<td>Surgical extraction or exploration</td>
</tr>
<tr>
<td>Qin (2011)</td>
<td>47</td>
<td>26–58</td>
<td>–</td>
<td>–</td>
<td>Kodak 9000C 3D</td>
<td>Surgical extraction or exploration</td>
</tr>
<tr>
<td>Wang (2011)</td>
<td>135</td>
<td>22–82</td>
<td>Vertical and oblique</td>
<td>Both</td>
<td>3DX Accuitomo; 80 kV, 5 mA, 17.5 s; voxel: 125 μm</td>
<td>Surgical extraction or exploration</td>
</tr>
<tr>
<td>Xue (2011)</td>
<td>84</td>
<td>20–89</td>
<td>Vertical</td>
<td>Both</td>
<td>Galileos Comfort; 85 kV, 35 mA s; voxel: 125 μm</td>
<td>Surgical extraction or exploration</td>
</tr>
<tr>
<td>Yan (2011)</td>
<td>23</td>
<td>–</td>
<td>Vertical</td>
<td>Both</td>
<td>3DX multi-image micro-CT; 80 kV, 5 mA, 17.5 s</td>
<td>Surgical extraction</td>
</tr>
<tr>
<td>Ding (2012)</td>
<td>38</td>
<td>57</td>
<td>All\textsuperscript{*}</td>
<td>Both</td>
<td>KaVo 3D eXam; 90–120 kV, 3–7 mA; voxel: 125 μm</td>
<td>Surgical extraction or exploration</td>
</tr>
<tr>
<td>Kajan (2012)</td>
<td>10</td>
<td>21–70</td>
<td>All</td>
<td>Endodontic</td>
<td>NewTom VG; 110 kV, 5.5 mA, 5.4 s</td>
<td>Surgical extraction</td>
</tr>
<tr>
<td>Metska (2012)</td>
<td>39</td>
<td>–</td>
<td>Vertical</td>
<td>Endodontic</td>
<td>NewTom 3 G or 3D Accuitomo 170; 110 kV, 3.9–5.6 mA or 90 kV, 5 mA; voxel: 200 or 80 μm</td>
<td>Surgical exploration or extraction</td>
</tr>
<tr>
<td>Liu (2013)</td>
<td>31</td>
<td>45</td>
<td>–</td>
<td>–</td>
<td>Planmeca ProMax 3D</td>
<td>Surgical extraction</td>
</tr>
</tbody>
</table>

\* All is indicative of vertical, oblique and horizontal fractures.

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Table 3 – Quality assessment of the included studies according to QUADAS-2.

<table>
<thead>
<tr>
<th>Study</th>
<th>Risk of bias</th>
<th>Applicability concerns</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Patient selection</td>
<td>Index test</td>
</tr>
<tr>
<td>Du (2010)</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Liu (2010)</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Edlund (2011)</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Ning (2011)</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Qin (2011)</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Wang (2011)</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Xue (2011)</td>
<td>Unclear</td>
<td>High</td>
</tr>
<tr>
<td>Yan (2011)</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Ding (2012)</td>
<td>High</td>
<td>Unclear</td>
</tr>
<tr>
<td>Kajan (2012)</td>
<td>High</td>
<td>Unclear</td>
</tr>
<tr>
<td>Metska (2012)</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Liu (2013)</td>
<td>Unclear</td>
<td>Unclear</td>
</tr>
</tbody>
</table>

High: high risk; unclear: unclear risk; low: low risk.

3.3. Description of outcomes

All the study outcomes proposed above were evaluated among the included studies, i.e., sensitivity, specificity, positive LR, negative LR and SROC.

3.4. Statistical pooling of outcomes

3.4.1. Sensitivity and specificity

Considering that a common effect size was shared among studies and no significant heterogeneity existed for sensitivity and specificity ($I^2 = 38.7\%$ and $24.5\%$, respectively), the Mantel–Haenszel fixed effect model was employed. As displayed in Fig. 2 A and B, the results showed that the pooled sensitivity and specificity were 0.92 (95% CI = 0.89–0.94) and 0.85 (95% CI = 0.75–0.92), respectively.

3.4.2. Positive LR and negative LR

Since a common effect size was shared among studies and no significant heterogeneity existed ($I^2 = 26.7\%$ and 0.0%, respectively), fixed effect model was used. The results revealed that

**Fig. 2** – The pooled diagnostic indices for the diagnosis of tooth fractures through CBCT. (A) The pooled sensitivity for the diagnosis of tooth fractures through CBCT; (B) the pooled specificity for the diagnosis of tooth fractures through CBCT; (C) the pooled positive likelihood for the diagnosis of tooth fractures through CBCT; (D), the pooled negative likelihood ratio for the diagnosis of tooth fractures through CBCT.
3.4.3. SROC
The SROC curve for discrimination of fractures and non-fractures is presented in Fig. 3. The pooled area under curve (AUC) of SROC was 0.94 (95% CI = 0.90–0.98).

3.5. Prevalences
Although a common effect size was shared among the included studies, random effect model was employed due to significant heterogeneity ($I^2 = 87.6\%$ for tooth fractures and non-fractures; $I^2 = 87.2\%$ for positive and negative test results). The meta-analysis revealed that the pooled prevalence of tooth fractures was 0.91 (95% CI = 0.83–0.97) (Fig. 4). Moreover, the results showed that the pooled prevalences of non-fractures, positive test results and negative test results were 0.09 (95% CI = 0.03–0.17), 0.87 (95% CI = 0.78–0.94) and 0.13 (95% CI = 0.06–0.22), respectively.

3.6. PPV and NPV
Through Bayes' theorem, PPV and NPV were calculated to be 0.98 and 0.43. Moreover, PPV and NPV were 0.99 and 0.77 for non-endodontically treated teeth; PPV and NPV were 0.98 and 0.28 for endodontically treated teeth.

3.7. Sensitivity analysis
Since reference standard test was not applied in all the patients in three studies, a sensitivity analysis was performed by excluding these three studies, but no significant changes were found (Table 4).

Seven included studies exhibited high risk of bias (Table 3), thus we performed a sensitivity analysis by excluding these studies with high risk of bias and found a moderate but non-significant increase in diagnostic accuracy (Table 4).

Changes in effect models (fixed vs. random effect model) failed to reveal any significant change in the pooled results (Table 4).
Table 4 – Sensitivity analysis and subgroup analysis.

<table>
<thead>
<tr>
<th>Item</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Positive LR</th>
<th>Negative LR</th>
<th>SROC</th>
<th>PPV</th>
<th>NPV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original estimate</td>
<td>0.92 (0.89, 0.94)</td>
<td>0.85 (0.75, 0.92)</td>
<td>5.68 (3.42, 9.45)</td>
<td>0.13 (0.09, 0.18)</td>
<td>0.94 (0.90, 0.98)</td>
<td>0.98</td>
<td>0.43</td>
</tr>
<tr>
<td>Random effect model</td>
<td>0.92 (0.89, 0.94)</td>
<td>0.85 (0.75, 0.92)</td>
<td>3.49 (1.91, 6.40)</td>
<td>0.13 (0.09, 0.18)</td>
<td>0.94 (0.90, 0.98)</td>
<td>0.97</td>
<td>0.43</td>
</tr>
<tr>
<td>Gold standard reference test</td>
<td>0.91 (0.88, 0.94)</td>
<td>0.85 (0.75, 0.92)</td>
<td>5.76 (3.35, 9.91)</td>
<td>0.13 (0.09, 0.20)</td>
<td>0.94 (0.89, 0.99)</td>
<td>0.98</td>
<td>0.43</td>
</tr>
<tr>
<td>Exclusion of high risk of bias</td>
<td>0.94 (0.90, 0.97)</td>
<td>0.93 (0.81, 0.99)</td>
<td>10.98 (4.12, 29.29)</td>
<td>0.10 (0.06, 0.18)</td>
<td>0.98 (0.95, 1.00)</td>
<td>0.99</td>
<td>0.50</td>
</tr>
<tr>
<td>Inclusion of only low risk of</td>
<td>0.92 (0.88, 0.95)</td>
<td>0.86 (0.75, 0.94)</td>
<td>6.35 (3.35, 12.05)</td>
<td>0.13 (0.09, 0.21)</td>
<td>0.95 (0.89, 1.00)</td>
<td>0.98</td>
<td>0.43</td>
</tr>
<tr>
<td>applicability</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subgroup analysis on vertical</td>
<td>0.89 (0.84, 0.93)</td>
<td>0.73 (0.55, 0.87)</td>
<td>3.40 (1.87, 6.17)</td>
<td>0.18 (0.10, 0.29)</td>
<td>0.88 (0.77, 0.99)</td>
<td>0.97</td>
<td>0.35</td>
</tr>
<tr>
<td>fracture</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subgroup analysis on endodontic</td>
<td>0.82 (0.72, 0.89)</td>
<td>0.82 (0.68, 0.92)</td>
<td>4.19 (2.82, 7.69)</td>
<td>0.25 (0.16, 0.39)</td>
<td>0.90 (0.81, 0.98)</td>
<td>0.98</td>
<td>0.28</td>
</tr>
<tr>
<td>teeth</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subgroup analysis on non-endodontic</td>
<td>0.97 (0.92, 0.99)</td>
<td>0.95 (0.76, 1.00)</td>
<td>13.70 (3.01, 62.42)</td>
<td>0.03 (0.01, 0.11)</td>
<td>–</td>
<td>0.99</td>
<td>0.77</td>
</tr>
</tbody>
</table>

PPV: positive predictive value, NPV: negative predictive value.

Among the included studies, fracture types consisted of vertical, oblique and horizontal (Table 2). However, the differential diagnostic accuracy of CBCT can only be assessed for vertical fracture. Thus, we conducted a subgroup analysis on vertical tooth fracture and found that a moderate but non-significant decrease in diagnostic accuracy (Table 4).

Both endodontically and non-endodontically treated teeth were studied in the included studies. Among the included studies, only Wang et al.51 evaluated the differential diagnostic accuracy of CBCT for each type. In total, two and four studies assessed the differential diagnostic accuracy of CBCT for non-endodontically and endodontically treated teeth, respectively. Thus, we performed a subgroup analysis and found that the sensitivity of CBCT was significantly higher for non-endodontically treated teeth (sensitivity: 0.97, 95% CI = 0.92–0.99) than for endodontically treated teeth (sensitivity: 0.82, 95% CI = 0.72–0.89). Moreover, a moderate but non-significant increased diagnostic accuracy was found for non-endodontically treated teeth regarding specificity, positive LR and negative LR (Table 4).

3.8. Cumulative meta-analysis

Cumulative met-analysis was performed to determine the chronological changes in diagnostic accuracy of CBCT for tooth fractures. The results showed no significant changes over time (data not shown).

3.9. Assessment of publication bias

Since Egger’s regression test and Begg’s rank correlation test would inflate Type I error and are unsuitable for diagnostic systematic review, we employed an adapted Egger’s and Begg’s tests specifically for diagnostic systematic reviews.24 The results revealed that neither adapted Egger’s (p = 0.12) nor Begg’s test (p = 0.84) indicated any evidence of publication bias.

4. Discussion

In this meta-analysis, the included 12 studies evaluated five outcomes. The pooled sensitivity, specificity, positive LR, negative LR and SROC were 0.92, 0.85, 5.68, 0.13 and 0.94, respectively. Sensitivity analysis and subgroup analysis showed consistent results in the meta-analysis except for the subgroup analysis on non-endodontically and endodontically treated teeth. Cumulative meta-analysis revealed no significant changes over time regarding the diagnostic accuracy of CBCT for tooth fractures. Furthermore, neither modified Egger’s test nor Begg’s test was indicative of any evidence of publication bias. Thus, in general, the results in the meta-analysis were robust.

According to QUADAS-2,13 qualities of included studies for diagnostic systematic review comprised two categories: risk of bias and applicability concerns. Specifically, risk of bias evaluates the potential for bias in each included studies while applicability concerns assess the potential for generalization or applicability of the results to real clinical scenarios. The results showed that risk of bias was medium to high and the applicability was of medium to low risk. In almost all the included studies, prior to CBCT exams, subjects were firstly diagnosed through periapical radiography but no convincing diagnosis was established. With regards to risk of bias, these included studies suffered from a significant bias—inappropriate patient selection. Specifically, these periapical-radiography-undetected patients were “difficult-to-diagnose” patients and may result in an underestimation of diagnostic accuracy of CBCT in this meta-analysis. Thus, high risk of bias was assigned to the category—risk of bias. Despite high risk of bias, the sensitivity analysis on exclusion of high risk of bias resulted in no significant changes in the results (Table 4), indicative of robustness of the results from the meta-analysis. Moreover, this is closer to real clinical scenarios: patients with clinically-suspected tooth fractures would be first diagnosed through periapical radiographs and, if undetected, would be further diagnosed by using CBCT. Thus, low risk was assigned to the category—applicability concerns. Similarly, a sensitivity analysis on inclusion of studies with low risk of applicability failed to reveal any significant change (Table 4). Since CBCT for tooth fracture is a clinical application rather than a theoretical issue, we would focus on its applicability and suggest that quality of the included studies in this meta-analysis are medium to high (medium to low risk).

In this meta-analysis, all included studies employed surgical extraction or exploration to establish the reference standard results. However, among the included studies, three26,29,32 did not apply the reference standard tests in all the patients, which may bias the results in the meta-analysis.

We performed a sensitivity analysis by excluding the three studies and found no significant changes from the original estimates, which indicates that the results in the meta-analysis were robust and not biased by these three studies.

The results revealed that pooled sensitivity and specificity were 0.92 and 0.85, respectively. By definition, sensitivity is the proportion of those with disease who have positive test results while specificity is the proportion of those without diseases who have negative test results. Thus, the results indicated that, among a group of patients with both tooth fractures and no fractures, 92% of the tooth fractures could be detected and 85% of the non-fractures could be ruled out through CBCT. Or alternatively, for a patient with tooth fractures, the chance of the diagnosis of tooth fracture is 92%; for a healthy person without tooth fracture, the chance of the diagnosis of non-fracture is 85%.

However, there would always be a trade-off between sensitivity and specificity. Thus, the two indices cannot reflect the diagnostic accuracy well individually. For this purpose, SROC has been proposed as an index to assess the diagnostic accuracy in meta-analyses and has been used in many recent diagnostic meta-analyses. SROC curve was constructed by plotting sensitivity against 1-specificity, thereby integrating both sensitivity and specificity into one index. In practice, the area under curve (AUC) of SROC has a range from 0.5 (no better than chance) to 1 (perfect test). In our study, the meta-analysis revealed that the pooled AUC of SROC was 0.94 (95% CI = 0.90–0.98), which indicates that CBCT has a high diagnostic accuracy for the diagnosis of tooth fractures.

The meta-analysis showed that the pooled positive LR and negative LR were 5.68 and 0.13, respectively. By definition, positive LR is the ratio of the true positive rate to the false positive rate and negative LR is the ratio of the false negative rate to the true negative rate. Thus, a diagnosis would be more accurate when positive LR becomes higher and negative LR becomes lower. It has been documented that positive LR greater than 5 or negative LR less than 0.2 can provide strong diagnostic evidence. Therefore, our results (positive LR = 5.68 > 5; negative LR = 0.13 < 0.2) indicate that CBCT is able to give a strong diagnostic value regarding tooth fractures. Given the prevalence of tooth fractures, through Bayes’ theorem, we are able to calculate the probabilities of true fracture and non-fracture among positive and negative test results, defined as positive and negative predictive values, respectively. The specific patient population in this meta-analysis is those with clinically suspected tooth fractures but undetected through periapical radiographs. The meta-analysis showed that the pooled prevalence of tooth fracture in this specific patient population was 0.91 (95% CI = 0.83–0.97). Then, the positive and negative predictive values were calculated to be 0.98 and 0.43. This indicates that, for a given patient diagnosed with tooth fractures by CBCT in this specific patient population, we have 98% confidence to say that he really has tooth fracture. Moreover, for a given patient diagnosed with non-fractures by CBCT, we have only 43% confidence to say that he is really free from tooth fractures, even worse than chance. However, these positive and negative predictive values would be susceptible to changes for different patient populations with different prevalences of tooth fractures: the positive and negative predictive values would be 0.85 and 0.88 if the prevalence of tooth fracture is 50%. Thus, the positive and negative predictive values calculated in this meta-analysis could be used in only the aforementioned specific patient population—those with clinically suspected tooth fractures but undetected by periapical radiographs. In real clinical scenarios, if a patient (clinically suspected tooth fractures but undetected by periapical radiographs) is diagnosed with tooth fractures through CBCT, we can be very confident that he suffered from tooth fractures and refer him to have his fractured teeth treated. If a patient is diagnosed without tooth fractures through CBCT (chances of negatives are very low in the real clinical scenarios since the pooled prevalence of negative test result is 13% for this subgroup of patients), we have only 43% of confidence of non-fractures and we suggest that a close follow-up is needed.

 Tooth fractures can be divided into different types based on the directions of fractures: vertical, horizontal, oblique. For different types of tooth fractures, diagnoses may be different. Unfortunately, in this meta-analysis, due to unavailability of original data, we were able to perform a subgroup analysis only for vertical tooth fractures, but failed to find any significant change from the original estimates (Table 4). This finding suggests the diagnostic accuracy of CBCT is similar among different types of tooth fractures.

It has been reported that the diagnostic accuracy of CBCT for endodontically-treated teeth can be reduced, which can be attributed to potential artefacts caused by root canal fillings. Consistently, in this meta-analysis, we found that sensitivity was significantly higher in non-endodontically treated teeth than in endodontically treated teeth [0.97 (95% CI = 0.92–0.99) vs. 0.82 (95% CI = 0.72–0.89)] while other indices (specificity, positive LR, negative LR and SROC) were similar. This indicates that, in clinical scenarios, the chance of diagnosis of tooth fractures is 97% for a non-endodontically treated tooth with fractures and that chance would be 82% for an endodontically treated tooth with fractures. Moreover, let the prevalence be 91%, the positive predictive values were calculated to be similar: 0.98 and 0.99 for endodontically and non-endodontically treated teeth, respectively; while negative predictive values were 0.28 and 0.77 for endodontically and non-endodontically treated teeth, respectively. Based on the CBCT results, we can easily know whether a tooth is an endodontically or non-endodontically treated tooth. If the result is positive, regardless of whether it is an endodontically or non-endodontically treated tooth, it is almost 100% chance of tooth fractures. However, if the result is negative, chances of false negatives are much higher for endodontically treated teeth (100–28% = 72%) than for non-endodontically treated teeth (100–77% = 23%) and we should be very cautious for these endodontically treated teeth with negative results.

The limitations of this meta-analysis were small sample sizes in some studies, no applying reference standard test for all patients in some studies, and unavailability of data for subgroup analysis for horizontal and oblique tooth fractures. Moreover, as mentioned in Table 2, CBCT devices and exposure protocols differed among included studies. Since image quality may vary among different CBCT devices and exposure protocols, the results in this meta-analysis should be interpreted with caution and may not be applied to all CBCT devices.
5. Clinical implications

According to European Guidelines (Radiation Protection 172: cone beam CT for dental and maxillofacial radiology) and the results in this meta-analysis, we suggest the following diagnostic pathway for patients with clinically-suspected tooth fractures (Fig. 5). A patient with clinically-suspected tooth fractures should be firstly diagnosed through periapical radiography. If tooth fractures are detected by periapical radiography, subsequent treatments should follow; if tooth fractures are not detected by the periapical radiography but symptoms persist, CBCT should be prescribed for further diagnosis. If tooth fractures are found by CBCT, regardless of endodontically or non-endodontically treated teeth, treatments should ensue; if tooth fractures are not found by CBCT, we should be very cautious due to chances of false negatives and thus close follow-ups are needed. Particularly, special attention should be given to endodontically treated teeth with negative CBCT findings.

Furthermore, in this meta-analysis, almost all the included participants were adults, thus the results should be limited to adults. Although CBCT exams for tooth fractures enjoy the aforementioned advantages, due to radiation risks, we suggest that CBCT exams for tooth fractures should be used unless good justifications are made (tooth fractures cannot be detected through periapical radiography). Moreover, radiation risks of CBCT are higher in children than in adults, thus we should be very cautious for prescribing CBCT exams in children. For the diagnosis of tooth fractures through CBCT, small and medium field of view (FOV) (effective dose: 11–674 μSv) should be used rather than large FOV (effective dose: 30–1073 μSv) for radiation protection.

6. Conclusion

We suggest that CBCT has a high diagnostic accuracy for tooth fractures and could be used in clinical settings. We can be very confident with positive test results but should be very cautious with negative test results. For patients with negative results, close follow-ups are recommended.

The diagnostic accuracy of CBCT is similar among different types of tooth fractures, which should be interpreted with caution due to unavailability of data for subgroup analysis on horizontal and oblique tooth fractures.

The diagnostic accuracy of CBCT is higher in non-endodontically treated teeth than in endodontically treated teeth. We can be very confident with the positive results for both but should be cautious with the negative results especially for endodontically treated teeth.

Clinical significance

Through an extensive meta-analysis, this systematic review critically examines the diagnostic performance of CBCT for tooth fractures and provides an evidence-based diagnostic pathway for tooth fractures. This diagnostic pathway would be beneficial for practitioners to make correct diagnosis and prudent treatment decisions.

Acknowledgement

This work was supported by National Natural Science Foundation of China (NSFC), Nos. 81070858 and 81100778.

References


