Evidence base for point-of-care ultrasound (POCUS) for diagnosis of skull fractures in children: a systematic review and meta-analysis

Georgios Alexandridis, Eva W Verschuuren, Arthur V Rosendaal, Danny A Kanhai

ABSTRACT
Background Blunt head trauma is a common presentation to emergency departments (EDs). Identifying skull fractures in children is important as they are known factor of risk for traumatic brain injury (TBI). Currently, CT is the reference standard for diagnosing skull fractures and TBI in children. Identifying skull fractures with point-of-care ultrasound (POCUS) may help risk-stratify children for TBI following blunt trauma. The purpose of this study is to evaluate the sensitivity, specificity, positive predictive value and negative predictive value of POCUS in identifying skull fractures in children.

Methods A systematic search was performed on 17 July 2020 in Ovid Medline, Cochrane Library, Google Scholar, Web of Science and Embase. Prospective studies reporting skull fractures diagnosed with ultrasound in children younger than 18 years due to blunt head injury were included. Studies that did not confirm the fracture with CT were excluded. The quality of studies was evaluated using the QUADAS-2 tool. Data were extracted from the eligible studies to calculate outcomes such as sensitivity and specificity; when possible overall outcomes were calculated.

Results Seven studies were included. All eligible studies included patients for whom the decision to perform a CT scan was made in advance. Overall, the included studies demonstrated low risk of bias or had minor concerns regarding risk of bias. The pooled data (n=925) demonstrated a sensitivity of 91%, specificity of 96%, positive predictive value of 88% and negative predictive value of 97%.

Conclusion The included studies demonstrate minor methodological limitations. Overall, the evidence suggests that POCUS is a valid option for diagnosing skull fractures in children visiting the ED after blunt head injury.

Key messages
What is already known on this subject
► Skull fractures are associated with traumatic brain injury; subsequently, clinical decision algorithms have been developed for head injured children that incorporate clinical suspicion for skull fractures.
► CT is the reference standard for diagnosing skull fractures and traumatic brain injuries; however, CT exposes children to radiation.
► Point-of-care ultrasound is a rapid and non-invasive diagnostic tool that has been used to identify skull fractures.

What this study adds
► This systematic review reveals that the included studies have minor methodological limitations and that point-of-care ultrasound has a high sensitivity and specificity to identify skull fractures in children with blunt head injuries.
► Point-of-care ultrasound could serve as an adjunct to increase the accuracy of clinical decision rules regarding using CT scans after head trauma in children; future research is necessary to define this role.

INTRODUCTION
Head injuries in children are a common presentation to emergency departments (EDs) point-of-care ultrasounds (POCUS). The Centers for Disease Control and Prevention in the USA reported 749,000 ED visits for injury to the head in children under the age of 15 years old in 2016.1 Up to 8% of children aged 3–17 years old have had a significant head injury in their lifetime, and it is one of the leading causes of mortality in children worldwide.2 Severely head-injured children are in general easily identified and treated. However, children who appear to have a low risk for traumatic brain injury (TBI) may still have clinically important injury.2 POCUS may have a potential role in the evaluation of low-risk paediatric patients, to identify skull fractures and subsequent TBIs.

Clinical decision algorithms have been developed to identify head-injured children with TBI (eg, Pediatric Emergency Care Applied Research Network [PECARN], Canadian Assessment of Tomography for Childhood Head injury [CATCH], National Institute for Health and Care Excellence [NICE] Head Injury guideline or Children’s Head injury Algorithm for prediction of Clinically Important Events [CHALICE]).3–9 Most of the clinical decision algorithms include clinical suspicion of a skull fracture because the presence of skull fracture increases the likelihood of an intracranial injury fourfold.2,4–6,10–13 Furthermore, TBI in the absence of skull fracture is rare in the paediatric population.14 The reported rate of skull fracture in children with blunt head trauma ranges from 16% to 63%.11–13 In addition, infants with skull fractures rarely present without local signs of head injury on physical examination.15–16 The diagnostic standard
tool to detect TBI is CT. CT exposes children to radiation that may increase lifetime risk of malignancy.\textsuperscript{15–19} Also, it has been demonstrated that low doses of ionising radiation to the brain in infancy may influence cognitive ability in adulthood.\textsuperscript{20} Occasionally sedation is needed during the diagnostic study to minimise motion artefacts; sedation is also associated with the risk of adverse respiratory events including desaturation and the need for airway intervention.\textsuperscript{21} The use of CT scanning also adds to the costs of healthcare.\textsuperscript{22}

‘Mild head injury’ patients are, according to the Head Injury Severity Scale classification, initially conscious at first assessment (GCS score 14–15), may have had a brief loss of consciousness or amnesia, but do not have any focal neurological deficits on admission.\textsuperscript{23} In mild head-injured children ultrasound might be utilised as a diagnostic tool for identifying skull fracture in children that may otherwise undergo a head CT.\textsuperscript{24–26}

POCUS has become an integral part of emergency medicine practice. It is a rapid, non-invasive and inexpensive diagnostic tool that does not carry the risk of radiation in comparison to CT.\textsuperscript{27} Furthermore, in children who are more anxious and easily overstimulated, POCUS may be used by the attending physician at the bedside.

Identification of skull fractures in children is clinically relevant because these fractures may need surgical intervention irrespective of the presence of TBI.\textsuperscript{28} Skull fractures could be associated with non-accidental trauma, and physicians should always consider this potential association.\textsuperscript{29} In addition, skull fractures may need follow-up because linear fractures may predispose children to uncommon but serious complications such as expanding fractures or leptomeningeal cysts.\textsuperscript{30–31}

Clinicians must weigh the risk of missing a clinically important skull fracture and potentially associated TBI and the risks associated with performing a CT. As children with TBI can be asymptomatic, it remains challenging to successfully identify children at very low risk for TBI and safely manage them without performing a CT scan. However, if it is possible to rule out skull fractures utilising POCUS with high sensitivity, then it is less likely that there is an associated TBI. This may reduce the number of CT scans performed. Also, in hospitals where CT is not readily available POCUS may be helpful in risk stratification and subsequent transport to another facility.

This systematic review evaluates the test characteristics of POCUS in identifying skull fractures in children that present with blunt head injury in the ED.

MATERIALS AND METHODS

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses guideline was used to conduct this review.\textsuperscript{32} Prior to performing this review, a protocol was developed (see online supplemental A). Consensus was reached among all authors on search syntax, inclusion and exclusion criteria, and the criteria for the assessment of validity and relevance in the identified articles.

Search strategy

A search was conducted on 17 July 2020 using the search engines Ovid Medline, Cochrane Library, Google Scholar, Web of Science and Embase. The search syntax encompassed ‘skull’, ‘ultrasound’, ‘child’ and ‘fracture’ (including their respective synonyms). Online supplemental B contains an overview of the complete search syntax. All articles which met the search terms were exported from the search engines to EndNote X9 (Clarivate Analytics, Philadelphia, Pennsylvania, USA).

Selection

Duplicates were excluded. We analysed all articles evaluating the outcome ‘skull fracture’. Prospective studies written in English, German, French and Dutch that studied children with blunt head injury who visited the ED were included. Based on the inclusion criteria (figure 1), two reviewers (GA and EV) independently screened the titles and later the abstracts of eligible articles. Review articles, conference abstracts and case reports were excluded. The full text of the remaining articles was screened independently by two reviewers (EV and GA). Additionally, references in review articles were screened using the same criteria.

Critical appraisal

The quality of the individual studies was evaluated using the Quality Assessment of Diagnostic Accuracy Studies 2 (QUADAS-2) tool.\textsuperscript{33} This tool aids in evaluating the quality of primary diagnostic accuracy studies. It consists of four key domains; patient selection, index test, reference standard and flow and timing. Each domain is assessed in terms of the risk of bias, as ‘low’, ‘high’ or ‘unclear’. Signalling questions are provided to help in judgement on the risk of bias. An overall judgement per study was given. If a study is judged as ‘low’ on all domains relating to validity than the overall judgement for that particular study was ‘low risk of bias’; when one or more domains in validity was judged as ‘unclear’ or ‘high’ than that particular study was considered to be ‘at risk of bias’.\textsuperscript{33}

Three authors (GA, EV and AVR) independently evaluated the quality of the eligible studies. In case of disagreements in the critical appraisal, consensus was reached through discussion.

Data extraction and statistical analysis

Two authors extracted data separately from the eligible studies (EV and GA). The following data were extracted: year of publication, study characteristics, baseline population characteristics, country and data on the test results. When possible, the data of the studies was pooled to calculate overall characteristics. A fixed-effect model was used to compute pooled sensitivity and
Systematic review

Table 1  Critical appraisal

<table>
<thead>
<tr>
<th>Study design</th>
<th>Relevance (applicability)</th>
<th>Validity (risk of bias)</th>
<th>Flow and timing</th>
<th>Remarks</th>
<th>Overall risk of bias</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weinberg36</td>
<td>Prospective observational study</td>
<td>Age &lt;25 years, urban centre.</td>
<td>CT</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Riera37</td>
<td>Prospective observational study</td>
<td>Age &lt;18 years, Tertiary care centre and trauma level one centre.</td>
<td>CT</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Parri35</td>
<td>Prospective observational study</td>
<td>Age &lt;18 years.</td>
<td>CT</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Rabiner38</td>
<td>Prospective observational study</td>
<td>Age &lt;21 years, trauma level two centre.</td>
<td>CT</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Choi39</td>
<td>Prospective observational study</td>
<td>Age &lt;4 years, Tertiary care centre and trauma level I centre.</td>
<td>CT</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Parri40</td>
<td>Multicentre prospective observational study</td>
<td>Age &lt;2 years.</td>
<td>CT</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Masaeli34</td>
<td>Prospective cross-sectional study</td>
<td>Age &lt;18 years, Tertiary care centre.</td>
<td>CT</td>
<td>Low</td>
<td>Low</td>
</tr>
</tbody>
</table>

POCUS, point-of-care ultrasound.

specificity. The homogeneity of the studies was determined with visual inspection; the homogeneity in age and trauma mechanism were analysed. I² was used to evaluate the between-study heterogeneity throughout the random-effects meta-analysis; Q-test was used to determine whether the heterogeneity was statistically significant. Publication bias was assessed through Egger’s regression test. Comprehensive Meta-Analysis V.3 (Biostat, Englewood, New Jersey, USA) was used to perform all statistical testing.

RESULTS

Search strategy and selection
The search resulted in 781 articles. After exclusion of duplicates 545 articles remained for title and abstract screening. Full text and reference assessment was completed for 16 articles; afterwards seven articles were excluded because they were reviews and two because they were retrospective studies (figure 1). We manually checked the references of the reviews; our search had identified all studies referenced in these reviews.

Critical appraisal
Seven studies were included; two studies had a low risk of bias.34,35 Five studies were at risk of bias in the domain ‘patient selection’.36–40 One study was at risk of bias in the domain ‘flow and timing’ because the time interval between POCUS and CT was unclear.36 An overview is presented in table 1.

All studies had a prospective observational study design and included patients with head trauma. In all eligible studies, the decision to perform a CT was made in advance.

Data extraction
The results of data extraction are shown in tables 2 and 3.

Statistical analysis
Visual inspection showed that two studies had a substantially higher percentage of skull fractures;35,40 subsequently, we divided the studies in two groups. In one group, the two studies with a high percentage of fractures were pooled and the other group contained the five studies with a low percentage of fractures. Furthermore, two studies included patients aged 18 years or older; subsequently, to assess the influence on outcome results a separate analysis was executed in which these two studies were excluded.36,38 Afterwards, the outcome results per group were calculated (see table 3). In the overall pooled data I² was 32.14 and Q was 8.84. The Egger’s regression intercept did not demonstrate a publication bias (p=0.313).

Patient characteristics
All studies included patients from the ED. The number of patients included in the studies ranged from 21 to 538. Three studies included patients up to 18 years old.34,35,37 The study of Parri et al35 included children under the age of 2 and the
Table 2  Study and population characteristics

<table>
<thead>
<tr>
<th>Study characteristics</th>
<th>Population characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>No of patients (N=)</strong></td>
<td><strong>Country</strong></td>
</tr>
<tr>
<td>Weinberg36</td>
<td>21</td>
</tr>
<tr>
<td>Riera37</td>
<td>40</td>
</tr>
<tr>
<td>Parri35</td>
<td>55</td>
</tr>
<tr>
<td>Rabine34</td>
<td>69</td>
</tr>
<tr>
<td>Choi39</td>
<td>87</td>
</tr>
<tr>
<td>Parri40</td>
<td>115</td>
</tr>
<tr>
<td>Masaeli34</td>
<td>538</td>
</tr>
</tbody>
</table>

mo, months; NR, not reported; y, year.

Table 3  Results

<table>
<thead>
<tr>
<th>No of patients (N=)</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Positive predictive value</th>
<th>Negative predictive value</th>
<th>False-positive</th>
<th>False negative</th>
<th>Risk of bias</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(95% CI)</td>
<td>(95% CI)</td>
<td>(95% CI)</td>
<td>(95% CI)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High percentage of fractures</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parri35</td>
<td>55</td>
<td>100 (88 to 100)</td>
<td>95 (73 to 100)</td>
<td>97 (84 to 100)</td>
<td>100 (79 to 100)</td>
<td>1: Non calcified suture ipsilateral to trauma</td>
<td>0</td>
</tr>
<tr>
<td>Parri40</td>
<td>115</td>
<td>91 (82 to 96)</td>
<td>85 (65 to 95)</td>
<td>95 (88 to 98)</td>
<td>74 (55 to 87)</td>
<td>4: Not reported</td>
<td>8: Fracture not underneath area that was imaged</td>
</tr>
</tbody>
</table>

Low percentage of fractures

| Weinberg36**  | 21          | 100 (20 to 100) | 100 (79 to 100) | 100 (20 to 100) | 100 (79 to 100) | 0 | 0 | At risk of bias |
| Riera37        | 40          | 67 (24 to 94) | 97 (83 to 100) | 80 (30 to 99) | 94 (79 to 99) | 1: Not reported | 1: Not reported | 1: No cooperation of patient | At risk of bias |
| Rabine38 **    | 69          | 88 (47 to 99) | 97 (88 to 99) | 78 (40 to 96) | 98 (90 to 100) | 1: Novice error | 1: Fracture adjacent to haematoma in the area that was not imaged | At risk of bias |
| Choi39         | 87          | 77 (46 to 94) | 100 (94 to 100) | 100 (66 to 100) | 96 (88 to 99) | 0 | 2: Difficult evaluation in area of orbital wall and skull base | 1: Fracture not imaged area, adjacent to haematoma | At risk of bias |
| Masaeli34      | 538         | 92 (83 to 97) | 96 (94 to 97) | 79 (69 to 87) | 99 (97 to 99) | 19: Not reported | 6: Not reported | Low risk of bias |
| Overall pooled data | 925        | 91 (87 to 94) | 96 (94 to 97) | 88 (84 to 92) | 97 (95 to 98) | 27 | 20 |
| Pooled data A | 925         | 91 (87 to 94) | 96 (94 to 97) | 88 (84 to 92) | 97 (95 to 98) | 27 | 20 |
| Pooled data B | 755         | 93 (87 to 97) | 89 (76 to 96) | 96 (90 to 98) | 84 (70 to 92) | 5 | 8 |
| Pooled data C | 720         | 92 (85 to 96) | 96 (95 to 98) | 85 (78 to 90) | 98 (97 to 99) | 22 | 12 |
| Pooled data D | 835         | 91 (87 to 95) | 96 (94 to 97) | 88 (84 to 92) | 97 (95 to 98) | 25 | 19 |

Pooled data A (studies with a high percentage in fractures): Parri35 and Parri40.  
Pooled data B (studies with a low percentage in fractures): Weinberg36, Riera37, Rabine38, Choi39 and Masaeli34.  
Pooled data C (studies with a low percentage in fractures, excluded the studies that contained patients aged >18 years): Riera37, Choi39 and Masaeli34.  
Pooled data D (all studies, excluded the studies that contained patients aged >18 years): Riera37, Parri35, Parri40, Choi39 and Masaeli34.

*Study that contained patients aged >18 years.
study of Choi et al.\textsuperscript{39} children up to 4 years of age.\textsuperscript{39,40} One study included patients up to 21 years and another study up to 25 years old.\textsuperscript{36,38} Four studies reported a mean age between 8 months and 7 years.\textsuperscript{35,38-40} Weinberg et al.\textsuperscript{46} reported a median age of 13 years, and Riera and Chen\textsuperscript{35} a median of 2 years.

Four studies included patients with minor head injury (GCS 14 or 15).\textsuperscript{34,39-40} Two studies did not report the GCS.\textsuperscript{36,37} Masaeli et al.\textsuperscript{34} reported that 11% of the included children had a GCS lower than 15; this particular study excluded patients that had a GCS of 13 or lower.\textsuperscript{34} Rabiner et al.\textsuperscript{40} reported a GCS below 15 in 12% of the included patients.\textsuperscript{38}

Training and experience

In all studies ultrasound was performed by emergency physicians or fellows. Four studies reported 1-hour training focused on ultrasonography of the skull.\textsuperscript{15,36,38,39} In two studies the clinicians were trained with videos and skills training.\textsuperscript{34,40} In four studies the ultrasonographer had varying levels of experience.\textsuperscript{34-40} Two studies did not report the previous experience of the sonographers.\textsuperscript{34,36} One study reported that the sonographers had 16 hours of experience.\textsuperscript{38} Training and experience are summarised in Table 2.

Diagnostic accuracy

Sensitivity ranged from 67% to 100% and specificity from 85% to 100%. The seven studies demonstrated a weighted percentage of skull fractures of 25%. The overall pooled data (n=925) demonstrated a sensitivity of 91%, a specificity of 96%, a positive predictive value of 88% and a negative predictive value of 97% (see Table 3).

The pooled results of studies with a high percentage of fractures were similar to those of the studies with a low percentage of fractures (pooled data A and B in Table 3). Furthermore, the results were similar whether those over 18 were included or excluded. (pooled data B, C, D and overall pooled data). To illustrate the similarities, we created a paired forest plot for sensitivity and specificity (see Figure 2).

False positive results

There were 27 false positive results (2.9% of all scans). In 24 of these cases, the cause was not reported. Parri et al.\textsuperscript{35} reported a false positive result due to a non-calcified ipsilateral suture. One case was the effect of a novice error, as the physician interpreted the ultrasound as negative for fracture.\textsuperscript{38} Another case was interpreted during the initial POCUS imaging as positive for a fracture and during re-evaluation by an expert paediatric emergency physician sonographer as a minimally displaced skull fracture; however, this fracture was not visualised by the CT scan.\textsuperscript{38}

False negative results

Twenty false negative cases were reported (2.2% of all scans). The majority of these false negatives (n=10) were the consequence of the fracture being adjacent to a haematoma and not in the area that was imaged.

DISCUSSION

The aim of this study was to evaluate the test characteristics of POCUS in identifying skull fractures in children that presented in the ED with blunt head injury. The pooled data showed a high sensitivity, specificity and predictive values in the studies included. Our systematic review, therefore, demonstrates that POCUS of the skull can be useful in accurately identifying skull fractures in children with head injury.

While conducting this systematic review, another systematic review by Gordon et al.\textsuperscript{41} was published;\textsuperscript{41} our findings are consistent with that review. Our review used a more extensive search, using more databases and including articles published in multiple languages. Subsequently, we identified an additional relevant study, which adds a substantial number of patients to our pooled data. Furthermore, additional subanalyses were performed to evaluate whether these subgroups (studies that included patients over the age of 18 years, and high vs low percentage of fractures per group) affected the results.

POCUS could serve as an adjunct to increase the accuracy of clinical decision rules regarding the use of CT scans after head trauma in children. POCUS is fast and may be performed at bedside, which provides benefits of rapid identification of skull fracture, that could help to prioritise patients. Furthermore, POCUS may help with the decision to transfer the patient to another facility. Moreover, no pharmacological sedation is needed for this diagnostic tool.

The identified studies in this review show possible limitations in applicability. First, all studies had varying experience in POCUS performers (see Table 2). Because the interpretation of POCUS is operator dependent, this may have affected the diagnostic accuracy.\textsuperscript{37} Rabiner et al.\textsuperscript{38} reported that the interobserver agreement was $\kappa=0.86$ (95% CI 0.67 to 1.0). The other studies did not report the inter-observer agreement among physicians that performed POCUS.

Second, the range in percentage of fractures per study was wide (10%–77%); potentially affecting the test accuracy. Parri et al.\textsuperscript{35} and Parri et al.\textsuperscript{40} had a higher percentage of fractures. The younger age of the population studied may have influenced the incidence; children under the age of 2 tend to be at higher risk of skull fractures.\textsuperscript{41} Although there was overall a high sensitivity and specificity of the test, this pretest probability has to be for accounted for. The study of Choi et al.\textsuperscript{39} did not apply clinical decision rules and this factor possibly led to a lower number of fractures; this could also have occurred in the other studies with a relatively low number of fractures.\textsuperscript{36-38}

Third, two studies included patients older than 18 years.\textsuperscript{36,38} For both studies, insufficient data regarding the proportion of patients aged 18 years or above was provided. However, it seems unlikely that a significant number of patients was older than 18 years because the reported mean age was 7 years in one study and in the other studies the reported median age 13 years; in addition, the subanalysis showed similar results. Hence, the influence seems to be minor.\textsuperscript{36-38}

Study name | Sens. | CI 95% | Spec. | CI 95% | Over-all data | Pooled data A | Pooled data B | Pooled data C | Pooled data D
--- | --- | --- | --- | --- | --- | --- | --- | --- | ---
Masaeli 2019 | 0.92 | 0.97 | 0.96 | 0.97 | 0.91 | 0.97 | 0.93 | 0.97 | 0.91
Parri 2018 | 0.91 | 0.98 | 0.95 | 0.98 | 0.91 | 0.97 | 0.92 | 0.97 | 0.91
Choi 2018 | 0.75 | 0.80 | 0.85 | 0.88 | 0.80 | 0.81 | 0.83 | 0.86 | 0.80
Rabiner 2013 | 0.77 | 0.86 | 0.81 | 0.91 | 0.83 | 0.90 | 
Riera 2012 | 0.07 | 0.11 | 0.05 | 0.10 | 0.06 | 0.10 | 0.07 | 0.10 | 0.06
Weinberg 2010 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00
Overall data | 0.91 | 0.93 | 0.95 | 0.96 | 0.91 | 0.93 | 0.93 | 0.95 | 0.91
Paper data A | 0.93 | 0.97 | 0.95 | 0.98 | 0.93 | 0.96 | 0.95 | 0.98 | 0.93
Pooled data B | 0.91 | 0.98 | 0.92 | 0.97 | 0.92 | 0.96 | 0.95 | 0.97 | 0.92
Pooled data C | 0.91 | 0.98 | 0.92 | 0.97 | 0.92 | 0.96 | 0.95 | 0.97 | 0.92
Pooled data D | 0.91 | 0.98 | 0.92 | 0.97 | 0.92 | 0.96 | 0.95 | 0.97 | 0.92

Figure 2
Fourth, many studies did not report the mechanism of injury; it seems likely that presence of a skull fracture may be associated with the mechanism. Furthermore, not all the studies reported GCS. It is unclear to what extent this influenced the results.

Finally, only two studies were multicentre. Three studies were conducted in a tertiary care centre, which may have influenced the population studied; in general, such centres receive more severely injured patients.

Five of the seven studies were at risk of bias because they studied a convenience sample; this might lead to under-representation of subgroups.

The study of Weinberg et al has a remarkably high sensitivity and specificity of 100%. This may be explained due to the relatively small sample size of 21 patients that might overestimate the results. Also, the study is at risk of biases that might influence the results positively.

The study of Riera and Chen has a notable lower sensitivity for identifying skull fractures; this lower sensitivity was attributed to the lower number of skull fractures in the studied population. Several studies demonstrated that not all skull fractures were located beneath the haematoma; those studies only imaged the haematoma area with ultrasonography. By imaging a larger part of the skull these missed fractures may have been avoided.

Two ‘false negative’ fractures were located in a position where ultrasound evaluation is difficult, for example, orbital wall and skull base. It might be advised to reconsider imaging in children that present with a haematoma at sites that are more challenging to ultrasound or when interpretation of the ultrasound is difficult. It is key to minimise false negatives, because of the association of skull fractures with TBI. Perhaps with better ultrasonography techniques in addition to better training, false negatives may be avoided in the future. However, none of the studies reported adverse events in the cases with a missed fracture.

Suture planes can complicate the identification of fractures, and could lead to false positive results. However, evaluation of the contralateral anatomy or tracking suture lines to the fontanelle may aid in this, and knowledge of suture line anatomy is essential.

Our search is limited to articles written in English, Dutch, German or French. During the abstract screening, none of the identified articles were excluded on language. The included studies all had positive results in favour of POCUS; it is possible that studies with other outcomes did not get published, therefore, creating publication bias. In any literature review, there is the possibility of publication bias; however, the Egger’s regression intercept did not demonstrate this particular bias.

This systematic review shows that POCUS proves to be a valid option for ruling out skull fractures in children visiting the ED after blunt head injury, although methodological limitations could be debated in several included studies.

We recommend consideration of POCUS in patients that meet no other major or multiple minor criteria for CT scan than a clinical suspected skull fracture, or when a skull fracture cannot be excluded; consequently, when no fracture is identified, a CT scan might not be needed. Therefore, to use POCUS to rule out a skull fracture could potentially reduce the utilisation of CT and unnecessary exposure of children to ionising radiation. The aim of POCUS is not to detect TBI, but it can identify skull fracture which is an important predictor of TBI.

Future research is necessary to define the role of POCUS in risk stratification for TBI and applicability in clinical prediction rules. Furthermore, additional research is needed to define whether extending the imaged area with POCUS to not only the area of haematoma but also adjacent areas will further improve the results.

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REFERENCES


A 21-year-old man presented to the emergency department with a 3 day history of sore throat and fever. The General Practitioner was now unable to swallow with worsening pain. A 3 day history of sore throat and fever. The General Practitioner was now unable to swallow with worsening pain.

**C.**

**B.**

**A.**

What is the most likely diagnosis seen in figure A 21-year-old man presented to the emergency department with a 3 day history of sore throat and fever. The General Practitioner was now unable to swallow with worsening pain.

**Figure 1**

Examination of the oral cavity.

**Examination of the oral cavity.**
Title
The evidence base for point-of-care ultrasound (POCUS) for diagnosis of skull fractures in children: a systematic review

Registration
This review has not been registered

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Written in line with the PRISMA-P 2015 checklist

Contributions:
EV and GA contribute equally in realizing the systematic review. A statistician was invited to evaluate the method of this review. An information specialist has been requested to create the search syntaxes. EV and GA performed the search, critical appraisal and extraction of data. EV and GA are first and second reviewer. AR is the third critical appraiser and companion in discussion. A paediatrician and a radiologist will be invited to thoroughly evaluate the review. All authors will contribute to data interpretation and article drafts.

Amendments
Important protocol amendments post registration will be recorded and included in dissemination.

Support
No sources of support or funding were provided for this review. EV and GA are emergency medicine residents-in-training. AR is an emergency medicine physician.
Introduction

Blunt head trauma is a common presentation to emergency departments (ED). Identifying skull fractures in children is important as they are a known risk factor for traumatic brain injury (TBI). Currently, computer tomography (CT) scan is the reference standard for diagnosing skull fractures and TBIs in children. However, CT scans expose children to radiation that may increase lifetime risk of lethal malignancy. Identifying skull fractures with point-of-care ultrasound (POCUS) may help risk-stratify children for TBI following non-penetrating trauma. The purpose of this study is to evaluate the sensitivity, specificity, negative predictive value and positive predictive value of POCUS in identifying skull fractures in children.

Objective

What is the sensitivity, specificity, negative predictive value and positive predictive value of POCUS in identifying skull fractures in children that present with blunt head injury in the emergency department?

Methods

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guideline shall be used to conduct this review. Prior to conducting this review consensus shall be reached among all authors on search syntax, criteria of inclusion and exclusion, and the criteria for the assessment of validity and relevance in the identified articles.

Eligibility criteria

- Children aged <18 years with blunt head injury visiting the emergency department
- Ultrasound and CT used as means to diagnose skull fracture
- Prospective study
- Articles in English, German, French or Dutch

Information sources

The search will be conducted in the search engines Ovid Medline, Cochrane Library, Google Scholar, Web of Science and Embase. Only the first hundred results in Google Scholar will be used for the selection process.

Search strategy

The search syntax encompasses ‘skull’, ‘ultrasound’, and ‘fracture’ (including their respective synonyms). See Table 1 for complete search syntax.
**Study records**

**Data management:**

Data will be managed using EndNote X9, Clarivate Analytics, Philadelphia, USA.

**Selection process**

Our aim is to include all prospective studies written in English, German, French or Dutch that assessed children with blunt head injury and visited the emergency department for this. Firstly, all duplicates shall be excluded. Based on the inclusion criteria two reviewers (GA and EV) screen the titles and abstracts of the articles. We shall exclude articles that are reviews, conference abstracts or case reports. The full text of the remaining articles will be screened by two reviewers (EV and GA). From these articles and the identified reviews, all references shall be screened utilizing the same criteria.

**Data collection process**

Two authors shall extract data separately from the eligible studies (EV and GA).

**Data items**

The following data shall be extracted: year of publication, study characteristics, baseline population characteristics and data on the outcomes.

**Risk of bias in individual studies**

The quality of the individual studies shall be evaluated utilizing QUADAS-2. Three authors (GA, EV and AR) will independently evaluate the quality of the eligible studies. The aim is to reach consensus among the critical appraisers through discussion.

**Data synthesis**

Data will be presented in tabulated form to allow for semi qualitative comparison of; study sample, population characteristics, training and experience of physicians, trauma mechanism and incidence of fractures. Preferably the sensitivity, specificity, negative predictive value and positive predictive value will be reported; moreover, the false positive and false negatives cases will be reported.
Meta-analysis

If possible, the data of the studies will be pooled to calculate overall outcomes. The homogeneity of the studies will be determined with visual inspection; we shall analyze the homogeneity in age and trauma mechanism.

Meta-biases

To identify possible ‘gray literature’ we shall include a computerized search in Google Scholar.

Acknowledgements

We would like to acknowledge Wichor M. Bramer (biomedical information specialist) for his aid in creating the search syntax and performing the initial search; moreover, that he combined the initial identified articles and was kind enough to remove the duplicates. In addition, we would like to acknowledge Erwin Birnie (statistician) for evaluating the method of this review.

References


<table>
<thead>
<tr>
<th>Table 1: Search syntax per search engine.</th>
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<tbody>
<tr>
<td><strong>Ovid Medline:</strong></td>
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<tr>
<td>(&quot;Head Injuries, Closed&quot;/ OR head/ OR Skull Fractures/ OR skull/ OR (skull OR cranium OR cranial OR calvarium OR scalp OR skullcap OR head).ab,ti,kw.) AND (Ultrasonography/ OR Ultrasonics/ OR (echogra* OR ultraso* OR sonogra* OR pocus).ab,ti,kw.) AND (Fractures, Bone/ OR Skull Fractures/ OR (fracture*).ab,ti,kw.) AND (exp child/ OR adolescent/ OR exp infant/ OR Pediatrics/ OR pediatric hospital/ OR childhood injury/ OR (child* OR infan* OR adolescen* OR pediatric* OR paediatr*).ab,ti,kw.)</td>
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<tr>
<td><strong>Embase:</strong></td>
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<tr>
<td>(‘head injury’/de OR ‘head’/de OR ‘skull injury’/exp OR ‘skull’/exp OR (skull OR cranium OR cranial OR calvarium OR scalp OR skullcap OR head):ab,ti,kw) AND (‘echography’/de OR ‘focused assessment with sonography for trauma’/de OR ultrasound/de OR (echogra* OR ultraso* OR sonogra* OR pocus):ab,ti,kw) AND (‘fracture’/de OR ‘skull fracture’/exp OR (fracture*):ab,ti,kw) AND (juvenile/exp OR pediatrics/exp OR ‘pediatric hospital’/de OR ‘childhood injury’/de OR (child* OR infan* OR adolescen* OR pediatric* OR paediatr*):ab,ti,kw)</td>
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<tr>
<td><strong>Cochrane CENTRAL</strong></td>
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<tr>
<td>((skull OR cranium OR cranial OR calvarium OR scalp OR skullcap OR head):ab,ti,kw) AND ((echogra* OR ultraso* OR sonogra* OR pocus):ab,ti,kw) AND ((fracture*):ab,ti,kw) AND ((child* OR infan* OR adolescen* OR pediatric* OR paediatr*):ab,ti,kw)</td>
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<tr>
<td><strong>Web of science</strong></td>
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<tr>
<td>TS=((skull OR cranium OR cranial OR calvarium OR scalp OR skullcap OR head)) AND ((echogra* OR ultraso* OR sonogra* OR pocus)) AND ((fracture*)) AND ((child* OR infan* OR adolescen* OR pediatric* OR paediatr*))</td>
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<tr>
<td><strong>Google Scholar</strong></td>
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<tr>
<td>skull</td>
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<td>Search Engine</td>
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<tr>
<td><strong>Ovid Medline</strong></td>
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# PRISMA 2009 Checklist

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<th>Checklist item</th>
<th>Reported on page #</th>
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<td>TITLE</td>
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</tr>
<tr>
<td>Title</td>
<td>1</td>
<td>Identify the report as a systematic review, meta-analysis, or both.</td>
<td>1</td>
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<tr>
<td>ABSTRACT</td>
<td></td>
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<tr>
<td>Structured summary</td>
<td>2</td>
<td>Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.</td>
<td>3</td>
</tr>
<tr>
<td>INTRODUCTION</td>
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<tr>
<td>Rationale</td>
<td>3</td>
<td>Describe the rationale for the review in the context of what is already known.</td>
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</tr>
<tr>
<td>Objectives</td>
<td>4</td>
<td>Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).</td>
<td>6-7</td>
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<tr>
<td>METHODS</td>
<td></td>
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<tr>
<td>Protocol and registration</td>
<td>5</td>
<td>Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.</td>
<td>7</td>
</tr>
<tr>
<td>Eligibility criteria</td>
<td>6</td>
<td>Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.</td>
<td>8</td>
</tr>
<tr>
<td>Information sources</td>
<td>7</td>
<td>Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.</td>
<td>7</td>
</tr>
<tr>
<td>Search</td>
<td>8</td>
<td>Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.</td>
<td>Supplement B and page 7</td>
</tr>
<tr>
<td>Study selection</td>
<td>9</td>
<td>State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).</td>
<td>7-8</td>
</tr>
<tr>
<td>Data collection process</td>
<td>10</td>
<td>Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.</td>
<td>8-9</td>
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<tr>
<td>Data items</td>
<td>11</td>
<td>List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.</td>
<td>9</td>
</tr>
<tr>
<td>Risk of bias in individual studies</td>
<td>12</td>
<td>Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.</td>
<td>8</td>
</tr>
<tr>
<td>Summary measures</td>
<td>13</td>
<td>State the principal summary measures (e.g., risk ratio, difference in means).</td>
<td>7</td>
</tr>
</tbody>
</table>
# PRISMA 2009 Checklist

## Synthesis of results
- **Checklist item**: Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I² for each meta-analysis).

## Results

### Risk of bias across studies
- **Checklist item**: Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).

### Additional analyses
- **Checklist item**: Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.

## Discussion

### Summary of evidence
- **Checklist item**: Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).

### Limitations
- **Checklist item**: Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).

### Conclusions
- **Checklist item**: Provide a general interpretation of the results in the context of other evidence, and implications for future research.

## Funding
- **Checklist item**: Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.
PRISMA 2009 Checklist


For more information, visit: www.prisma-statement.org.

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