The Use of Bedside Ultrasound in the Detection of Skull Fractures in Pediatric Patients

Janet Weidner
Pacific University

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Abstract
Background: Head injuries are common in children and account for over 600,000 emergency room visits annually. Many children receive CT scans as part of their work-up to evaluate for intracranial injury. CT scans add risk of sedation and ionizing radiation, and recent effort has been made to reduce the amount of CT scans ordered in the evaluation of a head-injured child. Skull fractures are an independent risk factor for intracranial injury, and ultrasound may be of use to the clinician trying to detect these fractures. In the pediatric patient with a minor head injury, is ultrasound effective for the detection of skull fractures when compared to the reference standard CT?

Methods: An exhaustive search of available medical literature was conducted on Medline-Ovid, Web of Science, and CINAHL-Ebscohost using the keywords “ultrasonography OR sonography” AND “skull fractures.” Reference lists from articles were examined, and any relevant sources were examined independently. The studies were evaluated and assessed using the GRADE method.

Results: Three prospective studies were evaluated. Ultrasound was examined as a diagnostic modality for skull fracture detection and was compared against the reference standard of CT. Ultrasound was found to have high specificity (94%, 95%, and 97%) and moderate sensitivity (82%, 100%, and 88%) respectively, in detecting skull fractures in pediatric patients.

Conclusion: Ultrasound detects skull fractures in children with high specificity, but this may not be relevant in clinical use. Clinical decision rules and algorithms, such as the PECARN score, are already well studied and used to guide clinicians in their evaluation of head-injured children. Future studies that evaluate ultrasound in conjunction with a clinical decision rule are needed to determine if the incorporation of ultrasound as a diagnostic modality will help decrease the use of CT scans in the pediatric population.

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First Advisor
Annjanette Sommers, PA-C, MS

Second Advisor
David Keene, PA-C, MS

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Jan Weidner

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Faculty Advisor: David Keene, PA-C, MS
Clinical Graduate Project Coordinator: Annjanette Sommers, PA-C, MS
Biography

[Redacted for privacy]
Abstract

**Background:** Head injuries are common in children and account for over 600,000 emergency room visits annually. Many children receive CT scans as part of their work-up to evaluate for intracranial injury. CT scans add risk of sedation and ionizing radiation, and recent effort has been made to reduce the amount of CT scans ordered in the evaluation of a head-injured child. Skull fractures are an independent risk factor for intracranial injury, and ultrasound may be of use to the clinician trying to detect these fractures. In the pediatric patient with a minor head injury, is ultrasound effective for the detection of skull fractures when compared to the reference standard CT?

**Methods:** An exhaustive search of available medical literature was conducted on Medline-Ovid, Web of Science, and CINAHL-Ebscohost using the keywords “ultrasonography OR sonography” AND “skull fractures.” Reference lists from articles were examined, and any relevant sources were examined independently. The studies were evaluated and assessed using the GRADE method.

**Results:** Three prospective studies were evaluated. Ultrasound was examined as a diagnostic modality for skull fracture detection and was compared against the reference standard of CT. Ultrasound was found to have high specificity (94%, 95%, and 97%) and moderate sensitivity (82%, 100%, and 88%) respectively, in detecting skull fractures in pediatric patients.

**Conclusion:** Ultrasound detects skull fractures in children with high specificity, but this may not be relevant in clinical use. Clinical decision rules and algorithms, such as the PECARN score, are already well studied and used to guide clinicians in their evaluation of head-injured children. Future studies that evaluate ultrasound in conjunction with a clinical decision rule are needed to determine if the incorporation of ultrasound as a diagnostic modality will help decrease the use of CT scans in the pediatric population.

**Keywords:** pediatric head injury, skull fracture, ultrasonography, sonography, ultrasound
Acknowledgements

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Table I: Characteristics of Reviewed Studies
Table II: Summary of Findings

List of Abbreviations

CDR………………..Clinical Decision Rule
CHI……………….Closed Head Injury
CT………………….Computed Tomography
ED………………….Emergency Department
GCS………………..Glasgow Coma Scale
GRADE…………….Grading of Recommendations, Assessment, Development and Evaluations
PECARN…………..Pediatric Emergency Care Applied Research Network
POC………………..Point of Care
TBI………………...Traumatic Brain Injury
US………………..Ultrasound
The Use of Bedside Ultrasound in the Detection of Skull Fractures in Pediatric Patients

BACKGROUND

Head injuries are among the leading causes of death in children worldwide. In the United States, head trauma in children <19 years old accounts for >600,000 emergency department visits, >60,000 hospitalizations, and >6000 deaths annually. The morbidity and mortality in patients who present with a head-injury can be reduced by identifying those with a clinically important traumatic brain injury (TBI) as early as possible. Clinically important TBI is defined as a head injury resulting in death from TBI, neurosurgery, intubation >24 hours, or hospital admission >2 nights. Patients with severe head injury are easily identified and treated, but patients who appear to have low risk for intracranial injury may later deteriorate and are associated with an increased risk of unexpected death.

Computed tomography (CT) is the standard diagnostic tool used to detect intracranial injury and determine which patients require acute intervention. Although sensitive, CT imaging should not be used to screen all pediatric patients presenting with head injury. In addition to high costs, CT is associated with risks connected to the required sedation (eg hypoxia, apnea, and aspiration), and an increased lifetime risk of malignancy due to ionizing radiation. Anywhere from 15-70% of pediatric patients who present to the emergency department (ED) with a minor head injury in the US and Canada receive CT scans, and the number of CT scans more than doubled between 1990 and 1999 in the US. The clinician is faced with the challenge of identifying patients at risk for clinically important TBI without subjecting all of the patients, some unnecessarily, to a CT scan.
There are clinical decision rules (CDRs) that have been developed to guide clinicians when considering a CT scan of the head-injured pediatric patient. These CDRs are tools and algorithms that have been developed in order to avoid some unnecessary CT scans. Most notable is the PECARN score,\(^1\) which outlines an algorithm for CT scanning in two groups: children <2 years old and children >2 years old. The PECARN score applies to patients with a Glasgow Coma Score (GCS) \(\geq 14\), and it attempts to identify patients in whom the risk of clinically important TBI is greater than the risks associated with CT. The PECARN score is widely used by ED clinicians, and it has been supported in a systematic review of similar CDRs.\(^1,10\) One of the clinical findings included in the PECARN algorithm is the presence of a skull fracture or basilar skull fracture, which is the main discussion point of this paper.

Skull fracture occurs in 16% of pediatric patients presenting to the ED with head injuries and is independently associated with a four-fold higher risk for intracranial injury.\(^11\) CT scan is the gold standard for diagnosis of skull fracture,\(^4\) and the aforementioned risks of CT must be considered. There have been some recent studies examining the efficacy of bedside ultrasonography (US) as an alternative to detecting skull fractures in children. Bedside ultrasound is already being used in the emergency department setting, and it is being applied to the diagnosis of fractures. Weinberg et al\(^12\) found that after 1 hour of focused training, novice sonographers were able to diagnose bone fractures in children and young adults with high specificity. Ultrasonography is an attractive option for diagnosis of skull fractures in children because it is inexpensive, can be done at the bedside or in a pediatrician’s office, and is not associated with the risks of sedation or ionizing radiation. If ultrasound can adequately detect skull fractures, its use in the ED, trauma bay, or pediatrician’s office may avoid CT scans in patients with a low suspicion for head injury. This review aims to assess the sensitivity and
specificity of ultrasound when used to detect skull fractures in pediatric patients as compared to CT scans.

METHODS

An exhaustive literature search was performed using Medline-Ovid, Web of Science, and CINAHL-Ebscohost using the keywords “ultrasonography OR sonography” AND “skull fractures.” Reference lists and citations from appropriate articles were examined, and any relevant sources were searched independently and examined. The search was narrowed using the following inclusion criteria: human studies, studies in the English language, studies that evaluate pediatric patients ranging 0-18 years, study participants received both ultrasound and CT scans regardless of findings. The search was further narrowed using exclusion criteria: studies in foreign language, studies with narrow age range (i.e. examining infants only), case reviews with a small (<25) number of participants. Included studies underwent a critical appraisal, and were then further examined using the Grading of Recommendations, Assessment, Development and Evaluations (GRADE) system.13

RESULTS

Initial search results yielded 157 studies. After screening the articles as described above for studies available for review, the search resulted in one case review and five observational studies. The case review14 of six patients was excluded due to its small sample size and poor comparison between cases. One study15 was written in German only, and was excluded. Another study16 examined only infants less than 1 year old, and was excluded. Three prospective studies remained that looked at the accuracy of bedside or point-of-care (POC) ultrasound. Those studies will be evaluated in this review: Riera & Chen,17 Parri et al,18 and Rabiner et al.19 See Table I.
Reira & Chen

A self-proclaimed “pilot study,” this prospective observational study investigated the feasibility of bedside ultrasound to detect skull fractures in children with a closed head injury (CHI), and the sensitivity and specificity of ultrasound was determined using CT as the comparison standard. The study was performed in the pediatric emergency department at a Level I trauma center. There were 46 patients with a mean age of 2 years who were enrolled over a 6-month period in a convenience fashion, dependent on available study sonographers. Patients were considered if they were <18 years old and underwent a head CT as part of their evaluation. They were included if there was a localized area of trauma (eg scalp hematoma) on physical exam. Patients were excluded if they presented with open fractures, if there was suspicion for non-accidental trauma, or if urgent intervention was needed. Patients received a bedside ultrasound and a CT scan. Pediatric emergency medicine physicians performed the ultrasounds, and the head CTs were read by radiologists. Radiologists were always blinded to the ultrasound results. The sonographers were occasionally aware of CT results before performing the ultrasound. The authors state that this occurred in 6 patients.

Sonographers used a 5-10 MHz probe of the SonoSite MicroMaxx® ultrasound system, and ultrasounds were performed by 1 of 4 pediatric emergency medicine physicians and verified via consultation with the Chief of Pediatric Radiology. Of the group of 4 study sonographers, one physician had 10 years of experience with pediatric ultrasound, and the remaining physicians underwent 1 month of dedicated ultrasound training either in a clinical rotation or in the hospital’s adult ED.
Ultrasounds were performed at bedside and determined as positive or negative for skull fractures. The results were compared against CT readings to determine sensitivity and specificity of the ultrasound. Ultrasound detected skull fractures in 9 patients that were verified by CT. Ultrasound detected skull fractures in 2 patients that were not seen on CT (false positive). CT detected skull fractures in an additional 2 patients that were not detected via ultrasound (false negative). The sensitivity of ultrasound was 82% (95% CI 48-97%) and the specificity was 94% (95% CI 79-99%). Results are summarized in Table II. Of note, one of the aforementioned false positive results was later determined by a repeat CT to be a skull fracture, and inclusion of this case would change the ultrasound sensitivity and specificity to 83% and 97% respectively.\textsuperscript{17}

The authors acknowledge that there are limitations to their study. Six ultrasounds (13%) were performed with prior knowledge of CT results. There were a limited number of sonographers trained and included in the study, which necessitated a convenience sample and limited the number of patients included. There was also no standardized training session for the study’s sonographers. The authors conclude that ultrasound can be used to diagnose skull fractures in children with CHI with high specificity and lower sensitivity. They argue that their study implies that ultrasound may be able to detect skull fractures that CT cannot. The authors call for larger studies and studies that examine the incorporation of ultrasound into existing CDRs.\textsuperscript{17}

**Parri et al**

This prospective observational study\textsuperscript{18} examined the use of bedside ultrasound to detect skull fractures in the pediatric patient and determined the sensitivity and specificity of ultrasound as a diagnostic modality as compared to the reference standard, CT scan.\textsuperscript{4} The study was done at
one pediatric ED in Florence, Italy, and 55 patients with a mean age of 3.7 years were consecutively enrolled over a 5 month period. Patients were considered for the study if they were <18 years and presented to the ED with a head injury requiring a CT ordered by the ED physician. They were ultimately included in the study if there was evidence of localized trauma of the scalp (e.g., hematoma, abrasion, tenderness), which provided sonographers a discrete area of the head to examine. It was deemed impractical to scan the entire scalp with the ultrasound probe. Patients were also excluded if they were uncooperative or if they presented with hemodynamic instability, neurologic deterioration, GCS <14, open skull deformity, or depressed fracture. Only three patients were excluded from the study, resulting in the 55 participants as mentioned above. All enrolled patients received an ultrasound of the scalp performed by a sonographer and a CT scan read by a radiologist. Both the sonographer and the radiologist were blinded to the clinical scenario and the results of the other diagnostic test.18

Ultrasonography was performed using a 7.5-MHz linear probe with a MyLab30® US machine. Each ultrasound was performed by one of the study sonographers: a group composed of six pediatric emergency physicians who were inexperienced in ultrasound prior to the study and one emergency medicine ultrasound fellow. The emergency physicians underwent ultrasound training prior to the start of the study. Training included a 16-hour ultrasound curriculum with a one-hour didactic session focusing on musculoskeletal and cranial applications, and practicing on volunteer models. The emergency medicine ultrasound fellow performed about half of the ultrasounds, and the remaining half were performed by one of the emergency physicians described above.18
Ultrasounds were performed at the bedside, and results were compared against CT scans to determine the sensitivity and specificity of ultrasound detection of cranial fractures. CT detected skull fractures in 35 of the 55 participants, and ultrasound scans identified all 35 of these fractures accurately. In one patient, the ultrasound scan was interpreted as positive, but was negative on CT. The remaining 19 participants received negative ultrasound and CT reports. There were no false negative ultrasound findings. Of note, there were several cases in which the initial CT result was negative and a later over-read indicated the presence of a skull fracture. Ultrasound sensitivity was 100% (95% CI 88.2-100%), and specificity was 95% (95% CI 75.0-99.9%). Results are summarized in Table II.

The authors outline the limitations of their study to include: a small sample size, single center enrollment, single ultrasound model, varying experience among sonographers, and ultrasound examinations focused on an area of visible trauma. The authors determined that ultrasound may be accurate in diagnosing skull fractures in pediatric patients with minor head trauma, and they call for future studies to examine the use of ultrasound in conjunction with CDRs. They argue that the 95% specificity of ultrasound is an acceptable level of inaccuracy, as any ultrasound uncertainty would necessitate further work up and a CT scan anyways. The authors also conclude that the study shows that emergency clinicians who are previously untrained in sonography can accurately diagnose skull fractures with appropriate training.18

Rabiner et al

This observational prospective study19 examined the use of point of care (POC) ultrasound to diagnose skull fractures as compared to CT and determined the sensitivity and specificity of ultrasound as a modality for skull fracture diagnosis in children. The study was
performed in the pediatric emergency departments of two different urban Level II trauma centers over the course of 16 months. There were 69 pediatric patients, with a mean age of 6.4 years, who were enrolled in the study in a convenience fashion, based on the availability of study sonographers. Patients were considered for enrollment if they were <21 years, and presented to the ED with a head injury or suspicion for a skull fracture that required CT imaging as determined by the pediatric emergency physician. Patients were excluded if they presented with completed radiologic studies, a confirmed skull fracture, an open skull fracture, or if the patient required urgent intervention. Pediatric emergency medicine physicians enrolled in the study performed all of the ultrasounds and were blinded to CT results. A pediatric emergency medicine physician with experience in ultrasonography reviewed all POC ultrasounds and was blinded to the patients’ clinical presentation, ultrasound findings, and CT results. A radiologist read the head CTs and was blinded to the ultrasound results. Patients who were not diagnosed with skull fracture underwent telephone follow-up one week later.19

Seventeen different clinicians were enrolled in the study as sonographers, and each used a 5-10 MHz probe with a SonoSite® ultrasound system. All sonographers were pediatric emergency medicine physicians, and all but one of them were novices to musculoskeletal ultrasound. All sonographers underwent a 1-hour training session with 30 minutes of didactic instruction and 30 minutes of practical training. All had access to a reference manual throughout the study.19

Ultrasounds were performed as POC, or at the bedside, reported as negative or positive, reviewed by an expert as mentioned above, and compared to CT readings. Ultrasound detected skull fractures in 7 patients that were verified by CT. Ultrasound detected 2 skull fractures that
were not detected by CT (false positive). There was one patient in which skull fracture was not detected by ultrasound, but was detected by CT (false negative). The sensitivity was 88% (95% CI 53-98%) and the specificity was 97% (95% CI 89-99%).\textsuperscript{19} Results are summarized in Table II.

The study acknowledges its limitations. The study sample is a convenience sample, and therefore the patient numbers are limited. Ultrasound is an operator dependent modality, and the study attempted to standardize the training. The ultrasound scanning technique missed a skull fracture adjacent to a scalp hematoma, and the authors recommend that future technique include scanning around focal areas of injury. The authors conclude that ultrasound detects skull fractures with high specificity. The also assert that with a 1-hour focused training session, novice sonographers are able to diagnose skull fractures with accuracy similar to experienced sonographers. They suggest that ultrasound detection of skull fractures may be best used in patients with a very low clinical suspicion of intracranial injury. The authors call for future research to help determine if ultrasound can be used to reduce the use of CT imaging in children with head injuries.\textsuperscript{19}

**DISCUSSION**

Head trauma is a common childhood injury, and most pediatric patients will have a minor head injury.\textsuperscript{2} Currently, CDRs and CT scans are used to evaluate patients for intracranial injury, and there is question if ultrasound can also be used to aid the ED clinician in their evaluations. Clinician-performed bedside ultrasound is emerging as a common diagnostic tool in emergency rooms and other acute care settings, and ultrasound is a rapid, cost effective imaging method that does not carry risks of ionizing radiation.\textsuperscript{12,19,20}
Ultrasound detection of skull fractures is not helpful in patients with major head trauma (such as an open fracture, GCS<14, or focal neurological deficits). These patients likely have intracranial injury and will require a CT. However, patients with minor head trauma present with a diagnostic dilemma. Emergency clinicians attempt to identify the patients who appear to have low risk for a clinically important TBI based on their presentation, but who have actually sustained an intracranial injury. Clinical look for many different signs and symptoms in children that indicate intracranial injury. One of the independent risk factors that they look for is a skull fracture. If ultrasound is effective for the detection of skull fractures, clinicians may be able to reduce the amount of CT scans they order to evaluate the head-injured pediatric patient. The reviewed studies all find that ultrasound diagnoses skull fractures with high specificity and with relatively high sensitivity.

Ideally, ultrasound would have a high sensitivity, because its use would be most applicable as an intracranial injury “rule out” test, avoiding a CT scan altogether. The negative likelihood ratios (see Table II) ranged from 0.12-0.19, which may support ultrasound use and the opportunity to avoid unnecessary CT scans. However, the studies have varying sensitivities and are 82%, 100%, and 88% respectively. The sensitivities are relatively high, but not high enough to recommend using skull ultrasound to eliminate the need for a head CT. Additionally, the varying levels of sensitivity and the extremely wide ranges in confidence intervals indicate that further studies may be needed with larger cohorts. However, it is worth considering that this level of sensitivity is adequate given that there are risks associated with CT scans in pediatric patients. The benefit of using ultrasound and forgoing a CT scan may outweigh the risk of misdiagnosing a clinically important TBI.
All three of the examined studies\textsuperscript{17-19} demonstrate that ultrasound detects skull fractures with high specificity when compared to the reference standard of CT. The specificity of ultrasound was 94\%, 95\%, and 97\% respectively, and the positive likelihood ratios ranged from 13.6-29.3 (see Table II). These results occurred with minimally trained emergency medicine physicians acting as sonographers rather than classically trained sonographers. Despite the indication that ultrasound is an adequate modality for diagnosing skull fractures, it may have little application clinically as a patient with an ultrasound-diagnosed skull fracture will require a CT scan to further evaluate for intracranial injury. However, the utilization of ultrasound in detecting skull fractures with this level of specificity may be important for clinical settings with limited access to CT (eg for rural and underserved populations).

Riera & Chen\textsuperscript{17} and Rabiner et al\textsuperscript{19} both describe instances in which ultrasound detected skull fractures when CT did not. This is important to note, as the sample sizes of these studies are small; a larger study may be required to determine if ultrasound is more specific than CT.

Even though ultrasound can detect skull fractures with some certainty, its potential clinical application is unclear. Of particular interest is the use of skull ultrasound in younger children, specifically in those <2 years old. The PECARN score differentiates this age group stating that children <2 years have a decreased ability to communicate (making it difficult to assess mental status and pain), a greater sensitivity to radiation, and unique mechanisms for intracranial injury. Accordingly, the PECARN score uses slightly different criteria in this group with the addition of the following criteria: no evidence of skull fracture and no non-frontal scalp hematoma (because hematomas are associated with skull fractures).\textsuperscript{1,6,17,21,22} Also, in children <2 years who have minor head trauma, skull fractures may be a better predictor for intracranial
injury than their clinical presentation.\textsuperscript{22} To summarize, this younger group is often asymptomatic when presenting with a head injury, more sensitive to ionizing radiation, and more likely to have skull fractures as an indicator for intracranial injury.\textsuperscript{1,6,21,22} It is reasonable to consider that in this younger population, the sensitivity of ultrasound detection of skull fractures may be adequate when weighed against the risks of CT.

The limitations and quality of each study will be discussed in this paragraph. Please also refer to Table I. All three studies\textsuperscript{17-19} have precision issues. First and foremost, all three studies\textsuperscript{17-19} had small sample sizes. Moreover, two studies\textsuperscript{17,18} were conducted at a single center. With the Reira & Chen study,\textsuperscript{17} there was poor blinding as the sonographers were occasionally aware of the CT results prior to their testing. This was a very serious limitation, and caused reduced the quality of the study to very low. With the Parri et al study,\textsuperscript{18} there were issues with non-standardized training of the sonographers, though this may represent a more realistic approach to training in the ED. Finally, in the Rabiner et al study,\textsuperscript{19} the strict blinding of sonographers and radiologists and the standardization of ultrasound training boosted the quality of the study and resulted in an overall moderate quality of evidence.

Further studies, which may be ongoing, are needed to investigate ultrasound as a modality that may sometimes replace and at other times supplement CT in the diagnosis of skull fractures. A new study should involve larger sample sizes, multiple pediatric centers, and standardized training for the enrolled physicians who will act as sonographers.

\textbf{CONCLUSION}

When the pediatric patient with a minor head injury presents to the ED, the clinician must consider and evaluate the patient for an intracranial injury. As part of this evaluation, the
clinician must assess the patient for the presence of a skull fracture. Ultrasound has high
specificity for diagnosing skull fractures as compared to CT. With further studies using larger
sample sizes, clinicians should be encouraged to incorporate focused skull ultrasound as part of
their clinical decision making when deciding to order a CT scan for a patient. Ultrasound
diagnosis of skull fractures may be incorporated into CDR like PECARN in the future and aid
the clinician in deciding to observe a patient instead of getting a CT. It may be that ultrasound
detection of skull fractures is most useful in the pre-verbal population (<2 years), or in rural
settings in which access to CT is limited or non-available. Pediatric emergency departments
should begin to offer focused training for the use of ultrasound in musculoskeletal fractures to
their physicians, as ultrasound offers a fast, bedside modality without ionizing radiation risks.
References


Table I. Characteristics of Reviewed Studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Design</th>
<th>Limitations</th>
<th>Indirectness</th>
<th>Imprecision</th>
<th>Inconsistency</th>
<th>Publication bias likely</th>
<th>Quality</th>
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<td>Riera &amp; Chen</td>
<td>Prospective observational US vs. gold standard</td>
<td>Very Serious limitations²⁻³</td>
<td>No serious indirectness</td>
<td>Serious imprecision¹</td>
<td>No serious inconsistency</td>
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<td>Very Low</td>
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<tr>
<td>Parri et al</td>
<td>Prospective observational US vs. gold standard</td>
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<td>No serious indirectness</td>
<td>Serious imprecision¹</td>
<td>No serious inconsistency</td>
<td>No</td>
<td>Moderate</td>
</tr>
<tr>
<td>Rabiner et al</td>
<td>Prospective observational US vs. gold standard</td>
<td>Serious limitations²</td>
<td>No serious indirectness²</td>
<td>No serious imprecision</td>
<td>No serious inconsistency</td>
<td>No</td>
<td>Moderate</td>
</tr>
</tbody>
</table>

a. Convenience sample relied on availability of sonographers
b. Some US were obtained with knowledge of a CT diagnosed skull fracture, no standardized training for sonographers
c. Small sample size, single center study
d. Inclusion of patients 19-21 years old in sample size