

Accuracy of Bedside Ultrasound for the Diagnosis of Skull Fractures in Children Aged 0 to 4 Years

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Objectives: The aim of this study was to investigate the accuracy of bedside ultrasound (US) performed by emergency physicians for diagnosing skull fractures in children 0 to 4 years old compared with the accuracy of head computed tomography (CT). We also sought to investigate characteristics and precautions associated with US.

Methods: This single-center prospective study involved children 0 to 4 years old who had a history of head trauma. Bedside US was performed by emergency medicine physicians, and the results were compared with CT scan interpretations provided by attending radiologists. The accuracy of US for the diagnosis of skull fractures was calculated, and the errors were reviewed.

Results: A total of 87 patients were enrolled. Skull fracture was present in 13 patients (14.9%), according to CT. Bedside US had a sensitivity and specificity of 76.9% (95% confidence interval [CI], 46.0%–93.8%) and 100% (95% CI, 93.9%–100%), respectively. Overall positive predictive value was 100% (95% CI, 65.5%–100%), and negative predictive value was 96.1% (95% CI, 88.3%–99.0%). Three false-negative cases were observed.

Conclusions: Bedside US performed by emergency medicine physicians with short focused US training is a useful tool for diagnosing skull fractures in children 0 to 4 years of age. However, there were 3 false-negative cases. A meticulous examination is needed in the area adjacent to the orbital wall and skull base.

Key Words: computed tomography, head trauma, skull fractures, ultrasound (*Pediatr Emer Care* 2020;36: e268–e273)

Head trauma commonly occurs during childhood, and many children visit the emergency department (ED) for such injuries. In the United States, among children younger than 14 years, traumatic brain injury (TBI) accounts for approximately 500,000 ED visits, 35,000 hospitalizations, and more than 2000 deaths annually. In particular, young children 0 to 4 years of age had the highest rate (1256 per 100,000 individuals) of TBI-related ED visits.¹ The incidence of intracranial injury among young patients with head trauma is 4% to 12%, and several studies that subdivide these injuries by age have shown a higher incidence among younger children (0–2 years).^{2–5}

Most pediatric head traumas are mild injuries, but some cases involve clinically important TBI. A head computed tomography (CT) scan is the criterion standard diagnostic test used to evaluate skull fractures and intracranial injuries. Many CT scans are performed in children with mild head trauma, although many of them reveal no intracranial injuries.⁶ Emergency department physicians must decide whether to perform a CT scan, particularly for infants and toddlers, by considering the benefits and risks.⁷ The use of a CT scan can increase the risk of ionizing radiation exposure, the

need for sedation, and health care costs. Reducing unnecessary CT scans is important because radiation can cause lethal malignancies, and the risk of these malignancies increases as patient age decreases.^{8–10}

Ultrasound (US) is an imaging modality that could be used to evaluate skull fractures, which are associated with intracranial injuries. In some studies, the presence of a skull fracture in a child is associated with a 4- to 20-fold increased risk of an underlying intracranial injury.^{11–13} On the contrary, a study concluded that children with isolated linear skull fractures are at very low risk of evolving other traumatic findings.¹⁴ Ultrasound is a rapid, easy, and cost-effective imaging modality that has been used for various conditions in EDs.¹⁵ Multiple studies have reported that clinician-performed US for various bone fracture diagnoses exhibits good accuracy in children.^{16–19} Recently, several studies^{19–22} have shown that a bedside US diagnosis of skull fractures performed by a pediatric emergency medicine (EM) physician has good sensitivities overall compared with CT. However, the populations of these studies were small, and no study was confined to specific age groups.

We hypothesized that an EM physician with focused bedside US training could accurately diagnose skull fractures in children younger than 4 years. The main objective of our study was to determine the sensitivity, specificity, and predictive values of bedside US performed by EM physicians for diagnosing skull fractures compared with head CT scans. The secondary objective was to investigate the characteristics and precautions associated with performing US in 0- to 4-year age group.

METHODS

Study Design and Setting

This prospective observational study evaluated the accuracy of bedside US for the diagnosis of skull fractures compared with that of CT scans in pediatric patients. The study was performed at an urban ED in a tertiary-care, level I trauma, academic university hospital in Incheon, South Korea, from January 2014 to June 2014. The ED has an annual census of approximately 100,000 patient visits per year, and among them, 32,000 are pediatric patients younger than 18 years. The study was approved by our hospital's institutional review board (no. GAIRB2014-19), and informed consent was obtained from the parents or guardians.

Study Population

Children 0 to 4 years of age presenting to the ED with a history of head trauma were considered for study enrollment. Subjects who had an initial Glasgow Coma Scale (GCS) score of 14 or greater and localized evidence of head trauma, such as swelling, hematoma, or focal tenderness, which was necessary to indicate the impact point for US examination, were included. A convenience sample of subjects was enrolled based on the availability of participating ED physicians. Patients were excluded if they presented with hemodynamic instability, neurological deterioration, a GCS score of less than 14, open deformity, or if urgent intervention was required.

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TABLE 1. Demographic Characteristics of Study Population

Study Population	n (%)
No. patients, n (%)	87 (100)
Age, mean $\pm$ SD, mo	21.3 $\pm$ 12.5
Sex, n (%)	
Male	42 (48.3)
Female	45 (51.7)
Mechanism, n (%)	
Fall <0.9 m	58 (66.8)
Fall $\geq$ 0.9 m	13 (14.9)
Direct blow	13 (14.9)
MVC	3 (3.4)
Hematoma/impaction site, n (%)	
Frontal	40 (46.0)
Temporal	12 (13.8)
Occipital	29 (33.3)
Parietal	6 (6.9)
Locations of fracture, n (%)	13 (14.9)
Frontal	5
Temporal	4
Occipital	4
Parietal	0

MVC indicates motor vehicle crash.

The patients without swelling, hematoma, or focal tenderness were excluded.

Bedside US

An emergency physician evaluated head CT scans for eligible patients. In 2014, our ED has not yet applied the clinical decision rules or guidelines to determining who needs a head CT. All efforts were made to perform the US examination before the CT scan. In some cases, the US examination was performed immediately after the CT scan. The investigators were blinded to the CT findings at the time that the bedside US was performed. The research study protocol did not interfere with the clinical care of the enrolled patients. The US results were not used to manage patient care.

Ultrasonography was performed using the linear transducer (10 MHz) of a Zonare US system (Zonare Inc, Sunnyvale, Calif). After applying US gel, the transducer was placed over the area of soft tissue swelling or the point of impact. Images were scanned in 2 perpendicular planes throughout the length of the hematoma to fully view the cranium below. The areas adjacent to the hematoma were also scanned. If the scan area was near or crossed a suture line, the contralateral zone of the skull was scanned for comparison. A positive skull US was defined as a cortical disruption, irregularity, or depression not correlating to anatomic sutures. Investigators recorded the bedside US findings (positive or negative for skull fracture) immediately after the procedure, and images and video clips were recorded and made available for further review. The stored bedside US images confirmed the accuracy of the EM attending physician. The US results were compared with the attending radiologist's report of the head CT findings. Radiologists were blinded to US examination results at the time of their interpretation. If a discrepancy was found between the CT and US results, an attending radiologist who was unaware of the initial results of the

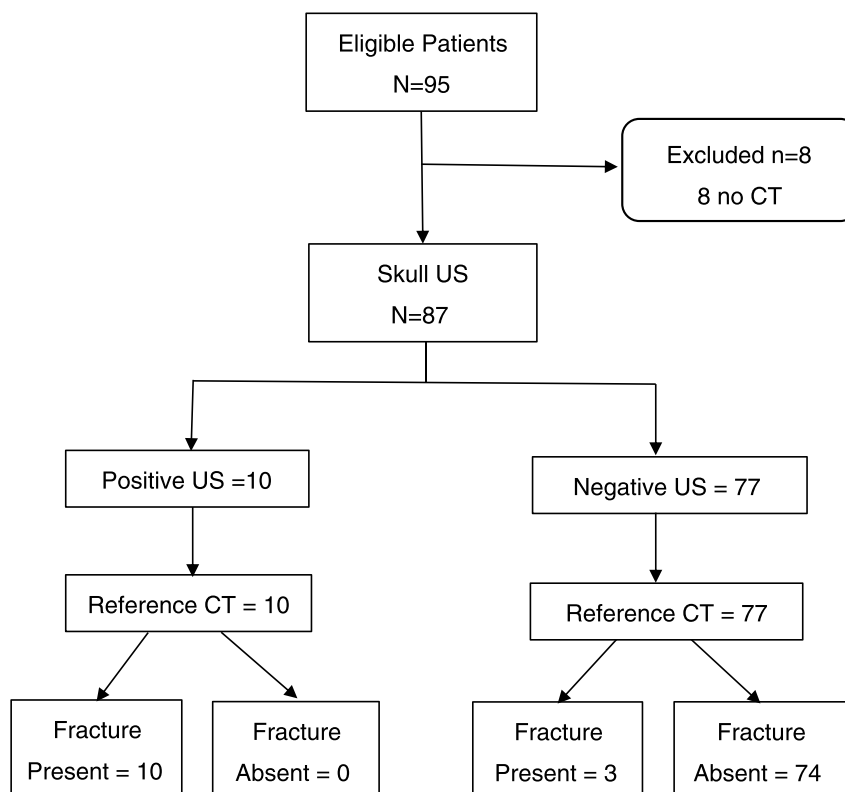
**FIGURE 1.** STARD (Standards for Reporting of Diagnostic Accuracy) flowchart.

TABLE 2. Bedside US Interpretation Compared With CT for Detection of Skull Fractures

	CT +	CT –
US +	10	0
US –	3	74

+ Indicates skull fracture; –, no skull fracture.

US and CT reviewed the case and determined the final CT scan interpretation.

Bedside skull US examinations were performed by 3 general EM fellows (2 had 1 year of training, and 1 had 2 years of training). Each of the emergency physicians participated in an 8-hour US training curriculum that focused on the principles and physics of US and core emergency US applications (not including musculoskeletal US examinations) before becoming a fellow. This curriculum provided a certificate of completion from the Korean Society of Emergency Medicine. The participating physicians had experiences of fewer than 25 scans in extended focused assessment with US for trauma and vascular access US, and no experience in musculoskeletal US. Before the start of the study, all enrolled physicians attended a 30-minute didactic session and a 30-minute hands-on practical session for bedside skull US. The session was taught by an EM attending physician with more than 10 years of US clinical and teaching experience. The attending physician performed pediatric skull US on more than 50 cases. In addition, after the didactic and practical session, the enrolled physicians performed 5 cranial US examinations on pediatric volunteers who were 0 to 4 years old under the supervision of the attending EM physician before participating in the study.

Statistical Analysis

Data were analyzed using SPSS Statistics (SPSS version 18.0; IBM, Armonk, NY). The sensitivity, specificity, positive predictive values, negative predictive values, and 95% confidence intervals (CIs) were determined using the attending radiologist's CT scan interpretation as the comparison standard. Descriptive statistical analyses were used for categorical data. Sample size of 81 patients would be needed by the formula²³ to obtain a 95% CI (SD, 5%) with an estimated 95% specificity for US diagnosis of skull fractures based on the prior published studies that had a specificity ranging from 94% to 100%.^{19–22}

RESULTS

Patient demographics and study characteristics are presented in Table 1. The study flowchart is presented in Figure 1. A total of

87 patients were analyzed in the study. All patients had an initial GCS score of 15. The mean patient age was 21.3 ± 12.5 months (range, 2–48 months). Skull fracture was present on CT in 13 cases (14.9%). Two patients (2.3%) had intracranial hemorrhage associated with skull fractures. One was a 5-month-old girl who had 4-mm epidural hematoma with parietal bone fracture. The other was a 6-month-old boy with 2-mm subdural hematoma and temporal bone fracture. Both patients were discharged from ED after 8 hours of observation. No patients required surgical intervention.

Using bedside US, skull fractures were diagnosed in 10 cases (11.5%). Three discrepancies (3.4%) (3 false-negative results and no false-positive results) were found between bedside US and CT scan results (Table 2). Three EM physicians performed 30, 30, and 27 cases of bedside US, respectively, and the numbers of discrepancies was 2, 0, and 1 cases. The discrepant patients were recorded at the first, third, and fifth months of the study period. Twelve of the 13 patients with skull fractures confirmed by CT were younger than 24 months, and 3 false-negative cases occurred in this age group. Table 3 shows the test performance of US compared with CT for detecting skull fractures.

Three false-negative cases occurred in children between 12 and 24 months of age (Table 4). These 3 discrepant cases were reviewed by the attending radiologist, but no change was seen in the initial CT scan interpretation. In the first case, the patient presented with forehead hematoma and orbital swelling. It was difficult to directly contact the hematoma site with the probe because the hematoma was only around eye. The CT scan revealed a superior orbital wall fracture (Fig. 2A). A discrepancy was observed between the fracture and swelling sites in the second case. No fracture was visualized on the bedside US, but according to the CT scan, the patient had a superior orbital wall fracture adjacent to (but not directly underneath) the forehead swelling (Fig. 2B). The third patient presented with occipital scalp swelling adjacent to the skull base, which is a difficult evaluation site because of its anatomic location (Fig. 2C).

DISCUSSION

Our study shows that with 1 hour of focused skull fracture US training, general EM physicians can accurately diagnose skull fractures in children 0 to 4 years of age.

Decision rules, such as the Pediatric Emergency Care Applied Research Network (PECARN) Head CT Rules, help reduce the number of CT scans performed on patients with minor head injuries. Despite recent TBI prediction rules for clinical assessments,^{2,5,24} the decision to perform head CT in mild pediatric head trauma cases is still difficult and challenging. Although head CT is the diagnostic modality of choice used to determine skull fracture and intracranial injury, disadvantages, such as exposure to ionizing radiation, sedation

TABLE 3. Comparison of Test Performance Characteristics for Bedside US Diagnosis of Skull Fractures Between Our Study and Published Studies

Study (Year)	n	Fracture, n (%)	Population	Sensitivity, % (95% CI)	Specificity, % (95% CI)	PPV, % (95% CI)	NPV, % (95% CI)
Our study	87	13 (14.9)	≤4 y	76.9 (46.0–93.8)	100 (93.9–100)	100 (65.5–100)	96.1 (88.3–99.0)
Weinberg et al ¹⁹ (2010)	21	2 (10)	<25 y	100 (20–100)	100 (79–100)		
Riera and Chen ²⁰ (2012)	46	11 (24)	≤18 y	82 (48–98)	94 (79–99)	82 (79–99)	94 (48–98)
Parri et al ²¹ (2013)	55	35 (64)	<18 y	100 (88.2–100)	95 (75–99.9)	97.2 (84.6–99.9)	100 (80.2–100)
Rabiner et al ²² (2013)	69	8 (12)	≤21 y	88 (53–98)	97 (89–99)	78 (45–94)	98 (91–100)

NPV indicates negative predictive value; PPV, positive predictive value.

TABLE 4. Characteristics of Three False Negative Cases

Case	Age/Sex	Mechanism	Hematoma/Impact site	Fracture Site
Case 1	16 mo/M	Fall >0.9 m	Forehead adjacent to orbit	Frontal bone (superior orbital wall)
Case 2	18 mo/F	Fall >0.9 m	Upper forehead	Frontal bone (superior orbital wall)
Case 3	19 mo/M	Fall ≤0.9 m (2 m)	Occipital adjacent to skull base	Occipital bone adjacent to skull base

needs, and high costs, must be considered. Skull US is a rapid, easy, and relatively accurate tool. In addition, it does not involve ionizing radiation exposure, and it can decrease the need for sedation. Some studies have suggested that US may be used to

diagnose minimally displaced or nondisplaced skull fractures that can be missed on a CT scan.^{20,22} Bedside US has been used by emergency physicians for a variety of conditions in the ED and has continued to rapidly expand. The importance of bedside US

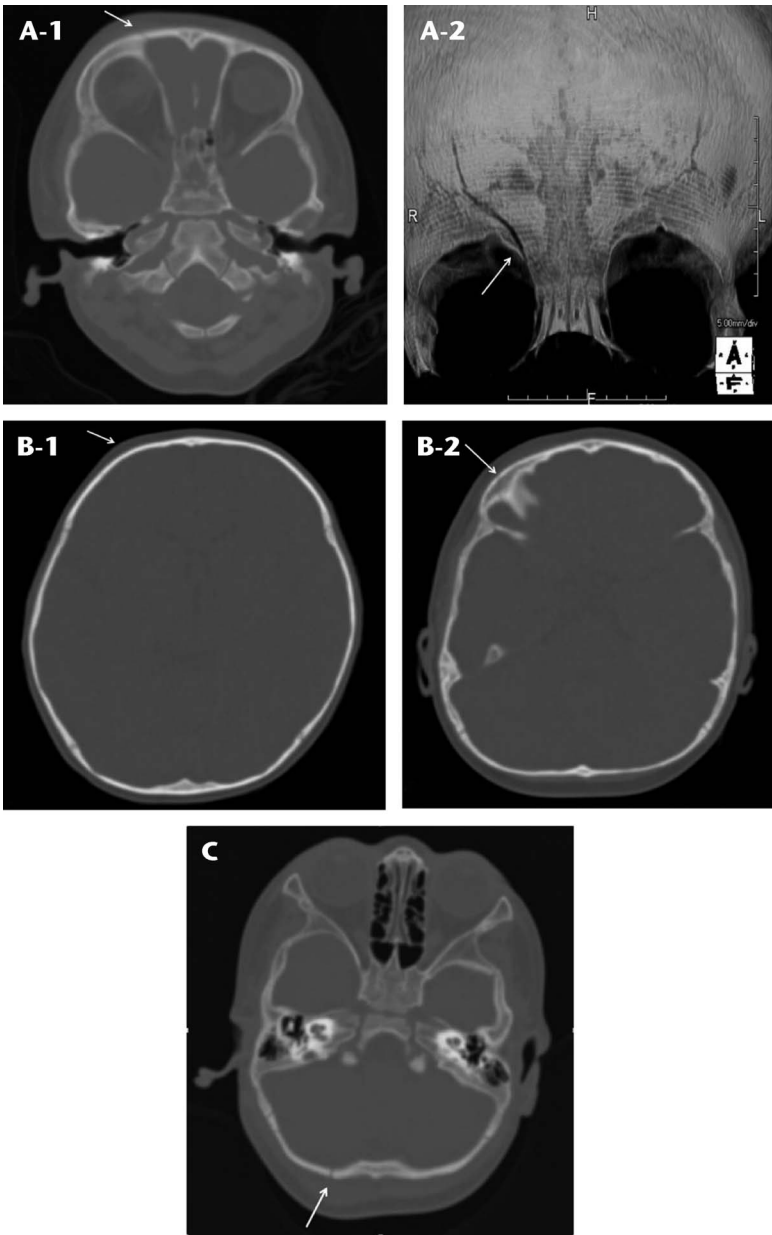


FIGURE 2. False-negative cases review. A, The fracture was seen on the medial side of the right superior orbital wall on CT scan (A-1, axial view; A-2, 3-dimensional view). B, The skull fracture adjacent to scalp hematoma on CT scan (B-1, scalp hematoma on frontal area; B-2, superior orbital wall fracture adjacent to scalp hematoma). C, The occipital scalp hematoma adjacent to skull base on CT scan. There are difficulties in differentiating from the neck fold and in performing US.

in the practice of EM is well established, and mounting research continues to demonstrate how bedside US can benefit pediatric ED patients.^{15–22} As the modality advances and becomes more available, it will be important to ensure that EM personnel have access to the proper training and equipment and that they are experienced.

Some studies have investigated the diagnostic usefulness of bedside US for pediatric fractures, and several recent US studies involving clinicians with focused training have also reported rapid and accurate skull fracture diagnoses in children; these studies have suggested a potential role for bedside US in diagnosing skull fractures.^{19–22} The results of our study were similar to those of previous studies with high sensitivity and specificity.

Some differences were observed between our study and previous studies (Table 3). While the specificity of our study was high, the sensitivity was lower than those in prior published studies. The sensitivity may be more useful in US application, as a screening test. This result may be due to different patient demographics, such as age, and the prevalence of skull fracture. Our study focused on much younger patients than those in previous studies (children and adolescents vs children aged 0–4 years). From a practical standpoint of performing US, close contact between the probe and scalp will increase the image resolution and sharpness.²⁵ For younger children, the surface that comes into contact with the probe is rather small; thus, practitioners should use sufficient gel and anchor the base of the hand on uninjured skull. Despite these differences, bedside skull US was accurate for the diagnosis of skull fractures, with high specificity in young children.

In previous studies, false-positive results were common, whereas we had only 3 cases of false-negative results (Table 5). A false-negative case reported by Rabiner et al²² involved a case in which the hematoma and skull fracture were not aligned. In our study, the second case shown in Table 4 was similar. Therefore, it was necessary to scan the suspected area more extensively. Two of the 3 false-negative cases involved a supraorbital wall fracture and a skull base fracture. More attention is required when examining these areas. In addition, these 3 diagnostic errors involved children 12 to 24 months old. In our study, all US examinations were performed by short focused trained general EM physicians, which may have had an effect on the results. Emergency medicine physicians may not be as comfortable with some techniques that are used by pediatricians, and these techniques may simplify the US process and enhance the performance (eg, soothing techniques,

scanning on a parent's lap, using copious amounts of gel on the probe to avoid putting pressure on areas of injury, etc). These techniques were discussed and recommended in the dedication session.

Our study strongly supports the finding of previous studies that clinicians can diagnose skull fractures, even in young children. When used with a clinical decision tool such as the PECARN Rules, which are for clinically important TBI, bedside US can be a useful tool to detect skull fractures and perform further risk stratification of minor head injuries. If skull US is performed together to confirm that there is no fracture, the caregiver may be more comfortable and satisfied. However, the sensitivity of US for fracture is not yet sufficient for its use as the sole method of detecting injury and for decision making. Therefore, caution is warranted when using US test results.

Based on false diagnosis cases in previous studies and the current study, several precautions should be taken when diagnosing pediatric skull fractures using bedside US (Tables 4 and 5). First, a skull fracture located adjacent to the hematoma (but not directly underneath it) may be missed.^{20,22} One study that reviewed all CT-positive skull fractures with overlying hematomas revealed that 1 (10%) of 10 cases displayed a visible fracture line adjacent to (but not directly underneath) the scalp hematoma. The authors suggested that a blunt impact to the cranium could cause the underlying skull to bend inward at the point of impact and cause a more peripheral area of the skull to bend outward. It is at the region of outward bending that a linear skull fracture begins, with potential extension toward the impact site during the rebound phase of trauma.²⁶ The use of dynamic oblique imaging through the entire hematoma, scanning the areas around the scalp hematoma, or using a peripheral stand-off pad or water-filled glove may increase sensitivity.^{20,22} Although the incidence was lower, our study also included a similar case (1/13). Meticulous examination and future investigations are needed.

Second, the process of how to take the best image of a cranium site must be addressed because it is difficult to apply a US probe to that site. The supraorbital area and the lower occipital area adjacent to the skull base are particularly difficult to evaluate. In our study, skull fractures in these areas were missed. Alternative techniques, such as the use of a water-filled glove or a stand-off pad, may provide better images to interpret,²⁰ and the selection of another US probe suitable for small children may be helpful.

Third, knowledge of suture anatomy and fracture distinction is necessary for skull US examinations of young children.

TABLE 5. Characteristics of False-Positive and False-Negative Cases in Previous Studies

Study (Year)	False-Positive Case	False-Negative Case
Riera and Chen ²⁰ (2012)	2 Cases (1 case, not described) 6-mo-old female infant Nondisplaced parietal skull fracture on US, negative on first CT, and positive on 2nd CT*	2 Cases Not described
Rabiner et al ²² (2013)	2 Cases Case 1: physician' technical error Case 2*: 16-y-old boy, minimally displaced temporal skull fracture on US, negative on CT	1 Case 7-mo-old male infant Parietal skull fracture, adjacent to but not directly beneath the scalp hematoma
Parri et al ²¹ (2013)	1 Case 6-y-old boy Anatomic abnormality of temporoparietal suture, asymmetrical suture	None
Our study (2014)	None	3 Cases As described in Table 4

*Studies suggested that US may diagnose minimally displaced or nondisplaced skull fractures that can be missed on CT scan.

Ultrasound findings of irregular, jagged, displaced, and asymmetric separation are more suggestive of a fracture, and the imaging and comparison of the contralateral area of the skull can be helpful in distinguishing these findings.^{20–22}

Our study has several limitations. First, this single-center study had a small sample size. Our study population was larger than those of published studies. However, the prevalence of skull fractures (15%) was relatively lower than that in other studies. Second, US is an operator-dependent modality. Although the 3 examiners received the same EM US training before the study, differences in examiner skill and ability may exist. Third, as mentioned earlier in Methods, no clinical decision rules were applied in determining who required a head CT in this study. Considering the PECARN prediction rules was published in 2009, nonadherence to the PECARN prediction rules makes our study population potentially different from other settings. Lastly, we did not evaluate the cost, time to diagnosis, sedation rate, discomfort related to imaging, or guardian's satisfaction compared with those for head CT scans. Further study of these issues is needed.

In conclusion, bedside US is a useful tool for diagnosing skull fractures in children 0 to 4 years of age with mild head injury, and bedside US performed by EM clinicians with short focused US training can accurately diagnose skull fractures compared with CT scans. To decrease diagnostic errors, a meticulous examination around the hematoma should be performed, and more attention should be directed toward the supraorbital wall and skull base. In addition, use of a suitable probe and alternative techniques should be considered.

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